SMITHSONIAN

MISCELLANEOUS COLLECTIONS

VOL. 139

"EVERY MAN IS A VALUABLE MEMBER OF SOCIETY WHO, BY HIS OBSERVATIONS, RESEARCHES, AND EXPERIMENTS, PROCURES KNOWLEDGE FOR MEN"—JAMES SMITHSON

(PUBLICATION 4468)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1961

PORT CITY PRESS, INC.
BALTIMORE, MD., U. S. A.

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LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

CONTENTS

1. Peabody, Frank E. The oldest known reptile, *Eosauravus copei* Williston. 13 pp., 1 pl., 3 figs. May 7, 1959. (Publ. 4377.)
2. Wetmore, Alexander. The birds of Isla Escudo de Veraguas, Panamá. 27 pp., 1 pl., 3 figs. July 8, 1959. (Publ. 4378.)
3. Grégoire, Charles. Further observations on distribution of patterns of coagulation of the hemolymph in Neotropical insects. 23 pp. Aug. 18, 1959. (Publ. 4379.)
4. Handley, Charles O., Jr. A review of the genus *Hoplomys* (thick-spined rats), with description of a new form from Isla Escudo de Veraguas, Panamá. 10 pp., 1 fig. July 3, 1959. (Publ. 4380.)
5. Cooper, G. Arthur. Genera of Tertiary and Recent rhynchonelloid brachiopods. 90 pp., 22 pls., 1 fig. Nov. 23, 1959. (Publ. 4382.)
6. Boardman, Richard S. A revision of the Silurian bryozoan genus *Trematopora*. 14 pp., 2 pls., 1 fig. Oct. 29, 1959. (Publ. 4383.)
7. Gazin, C. Lewis. Early Tertiary *Apheliscus* and *Phenacodaptes* as pantolestid insectivores. 7 pp., 2 pls. Aug. 12, 1959. (Publ. 4385.)
8. Snodgrass, R. E. The anatomical life of the mosquito. 87 pp., 30 figs. Nov. 4, 1959. (Publ. 4388.)
9. Abbot, C. G. A long-range forecast of United States precipitation. 78 pp., 12 figs., 9 charts. Mar. 23, 1960. (Publ. 4390.)
10. Williams, Jerome; Johnson, E. R. Fenimore; and Dyer, Albert C. Water transparency observations along the east coast of North America. 181 pp., 2 pls., 13 figs. Oct. 26, 1960. (Publ. 4391.)
11. Wetmore, Alexander. A classification for the birds of the world. 37 pp. June 23, 1960. (Publ. 4417.)

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 1

Charles D. and Mary Vaux Walcott Research Fund

THE OLDEST KNOWN REPTILE, EOSAURAVUS COPEI WILLISTON

(With 1 Plate)

By
FRANK E. PEABODY
Department of Zoology
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(Publication 4377)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MAY 7, 1959

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THE LORD BALTIMORE PRESS, INC.
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FOREWORD

Dr. Frank E. Peabody died on June 27, 1958, leaving several manuscripts in various stages of completion. The one published here, based on a specimen in the collections of the United States National Museum, was complete except for final touching up of some of the illustrations; these illustrations have been finished by Miss Madeline M. Peabody with the help of Dr. Theodore H. Eaton, Jr. The manuscript has been edited by Dr. Eaton and myself. Dr. Peabody's paper presents a welcome clarification of the relationships of an important, and heretofore much misunderstood, early reptile.

Peter P. Vaughn

Charles D. and Mary Vaux Walcott Research Fund

THE OLDEST KNOWN REPTILE, EOSAURAVUS COPEI WILLISTON

By FRANK E. PEABODY
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(With One Plate)

One of the most tantalizing examples of Carboniferous tetrapods is the posterior part of a small skeleton from Linton, Ohio, described by Cope in 1897 as the earliest known reptile. Some 60 years later, and after many taxonomic vicissitudes, the specimen seems in danger of slipping into obscurity among the microsaur Amphibia. Meanwhile no more reptiles have been found at Linton or in earlier horizons.[1] Various students have described Cope's specimen, but most have tended to discount its importance because the anterior part of the skeleton, including the skull, is missing, and have tended to accept the early descriptions with little question. Present high interest in the origin of reptiles during the Carboniferous prompted a restudy of Cope's historic specimen. It was found that strong lighting from a very low angle, and directed from various positions, revealed much new detail that can be demonstrated by photographic enlargements. The result is a new interpretation, particularly of the vertebrae and tarsus, which reaffirms the reptilian affinities of the specimen and furthermore strongly suggests a captorhinomorph relationship.

I am indebted to Dr. Peter P. Vaughn of the United States National Museum for permission to borrow Cope's specimen, and to Miss Madeline M. Peabody, my sister, for assistance with the illustrations.

1 [*Cephalerpeton ventriarmatum,* apparently a captorhinomorph reptile (see Gregory, 1950), is known from the nodule beds at Mazon Creek, Ill., which represent a somewhat earlier horizon (but still within the Allegheny series). —Ed.]

SYSTEMATIC DESCRIPTION

EOSAURAVUS COPEI Williston

PLATE 1; TEXT FIGURES 1-3

Isodectes punctulatus COPE, Proc. Amer. Philos. Soc., vol. 36, pp. 88-90, pl. 3, fig. 3, 1897; WILLISTON, Journ. Geol., vol. 16, pp. 395-400, text fig. 1, pl. 1, 1908; MOODIE, Proc. U. S. Nat. Mus., vol. 37, pp. 11-16, pls. 4-5, 1909.

Eosauravus copei WILLISTON, Bull. Geol. Soc. Amer., vol. 21, p. 272, 1910; CASE, Carnegie Inst. Washington Publ. 145, pp. 31-32, text fig. 8, 1911.

Tuditanus punctulatus ROMER, Bull. Amer. Mus. Nat. Hist., vol. 59, pp. 134-135, 1930; Bull. Mus. Comp. Zool., Harvard Coll., vol. 99, p. 300, 1947; Amer. Journ. Sci., vol. 248, p. 641, 1950; HUENE, Paläontologie und Phylogenie der niederen Tetrapoden, p. 163, 1956.

?*Tuditanus* ROMER, Osteology of the reptiles, p. 483, 1956.

Type.—U.S.N.M. No. 4457; posterior $\frac{2}{3}$ of a reptilian skeleton preserved belly-down on a slab of coal from Linton, Ohio.

Horizon.—Allegheny group, Middle Pennsylvanian (Westphalian).

Diagnosis.—Small reptile with a minimum of 28 presacral vertebrae of generally captorhinid structure, with broad, swollen neural arches, low neural spines, zygapophyseal facets in horizontal plane, and small intercentra; free ribs on all vertebrae except distal caudals; distal caudal vertebrae with low neural arches and probably without haemal spines, centra occasionally fused forming relatively stiffened axis; one principal and one accessory sacral rib; hind limb with prominent internal trochanter, with relatively short epipodial (=zeugopodial) segment having relatively massive fibula; primitive, well-ossified tarsus of basic captorhinid or pelycosaurian plan with separate median and lateral centrale and with a 6th distal tarsal (=postminimus); phalangeal formula 2-3-4-5-4, terminal phalanges blunt-ended. No gastralia present; possibly with body scales, having striae radiating from anterior margin of scale. No obvious aquatic adaptations of well-ossified skeleton. Anterior skeleton unknown.

Taxonomic notes.—The taxonomic history of Cope's specimen is so devious and confusing that a short explanation is necessary to supplement the synonymy listed above. Cope (1897) described the posterior skeleton and believed it to be conspecific with another small vertebrate represented by a skull and anterior two-thirds of a skeleton. The latter had been described by Cope (1874, p. 271) as *Tuditanus punctulatus,* but in his 1897 paper, it was referred along with the posterior skeleton to the genus *Isodectes.* Williston (1908) and Moodie (1909) offered new descriptions of the posterior skeleton, treating it as distinct from the anterior skeleton, but tending to overlook the fact that the anterior skeleton is the type of *Isodectes* *punctulatus*. (Moodie's plate description (p. 28) in fact refers to the posterior skeleton as "the type specimen of *Isodectes punctulatus*," which, of course, it is not.) Later, Williston (1910) and then Case (1911) established the posterior skeleton as a new genus and species, *Eosauravus copei* Williston. Unfortunately, the European genus *Sauravus* to which Williston related the posterior skeleton is clearly an amphibian with nectridian vertebrae, so the name *Eosauravus* is inappropriate morphologically but remains valid taxonomically.

Romer (1930) restudied the Linton fauna and, in a commendable attempt to reduce the large number of artificial species, referred Cope's posterior skeleton again to the anterior skeleton now designated as *Tuditanus punctulatus*. The synonymy of *Tuditanus* with *Isodectes* had proved to be wrong since the latter genus now appears to be a captorhinomorph (Gregory et al., 1956, p. 2), and the former genus is a microsaur. Romer's decision apparently rested mainly on the improbability that there might be more than one reptile at Linton, and that there was the distinct possibility that the smaller, less ossified anterior skeleton merely represents a more immature individual than the posterior skeleton. The two specimens were regarded by Romer as reptilian with no recognizable ordinal characters. Later, Romer (1947, p. 300) suggested that the two specimens together represent either a seymouriamorph or cotylosaur on the basis of a stemmed interclavicle, seemingly broad-arched vertebrae, and a pes with a phalangeal formula 2-3-4-5-4. Still later, Romer (1950, p. 641) discounted the importance of the stemmed interclavicle and phalangeal formula, and, while noting a presumed high presacral count of vertebrae, long, slender body proportions, apparent lack of caudal chevrons, and long postorbital region of the skull, concluded that *Tuditanus punctulatus* (based on anterior and posterior skeletons) "is not improbably a microsaur." This conclusion, undoubtedly influenced by increased understanding of microsaurs, was followed by both Piveteau (1955) and Huene (1956) in their valuable compendia of vertebrate paleontology. Meanwhile, Romer (1956, p. 483) apparently turned once more toward Williston's opinion of the posterior skeleton as shown by the lone entry "[Reptilia] Incertae sedis. ?Seymouriamorpha. *?Tuditanus* Cope 1874 (*Eosauravus* Williston 1910)." Thus at present, the posterior skeleton designated as *Eosauravus copei* by Williston, is in an obscure position both taxonomically and phylogenetically. The anterior skeleton is best considered a probable microsaur amphibian under the designation *Tuditanus punctulatus*. In any case it is difficult to demonstrate distinctive reptilian characteristics in

T. punctulatus, and especially difficult to demonstrate any real affinities with *Eosauravus copei.*

Description.—The specimen consists of the posterior two-thirds of a postcranial skeleton preserved belly-down on a coal stratum. Neither the opposing slab, probably containing a dozen thoracic vertebrae and caudal neural arches, nor adjoining blocks of matrix containing the tip of the tail, some terminal phalanges of the left pes, and the anterior end of the skeleton, were collected. The remaining parts of the skeleton have undergone very little deterioration since Cope's time, judging from the excellent photograph presented by Williston (1908) and republished (with inaccurate retouchings) by Moodie (1909).

The presacral, sacral, and anterior caudal vertebrae lie on their right sides (as observed by Cope, 1897) in such a manner as to cover the proximal tips of the right ribs while the proximal ends of the left presacral ribs are pressed against the upper (left) surfaces of their corresponding centra. The outline of successive neural spines is clearly visible on the right side between successive ribs. The caudal vertebrae posterior to the rib-bearing caudals are preserved with ventral side down and have lost their neural arches, thus exposing the neural canal as a longitudinal groove in the dorsal surface of the centra. Unfortunately, Moodie (1909, pl. 5) illustrated the entire column as though it were oriented with the dorsal side uppermost (figure reproduced by Case, 1911, fig. 8). The result is an erroneous picture of the vertebrae from anterior caudals forward. Cope's illustration (1897, pl. 3) shows the correct orientation, but is only slightly suggestive of the true form of the vertebrae.

The true form of the presacral and anterior caudal vertebrae may be reconstructed with reasonable accuracy from a composite of details exhibited along the column. Specifically the impression of the anterior presacrals clearly shows the contour of the centrum; the first 5 presacrals and anterior caudals preserve details of swollen neural arches as well as of the centra and intercentra. The position of intervertebral foramina is clearly indicated by a series of circular pits. Figure 1 is presented as a reconstruction based on composite detail.

There seems to be little doubt that the neural arch is low and broad as mentioned by Romer (1947, p. 300), has a low spine, and has a perceptible swelling above the posterior zygapophysis; also that small intercentra are present. The latter are indicated between the first several presacral centra, between the 1st and 2d caudal centra, and by a haemal wedge between the 3d and 4th caudal centra. In the presacral series the left ribs appear to have been crushed precisely against

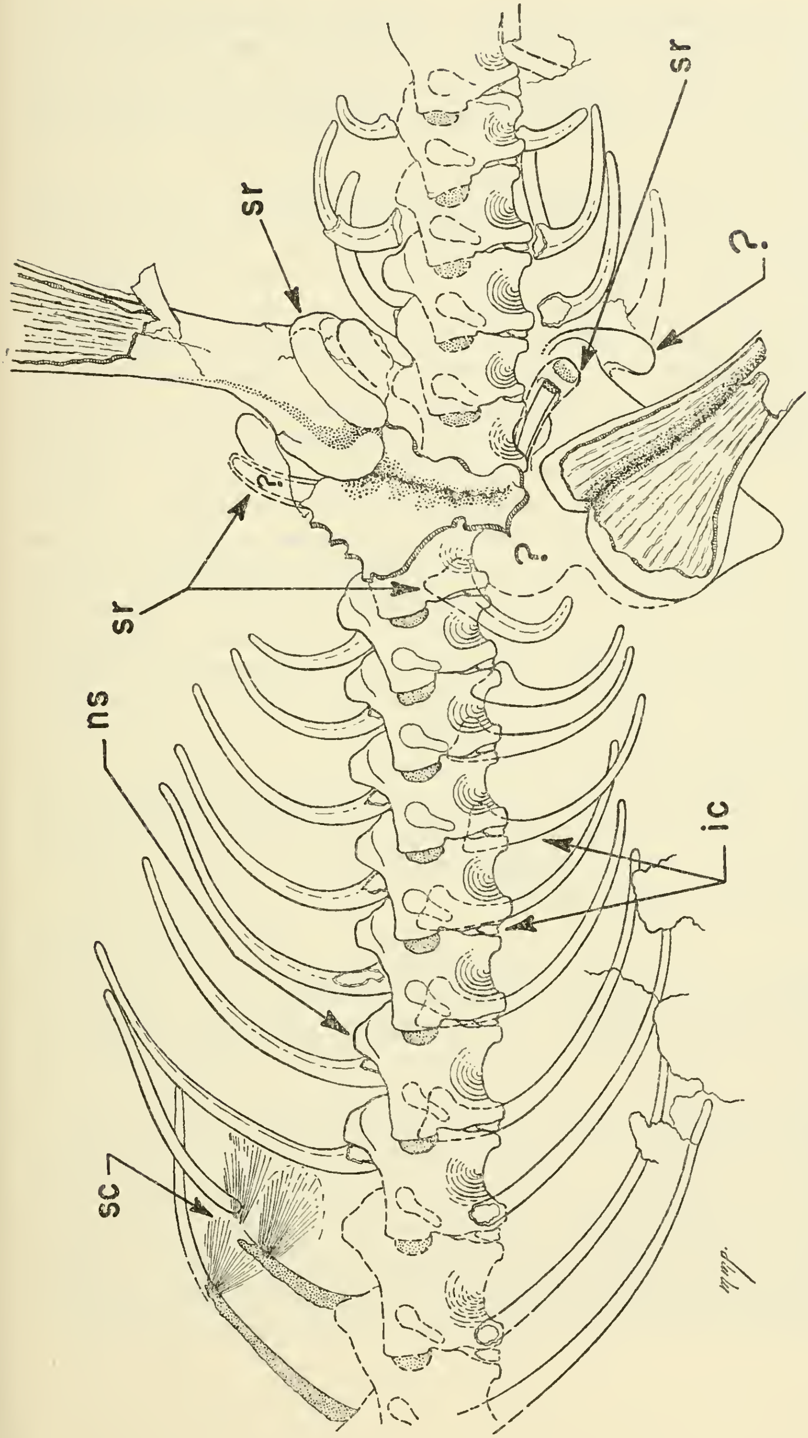

Fig. 1.—Lumbar, sacral, and anterior caudal region of *Eosauravus copei*, reconstructed from composite detail of type specimen. Possible body scales (sc), neural spine (ns), sacral ribs (sr), intercentra (ic).

the intervertebral area; thus the supposed intercentra here may be parts of the ribs. However, there appears to be a distinct intercentral space coincidental with the position of the ribs, and, in any case, the evidence for intercentra in the anterior caudals is clear and unobscured by ribs.

Evidence of 24 presacral ribs on the left side is fairly clear, although the first presacral is difficult to see, and only the distal tip of the 24th presacral is preserved on the edge of the slab. The general pattern and number of the presacral ribs and the far anterior position of the left manus have led to the opinion (Romer, 1950, p. 641) that the presacral count is significantly higher than the 25-27 vertebrae usually found in the most primitive reptiles. However, the 5 most anterior ribs are clearly more massive than following ribs, and the distal ends are slightly spatulate—all indicative of an extreme anterior thoracic position related to serrati muscles of the pectoral girdle. Also, the successive positions of the distal ends of the 5 anterior ribs suggest a progressive shortening in a forward direction as might be expected in a smooth transition to the cervical region. Accordingly, a reconstruction will show that the total number of presacrals may have been as few as 28. The forward position of the left manus as an indicator of a far anterior position of the pectoral girdle is probably misleading. The girdle probably shifted forward or to the right side away from its life position lateral to the 5 anterior ribs.

Rib heads are obscured in the presacral series generally, but the 3d to 8th left presacral ribs appear to have a proximal expansion commensurate with the elongate diapophysis of the neural arch. Certainly these ribs are not single-headed as in lizards, but bear a general resemblance to captorhinid ribs.

The pelvic girdle and sacral vertebrae are distorted beyond certain recognition of salient features, although the spacing of vertebral segments and disposition of lumbar and caudal ribs suggest the presence of two sacral vertebrae. A short, thick element lying across the adductor fossa of the right femur may be a right second sacral rib; an obscure spatulate structure immediately anterior to the anteriormost left caudal rib may be the first or principal sacral rib. Except for a general outline of the acetabular regions of the girdle, little can be demonstrated here except that the mass lying between the heads of the femora probably constitutes a pelvic girdle and sacrum of primitive reptilian plan. According to my interpretation, Moodie (1909, pl. 5) included the internal trochanter of the left femur in his outline of the left acetabular region, thus giving the left pelvis a more distinct outline than is warranted. A thin plate lying anterior to the head of the right femur may represent the left ilium broken over to the right. Although the thin plate may be regarded as a patch of overlying matrix such as obscures the centrale of the left tarsus (see below), there is a definite anterior border that looks much like the anterior edge of an iliac blade. Nowhere is there evidence of a long posterior process of the ilium like that of *Eogyrinus*.

The anterior 4 or 5 caudal vertebrae are associated with 3 pairs of sharply curved ribs. In addition, there are short structures faintly shown on the left side that are not curved and probably represent short haemal spines nearly in the correct position. Also, there is a distinct haemal wedge between the 3d and 4th caudal centra. Certainly there is enough evidence to question seriously earlier observations (Cope, 1897, p. 89; Romer, 1950, p. 641) that there are no haemal spines in the tail.

The caudal series becomes twisted, possibly 180 degrees, at the position of the 7th vertebra, which appears to be lying on its left side. Posteriorly the series is oriented with ventral side down—an unusual position if neural and haemal arches were at all well developed here, or if there was any lateral compression of the centra. Under these conditions the vertebrae would be almost certainly lying on one side or the other as in the anterior column. However, the caudal centra appear broader than high, and occasional fusion of neighboring centra seems to have occurred. All features of the tail, including the orientation, suggest some specialized function—perhaps a prehensile action in the dorsoventral plane. A special aquatic function does not seem possible, insofar as a lateral sculling motion is concerned, although the fused vertebrae may suggest a stiffened axis serving as the foundation for a rudder.

Part of the left manus (omitted in Cope's figure, 1897, pl. 3) lies disarticulated near the anterior end of the vertebral column. Enough is shown to indicate that the carpus was definitely as fully ossified as the tarsus, and less surely that the phalangeal formula was comparable to the reptilian count in the pes.

Both limbs are complete except for the loss of some terminal phalanges on the left side. The left femur is preserved with the dorsal surface uppermost—the right femur with the ventral surface uppermost. Thus the whole contour of the bone can be recognized in composite. The femoral head, internal trochanter, adductor fossa, and distally the tibial and fibular condyles resemble those of primitive reptiles such as ophiacodonts and captorhinids. The trochanter is especially prominent and extends proximally nearly in line with the femoral head. Ossification is fully developed in the femur as well as in the more distal elements.

The tibia and fibula are short, stout bones of generally primitive contour; the fibula appears relatively more massive than is usually the case in the tetrapod limb. The distal end of the left tibia appears to have slipped slightly upward from the life position and now rests on the neck of the astragalus. Otherwise, the left femur, tibia, and fibula are in normal articulation.

The right pes is twisted so as to obscure details of the tarsus, but details of the digits help to complete a restoration of the left pes. The left pes is preserved dorsal side uppermost and exhibits one of the most perfect preservations of tarsal structure known from the Carboniferous, indeed, from the Paleozoic, as will be demonstrated presently. The pes has been given several superficial descriptions (Cope, 1897; Williston, 1908; Moodie, 1909) which fail to recognize the extent of ossification in the tarsus, but nevertheless establish two proximal elements in the tarsus and a phalangeal formula of 2-3-4-5-4. A main difficulty lies in the interpretation of tarsal elements distal to the presumed astragalus and calcaneum, especially in the medial region of the tarsus where no one has been able to recognize central elements. Moodie's figure (1909, pl. 5), republished by Case (1911), is particularly misleading in that the tarsus appears to have an enigmatic pattern, doubtfully reptilian. (Also, in Moodie's figure a nonexistent element is added distal to the lateralmost distal tarsal, although none is shown in Moodie's retouched photograph—his pl. 4). My photographs (pl. 1A, B), taken under low-angle light from first one direction and then from the opposite direction, demonstrate the wealth of detail making possible text figure 2. The two proximal bones of the tarsus are clearly the astragalus and calcaneum which enclose between them a perforating foramen, not previously noted. The astragalus has a small but definite tibial facet directed mostly preaxially. There is no evidence of tripartite structure such as exhibited by *Captorhinus* (Peabody, 1951). The preaxial border between the astragalus and the first metatarsal clearly exhibits two bones that must be a median centrale and distal tarsal 1. A thin veneer of matrix obscures part of the dorsal surface of these bones, but the oblique lighting (pl. 1A) clearly brings out their contours in the preaxial border. Lateral to these bones and median to the large distal tarsal are at least 2 and probably 3 separate bones that are identifiable as the lateral centrale and distal tarsals 2 and 3. A slight proximal jamming (see fig. 2) has forced distal tarsals 2 and 3 slightly out of position. The existence of two separate centralia seems certain although the separation between the lateral centrale and distal tarsal 2 is not clear—probably because of a slightly overriding relationship due to jamming. A unique feature of the tarsus is a postminimus or distal tarsal 6 in the postaxial border. Such an element is unknown in reptiles but is found in the tarsal pattern of the urodele, *Salamandrella,* by Holmgren (1933, p. 217).

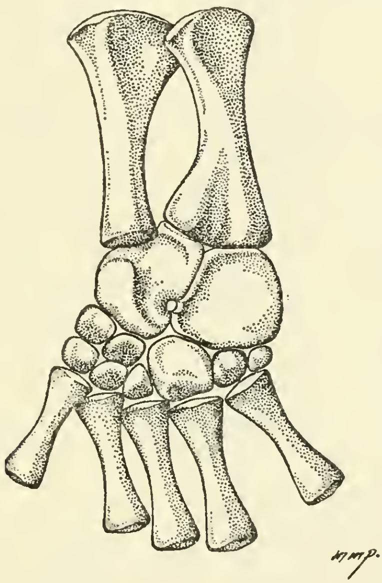

FIG. 2.—Left pes of *Eosauravus copei* showing primitive reptilian pattern with separate median and lateral centrale, and with unique postminimus or distal tarsal 6 on postaxial border.

There is no doubt that the tarsal pattern is generally comparable to primitive captorhinids and pelycosaurs.

The metatarsals are all well developed as indicated in figure 2. No special features seem to be present except for a generally robust ossification (like that of more proximal bones) that contrasts markedly with a seemingly delicate ossification of the phalanges.

The phalanges may be confidently restored with a 2-3-4-5-4 formula, using the evidence from both feet. The terminal phalanges are not acutely pointed and cannot be considered as definitely bearing claws. The relative length of the 5th digit suggests no obvious aquatic adaptation—in the obviously aquatic *Mesosaurus,* the 5th digit is longer than the 4th. This condition may also be noted in nothosaurs.

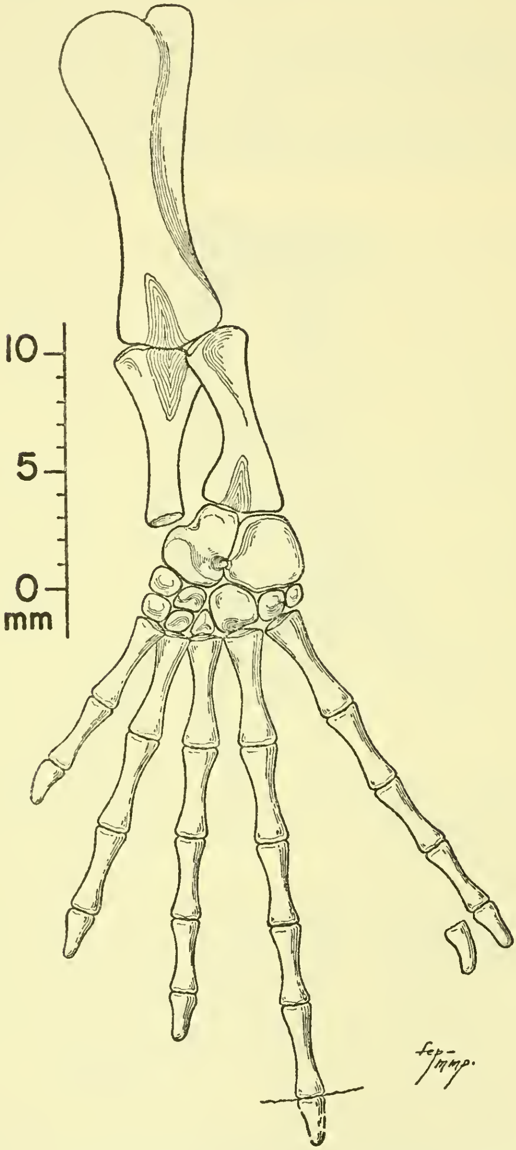

FIG. 3.—Left limb of *Eosauravus copei* reconstructed in fully extended position.

The surface surrounding the skeleton seems devoid of structures resembling gastralia as indicated by early descriptions. However, a problematical object that may be an unidentified bone from the anterior skeleton lies just to the left of the distal tail. Possibly of more importance, an enlarged view of the surfaces near the skeleton reveals a number of delicate, ovoid areas with fine striae radiating from a point near one border. The striated areas occur only close to the skeleton; an example of the striated areas can be seen clearly between the right ribs in plate 1C. It is possible that these striated areas represent body scales developed from the epidermis of *Eosauravus*. No bone is indicated in the delicate impressions

Conclusions.—It is concluded that Cope's historic specimen from Linton, Ohio, is surely a reptile that has evolved beyond the seymouriamorph level. The broad-arched, cotylosaurian vertebrae possess small intercentra, and the narrow space between successive pleurocentra is in decided contrast with the wide, unossified gap seen in seymouriamorphs. Here, the pedicel of the neural arch has a marked overhang above the intercentral gap. The tarsus has a characteristic reptilian astragalus and calcaneum, with enclosed perforating foramen in the usual position. The astragalus is fully developed with no indication of a compound origin as in the relict *Captorhinus aguti* of Early Permian age (Peabody, 1951). The whole structure of the pes is of basic reptilian pattern except for the 6th distal tarsal or postminimus. The latter may be considered an amphibian feature rather than a supernumerary element that widens the pes surface in correlation with aquatic adaptations—an untenable point of view considering the general lack of characteristics suggesting aquatic habits of *Eosauravus*. The combination of vertebral and tarsal characteristics is consonant with other features of the skeleton; together they strengthen the evidence that the astragalar bone, originating from a fusion of tibiale, intermedium, and proximal centrale of the amphibian foot, may be regarded as a reliable osteological indication of the attainment of the amniote level of organization—at least until conflicting evidence is found.

If it be granted that *Eosauravus* is a reptile, there is a question as to its subgroup affiliation. Current evidence strongly suggests that early ophiacodont pelycosaurs and captorhinomorphs are very close to the root of the reptilian stock. The tarsus of *Eosauravus* is exceedingly primitive in the possession of separate median and lateral centrale, and of the postminimus. Only early pelycosaurs have separate centralia—they are fused in *Captorhinus* and *Limnoscelis*. No reptiles presently known have a postminimus. The nature of the vertebrae of *Eosauravus* would indicate that its affinities probably lie with the captorhinomorphs. No pelycosaur is presently known to possess vertebrae of a pure cotylosaur type such as is evident in *Eosauravus*. In view of the primitive pattern of the tarsus, a position near the base of the captorhinomorphs is indicated.

Establishment of a true reptile of captorhinomorph affinities deep in the Middle Pennsylvanian helps to clear away some of the uncertainty surrounding the time of origin of reptiles. The varied reptiles found in the Upper Pennsylvanian of Kansas (Peabody, 1954) and more fragmentary remains from elsewhere indicate that the evolution of pelycosaurs and captorhinomorphs (if petrolacosaurs be considered an offshoot of the captorhinomorphs as suggested by Vaughn, 1955, p. 446) was well advanced. *Eosauravus* appears to have been at an evolutionary stage which could be ancestral to any known later reptile.

The particular adaptations of *Eosauravus* to life in a coal swamp are difficult to assess. Moodie (1909, p. 12) suggests that the reptile was aquatic or semi-aquatic mainly on the basis of an "expanded foot" similar to the broad foot of the obviously aquatic mesosaurs. However, the foot of *Eosauravus* and the rest of the preserved skeleton have little to suggest even semi-aquatic habits, but do allow the possibility that this small reptile spent most of its time in the "upper story" of the coal forest at Linton.

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1910. *Cacops, Desmospondylus;* new genera of Permian vertebrates. Bull. Geol. Soc. Amer., vol. 21, pp. 249-284, 12 pls.

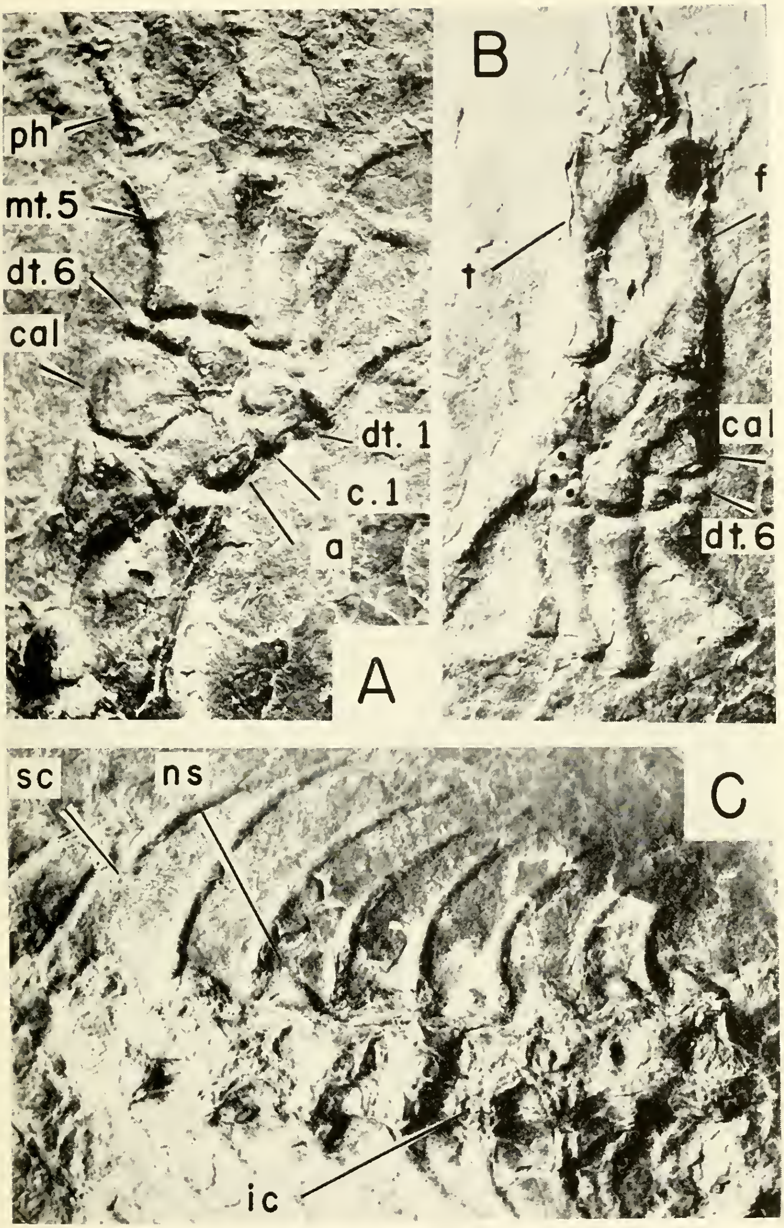
EXPLANATION OF PLATE 1

Left pes and lumbar region of *Eosauravus copei* seen under low-angle illumination.

A. Pes, lighted from distal direction, showing clearly: Two elements—median centrale (c. 1) and 1st distal tarsal (dt. 1)—lying between astragalus (a) and 1st metatarsal; and 6th distal tarsal (dt. 6) lying between calcaneum (cal) and 5th metatarsal (mt. 5).

B. Pes, lighted from proximal direction, showing 3 distinct elements (indicated by black dots) lying median to large 4th distal tarsal.

C. Presacral vertebrae of lumbar region, lighted from anterior direction, showing low neural spine (ns), presence of intercentrum (ic), and striated patches (sc) possibly representing body scales.



(For explanation, see p. 14.)

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 2

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(WITH ONE PLATE)

BY

ALEXANDER WETMORE
Research Associate
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(PUBLICATION 4378)

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THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

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(With One Plate)

Isla Escudo de Veraguas lies in the southern Caribbean Sea at lat. 9°06′ N., long. 81°34′ W., distant a little more than 18 kilometers from Coco Plum Point on the base of the Valiente Peninsula, Province of Bocas del Toro. The island is roughly rectangular, with a projecting point at the southeast and a somewhat irregular shoreline on the western and northern sides. It is a little over 4 kilometers long by less than 1½ wide, with the long axis running east and west. A sand beach extends along three-fourths of the southern side, around the flat, open southeastern point, and across the eastern side, past the mouth of a small stream, to end against a cliff, 12 meters high, of sandy, indurated clay. Similar bluffs separated by short stretches of beach mark the shoreline along the west and north. The northern side is broken by a small bay with a sand beach at its head. On the west the sea has cut back into the land, leaving several small islets, some of them barren except for grass and other low herbage, and some with a crown of brush and trees. Wave action is steadily eroding the low cliffs, forming small caves, and in some cases arches that pass through projecting points to the sea on the opposite side. The shallow bank surrounding the island indicates that this process has served to reduce it in size. The land back of the southern beach, elevated sufficiently above high-tide line to form a flat, is fringed with coconut palms on the sea side. Behind these extends low jungle in which scattered trees rise 15 to 20 meters tall. Toward the center the surface is lower and is swampy, with two or three trickles of fresh water, discolored by swamp peat, that drain to the sea. There is a small stand of mangroves at the mouth of the stream that enters the sea above the southeastern point.

Columbus during his fourth voyage sighted the island on October 17, 1502, when he came out of the Laguna de Chiriquí through Canal del Tigre (Tiger Channel) (Morison, 1942, vol. 2, p. 350). He gave it the name El Escudo as it appeared to resemble an escudo, or shield. In the following years the island became a landmark for navigators along this stretch of coast, and is mentioned from time to time in ancient documents, the name being abbreviated often to Scudo, Scuda, or sometimes modified to Skoday (Anderson, 1911, p. 371). Presently it was designated Escudo de Veragua, and finally the latter part of the name became Veraguas. In the last voyage of Sir Francis Drake (Hakluyt, 1904, pp. 239-240) it is related that his ships came to Escudo on January 10, 1596, where they anchored on the southern side, remaining until January 23. The island was described as "not past two leagues long full of wood, and hath great store of fresh water . . . and that very good." Many of the men soon fell sick, and Drake himself contracted the illness that caused his death on January 28 when they were near Portobello. He was buried at sea off that harbor.

In occasional seventeenth-century accounts of buccaneers and other voyagers there is casual reference to Escudo de Veraguas as a place of shelter or a source of water. Dampier's observation (Dampier, 1697, p. 39) made in 1681 that "We past by *Scuda,* a small Island (where 'tis said *Sir Francis Drake's* Bowels were bury'd)" repeats a tale, apparently of common belief, that cannot concern this island since Drake's death and burial, off Portobello, came more than 200 kilometers to the east. Escudo was visited by Indians, since Dr. Matthew W. Stirling of the Smithsonian Institution informs me that in the town of Bocas del Toro he was shown artifacts found on the island, proof that aboriginal people had lived there, at least from time to time. But there may be confusion with some larger place in the report (Anderson, p. 272) that records a considerable Indian population, divided under two caciques or chiefs. The land area, with due allowance for a reasonable amount of erosion since these early times, is too small to have permitted permanent residence for many persons.

At present men come at intervals to gather the coconuts, or occasionally to fish, search for turtles, or to hunt the introduced wild pigs. There is no permanent human resident, and the wildlife, except for the pigs, is tame.

I was able to visit Escudo de Veraguas through the kind assistance of George Munch, manager of the Almirante Division of the Chiriquí Land Co., which has its headquarters at Almirante, Province of Bocas del Toro. We left Almirante on February 28, 1958, shortly before midnight, on the diesel launch *Talamanca,* entered the sea through the pass of Boca del Toro, and before dawn anchored in the lee on the southeastern end of the island. Accompanied by Ziska Hartmann and Jorge Burke, I was ashore near the southeastern point shortly after 7 o'clock and during the forenoon worked through the southern, level section parallel to the beach nearly to the western end. As the sun rose higher the humidity and heat of the dense jungle, where no breeze could enter, became oppressive, so that it was pleasant at the end to walk back to our cayuco along the open beach.

At dawn the following morning the breeze blew from the mainland to the south, so that waves were breaking on the beach. We went off before 7:00 in a choppy sea, and finally landed near the mouth of the small stream. I crossed first into the ridge area at the northeast, but finding this difficult travel and unproductive I sought more level ground. Through this I crossed again toward the western end parallel to the northern shore. The sky was overcast, one shower of rain came, and at times it was difficult to see birds in the heavy jungle shadows.

Though there were no trails, the low jungle was open and easy to penetrate. Where the growth became dense the ground was covered heavily with vines. On the north and west the surface rose 10 to 25 meters in broken, steep-sided ridges, separated by little valleys. Here there was much undergrowth of the spiny pita (a plant of the pineapple family) which, with the steep, slippery slopes, and the swampy floors of the small valleys between, made it difficult to get about. The taller trees that grow along the crests of these ridges from the sea give a misleading appearance of true high forest.

On this final day we returned to the launch a little after 11:00 and, as the sea was rising, left for Almirante, returning through Crawl Cay Channel.

The only record of any earlier visit of a naturalist to the island is the skin of a white-crowned pigeon in the collections of the University of California at Los Angeles. From the end of February to early in April 1936, Dr. Loye Holmes Miller of the Department of Zoology of that Institution, on sabbatical leave, accompanied by a graduate student, Frank Richardson, as assistant, visited the Laguna de Chiriquí, living on a barge that served as a base for a Navy Hydrographic Office detail engaged in a survey of the area. Dr. Miller informs me that on March 2 Richardson accompanied a shore party of Navy personnel to Escudo and brought back a white-crowned pigeon. No other specimens were taken.

While Escudo de Veraguas lies well offshore, it is located on a bank where the sea is shallow. A narrow trench of 24 to 35 fathoms lies to the west and southwest, but elsewhere the depths are considerably less. Since it is estimated that sea levels dropped from 90 to 120 meters during the last period of extensive glaciation in Wisconsin time during the Pleistocene, it is apparent that then the island was part of the mainland. A similar connection should have come during part or all of the three preceding periods of maximum glacial ice. Return of warmer temperatures in the interglacial periods, which melted the ice, again raised the water level, placing Escudo once more as an island, remote at sea. It is reasonable to suppose that the resident wren and the manakin, as well as the peculiar spiny rat of the island, were established there during one of the periods of land connection, since they are jungle creatures that do not range far from cover, nor are the birds of kinds that would be readily windblown by violent storms. Whether the characters of size and color that now mark them were theirs in whole or in part on their arrival, or whether these are distinctions that have developed during isolation, cannot be said, except that it seems probable that the peculiarity of greater size may have become intensified, since this condition is found regularly in populations that seem to have been restricted for long periods to small islands. The manner of development of the differences that mark the blue-gray tanager is not easily understood since in mainland regions these birds appear to roam far. It would appear that they may not cross fairly wide water barriers, since another insular form is found on Isla Coiba off the Pacific coast of Panamá (Wetmore, 1957, p. 94).

Though there were few species of resident birds on Escudo de Veraguas, individuals were fairly numerous. The songs of the bay wren, joined occasionally by the raucous notes of a small flock of parrots, were regular bird notes of the jungle, aside from which there were only the subdued sounds of the wind in the higher treetops, and of the wash of waves against the shoreline. The smaller birds were encountered mainly in the more level areas, where at times they were detected with difficulty in the dim shadows that prevailed in the thickets when the sky was overcast. Occasionally I noted large spiny rats of the genus *Hoplomys.* One that I shot on the ground proves to be a form new to science.

ANNOTATED LIST

Family Pelecanidae: Pelicans

PELECANUS OCCIDENTALIS Linnaeus: Brown Pelican, Alcatraz

Pelecanus occidentalis Linnaeus, Systema naturae, ed. 12, vol. 1, 1766, p. 215. (Jamaica.)

Several were fishing around the island on the morning of March 2.

Family Sulidae: Boobies

SULA LEUCOGASTER LEUCOGASTER (Boddaert): Brown Booby, Piquero Moreno

Pelecanus Leucogaster Boddaert, Table des planches enluminées, 1783, p. 57. (Cayenne.)

Scattered groups rested on small islets off the western end of the island, selecting those that were rocky or covered with short herbage. They were nesting here, as I noted several large down-covered young. At sunset adults came in from the open sea, flying low above the water, singly or in groups of three or four. As our launch passed, a number, part of them fully grown young, came flying out from the islets to circle about with evident curiosity. There were no frigate-birds here, and so the boobies were free from molestation. I estimated that about 200 individuals were present.

Family Charadriidae: Plovers, Turnstones

CHARADRIUS SEMIPALMATUS Bonaparte: Semipalmated Plover, Chorlito Semipalmado

Charadrius semipalmatus Bonaparte, Journ. Acad. Nat. Sci. Philadelphia, vol. 5, August 1825, p. 98. (Coast of New Jersey.)

A flock of 14 ranged the beach at the southeastern end of the island.

Family Scolopacidae: Snipe, Woodcock, Sandpipers

ACTITIS MACULARIA (Linnaeus): Spotted Sandpiper, Playerito Coleador

Tringa macularia Linnaeus, Systema naturae, ed. 12, vol. 1, 1766, p. 249. (Pennsylvania.)

One seen on March 1.

NUMENIUS PHAEOPUS HUDSONICUS Latham: Whimbrel, Zarapito Trinador

Numenius hudsonicus Latham, Index ornithologicus, vol. 2, 1790, p. 712. (Hudson Bay.)

One seen on the beach March 1.

Family Columbidae: Pigeons, Doves

COLUMBA LEUCOCEPHALA: White-crowned Pigeon, Paloma Cabeciblanca

Columba leucocephala Linnaeus, Systema naturae, ed. 10, vol. 1, 1758, p. 164. (Bahama Islands.)

Two were seen March 1 in the top of a thickly leaved tree. A male in the collection of the University of California at Los Angeles was shot on March 3, 1936, by Frank Richardson, now of the Department of Zoology of the University of Nevada, at the time student assistant with Dr. Loye Holmes Miller (see p. 3).

Family Psittacidae: Parrots, Macaws

AMAZONA AUTUMNALIS SALVINI (Salvadori): Red-fronted Parrot, Loro Frentirrojo

Chrysotis salvini Salvadori, Catalogue of the birds in the British Museum, vol. 20, 1891, p. 271. (Lion Hill Station, Canal Zone, Panamá.)

Three pairs were seen in the early morning of March 1, and a female was collected. The same small group was observed the following day.

Family Trochilidae: Hummingbirds

AMAZILIA TZACATL TZACATL (De la Llave): Rieffer's Hummingbird, Colibrí Colimorena

Trochilus Tzacatl, De la Llave, Registro Trimestre, vol. 2, No. 5, 1833, p. 48. (México.)

Several were observed among the lower shrubs back of the beaches.

Family Alcedinidae: Kingfishers

MEGACERYLE TORQUATA TORQUATA (Linnaeus): Ringed Kingfisher, Martín Pescador Grande

Alcedo torquata Linnaeus, Systema naturae, ed. 12, vol. 1, 1766, p. 180. (México.)

One was recorded on March 2 near the mouth of the small stream at the southeastern end.

Family Pipridae: Manakins

MANACUS VITELLINUS (Gould): Gould's Manakin, Matraco

Pipra vitellina Gould, *in* Hinds, R. B. (editor), Zoology of the Voyage of H.M.S. *Sulphur* under the command of Captain Sir Edward Belcher, R.N., F.R.G.S., etc., during the years 1836-42, vol. 1, pt. 3 (Birds, pt. 1), October 1843, p. 41, pl. 21. (Panama = Panama City, Panamá.)

The manakin (fig. 1) was fairly common, ranking next to the wren in abundance. The birds were found among the branches of the smaller trees, where they were quiet, moving about rather slowly, often remaining motionless for several minutes at a time. I regretted that there was no indication of display among the males, as their larger size should make the noises that accompany these activities definitely impressive.

The bird of Escudo de Veraguas was so different from the representative of this species around Almirante Bay that I recognized it as an unknown race when the first specimen came to hand. It is described in the following paragraphs:

MANACUS VITELLINUS AMITINUS, subsp. nov.

Characters.—Similar to *Manacus vitellinus cerritus* Peters[1] but definitely larger; bill distinctly larger and heavier; tarsi and toes

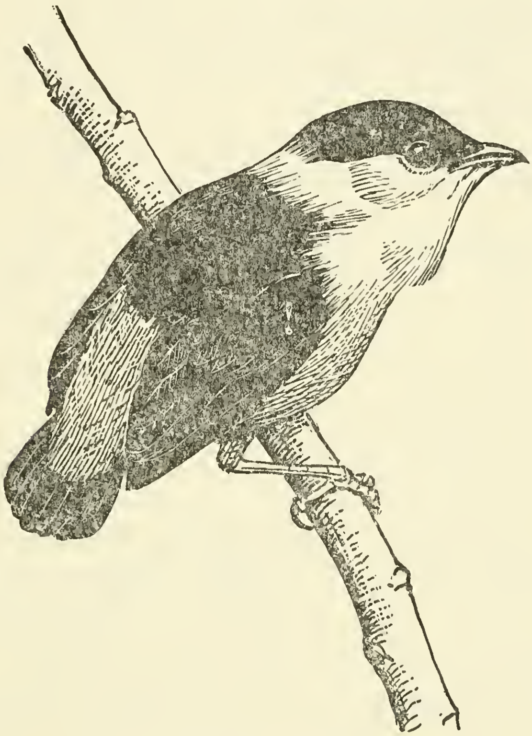

FIG. 1.—Gould's manakin, Matraco.

heavier; adult male with lower back, rump, and posterior ventral surface, including the sides and under wing coverts, darker green; female and immature male somewhat darker green throughout, with the abdomen less yellowish.

Description.—Type, U.S.N.M. No. 468919, male adult, from Isla Escudo de Veraguas, Prov. Bocas del Toro, Panamá, March 2, 1958, collected by Alexander Wetmore (orig. No. 22241). Entire crown

[1] *Manacus cerritus* Peters, Proc. New England Zoöl. Club, vol. 10, September 22, 1927, p. 9. (Almirante, Bocas del Toro, Panamá.)

to nape, including the lores, wings (except inner lesser coverts), upper back, and tail black; sides of head, throat and neck, including hindneck, bright apricot yellow, becoming lemon chrome as the yellow collar meets the black of the back; lesser wing coverts, except the outermost, lemon chrome; lower back, rump, and upper tail coverts yellowish oil green; breast, sides, flanks, abdomen, and under tail coverts between warbler green and olive-green; an indefinite light wash of lemon yellow on center of breast and abdomen; outer under wing coverts Roman green, inner ones yellowish citrine; under surface of inner webs of primaries and secondaries, except toward the tips, dull white. Bill dull black; tarsus and toes fuscous; claws dark neutral gray (from dried skin).

Measurements.—Males (3 specimens), wing 59.3-61.4 (60.6), tail 39.2-42.0 (40.2), culmen from base 14.0-14.8 (14.5), tarsus 23.8-24.5 (24.1) mm.

Females (2 specimens), wing 59.5-60.0 (59.7), tail 38.2-38.3 (38.3), culmen from base 14.7-14.7 (14.7), tarsus 21.0-21.5 (21.2) mm.

Type, male, wing 59.3, tail 39.4, culmen from base 14.6, tarsus 23.8 mm.

Range.—Isla Escudo de Veraguas, at sea off the base of Peninsula Valiente, Bocas del Toro, Panamá.

Remarks.—The greater size of this handsome bird as compared with mainland forms is evident on comparing the measurements with those listed in succeeding paragraphs. In bulk the island birds appear nearly one-third greater. In drawing the description comparison has been made with *cerritus* since the shades of yellow on head and neck of these two are more nearly in agreement. In terms of present distribution *Manacus v. vitellinus* is assumed to be the form of the mainland opposite Isla Escudo, since it is the one recorded at Cricamola on the shores of Laguna de Chiriquí, opposite Peninsula Valiente. *Manacus v. cerritus* is known to range south only to the southern shores of Almirante Bay so that if the water barrier is disregarded, *cerritus* and *amitinus* are separated by an intervening population of typical *vitellinus*.

The name is taken from the Latin *amitinus*, a cousin.

To determine clearly the affinities of the manakin from Escudo a survey has been made of the related members of the genus *Manacus* found in Panamá, particularly *Manacus vitellinus*, of which an excellent series is at hand from the entire range including Colombia. It became evident immediately that *cerritus*, described by James L. Peters as a distinct species, was in fact a geographic race of *M. vitellinus*, as the supposed specific characters break down when the entire area occupied by this bird is given review. It may be noted also that the display of males of *cerritus,* as I saw it in January and February 1958, was similar to that of typical *vitellinus.*

Following is a summary of the subspecies of *vitellinus* based on this examination, with the races arranged in geographic sequence from west to east.

MANACUS VITELLINUS CERRITUS Peters

Manacus cerritus J. L. Peters, Proc. New England Zoöl. Club, vol. 10, September 22, 1927, p. 9. (Almirante, Bocas del Toro, Panamá.)

Characters.—Similar in color pattern, and in colors in general, to *Manacus v. vitellinus.* Male, with throat, sides of head, and band across hind neck and upper back more yellow, less orange, varying in some to completely bright yellow; lower breast, abdomen, sides, flanks, and under tail coverts more greenish yellow; rump and upper tail coverts brighter green; female, and male in immature plumage, darker green throughout.

Measurements.—Males (9 specimens), wing 51.8-54.2 (53.3), tail 31.2-35.8 (34.2), culmen from base 11.1-12.3 (11.7), tarsus 20.0-22.6 (21.5) mm.

Females (3 specimens), wing 54.0-55.7 (54.9), tail 33.1-34.4 (33.9), culmen from base 11.8-12.5 (12.0), tarsus 20.2-21.4 (20.9) mm.

MANACUS VITELLINUS AMITINUS Wetmore

Characters.—Generally similar to *M. v. cerritus,* but decidedly larger; darker green.

Range.—Isla Escudo de Veraguas, Province of Bocas del Toro, Panamá.

Full details of differences, and of measurements, are given in the description above.

MANACUS VITELLINUS VITELLINUS (Gould)

Pipra vitellina Gould, *in* Hinds, R. B. (editor), Zoology of the Voyage of H.M.S. *Sulphur,* under the command of Captain Sir Edward Belcher, R.N., F.R.G.S., etc., during the years 1836-42, vol. 1, pt. 3 (Birds, pt. 1), October 1843, p. 41, pl. 21. ("Panama"= Panama City, Panamá.)

Characters.—Similar to *M. v. cerritus,* but male decidedly orange on foreneck, throat, sides of head, and band across base of neck; posterior under surface more greenish; rump and upper tail coverts grayer green.

Measurements.—Males (47 specimens), wing 50.4-55.7 (52.3), tail

25.8-31.5 (28.3), culmen from base 11.0-13.0 (11.8), tarsus 20.4-22.4 (21.4) mm.

Females (46 specimens), wing 50.7-54.9 (53.2), tail 27.3-31.7 (29.3), culmen from base 11.1-12.7 (12.0), tarsus 18.3-20.7 (19.4) mm.

Range.—On the Pacific slope from the foothills of eastern Veraguas (Santa Fé) eastward through the western part of the Province of Panamá (La Campana, Chorrera), throughout the Canal Zone, and eastern Panamá, to extreme eastern Darién (Jaqué, Río Jaqué, Cana); on the Caribbean slope from central Bocas del Toro (Cricamola), through northern Veraguas (Guaval on Río Calovevora), northern Coclé (El Uracillo), the Province of Colón (Chilar, Portobello) and the Comarca de San Blas (Mandinga, Permé, Obaldía); entering Colombia on the western side of the lower Río Atrato (Unguía, Chocó) and along the shores of the Gulf of Urabá at Acandí, Chocó, on the western side, and Necoclí, Antioquia, on the east.

This is the first published report of this race for Colombia. Specimens from Acandí and Unguía, both near the Panamanian boundary, are like typical examples from Panamá. A series of 7 males from Necoclí on the eastern shore of the mouth of the Gulf of Urabá averages faintly paler, more yellowish green below, and very faintly more yellowish orange on the head. They thus show an approach toward the paler *milleri* of the Sinú Valley to the east, but are to be placed with *vitellinus.*

Gould published the description of this manakin twice, first in the Zoology of the Voyage of H.M.S. *Sulphur,* where it appeared in October 1843 as indicated above. The bird was displayed with 8 other new species from this voyage at a meeting of the Zoological Society in London in July 1843, but publication in the Proceedings did not come until December. In the first publication, in October, Gould states that "The specimen here figured was procured by Mr. Hinds at Panama, and is the only one I have seen." The introduction to the Voyage of the *Sulphur* indicates that the vessel made surveys along the entire Pacific coast of the Republic, but it appears clear that the locality "Panama" refers to the vicinity of Panama City, which is the only place mentioned that lies within the range of *vitellinus.* This is accepted, therefore, as the restricted type locality.

MANACUS VITELLINUS VIRIDIVENTRIS Griscom

Manacus vitellinus viridiventris Griscom, Bull. Mus. Comp. Zoöl., vol. 69, April 1929, p. 179. (Jiménez, near Buenaventura, Valle, Colombia.)

Characters.—Similar to *M. v. vitellinus,* but male with lower breast, abdomen, sides, flanks, under tail coverts, rump, and upper tail coverts definitely darker green; yellow of anterior part of body, including the neck band, somewhat less orange, more yellow; female darker green, in this resembling female *M. v. cerritus,* from which it differs in being somewhat less yellowish on the abdomen, and duller green above.

Measurements.—Males (14 specimens), wing 50.6-53.7 (52.2), tail 26.3-30.6 (28.7), culmen from base 10.8-12.5 (11.6), tarsus 20.4-22.7 (21.5) mm.

Females (6 specimens), wing 53.0-54.3 (53.5), tail 28.1-30.1 (29.5), culmen from base 11.6-12.4 (11.9), tarsus 19.1-20.0 (19.6) mm.

Range.—Western Colombia, from northern Chocó (Río Juradó, Río Jurubidá, Nuquí) and northwestern Antioquia (Villa Artiaga, Dabeiba) south through western Caldas (Santa Cecilia) and Valle (Puerto Muchimbo, Jiménez), including the upper Cauca Valley (Riofrío, Cali).

This race has been supposed to range into extreme eastern Darién at Cana but specimens from that locality agree best with typical *vitellinus.*

MANACUS VITELLINUS MILLERI Chapman

Manacus vitellinus milleri Chapman, Bull. Amer. Mus. Nat. Hist., vol. 34, Dec. 30, 1915, p. 645. (Puerto Valdivia, Antioquia, Colombia.)

Characters.—Much paler than *M. v. vitellinus;* male with head (except for the black crown) and band across hindneck bright, light yellow, without orange; rest of lower surface much paler, being grayish green with a wash of yellow; rump and upper tail coverts paler; female, definitely paler below, being whitish on abdomen, and duller, grayer green above.

Measurements.—Males (11 specimens), wing 49.7-52.9 (51.6), tail 26.8-30.4 (28.6), culmen from base 10.8-12.2 (11.5), tarsus 20.6-22.3 (21.3) mm.

Females (6 specimens), wing 52.5-54.5 (53.7), tail 28.8-30.8 (29.6), culmen from base 11.0-12.0 (11.6), tarsus 19.0-20.0 (19.4) mm.

Range.—Northwestern Colombia, from the valley of Río Sinú (Nazaret, Socarré) in western Bolívar, south to the middle Cauca Valley in northern Antioquia (Tarazá, Puerto Valdivia); recorded from Remedios in east central Antioquia at the head of Río Ité, a tributary of the lower middle Río Magdalena.

In the series at hand this race is typical on the middle Río Cauca in northern Antioquia. In some specimens from the lower Río Sinú, taken at Nazaret, Tierra Alta, Socarré, and Quebrada Salvajín, most of the males have the head somewhat more orange, and the breast and abdomen somewhat darker, varying in the direction of *vitellinus*. They are thus somewhat intermediate, but are definitely near *milleri*.

It has been suggested that *Manacus aurantiacus* (Salvin) found on the Pacific slope of western Panamá would eventually prove to be conspecific with *M. vitellinus*, but my studies to date do not bear out this supposition. Brighter color, particularly in the male, and smaller size mark *aurantiacus* uniformly throughout its range from southwestern Costa Rica through Chiriquí, southern Veraguas, and both sides of the Azuero Peninsula in Veraguas, Herrera, and Los Santos. *Manacus vitellinus vitellinus* from near Santa Fé, Veraguas, and La Campana and Chorrera in the western section of the Province of Panamá, where intergradation, if present, should occur, show no variation from the normal pattern of that race. From present information the two groups appear to be separated by a savanna area in which neither is found. The two appear so completely distinct that there is no basis for uniting them.

Aldrich (1937, p. 95) separated the population of the western side of the Azuero Peninsula as *Manacus aurantiacus flaviventris*, as a series from that area appeared brighter colored than those available at the time from western Chiriquí and southwestern Costa Rica. During the course of my own field investigations I have accumulated a considerable series from Veraguas and eastern Chiriquí, and have examined additional material from western Chiriquí and Costa Rica. A study of this extensive material indicates that the supposed differences do not hold. Males in fresh plumage from both areas are strongly orange, but as the season progresses there is fading, particularly in the dry months when sun is more intense.

The following measurements may be useful for comparison with those of the races of *Manacus vitellinus*.

Males (25 specimens), wing 44.8-47.8 (46.3), tail 26.0-30.2 (28.7), culmen from base 11.2-12.2 (11.7), tarsus 19.5-20.6 (20.1) mm.

Females (21 specimens), wing 47.8-50.0 (48.7), tail 29.0-30.9 (30.3), culmen from base 11.3-12.3 (11.8), tarsus 18.2-20.5 (19.1) mm.

Family Tyrannidae: Tyrant Flycatchers

TYRANNUS MELANCHOLICUS CHLORONOTUS Berlepsch: Tropical Kingbird, Pechi-amarillo Grande

Tyrannus chloronotus Berlepsch, Ornis, vol. 14, 1907, p. 474. (Temax, Yucatán.)

A female was collected and several others seen along a stretch of sandy beach, where they rested on the open ends of branches, or on the tops of low shrubs.

Family Hirundinidae: Swallows

PROGNE SUBIS (Linnaeus): Purple Martin, Golondrina Turquina

Hirundo Subis Linnaeus, Systema naturae, ed. 10, vol. 1, 1758, p. 192. (Hudson Bay.)

On the return journey on March 2 I noted an occasional purple martin flying northward, low over the water, near the mainland coast from the vicinity of Plantain Cay to Chiriquí Point. These swallows are known as migrants through México and Central America, but little is reported regarding them in Panamá. The only published record that has come to my attention is by Zimmer (1955, pp. 4, 5) of an immature male of the southwestern subspecies, *Progne subis hesperia* Brewster, taken at Cocoplum, Bocas del Toro, October 27, 1927.

At Almirante on February 18, 1958, during a forenoon of nearly constant rain, a band of 8 purple martins came to rest in dead branches of a tall avocado tree beside our house. At intervals others arrived until finally between 35 and 40 were present, resting in close formation. When the rain ceased and the sky became lighter two hours later they disappeared. From then until March 6, I recorded purple martins in northward flight, singly or in scattered, straggling groups, across Almirante Bay, along its shoreline, or over the outer beach near Boca del Drago. Occasionally a few came to rest in the tree beside the house. It appears that there is a regular flight in migration along the Caribbean coast.

The female of a pair taken on February 18, in its darker color on the under surface and in wing length of 148 mm., represents typical *Progne subis subis*. The male, with the wing 149.7 mm., agrees in size with that race.

Family Troglodytidae: Wrens

THRYOTHORUS NIGRICAPILLUS Sclater: Bay Wren, Cucarachero Castaño Cabecinegro

Thryothorus nigricapillus Sclater, Proc. Zool. Soc. London, pt. 28, May 1860, p. 84. (Nanegal, 4,000 feet elevation, Ecuador.)

This wren (fig. 2) was the most common land bird on the island, found in pairs scattered through the undergrowth. Though they were encountered most often in low tangles, where creepers were matted and cover was dense, they ranged also out into more open areas, and at times worked up through branches and creepers into the tops of the taller trees. They were quite tame, often appearing within 6 feet or so. On our second day ashore the sky was overcast and it was often difficult to see these birds in the darkly shadowed coverts. We were usually notified of the presence of a pair by the series of repeated notes that made up the clear song. This resembled closely that of *Thryothorus nigricapillus costaricensis* as heard at Almirante, but seemed to be higher in tone and somewhat less varied in repertoire.

One pair worked busily at a nearly completed nest located near the tip of a leafy branch about 6 feet from the ground in heavy undergrowth. This was a ball, nearly round, of palm and other slender

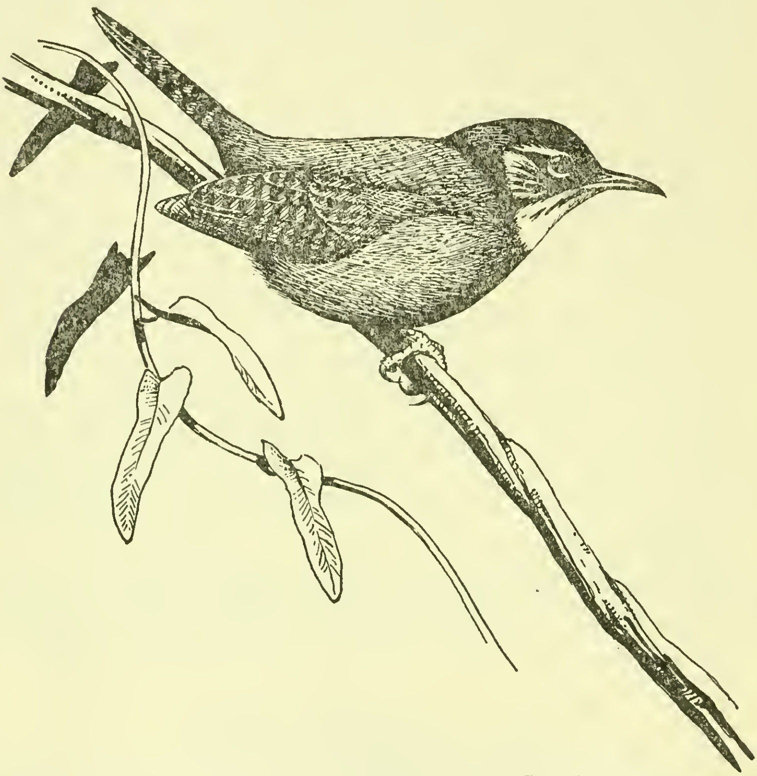

FIG. 2.—Bay wren, Cucarachero Castaño Cabecinegro.

fibers, with the ends projecting all around as a rough fringe. The entrance was in one side.

The larger size and paler color of this island population in comparison with the birds of the adjacent mainland were easily evident in the field. A description of this previously unknown race follows.

THRYOTHORUS NIGRICAPILLUS ODICUS subsp. nov.

Characters.—Similar to *Thryothorus nigricapillus costaricensis* (Sharpe)[2] but larger, with longer, heavier bill; in color paler brown.

[2] *Thryophilus costaricensis* Sharpe, Catalogue of the birds in the British Museum, vol. 6, 1881, p. 217. (Valley of the Río San Carlos, Alajuela, Costa Rica.)

Description.—Type, U.S.N.M. No. 469015, male adult, from Isla Escudo de Veraguas, Bocas del Toro, Panamá, taken March 1, 1958, by Alexander Wetmore (original No. 22230). Throat, upper foreneck, malar region, loral area, a line on the margin of upper and lower eyelids surrounding the eye, a superciliary line extending back from the center of the eye, and the auricular region white, with some mixture of black on loral area and along upper eyelid; crown, hindneck, side of neck, side of head, except as noted above, and a line separating the white malar area from the throat, deep black; back, rump, and upper tail coverts auburn, the tail coverts with short central bars of black along the shaft; wing coverts auburn, with irregular shaft lines and subterminal bars of dusky neutral gray; tertials and outer webs of secondaries auburn, barred heavily with dusky neutral gray; outer webs of innermost primaries auburn, changing on the outer ones to hazel, the brighter color finally reduced to a narrow edging on the ninth and tenth; concealed webs of remiges fuscous-black; rectrices dusky neutral gray, barred narrowly with hazel; breast and center of abdomen ochraceous-tawny; sides and flanks hazel; under tail coverts ochraceous-tawny, barred heavily with black; axillars ochraceous-tawny; under wing coverts ochraceous-buff, mixed with white; edge of wing white. Maxilla dusky neutral gray; mandible pale smoke gray, becoming smoke gray at the base; tarsus and toes fuscous-black (from dried skin).

Measurements.—Males (5 specimens), wing, 75.2-79.2 (77.0), tail 58.6-62.3 (60.2), culmen from base 21.8-24.2 (23.2), tarsus, 28.4-31.8 (29.7) mm.

Females (6 specimens), wing 70.2-72.8 (71.6), tail 54.5-58.8 (56.8), culmen from base 21.0-22.3 (21.5), tarsus 26.2-28.7 (27.2) mm.

Type, male, wing 75.2, tail 58.8, culmen from base 24.0, tarsus 29.1 mm.

Range.—Isla Escudo de Veraguas, at sea off the base of the Valiente Peninsula, Bocas del Toro, Panamá.

Remarks.—The actual difference in measurements will be indicated by consulting the summary of a series of *Thryothorus nigricapillus costaricensis,* the nearest relative, both physically and geographically, that is given in the review of the species that follows.

The name of the new race is from the Latin *odicus,* musical, appropriate because of the pleasing song.

The complete and definite dissimilarity in the lower surfaces found in this group of wrens between the chestnut-breasted, white-throated groups of the Caribbean slope of Nicaragua, Costa Rica, and Bocas del Toro, and the forms with the anterior under surface barred closely with black and white that range from eastern Darién through western Colombia to Ecuador, long led to their separation under two specific names. The series of specimens now available justifies their union under the specific name *nigricapillus,* though it may be supposed that the two terminal groups must have been separated for a long period to have become so completely different. In *costaricensis,* the darkest of the Central American races, and the one farthest removed from those of South America, remote common ancestry with the other is indicated in the rather indistinct black bars found on the breast and sides in the juvenile plumage. This marking may persist in the following plumage, especially on the abdomen, but many are plain chestnut on the posterior lower surface except for the bars on the lower tail coverts that are common to many of the numerous species of the genus *Thryothorus.* Proceeding eastward along the Caribbean coast of Panamá from the valley of the Río Calovevora, on the boundary between the provinces of Bocas del Toro and Veraguas, the wrens of the species under discussion become paler brown, with sides and flanks barred with black, except for occasional plain individuals. This group —the race *castaneus*—is found through the lowland Caribbean drainage of the Canal Zone.

Continuing eastward there is an abrupt change near Portobello and in the foothills of the Cerro Azul in which the plain white of the throat extends down on the upper breast, the brown on the sides becomes paler, and there are strongly marked black bars on sides, lower breast, and abdomen in most individuals. This style—the race *reditus*—crosses to the Pacific slope along the base of the Cerro Azul, and at Chimán has reached the coastal lowlands. On the Caribbean slope it continues almost to the Colombian boundary in the Comarca de San Blas, and on the Pacific side to about the western boundary of Darién near the Golfo de San Miguel. There is then rather abrupt transition to birds with lower surface heavily barred—the race *schottii.* Markings on the white throat are faint or absent, and the brown is restricted to the flanks and under tail coverts. In the valley of the Atrato the barring reaches its maximum and here the throat in most specimens is heavily marked. The plainer throat persists to the eastward in Colombia along the Río Sinú, and on the middle and upper Río Cauca. In southwestern Colombia, beginning in the Department of Cauca, the throat bars begin to lighten still more and to disappear, and farther south, in Nariño, the upper breast also becomes less heavily marked. This style leads over to typical *nigricapillus* of Ecuador, in which throat and upper breast are white, without bars, and the flanks and under tail coverts are lighter brown. In all the changes that have been described these wrens have remained uniformly chestnut above, with black crowns.

One possible explanation of this interesting gradient might be that the plain, chestnut-breasted forms had become established fairly early in the Central American area where they have continued with modification toward the elimination of barring. In the South American area, on the other hand, the barring became intensified. Through a subsequent spread of range in the latter population, the two groups have been brought in contact, with resultant hybridization that has caused the mixing that has been described.

The races recognized as *reditus* and *castaneus* represent two stages in this process. It would appear that the *schottii* group has been the one in active expansion because of the extensive range that it now occupies. It is interesting that the chestnut-breasted group is not found farther north in Central America, though there would appear to be no ecological barrier to prevent this.

Hellmayr (1934, p. 180) includes another group, *Thryothorus semibadius* Salvin, found in tropical lowlands of the Pacific slope from southwestern Costa Rica to western Chiriquí, also as a race of *nigricapillus,* but this does not seem justified. The bird in question is more finely barred, with 3 narrow dark bars on the individual feathers of the breast, and the crown chestnut, concolor with the back; also it is smaller. In the *schottii-nigricapillus* group, which *semibadius* resembles superficially, the black bars are heavier, there are 2 bars on the individual feathers of the breast, the crown and upper hindneck are deep black, and the size is larger. There is no indication whatever of hybridization between *semibadius* and the adjacent *Thryothorus n. costaricensis.* While juveniles of the *costaricensis-nigricapillus* group show spots or a slight wash of brown on the pileum and hindneck, the crown cap remains plainly defined. *Thryothorus semibadius* would appear to be an older offshoot of the ancestral stock that has produced the forms with barred breast, and from its limited range one that may be on its way to extinction.

The following summary, based on extensive series throughout the entire range of these birds, outlines findings as to their relationships and distribution. It should be noted that museum series of skins almost invariably include immature individuals that are not fully grown, especially in the development of the wings. These are easily detected and have been omitted in the measurements that are given under the different forms.

THRYOTHORUS SEMIBADIUS Salvin: Salvin's Wren, Cucarachero Castaño Cabecimoreno

Thryothorus semibadius Salvin, Proc. Zool. Soc. London, November 1870, p. 181. (Bugaba, Chiriquí.)

Characters.—Crown and hindneck chestnut, concolor with the back; under surface white, barred, except for the throat, narrowly with black, the breast feathers having three black bars; size smaller.

Measurements.—Males (8 specimens), wing 61.4-65.5 (63.3), tail 42.0-49.2 (46.3), culmen from base 18.7-21.0 (19.9), tarsus 23.4-24.0 (23.7) mm.

Females (4 specimens), wing 61.2-64.7 (63.2), tail 43.7-47.4 (45.8), culmen from base 19.9-20.8 (20.3), tarsus 23.1-24.5 (23.8) mm.

Range.—Tropical zone of the Pacific slope from southwestern Costa Rica in the valley of the Río Pirris to western Panamá in the Comarca del Barú (Puerto Armuelles), and the lowlands of extreme western Chiriquí (Divalá, Bugaba).

THRYOTHORUS NIGRICAPILLUS Sclater: Bay Wren, Cucarachero Castaño Cabecinegro

Thryothorus nigricapillus Sclater, Proc. Zool. Soc. London, pt. 28, May 1860, p. 84. (Nanegal, 4,000 feet elevation, Ecuador.)

Characters.—Crown and hindneck deep black, in sharp contrast to the chestnut of the remainder of the upper surface; under surface chestnut, auburn, chestnut-brown, clay color, or white, barred more or less with black; in the races that are white below, with 2 black bars on each breast feather; size larger.

THRYOTHORUS NIGRICAPILLUS COSTARICENSIS (Sharpe)

Thryophilus costaricensis Sharpe, Catalogue of the birds in the British Museum, vol. 6, 1881, p. 217. (Valley of the Río San Carlos, Alajuela, Costa Rica.)

Characters.—Throat and upper foreneck white, rest of lower surface auburn to hazel; sides in some specimens with a few bars of black, which usually are indistinct.

Measurements.—Males (17 specimens), wing 66.5-72.0 (69.3), tail 51.0-56.8 (54.3), culmen from base 20.4-22.7 (21.3), tarsus 24.5-27.8 (25.9) mm.

Females (9 specimens), wing 62.5-67.2 (64.6), tail 47.8-54.0 (50.2), culmen from base 19.4-21.7 (20.5), tarsus 23.2-25.6 (24.5) mm.

Range.—Caribbean slope from southeastern Nicaragua (Los Sábalos, Río Escondido, San Juan del Norte) through eastern Costa Rica (Río Frío, Guayabo, Bonilla, Jiménez, Reventazón) to central Bocas del Toro, Panamá. Specimens from Cricamola at the eastern end of the Laguna de Chiriquí are intermediate toward *castaneus.*

Sharpe described this bird from a single specimen that he said was collected by Adolphe Boucard in Costa Rica, without giving a more definite locality. Boucard (1878, p. 51) in an account of his collections made in Costa Rica listed this wren as *Thryophilus castaneus* Lawrence, with the statement "Several specimens, from San Carlos; killed in February." In his itinerary he says that this locality was in the Valley of the Río San Carlos, a tributary of the Río San Juan on the Atlantic slope. I have therefore designated this area as the type locality.

THRYOTHORUS NIGRICAPILLUS ODICUS Wetmore

Characters.—Similar to *T. n. costaricensis* but larger, with longer, heavier bill; paler brown.

Measurements.—Given above.

Range.—Confined to Isla Escudo de Veraguas, off the base of the Valiente Peninsula, Bocas del Toro, Panamá.

THRYOTHORUS NIGRICAPILLUS CASTANEUS Lawrence

Thryothorus castaneus Lawrence, Ann. Lyc. Nat. Hist. New York, vol. 7, June 1861, p. 321. ("Atlantic slope near the Panama Railroad" = Lion Hill, Canal Zone.)

Characters.—Similar to *T. n. costaricensis,* but paler brown on ventral surface, with the white of the throat extending farther down on the foreneck, in some reaching the upper breast; more definitely barred with black on sides and flanks, in some specimens with the bars extending across the lower breast and abdomen.

Measurements.—Males (14 specimens), wing 66.2-70.7 (68.9), tail 49.4-53.7 (51.7), culmen from base 20.3-22.0 (21.0), tarsus 24.9-27.5 (25.8) mm.

Females (17 specimens), wing 63.1-67.0 (64.8), tail 46.3-53.4 (49.2), culmen from base 19.3-21.9 (20.2), tarsus 23.4-25.7 (24.7) mm.

Range.—Caribbean slope from the valley of the Río Calovevora in eastern Bocas del Toro, through northern Veraguas, northern Coclé (extending inland on the northern slope in the higher foothills to the headwaters of the Río Coclé del Norte and the Río Indio), and western Colón (Chilar, Río Indio, Colón, Marajal), to the Canal Zone (Gatún, Lion Hill, Barro Colorado Island, Frijoles).

Back of El Valle, Coclé, I found these birds at 2,000 feet elevation along the upper course of the Río Mata Ahogada, ranging on its higher branches to 2,500 feet. The divide here between this stream, which flows into the Pacific, and the Río Indio of the Caribbean side is low so that rainfall in the heads of the valleys is sufficient to maintain the type of green-leaved undergrowth that these wrens frequent across for a short distance on the Pacific side. The birds here do not range below 2,000 feet elevation where the scrub growth changes to the semiarid type characteristic of the Pacific lowlands of this area. This is the only point known to me at which the race *castaneus* crosses to the Pacific slope. Records of Salvin (1867, p. 134) and of Salvin and Godman (1880, p. 88) for Santiago de Veraguas are not supported by specimens in the Salvin and Godman collections now in the British Museum (Natural History) and are certainly in error.

The type specimen of *castaneus,* described by Lawrence, came to him in a collection made by James McLeannan and John R. Galbraith during the winter of 1860-1861. The collectors were located at Lion Hill, but it must be borne in mind that it is certain they covered a considerable area along the line of the railroad in the course of their work. In the present instance Lawrence (1861, pp. 315-316) states that their specimens were taken "on the Atlantic side of the isthmus" except for half a dozen species that he lists, which do not include the bird here under consideration. Though the type specimen of *castaneus* is labeled only "Panama" with the initials of the collectors, the designation "Lion Hill" found in current literature may be accepted as the restricted type locality.

THRYOTHORUS NIGRICAPILLUS REDITUS Griscom

Thryophilus nigricapillus reditus Griscom, Bull. Mus. Comp. Zoöl., vol. 72, January 1932, p. 358. (Permé, Comarca de San Blas.)

Characters.—Similar to *T. n. castaneus* but with white of breast more extensive; sides, abdomen, and under tail coverts paler, duller brown; more heavily and extensively barred with black.

Measurements.—Males (15 specimens), wing 67.0-70.5 (68.9), tail 47.5-54.3 (52.0), culmen from base 19.3-21.9 (20.9), tarsus 24.0-26.5 (25.5) mm.

Females (11 specimens), wing 63.2-67.7 (65.4), tail 45.0-51.4 (48.5), culmen from base 19.0-21.5 (20.1), tarsus 23.1-26.3 (24.7) mm.

Range.—From eastern Colón (Portobello) eastward on the Caribbean slope through the Comarca de San Blas (Mandinga, Permé, Puerto Obaldía), crossing through the western Cerro Azul to the head of the Río Pacora on the Pacific slope, ranging eastward in the Province of Panamá along the Pacific side of the Serranía de Majé

(Quebrada Cauchero, on the base of Cerro Chucantí), reaching tide-water at Chimán, and on the Río Majé (Charco del Toro).

This race constitutes the definite intergrade between the western group with bright brown breast and little or no barring, and the eastern and southern population with completely barred breast. Transition between *castaneus* and *reditus* on the west is fairly abrupt, an intermediate condition being evident in one specimen from near Frijoles in the Chagres drainage. Birds from near Colón are definitely *castaneus,* while those from near Portobello, 30 kilometers to the east, are *reditus.* At the eastern end the type locality at Permé is barely within the range, since skins from Puerto Obaldía, about 15 kilometers farther east, are intermediate toward *schottii,* which is the race found on the coast at Acandí, Chocó, Colombia, 25 kilometers beyond Puerto Obaldía.

THRYOTHORUS NIGRICAPILLUS SCHOTTII (Baird)

Thryophilus schottii Baird, Review of American birds in the Museum of the Smithsonian Institution, vol. 1, August 1864, p. 123 (in Key); September 1864, p. 133. (Río Truandó, Chocó, Colombia.)

Thryophilus nigricapillus connectens Chapman, Bull. Amer. Mus. Nat. Hist., vol. 31, July 23, 1912, p. 157. (Cocal, 5,000 feet elevation, Cauca, Colombia.)

Characters.—White of throat and foreneck extending down over breast, sides, and center of upper abdomen; lower surface heavily barred with black, in typical form the bars covering the throat, but in intermediate stage the throat partly or wholly plain.

Measurements.—Males (16 specimens), wing 64.0-66.9 (67.3), tail 44.6-51.6 (48.2), culmen from base 19.5-21.5 (20.4), tarsus 24.4-26.8 (25.4) mm.

Females (10 specimens), wing 59.9-65.6 (63.0), tail 43.0-47.8 (45.6), culmen from base 19.0-20.8 (19.6), tarsus 23.0-25.0 (24.1) mm.

Range.—Darién, eastern Panamá, from the lower Río Sambú (Jesusito), and the lower Río Tuira (Cituro, on Río Cupe) inland to 600 meters elevation near Cana, and south to the valley of the Río Jaqué; continuing in Colombia throughout Chocó (from the Pacific coast across to Acandí on the Gulf of Urabá), and western Antioquia in the Atrato valley (Villa Artiaga), and western Valle (Buenaventura and San José), to western Cauca (Cocal); east into southern Bolívar in the upper Sinú Valley (Socarré, Quebrada Salvajín), and northern Antioquia in the lower Cauca Valley (El Pescado), and the valley of the Río Nechí (Regeneración, El Real, Hacienda Belén), crossing to the Río Magdalena drainage on the Quebrada Enanea (Volador).

Remarks.—The typical form of this race, with the throat and foreneck distinctly barred with black, is found mainly in the Chocó. In southwestern Colombia, through western Cauca, the throat barring disappears, and in Nariño the breast appears whiter as the barring on this area is reduced. The birds of this region are intergrades of unstable character between *schottii* and *nigricapillus*. The influence of the *reditus* style of markings produces similar intergrades on the opposite side of the range, beginning in northern Chocó at Acandí on the Gulf of Urabá, and extending across to the upper Sinú Valley and the lower Nechí. Specimens from this area are identical in appearance with those of western Cauca which Chapman named *connectens*. Under these circumstances there is no basis for recognition of such a race, as the supposed characters, unstable at best, are duplicated on the opposite side of the population of typical *schottii*. The birds described are allocated as intermediates to *schottii*, except for those of Nariño which are placed best with typical *nigricapillus*.

THRYOTHORUS NIGRICAPILLUS NIGRICAPILLUS Sclater

Thryothorus nigricapillus Sclater, Proc. Zool. Soc. London, pt. 28, May 1860, p. 84. (Nanegal, 4,000 feet elevation, Ecuador.)

Characters.—Similar to *T. n. schottii*, but averaging lighter brown on back, flanks, and under tail coverts; throat, foreneck, and center of upper breast immaculate, with the barring reduced on the sides.

Measurements.—Males (13 specimens), wing 62.6-67.1 (65.1), tail 44.2-50.8 (48.1), culmen from base 19.1-20.9 (20.1), tarsus 24.0-25.5 (24.6) mm.

Females (6 specimens), wing 63.9-66.8 (65.5), tail 46.6-50.7 (48.7), culmen from base 19.2-21.6 (20.0), tarsus 23.0-25.3 (24.2) mm.

Range.—From western Nariño (intermediate) in Colombia south through the tropical zone of western Ecuador, nearly to the boundary with Perú.

Remarks.—As indicated under *schottii*, specimens from Nariño are intermediate.

Family Mimidae: Mockingbirds, Thrashers

DUMETELLA CAROLINENSIS (Linnaeus): Catbird, Pájaro Gato

Muscicapa carolinensis Linnaeus, Systema naturae, ed. 12, vol. 1, 1766, p. 328. (Virginia.)

Three were noted, and one female was collected.

Family PARULIDAE: Wood Warblers

DENDROICA PETECHIA ERITHACHORIDES Baird: Golden Warbler, Canario Manglero

Dendroica erihtachorides (= *erithachorides,* typographical error, corrected in index) Baird, Report of explorations and surveys . . . for a railroad from the Mississippi River to the Pacific Ocean, vol. 9, pt. 2, Birds, 1858, pp. 283, 976. (Cartagena, Colombia.)

These warblers (fig. 3) were found scattered through the taller trees where they were fairly common, though each of the four taken appeared to be alone. It should be noted that on Escudo they were not restricted to the limited growths of mangroves found near the sea, as is the case on the mainland, but ranged throughout the forest growth, as appears to be the regular habit of this warbler when found on small islands. On the present island they ranked third in abundance among the smaller land birds. The four taken include three adult males which are similar to a small series from the shores of Almirante Bay on the nearby mainland. A female that had just begun the molt from the gray juvenile dress to the yellow adult plumage had the skull fully ossified, indication that this character as a criterion of age is not reliable in tropical areas, where the life cycle of an individual bird is not necessarily arranged on a calendar year basis.

The series from Escudo and from Almirante Bay agree fully with type material of this race, which is interesting since specimens from Limón, Costa Rica, about 100 kilometers to the north, are *Dendroica p. bryanti.*

Family THRAUPIDAE: Tanagers

THRAUPIS VIRENS (Linnaeus): Blue-gray Tanager, Azulejo

Loxia virens Linnaeus, Systema naturae, ed. 12, vol. 1, 1766, p. 303. (Surinam.)

Blue-gray tanagers were fairly common in the taller trees, a number being seen and three collected. It has been unexpected to find that they are so different from the widely distributed race of the mainland that they merit description as an additional subspecies.

THRAUPIS VIRENS CAESITIA subsp. nov.

Characters.—Similar to *Thraupis virens diaconus* (Lesson)[3] but darker, particularly below; central lower surface nearly uniform in shade from throat to under tail coverts; sides definitely darker; bill longer and heavier.

[3] *Tanagra* (*Aglaia*) *diaconus* Lesson, Rev. Zool., June 1842, p. 175. (Realejo, Nicaragua.)

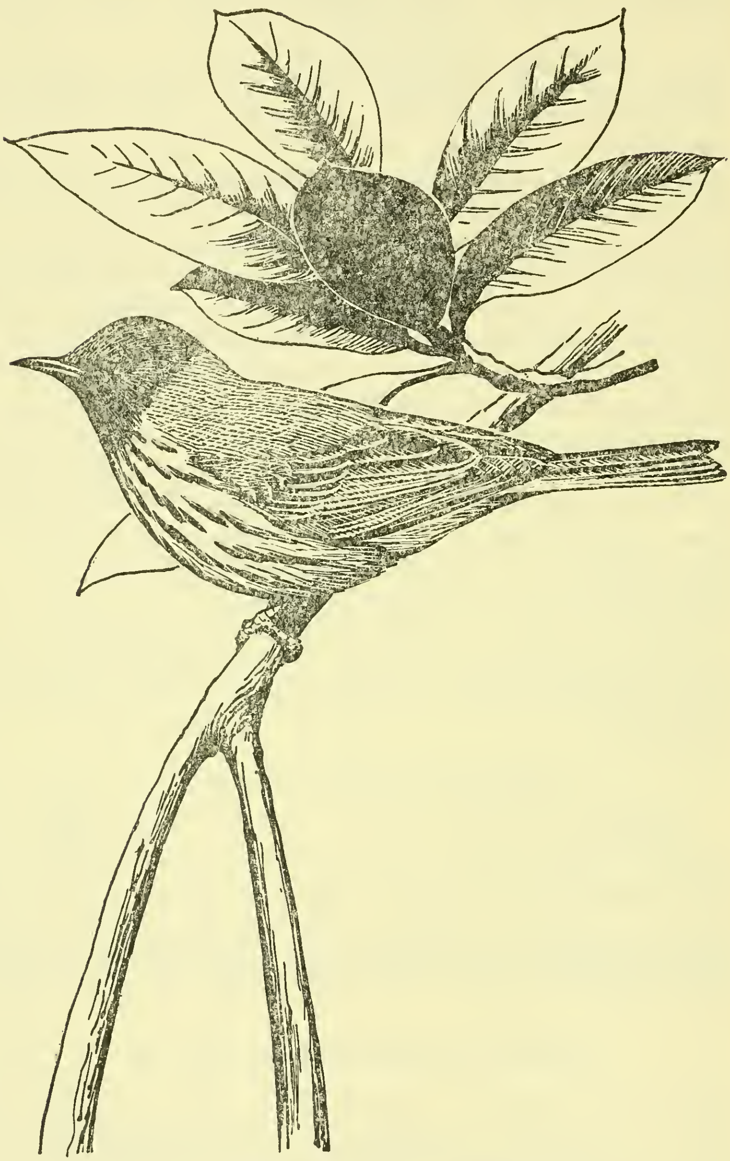

Fig. 3.—Golden warbler, Canario Manglero.

Description.—Type, U.S.N.M. No. 469168, female, Isla Escudo de Veraguas, Bocas del Toro, Panamá, March 2, 1958, collected by Alexander Wetmore (original No. 22248). Crown mineral gray, with a faint wash of gnaphalium green, which is stronger on hindneck; back and scapulars dull greenish glaucous-blue, changing to light glaucous-blue on rump; upper tail coverts bluish gray-green, washed with greenish glaucous-blue at tips; shoulder patch formed by lesser and middle coverts, grayish violaceous blue; primaries and secondaries dusky neutral gray, with outer webs, except for the tips of the primaries, dull Venetian blue; outer webs of scapulars dark gobelin blue; central rectrices and outer webs of others dark gobelin blue, with inner webs of all but the central pair dark neutral gray; median under surface between court gray and gnaphalium green, with center of abdomen faintly whitish; sides gnaphalium green; edge of wing glaucous-blue; under wing coverts light gull gray to white. Bill dull black, except for a wash of hair brown toward base of gonys; tarsus, and toes dusky neutral gray (from dried skin).

Measurements.—Females (3 specimens), wing 87.5-90.1 (88.4), tail 60.1-62.8 (62.3), culmen from base 16.4-18.0 (17.1), tarsus 20.4-20.7 (20.6) mm.

Type, female, wing 90.1, tail 62.8, culmen from base 18.0, tarsus 20.4 mm.

Range.—Isla Escudo de Veraguas, at sea off the base of the Valiente Peninsula, Bocas del Toro, Panamá.

Remarks.—The fact that this widely distributed tanager was represented by a distinct form on this small island was not detected until I began examination of specimens in the preparation of the present report. The three specimens, all females, were taken merely as a matter of routine during my visit. Comparison has been made with a series of recently collected skins, consisting of 15 females of *Thraupis virens diaconus,* and 21 of *T. v. cana.* In none of these is there duplication of the characters on which the race *caesitia* is based. Attention was first drawn to the island form by the large bill, this measuring 13.8 to 15.7 (14.6) mm. in the 15 *diaconus,* and 13.7 to 15.7 (14.7) mm. in the 21 *cana.*

Hellmayr (1936, p. 214) expressed doubt as to the validity of the race *diaconus,* and recently Blake (1958, p. 566) has combined this form with *cana.* In comparing an extensive series taken throughout the range of the two subspecies in question I find, however, that while the two are similar in general, *diaconus* is darker on the back, and slightly duller blue on the rump, in addition to averaging somewhat darker in color below. These characters hold in birds of Central America south through the Isthmus of Panamá, with intergradation in extreme northwestern Colombia. In making comparison it is necessary to separate adult from immature birds, since the distinctions listed are masked when this is not done. I believe the confusion regarding the two races has been due to lack of understanding of this fact.

The name given to the new race, in connection with its darker coloration, is from the Latin *caesitius,* meaning bluish.

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1. Western end of Isla Escudo de Veraguas, from the south.

2. Southern shore of eastern end of Isla Escudo de Veraguas.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 3

FURTHER OBSERVATIONS ON DISTRIBUTION OF PATTERNS OF COAGULATION OF THE HEMOLYMPH IN NEOTROPICAL INSECTS

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(Publication 4379)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
AUGUST 18, 1959

THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

FURTHER OBSERVATIONS ON DISTRIBUTION OF PATTERNS OF COAGULATION OF THE HEMOLYMPH IN NEOTROPICAL INSECTS[1]

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The present paper is a contribution to a long-term inquiry on distribution of patterns of hemolymph coagulation in various arthropods, especially in insects.

The reactions of the main elements involved in the process of coagulation of the hemolymph—a category of unstable hyaline hemocytes (coagulocytes: Grégoire and Florkin, 1950) and the plasma—differ in various insects. These differences, appreciated by phase-contrast microscopy, have been classified into four patterns of microscopic pictures (Grégoire, 1951).

The characters of these patterns may be described as follows:

Pattern I. Inception of the plasma coagulation in the shape of islands of coagulation around the hyaline hemocytes.—Selective alterations in the unstable hyaline hemocytes (shrinkages of the cell body and occasionally of the nucleus, sudden expansions, bulging of blisters and of blebs) result in exudation or in explosive discharge of cell material into the surrounding fluid. Coagulation of the plasma starts in the shape of circular islands of granular consistency around the altered hyaline hemocytes. The islands of coagulation develop to a certain size; then their increase stops. At the beginning of the process, the islands are scattered and separated by fluid channels. When the coagulation proceeds farther, the plasma in these channels clots into a granular substance in which the islands preserve generally their original size and shape.

The mechanism involved in pattern I is identical to one of the types of coagulation described by Hardy (1892), Tait (1910, 1911), Tait and Gunn (1918), Numanoi (1938), and Grégoire (1955b) in crus-

[1] This is No. 9 in a series of papers entitled "Blood Coagulation in Arthropods" published in various journals.

tacean blood, in which a special category of cells, the Hardy's explosive corpuscles, corresponding to the insect hyaline hemocytes or coagulocytes, plays a selective part in the inception of the coagulation of the plasma.

Pattern II. Extrusion of cytoplasmic expansions by hyaline hemocytes, with development of cytoplasmic meshworks. Reaction in the plasma in the shape of veils.—On contacting the glass, a category of fragile hyaline hemocytes undergoes alterations that differ from those characterizing pattern I. These corpuscles extrude threadlike cytoplasmic expansions, sometimes of considerable length. These expansions are highly adhesive to solid particles (dust, chitinous debris), other hemocytes, and physical interfaces (bubbles). These alterations result in formation of cytoplasmic meshworks of various complexity, on which the other kinds of hemocytes are passively agglutinated.

The reaction in the plasma after these cellular changes occurs in the shape of transparent, elastic, and contractile veils, developed within the cytoplasmic systems built up by the hyaline hemocytes, or in their vicinity.

In various insects the alterations in the unstable hemocytes are not followed by changes in the plasma, and the modifications of the hemolymph in vitro consist only of a cellular reaction.

Pattern III. Patterns I and II combined.—Association of the reactions taking place in patterns I and II characterizes the picture in pattern III. In the same film of hemolymph, hyaline hemocytes send out cytoplasmic expansions (pattern II) while islands of coagulation (pattern I) appear around the body of these corpuscles. When they develop within the veils, which characterize the reaction in the plasma in pattern II, the islands form circular, denser areas centered by the altered unstable corpuscles.

Pattern IV. No modification in the hyaline hemocytes, or alterations not followed by visible reaction in the plasma, in the optical conditions of phase-contrast microscopy.—In the pictures of this pattern, hemocytes resembling in their cytological characters the unstable corpuscles involved in the other patterns do not visibly alter. They appear as pale vesicles containing a few dark particles. In several insects, these corpuscles are the remnants of darker refractile, hyaline, frequently oenocytoid-like hemocytes, which undergo clarification after explosive discharge of a part of their cytoplasm. In the vicinity of these inert or altered hyaline hemocytes, no change can be detected under the phase-contrast microscope in the consistency of the plasma.

Specimens from more than 1,000 species of insects and of other arthropods have already been tested about the pattern of coagulation of their hemolymph or blood (Grégoire, 1951, 1953, 1955a, b, 1957, unpublished observations on palearctic insects (1957-1958) ; Grégoire and Jolivet, 1957). Predominance of one of the patterns has been observed in several taxonomic groups. In other groups, owing to the scarcity of the data available, or to large variations in the results, the pattern representative of a species or of a group at a supraspecific level could not be established.

The aim of the present study was to fill some gaps in the data. Four hundred Neotropical insects, belonging to 215 species, including 185 species not yet investigated, were collected and studied during visits to Tingo María, Peru (Estación Experimental Agricola), August 1956, and to the Smithsonian Institution's tropical preserve on Barro Colorado Island (Canal Zone Biological Area), October 1956.

MATERIAL AND METHODS

The samples of hemolymph were mostly thin films prepared as soon as possible after capture. The hemolymph issuing from severed or punctured appendages (antennae, legs, wings, joints of the wing-cases) was placed immediately in contact with the edge of a cover glass lying on a slide and was allowed to spread out into films.

A phase-contrast optical equipment WILD M/10 was used for the observations (see Grégoire, 1955a, p. 105, and 1957, pp. 1 and 3).

RESULTS

DISTRIBUTION OF THE PATTERNS OF COAGULATION OF THE HEMOLYMPH IN INSECTS (TABLE 1)

Detailed descriptions of the four patterns of coagulation of the insect hemolymph, used in the present study, have been given elsewhere (Grégoire, 1955a, p. 104; 1957, pp. 4-6 and text figs. 1-4).

In the table, the names of the species are followed by the numbers of specimens studied (adults, unless otherwise stated) and by the patterns of coagulation provisionally found predominant or representative on the basis of the study of several samples of hemolymph obtained from these specimens. Incidental findings of other patterns are reported under "Comments."

In order to avoid duplication, the patterns recorded in the present study in 50 insects belonging to Neotropical species previously investigated (Grégoire, 1957) are reported in the notes, preceded by the date "(1957)."

The patterns of coagulation have been represented in the table by the following symbols:

●: pattern I: inception of the plasma coagulation in the shape of islands of coagulation around the unstable hyaline hemocytes. Various degrees of extension of the process in the films.

○: pattern II: development of cytoplasmic meshworks by hyaline hemocytes. Reaction in the plasma in the shape of veils.

⊖: pattern II incomplete: emission of cytoplasmic expansions, characterizing the reactions of the hyaline hemocytes in pattern II, but unaccompanied by formation of veils in the plasma.

⊙: pattern III: patterns I and II combined.

—: pattern IV: no visible coagulation by phase-contrast microscopy.

( ): pattern incidentally or exceptionally recorded in limited fields of preparations exhibiting predominantly another pattern.

(?): microscopical characters of a pattern not clear-cut or equivocal. Artifacts possibly involved.

Other abbreviations used: sp., species; spm., specimen; T., specimen captured and studied at Tingo María; B., specimen captured and studied on Barro Colorado Island.

Gradations in the intensity of the reactions, especially with regard to pattern I, are indicated by the following symbols: I poor (scarce fringes of clotted plasma around a limited number of altered fragile hyaline hemocytes, without extension of the coagulation; I (scattered islands of coagulation of various sizes, with moderate coagulation of the fluid outside the islands); I*, I**, I*** (islands around all the hyaline hemocytes, substantial and general coagulation of the film).

TABLE I.—*Patterns of coagulation*

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
Orthopteroid Complex			
DICTYOPTERA			
BLATTODEA [1, 2]			
Periplaneta australasiae (Fabricius) (adult and larva) (T.)..........	2	●	**
Archimandrita tessellata Rehn (B.).	I	●	
PHASMATIDAE [1]			
Pseudophasma menius Westwood ♂ (B.)	I	●	*
Prisopus cerosus Westwood (B.)...	I	●	*
Prisopus ariadne Hebard (B.).....	I	●	**
3 undet. sp. (2 adults, I larva) (T.).	3	●	(**) (***)
ORTHOPTERA			
TETTIGONIIDAE [1-3]			
Scudderia paronae (Griffini) (T.)...	I	●	*
Eupcucestes crassifolius (Haan) ♀♂ (T.)	2	●	**(♂)
Undet. larva (Phaneropterinae) (T.)	I	●	
Acanthodes aquilina (Linnaeus) (B.)	I	●	*
Microcentrum sp.? (B.)...........	I	●	
Neoxiphidion conocephalus saltator (Saussure) ♀ (T.).............	I	●	***
Moncheca pretiosa (Walker) (T.)..	I	●	**
EUMASTACIDAE			
Paramastax sp. (T.)..............	3	●	
GRYLLIDAE [1]			
Paragryllus temulentus Saussure ♂ (B.)	I	●	**
GRYLLACRIDAE [1]			
Abelona salvini (Saussure and Pictet) ♂ (B.)	I	●	

[1] Det. by Dr. C. Willemse.
[2] (Grégoire, 1957) *Epilampra azteca* Saussure (B.): I ***.
[3] (1957a) *Neoconocephalus affinis* (P. de B.) ♀ (B.): I (**); *Caulopsis microprora* Hebard (B.): I.

TABLE 1.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
ORTHOPTERA (continued)			
PROSCOPIIDAE			
Apioscelis verrucosa Brunner Von Wattenwyl ♀ (T.)	1	●	poor
ACRIDIDAE [1–4]			
Orphulella concinnula Walker (T.)	1	●	*
Tetrataenia surinama (Linnaeus) ♀♂♂ (T.)	3	●	poor
Leptysma insularis (Bruner) (T.)	1	●	poor
Undet. sp. (T.)	1	●	**
Dicaearchus (gen. sp. nov.?) (T.)	1	●	**
Legua crenulata Stoll (B.)	1	●	**
DERMAPTERA [1]			
2 undet. sp. (T., B.)	2	●	(**)
Hemipteroid Complex			
HEMIPTERA			
REDUVIIDAE [5, 6]			
Saica meridionalis Fracken and Bruner (B.)	1	—	
Stenopoda cinerea Laporte (B.)	3	—	(○ poor or ⊖)
Rasahus sulcicollis (Serville) (B.)	1	—	(● ?)
Zelus sp.? (nymph) (T.)	1	—	
Zelus sp.? (nymph) (T.)	1	—	
Castolus subinermis (Stål) (B.)	1	—	
Montina lobata Stål (T.)	2	—	
Montina fumosa (Stål) (T.)	1	—	
Brontostoma notatum Stål (B.)	1	—	
Doldina bicarinata Stål (T.)	1	—	
PYRRHOCORIDAE [5]			
Largus balteatus Stål (T.)	1	—	
Dysdercus incertus Distant (T.)	12	—	(⊖)

[4] (Grégoire, 1957) *Copiocera specularis* Gerstaecker: I; *Osmilia flavolineata* (de Geer) (T.): I poor; *Xyleus rosulentus* Stål, 3 larvae (T.): I (**); *Schistocerca paranensis* Burmeister (T.): I poor.

[5] Det. by Dr. J. C. Lutz.

[6] (Grégoire, 1957) *Saica apicalis* Osborn and Drake (B.): —; *Zelurus spinidorsis* (Gray) (B.): — (II poor or incomplete); *Panstrongylus rufotuberculatus* (Champion) (B.): —; *Panstrongylus geniculatus* (Latreille), 3 spm. (B.): — (I?).

TABLE I.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
HEMIPTERA (continued)			
PYRRHOCORIDAE (continued)			
Dysdercus ruficeps (Perty) (T.)...	1	—	(⊖)
Dysdercus sp.? (nymph) (T.).....	1	—	
COREIDAE [5]			
Phthia decorata Stål (T.).........	1	—	
Spartocera fusca (Thunberg) (T.).	1	—	
Plapigus foliaceatus (Blanchard) (nymph) (T.)	2	—	
Anasa haglundi Stål (T.)..........	1	—	
Hypselonotus striatulus (Fabricius) (T.)	1	—	
Paryphes adelphus mutans Horvath (T.)	1	—	
Hyalymenus tarsatus (Fabricius) (T.)	1	—	
Leptocorisa filiformis (Fabricius) (B.)	2	—	
Zoreva dentipes (Fabricius) (T.)...	5	—	(⊖ ?)
Zoreva spinifera Stål (T.).........	2	—	
GELASTOCORIDAE [5]			
Nerthra peruviana (Montandon) (T.)	1	—	(O)
PENTATOMIDAE [5–7]			
Symphylus deplanatus (Herrich-Shäffer) (T.)..................	1	—	
Augocoris gomesii Burmeister (T.).	1	—	
Macropygium reticulare (Fabricius) (T.)	2	—	
Euschistus crenator (Fabricius) (T.)	2	—	
Euschistus sp.? (nymph) (T.).....	1	—	(⊖ ?)
Loxa picticornis Horvath (B.).....	1	—	
Peromatus sp.? (B.).............	1	—	
Edessa affinis Dallas (T.).........	2	—	
Edessa polymita Distant (B.)......	1	—	
Edessa sp. #1 (?) (T.)..........	1	—	

[7] (Grégoire, 1957) *Mecistorhinus piceus* (Palisot de Beauvois) (T., B.), 2 spm.: —; *Edessa rufomarginata* De Geer, 4 spm. (B.): —; *Acrosternum scutellatum* Distant (T.): —; *Neodine macraspis* (Perty), (B.): —.

Table 1.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
HEMIPTERA (continued)			
PENTATOMIDAE (continued)			
Edessa sp.? (B.)	1	—	
Edessa sp.? (nymph) (T.)	1	—	
Edessa sp.? (nymph) (T.)	1	—	
MIRIDAE[5]			
Mimoncopeltus, n. sp. (T.)	1	—	
HOMOPTERA			
CICADIDAE[8]			
Carineta sp., near *boliviana* Distant ♂ (T.)	1	●	
FULGORIDAE[9, 10]			
Copidocephala ornanda (Distant) (B.)	1	●	***
Odontoptera sp. (B.)	1	●	***
Diareusa annularis imitatrix (Ossiannilsson) (B.)	1	●	***
Gen. and sp. unknown (B.)	1	●	**
CIXIIDAE[9]			
Gen. and sp. unknown (B.)	1	—	(?)
DICTYOPHARIDAE[9]			
Nersia florens Stål (B.)	3	●	**
Taosa herbida (Walker) (B.)	1	●	*
Gen. and sp. unknown (B.)	1	●	***
MEMBRACIDAE[8]			
Stictolabus sp. ♀ (T.)	1	●	**
CERCOPIDAE[8]			
Cephisus siccifolius Walker ♀ (B.)	1	●	**
Zulia sp. #1 ♀♂ (T.)	2	●	**
Zulia sp. #2 ♀♂ (T.)	2	⊙	***
Tomaspis sp. #1 ♀ (T.)	1	●	(⊙ ?)
Tomaspis sp. #2 ♂ (T.)	1	●	***(⊙***)
Tomaspis sp. #3 ♀ (T.)	1	●	***
Tomaspis sp. #4 ♂ (T.)	1	●	***
Tomaspis sp. #5 ♂ (T.)	1	●	**
Tomaspis sp. #6 ♀ (T.)	1	⊙	***

[8] Det. by Miss Louise M. Russell.
[9] Det. by Dr. D. A. Young; *Diareusa* by Dr. V. Lallemand.
[10] (Grégoire, 1957) *Calyptoproctus elegans* (Olivier), 2 spm. (B.): I ***; *Cathedra serrata* (Fabricius) (B.): I ***.

TABLE 1.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
HOMOPTERA (continued)			
CERCOPIDAE (continued)			
Tomaspis sp. #7 ♀♂ (T.)	2	●	***(⊙)
Tomaspis sp. #8 ♂ (T.)	1	⊙	***
Tomaspis sp. #9 ♂ (B.)	1	—	(● ?)
CICADELLIDAE[9]			
Tettigellinae			
Diestostemma nigropunctata (Signoret) (T.)	1	●	**(⊙)
Diestostemma sp. ♀ (T.)	1	●	**
Baleja flavoguttata (Latreille) (B.)	1	●	**
Sp. unknown ♀ (T.)	1	●	
Oncometopia sp. # 1, sex anomaly (T.)	1	●	poor (⊙)
Oncometopia sp. #2, normal ♀ (T.) .	1	—	
Sp. unknown (B.)	6	●	* to **
Iassinae			
"Gypona" decorata Fowler (B.)	2	●	poor
Gypona atitlana Fowler (B.)	1	—	(?); ● probable
Gypona hebes Fowler (B.)	3	●	poor to **; (⊙); — in 1 spm.
Polana sp. (B.)	1	—	(?); dry spm.
Ponana sp. (B.)	3	—	(● ?) in 1 spm.
Gyponana sp. ♀ (B.)	1	●	probable.
Negosiana sp. #1 (B.)	1	⊙	
Negosiana sp. #2 ♀ (B.)	2	—(● ?)	● probable
FLATIDAE[9-11]			
Anormelis nigrolimbata (Fowler) (B.)	8	—	(● poor)
Flatormenis sp. (?) (B.)	2	—	(?)
Paradascalia nietvi (Distant) (B.) ..	6	—	(● ?)
ISSIDAE[9]			
Oronoqua sp. (B.)	1	—	

[11] (Grégoire, 1957) *Carthaeomorpha rufipes* Melichar, 3 spm. (B.): 1 **; (—?) in 1 spm.

TABLE 1.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
COLEOPTERA			
ADEPHAGA			
CARABIDAE[12]			
Harpalinae sp. #1 (B.)	1	—	
Harpalinae sp. #2 (B.)	1	—	
Harpalinae sp. #3 (B.)	1	⊖	
Agra sp. #1 (B.)	1	⊖	poor (—)
Agra sp. #2 (B.)	1	○	⊙ probable
Lebiini sp. (T.)	1	—	
POLYPHAGA			
PASSALIDAE[13, 14]			
Passalus (*Neleus*) *interstitialis* Eschsch. (B.)	1	⊖ —	
Veturius sp. (B.)	1	—	(⊖)
SCARABAEIDAE[13]			
Coprinae (Scarabaeinae)[13]			
Canthon sp. (T.)	1	○	
Uroxys gorgon Arrow (B.)	2	—	(⊖)
Rutelinae[13]			
Mesomerodon spinipenne Ohaus (T.)	2	○	*
Pelidnota chlorana Erichson (T.)	2	○	
Anomala virescens Burmeister (T.)	2	○	(⊖)
Anomala sp. (T.)	3	○	
Dynastinae[13, 15]			
Gen. near *Bothynus* (T.)	1	○	
CEBRIONIDAE[16]			
Gen. unknown (T.)	1	●	*
ELATERIDAE[17]			
Chalcolepidius sp. (B.)	1	⊙	(●)
Semiotus sp. (B.)	1	⊙	
LYCIDAE[16]			
Lycus sp. (T.)	1	?	(○ ?)
LAMPYRIDAE[16]			
Photinus sp. (T.)	2	?	

[12] Det. by G. Fagel.
[13] Det. by O. L. Cartwright.
[14] (Grégoire, 1957) *Veturius platyrhinus* Westwood (B.): — (III?).
[15] (Grégoire, 1957) *Aspidolea singularis* Bates (B.): II.
[16] Det. by T. J. Spilman.
[17] Det. by Dr. Ch. Jeuniaux.

TABLE I.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
POLYPHAGA (continued)			
LYMEXYLIDAE [18]			
Melitomma sp. (B.)	1	● or ⊙	
ENDOMYCHIDAE [19]			
Probably *Amphix* sp. (T.)	1	⊖	
COCCINELLIDAE [20]			
Epilachna sp. (T.)	1	—	
Monomeda marginata (Linnaeus) (T.)	1	—	
EROTYLIDAE [19]			
Erotylus, prob. *spectrum* Thomson (T.)	1	○	(⊙ ?)
Prob. *Homoeotelus* sp. (T.)	1	⊖	*, ⊙ probable
Gen. unknown (T.)	1	⊖	
Gen. unknown (T.)	1	⊖	
TENEBRIONIDAE [21]			
Strongylium auratum Laporte (T.)	1	⊙	probable
MELOIDAE [22]			
CERAMBYCIDAE [23]			
Prioninae			
Stenodontes sp. (T.)	1	●	***
Pyrodes sp. (T.)	1	●	***(⊙)
Lamiinae			
Desmiphora sp. (B.)	1	●	(⊙ ?)
Estola sp. (B.)	1	●	poor
Oreodera glauca (Linnaeus) (B.)	1	●	**
Acanthoderes bivitta White (B.)	1	⊙	**(●).
Lagocheirus sp. #1 (B.)	1	●	**
Lagocheirus sp. #2 (B.)	1	●	***
Colobothea sp. (T.)	1	●	**
Charoides sp. #1 (T.)	1	●⊙	***
Charoides sp. #2 (T.)	1	●	**

[18] Det. by Dr. J. G. Rozen.

[19] Det. by Dr. J. G. Rozen.

[20] Det. by Dr. E. A. Chapin.

[21] Det. by T. J. Spilman. (Grégoire, 1957) *Zophobas* prob. *atratus* (Fabricius) (B.): III ** probable.

[22] Det. by T. J. Spilman. (Grégoire, 1957) *Epicauta grammica* (Fischer von Waldheim), 3 spm. (B.): I *** (III).

[23] Det. by George B. Vogt. (Grégoire, 1957) *Taeniotes scalaris* (Fabricius) (B.): I (III).

TABLE I.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
POLYPHAGA (continued)			
CHRYSOMELIDAE br. sense [24]			
EUMOLPIDAE: poss. near *Prionodera* sp. (T.)	1	—	
Chrysomelinae			
Doryphora sp. (T.)	1	—	(⊖)
Stilodes(?) sp. (T.)	1	⊙	
Cosmogramma sp. (T.)	1	(⊖ ?)	(—)
Galerucinae			
Diabrotica sp. (T.)	1	—	
Andrector sp. (T.)	1	—	
Alticinae			
Oedionychus sp. #1 (T.)	2	—	
Oedionychus sp. #2 (T.)	1	—	
Hispinae			
Oediopalpis guerini Baly (B.)	2	—	
Cassidinae			
Cyclosoma tristis Boheman (T.)	1	⊖ —	
Echoma sp., prob. *aulica* Boheman (T.)	1	⊖	poor
CURCULIONIDAE [25]			
Naupactus sp. #1 (T.)	4	—	
Naupactus sp. #2 (T.)	1	—	
Compsus sp. (T.)	3	—	
Heilipus sp. #1 (B.)	1	—	
Heilipus sp. #2 (T. B.)	3	—	
Metamasius sp. (T.)	1	—	
Panorpoid Complex			
NEUROPTERA-PLANNIPENNIA			
MANTISPIDAE [26, 27]			
Climaciella semihyalina (Serville) (B.)	1	—	(⊖ ?)

[24] Det. by George B. Vogt.

[25] Det. by Miss Rose Ella Warner. (Grégoire, 1957) *Exophthalmus jekelianus* (White), 2 spm. (T., B.) : —.

[26] Det. by Miss Sophy Parfin.

[27] (Grégoire, 1957) *Mantispa phthisica* Gerstaecker (B.) : —.

TABLE I.—*Patterns of coagulation*—continued

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
NEUROPTERA-SIALODEA [26]			
CORYDALIDAE			
Corydalus sp., near *armatus* Hagen ♀ (B.)	1	●	***
TRICHOPTERA			
HYDROPSYCHIDAE [28]			
Prob. *Leptonema* sp. ♂ (B.)	1	●	very poor (—)
LEPIDOPTERA			
AMATIDAE sp. (adult)[29] (B.)	1	—	
SATURNIIDAE sp. (larva) (T.)	1	○	*
ARCTIIDAE sp. (larva) (T.)	1	○	poor or ⊖
DIPTERA			
LARVAEVORIDAE [30]			
Ormiophasia bushkii TNS.	1	—	
HYMENOPTERA			
ICHNEUMONIDAE [31]			
Netelia sp. ♀ (B.)	1	—	possibly ●
FORMICIDAE [32]			
Azteca sp. #1 ♀ (B.)	3	—	
Azteca sp. #2 ♀ (B.)	4	—	
Pachycondyla crassinoda (Latreille) ♀ (T.)	1	●	
Dinoponera sp. (worker) (T.)	1	●	***(⊙)
Labidus coecus (Latreille) ♂ (B.) ..	1	?	possibly ⊙
VESPIDAE [33, 34]			
Pachymenes sp. (T.)	1	○	
Polistes major weyrauchi Bequaert (T.)	4	●	
POMPILIDAE [33, 35]			

[28] Det. by Dr. A. B. Gurney.
[29] Det. by W. D. Field.
[30] Det. by C. W. Sabrosky.
[31] Det. by Miss Luella M. Walkley.
[32] Det. by Dr. M. R. Smith. (Grégoire, 1957) *Paraponera clavata* (Fabricius) ♂ (B.): I **; *Camponotus sericeiventris* Guérin, br. sense, 4 workers (B.): possibly III.
[33] Det. by K. V. Krombein.
[34] (Grégoire, 1957) *Polistes canadensis panamensis* Holmgren, 4 spm. (B.): I.
[35] (Grégoire, 1957) *Anoplius a-amethystinus* (Fabricius) (B.): III.

TABLE 1.—*Patterns of coagulation*—concluded

Material	Number of specimens	Patterns of coagulation representative or predominant in samples	Comments
HYMENOPTERA (continued)			
SPHECIDAE [33]			
Sceliphron fistulare (Dahlbom) (B.)	1	●	**
Stictia maculata (Fabricius) (B.)	1	●	**(◉)
ODONATA			
AGRIONIDAE [36]			
Megaloprepus coeruleatus (Drury) (B.)	1	—	
ARACHNIDA [37]			
Araneae			
THERAPHOSIDAE			
Eury (*Brachypelma*) sp. (B.)	1	—	
THOMISIDAE			
Epicadus heterogaster (Guérin) (B.)	1	—	
OPILIONES [37]			
Cosmetidae sp.	1	—	
PEDIPALPIDA [37]			
Tarantula palmata barbadensis Pocock (B.)	1	—	
IXODIDAE [37]			
Amblyomma humerale Koch ♂ (B.)	1	—	

[36] Det. by Dr. A. B. Gurney.
[37] Det. by Dr. J. Cooreman.

MICROSCOPY

The microscopical features of the reactions which characterize the coagulation of the hemolymph in several supraspecific groups of insects (Orthopteroid Complex, Heteroptera, Homoptera, Scarabaeidae, Cerambycidae, Hymenoptera, Lepidoptera) have been described elsewhere (Grégoire, 1955a, pp. 109, 111, 115, 118, 123; 1957, pp. 7, 27, 28; Grégoire and Jolivet, 1957, pp. 28-33). They were also observed in the corresponding groups of the present material. A few particular reactions will be briefly mentioned below.

Phasmoptera.—As repeatedly pointed out (Grégoire, 1951, 1955a, 1957; Grégoire and Jolivet, 1957) the various categories of hemocytes are passively embedded in the coagulum initiated by the alterations in the fragile hyaline hemocytes or coagulocytes. Modifications of the plasma induced around the former corpuscles are exceptional. Such modifications, recorded previously in two specimens of Neotropical stick insects (Grégoire, 1957, p. 7), were observed in *Prisopus cerosus* (table 1) around macronucleocytes of small size (stem cells), secondarily to the typical formation of islands of coagulation around the unstable hyaline hemocytes.

Heteroptera.—Granular precipitates, unrelated to the presence of hemocytes in the vicinity, recorded previously in the same group of insects, were observed in the present material in *Montina lobata, Saica apicalis* (Reduviidae), *Macropygium reticulare,* 3 species of *Edessa* (Pentatomidae), *Anasa haglundi, Zoreva dentipes* (Coreidae). A tentative interpretation of these occasional findings has been given elsewhere (Grégoire, 1957, p. 7).

Coleoptera.—The sequence in the alterations in the fragile hemocytes and in the plasma, characterizing pattern III (see Grégoire, 1957, p. 2 and text fig. 3), appeared with great clarity in the two specimens of Elateridae mentioned in table 1.

In the samples of hemolymph from *Compsus* sp., *Heilipus* sp., *Exophthalmus jekelianus* (Curculionidae), characterized, as shown in the table, by the absence of detectable alteration in the plasma, in the conditions of phase-contrast microscopy, a category of highly labile hemocytes, unrelated to the unstable hyaline hemocytes, underwent considerable modifications in their shape: immediately upon withdrawal and spreading out into films of the hemolymph, these hemocytes appeared spindle-shaped, with two straight expansions on both sides of the cell body. The expansions became progressively flexuous and exhibited continuous trepidations and jerks. They reached great lengths, bent suddenly at right angles, and sent out lateral ramifications in various directions. Simultaneous development of such changes in neighboring hemocytes resulted in constitution of loose meshworks in wide areas of the preparations. Similar labile hemocytes have been reported in African weevils (Grégoire and Jolivet, 1957, p. 32) and in Diptera by Grégoire (1955a) and Jones (1956). In the present material they appeared in *Ormiophasia bushkii* (Diptera).

Much smaller bipolar corpuscles, of unknown origin, unrelated to the labile elements described above, developed similar modifications. A detailed study of these corpuscles will be reported later.

Arachnida. Araneae.—In *Epicadus* and in *Eurypelma,* a category of hemocytes with coarse refractile granules scattered in their cytoplasm and highly sensitive to foreign surfaces underwent disintegration immediately upon shedding of the blood, in contrast to other categories of more resistant blood cells, such as macronucleocytes of small size (stem cells) and other kinds of granular hemocytes. A similar "differential sensitiveness" has been formerly observed in extensive material of spiders (see Grégoire, 1955b).

DISCUSSION

DISTRIBUTION OF THE PATTERNS OF COAGULATION IN THE VARIOUS TAXONOMIC CATEGORIES OF INSECTS

Detailed accounts on the relationships between pattern of coagulation of the hemolymph and taxonomic category have been given in previous papers (Grégoire 1955a, pp. 132-137; 1957, pp. 28-32; Grégoire and Jolivet, 1957, pp. 34-37). In this respect, the information obtained in the present material supports our former conclusions. With one exception (*Carthaeomorpha rufipes,* see below), the pattern detected in the samples of hemolymph collected in the present study (table, notes) from 50 specimens belonging to 30 neotropical species already investigated (1957), were identical to those recorded previously.

1. *Orthopteroid Complex.*

That broad group constitutes a highly homogeneous category with regard to the pattern consistently recorded at the specific and at the supraspecific levels.

2. *Hemipteroid Complex.*

Hemiptera.—With the exception of Nepidae and Belostomatidae, studied previously (Grégoire, 1955a; Grégoire and Jolivet, 1957), all the specimens from 14 other families of Hemiptera investigated, including Reduviidae, Pyrrhocoridae (see 1955a), Coreidae, Gelastocoridae, Pentatomidae, Miridae of the present (38 species) and of former materials, exhibited consistently the pattern IV.

Homoptera.—The present material includes 41 species not investigated previously (Grégoire, 1955a, p. 110; 1957, pp. 15 and 16). Pattern I was predominant in Cicadidae, Fulgoridae, Dictyopharidae, Cercopidae, Cicadellidae, and was recorded in the only specimen of Membracidae captured, a family not yet investigated. In a few Cercopidae (see also 1955a, p. 110) and Cicadellidae, pattern I was associated with pattern II (= pattern III).

A substantial coagulation of the hemolymph, developing rapidly, sometimes instantaneously, characterized these families, with the exception of Cicadellidae, and was especially conspicuous in Fulgoridae.

In Cicadellidae, the amount of clotted material varied greatly and appeared scarcer than in the other groups listed above.

Pattern IV was observed in the samples of Cixiidae, Flatidae, and Issidae. However, in Flatidae, pattern I was found in *Carthaeomorpha rufipes* (table, note 11), a species in which pattern IV had been recorded previously in the only specimen available (Grégoire, 1957, p. 16). Pattern I appeared also incidentally in *Anormelis nigrolimbata* and in *Paradascalia nietvi.* Pattern IV, observed to occur predominantly in the few samples examined till now, is then questionable as being representative of Flatidae, a family which requires further investigation.

3. *Coleoptera.*

The patterns predominant or representative in several groups formerly investigated were seen again in the present material: pattern II in Scarabaeidae (Rutelinae, Dynastinae), pattern III in Elateridae and in Tenebrionidae, pattern I in Meloidae (note 22), Cerambycidae (very substantial coagulation), pattern IV in Curculionidae.

Pattern I, alone or associated with pattern II (= pattern III) was recorded in specimens of Cebrionidae and of Lymexylidae, two families not represented in our former data.

In the other groups listed in the table, scarcity in the material, large variations at the individual, specific, and generic levels, already noticed previously, do not permit conclusions about the pattern predominant or representative of these groups.

In this and in former studies (Grégoire, 1957, p. 22; Grégoire and Jolivet, 1957, pp. 22 and 23), absence or scarcity in clotting substances was observed in several specimens of Eumolpidae and of Cassidinae.

In the present material, pattern III was recorded in one (*Stilodes*) out of 3 specimens of Chrysomelidae s.s., a family involving genera with obviously predominant patterns (see 1955, p. 114: *Chrysolina,* 7 species: patterns I and III; *Timarcha,* 5 species: patterns I and III).

4. *Panorpoid Complex.*

The present results are in agreement with former data with regard to Mantispidae (pattern IV: see Grégoire, 1957, p. 23), Sialodea: *Corydalus* sp. (pattern I, instantaneous reaction: see 1955a, p. 115:

Sialis flavilatera L.); Trichoptera: *Leptonema* (pattern I: see 1955a, p. 116: Limnophilidae sp. and *Anabolia nervosa* Leach); larvae of Lepidoptera (pattern II, see 1955a, pp. 116-118; 1957, p. 23; Grégoire and Jolivet, 1957, p. 25), and adult Diptera (*Ormiophasia bushkii:* pattern IV, see Grégoire, 1955a, p. 121).

As already pointed out, pattern I frequently characterizes insects belonging to relatively archaic orders (Plecoptera, see 1955a, p. 107; Megaloptera, 1955a, p. 115).

5. *Hymenoptera.*

Patterns I and III are representative in several families of this order (Grégoire, 1955, pp. 122-123; 1957, pp. 24-26; Grégoire and Jolivet, 1957, p. 25). However, individual and specific variations may mask the representative pattern of the genus or of the family when only limited material is available.

In the present (note 32) and previous materials (1957, p. 24) of Formicidae, a substantial pattern I characterizes the genus *Paraponera.* Patterns I and III were also recorded, though not consistently, in several specimens of the genus *Camponotus* (1955a, p. 123; 1957, p. 24; Grégoire and Jolivet, 1957, p. 25).

On the other hand, no coagulation could be observed (pattern IV) in seven females of *Azteca* sp., from which the films of hemolymph were collected and prepared without interference of any artifact.

The present observations on Vespidae (note 34), Pompilidae (note 35) and Sphecidae are in agreement with those made previously (pattern I and/or III: 1955a, p. 123; 1957, pp. 25-26).

6. *Odonata.*

As in former studies (1955a, p. 107; 1957, p. 26), pattern IV was recorded in the only (adult) specimen of this order collected in the present material.

7. *Arachnida.*

Coagulation of the blood was not detected in the present and former specimens of Pedipalpa, Ixodidae (1955b, pp. 497-498). Pattern IV was also recorded, in this and in previous studies, in specimens of Opiliones and of *Brachypelma* (Theraphosidae, Araneae), while other specimens of the latter genus exhibited pattern II, sometimes substantial, sometimes incomplete (see 1955b, p. 495).

ON THE DISPARITIES IN THE REACTIONS OF COAGULATION OF THE HEMOLYMPH RECORDED AT THE SUPRASPECIFIC, SPECIFIC, AND INDIVIDUAL LEVELS

1. In contrast to the taxonomic categories characterized by a pattern of coagulation representative or predominant, other groups, especially Carabidae (Grégoire, 1955a, p. 111; 1957, p. 16; Grégoire and Jolivet, 1957, p. 12), exhibit such variations that, in spite of increased samplings, a representative pattern did not appear clearly in these groups at the family level, but provisionally at the generic or specific levels.

In that respect, incidental coincidences may be deceptive and suggest erroneously that a pattern is characteristic of a genus, when it may actually represent an incidental failure of the true pattern to appear with all its particularities in a set of specimens being provisionally, at the time of capture, in similar abnormal conditions. For instance, in three specimens belonging to three different species of the genus *Agra* (Carabidae), pattern II, incomplete in two of these specimens, was predominantly observed in the present study, while formerly, in three other species of the same genus, pattern I had been consistently found (Grégoire, 1957, p. 16). Pattern III, possibly dissociated in the individual samplings into its two components (patterns I and II), might be the representative pattern of the genus *Agra*. Other examples are furnished in Hymenoptera in the genera *Eciton* (1957, p. 24) and *Azteca* (table), in which the predominant patterns are possibly not the actual ones.

In families such as Lycidae, Lampyridae, Coccinellidae, Chrysomelidae (*Cosmogramma*), and Cassidinae (*Cyclostoma*), the observations were handicapped by the presence in the hemolymph of particles floating in considerable numbers, a finding already noticed (1955a, p. 106; 1957, p. 27; Grégoire and Jolivet, 1957, p. 30).

2. Divergences at the specific or individual level recorded in genera characterized by a pattern predominant or representative, appear, for instance, in specimens of Cicadellidae. However, the pattern characterizing the group was found incidentally in the samples (see under comments in the table).

At the individual level, pictures of another pattern were recorded incidentally in limited fields of preparations exhibiting a predominant pattern (Reduviidae: *Stenopoda, Rasahus, Dysdercus;* see also 1955a, p. 109; 1957, p. 13; Grégoire and Jolivet, 1957, pp. 10-11).

Tentative interpretation of these divergences have been presented elsewhere (1955a, pp. 111, 124, 126; 1957, discussion; Grégoire and

Jolivet, pp. 36 and 37). Artifacts of preparation are responsible for a part of the pictures recorded. Nutritional balance of the specimens at the time of capture, seasonal and pathological conditions, able to alter the sensitivity of the unstable hemocytes or the amounts of the coagulable substances in the hemolymph, are among the factors which might explain these discrepancies: change in the pattern of coagulation has been observed in infected insects belonging to species or to groups characterized in their normal conditions by another pattern (Acrididae, Dermaptera, Cerambycidae) (see Grégoire and Jolivet, 1957, p. 36). Similarly, in a specimen of *Gypona hebes* from the present material, exhibiting pattern IV (table, comments), the unstable hemocytes responsible for the inception of the coagulation contained unusual coarse granules, absent in the other normal specimens in which the pattern representative of the group was observed.

The present results support former conclusions (1957, p. 30) that the patterns of coagulation are not individual particularities, but rather characterize species, more frequently supraspecific categories.

DIVERGENCES BETWEEN NEOTROPICAL MATERIAL AND INSECTS FROM THE OLD WORLD

In 10 specimens belonging to 6 species of Neotropical Passalidae (1957, p. 18, and here, table 1), pattern I was recorded exceptionally in one sample from a single species, while this pattern, unmixed or associated with pattern II (= pattern III), appeared in the 5 African species (25 specimens) available (Grégoire and Jolivet, 1957).

Pattern I, absent from the samples of Neotropical Coprinae (4 species, 8 specimens), was found, alone or associated with pattern II (= pattern III), in 12 (29 specimens) out of 17 African species examined (Grégoire and Jolivet, 1957), and was questionable in three other species (5 specimens).

These data might suggest the possibility of discrepancies, with regard to these two families, between Neotropical and Old World material. However, as already pointed out (Grégoire, 1957, p. 32), large individual variations characterize these families, especially Passalidae. Numerous samplings from insects of both origines, and belonging to genera and species more closely related than those available, are required before any conclusion might be drawn about the existence of such discrepancies.

SUMMARY

1. Coagulation of the hemolymph from 400 (mostly adult) specimens, belonging to 215 Neotropical species of insects, and including

185 species not yet investigated, has been observed on films in vitro by phase-contrast microscopy. In that material, the pattern of coagulation predominant in the samples or representative for the species or for the supraspecific taxonomic category has been recorded.

2. The material contained insects from 14 families poorly (Dictyopharidae, Cercopidae, Cicadellidae, Flatidae) or not (Gelastocoridae, Membracidae, Cixiidae, Issidae, Cebrionidae, Lymexylidae, Erotylidae, Hispidae, Corydalidae and Larvaevoridae) represented in previous studies.

3. Additional information obtained for the present paper was consistent with former data, with regard to the pattern predominant or representative, in the Orthopteroid Complex, in several families of Heteroptera (Reduviidae, Pyrrhocoridae, Coreidae, Pentatomidae, Miridae), of Homoptera (Cicadidae, Fulgoridae, Dictyopharidae, Cercopidae, Cicadellidae), of Coleoptera (Scarabaeidae, Elateridae, Tenebrionidae, Meloidae, Cerambycidae, Curculionidae), of Hymenoptera (Formicidae, Vespidae, Sphecidae).

4. In the families not represented in former investigations, pattern I was recorded in specimens of Cebrionidae and of Lymexylidae (Coleoptera).

5. Pattern I was also observed in specimens of Corydalidae (Sialodea) and of Hydropsychidae (Trichoptera), in agreement with previous results on palearctic representatives belonging to these groups.

6. Divergences in the reactions of coagulation observed in the present and in a former study between Neotropical and African Passalidae and Copridae (Coleoptera) require further investigations on more extensive material, owing to the large variations existing in these groups of insects.

7. The reactions of the blood in vitro observed in five specimens of Arachnida (Araneae, Ixodidae, Opiliones, Pedipalpa) are briefly mentioned in relation to previous results on more extensive material.

ACKNOWLEDGMENTS

I am grateful to Dr. Carl B. Koford, former resident naturalist of the Canal Zone Biological Area, for invaluable help in supplying me rapidly with adequate equipment. I also wish to express my thanks to Mrs. A. Gomez, administrative assistant at the station, who, as usual, was very cooperative in arranging for living accommodations in the Canal Zone.

I am greatly indebted to Dr. Ing° Oswaldo Vargas Gonzales, head of the Sección Entomología de la Estación Experimental Agricola en Tingo María (Peru), for authorization to carry on my work in his department. I acknowledge with sincere appreciation the assistance of Dr. Ing° Matias Reyes Valdivieso for rapid and clever adjustment of my optical equipment to one of the microscopes of the department.

I wish to thank Dr. Remington Kellogg, Director of the United States National Museum; Dr. Waldo L. Schmitt, former head curator of the department of zoology, for authorization to have the material determined in the Museum; and Dr. J. F. Gates Clarke, curator of the division of insects, for collecting and mailing the data. I also wish to express my gratitude to the following specialists for identification of the specimens: O. L. Cartwright, Dr. E. A. Chapin, Dr. J. Cooreman, G. Fagel, W. D. Field, Dr. A. B. Gurney, Dr. Ch. Jeuniaux, K. V. Krombein, Dr. V. Lallemand, Dr. J. C. Lutz, Miss S. Parfin, Dr. J. G. Rozen, Miss Louise M. Russell, C. W. Sabrosky, Dr. M. R. Smith, T. J. Spilman, George B. Vogt, Miss Luella L. Walkley, Miss Rose Ella Warner, Dr. C. Willemse, Dr. D. A. Young.

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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 4

A REVIEW OF THE GENUS HOPLOMYS (THICK-SPINED RATS), WITH DESCRIPTION OF A NEW FORM FROM ISLA ESCUDO DE VERAGUAS, PANAMÁ

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(Publication 4380)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
JULY 3, 1959

THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

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A specimen of the thick-spined rat, *Hoplomys gymnurus* Thomas, that Alexander Wetmore shot in a thicket on Isla Escudo de Veraguas on the morning of March 1, 1958, is probably the only mammal from this Caribbean island that is preserved in a museum. Other rats that Wetmore saw in coconut palms on the same day apparently were of another genus. No other mammals have been reported from this locality except feral hogs. Although Indians once lived on the island, human beings are now only transients there.

Escudo de Veraguas is a low island, about 1 mile wide and 2.5 miles long, in the Caribbean Sea, 11 miles off the base of the Valiente Peninsula, Province of Bocas del Toro, north coast of the Republic of Panamá. Wetmore (Smithsonian Misc. Coll., vol. 139, No. 2, 1959) has given a detailed account of the history, geography, and zoological position of the island.

Other echimyid genera, *Diplomys* and *Proechimys,* are known to occur on certain islands in the Gulf of Panamá and elsewhere, but no insular populations of *Hoplomys* have been reported. The Escudo de Veraguas *Hoplomys* differs in so many respects from other known populations of the thick-spined rat that it has prompted a brief review of the genus.

Many of the National Museum (US) specimens reported here were collected in cooperation with the Gorgas Memorial Laboratory, Panamá. I express my thanks to Carl Johnson, director, and other members of the laboratory staff for numerous courtesies and assistance in fieldwork. Some of the specimens were collected by C. M. Keenan of the Army Preventive Medicine Survey Detachment, Ft. Clayton, Canal Zone. Richard Van Gelder kindly permitted the study of specimens in the American Museum of Natural History (AMNH), New York.

Genus HOPLOMYS J. A. Allen

1908. *Hoplomys* J. A. Allen, Bull. Amer. Mus. Nat. Hist., vol. 24, p. 649.

Genotype.—*Hoplomys truei* J. A. Allen.

Distribution.—The genus has a limited distribution in Central America and northwestern South America. It is monotypic. Published records of collecting localities are mapped in figure 1. *Hoplomys* is known to occur at medium elevations (800-3,100 ft.) on the Caribbean slope of the highlands of Nicaragua and Costa Rica; near sea level on the Caribbean coast of Panamá; at medium elevations (600-4,000 ft.) on the Pacific slope of eastern Panamá, Colombia, and Ecuador; and near sea level in extreme southwestern Colombia and northwestern Ecuador. The distribution of *Hoplomys* in South America appears to be limited by the Western Andes. J. A. Allen's record for Puerto Valdivia on the Río Cauca (Bull. Amer. Mus. Nat. Hist., vol. 35, p. 207, 1916) is erroneous (the specimen is a *Proechimys*). *Proechimys cayennensis hoplomyoides* Tate (Bull. Amer. Mus. Nat. Hist., vol. 76, p. 179, 1939) from Mt. Roraima, Venezuela, appears not to be a *Hoplomys,* although a relationship has been suggested (Moojen, Univ. Kansas Publ., Mus. Nat. Hist., vol. 1, p. 324, 1948).

In the Caribbean lowlands of Panamá, where *Proechimys* is abundant and *Hoplomys* seemingly rare, I have trapped individuals of both genera under the same log on successive nights. At medium altitudes in the mountains of Panamá where *Hoplomys* is fairly common, *Proechimys* apparently does not occur.

All the *Hoplomys* that I have collected in Panamá were caught in banana-baited live traps under large decaying logs—in fairly open mature rain forest, in grassy clearings and adjacent streamside thickets, and in dense, hillside *Heliconia* thickets. Goldman (Smithsonian Misc. Coll., vol. 69, No. 5, p. 124, 1920) found *Hoplomys* associated with fallen trees and rocks in Panamanian forests.

Diagnosis.—Dorsum, flanks, and rump, in both adult and juvenile pelages, with spines 26 to 33 mm. in maximum length and 1.5 to 2.0 mm. in maximum diameter, tending to obscure soft fur. Tail shorter than head and body, scaly, and sparsely haired. Ears scantily haired. Hind feet long and narrow; fifth toe scarcely longer than first; claws relatively straight, but claw of second toe slightly expanded. Skull prominently ridged, and supraorbital shelf beaded; rostrum relatively broad at tip; auditory bullae relatively small; and infraorbital foramen without subsidiary canal on floor, and with external wall thin in lateral view. Cheek teeth with oblique folds; counterfold formula normally 4/4-4/4-4/4-4/4, rarely 4/4-4/3-4/3-4/3.

Variation.—Specimens of *Hoplomys* have never before been available in series. Fourteen specimens, seven of which are adult, recently collected on Cerro Azul, Panamá, now permit a fairly good estimate

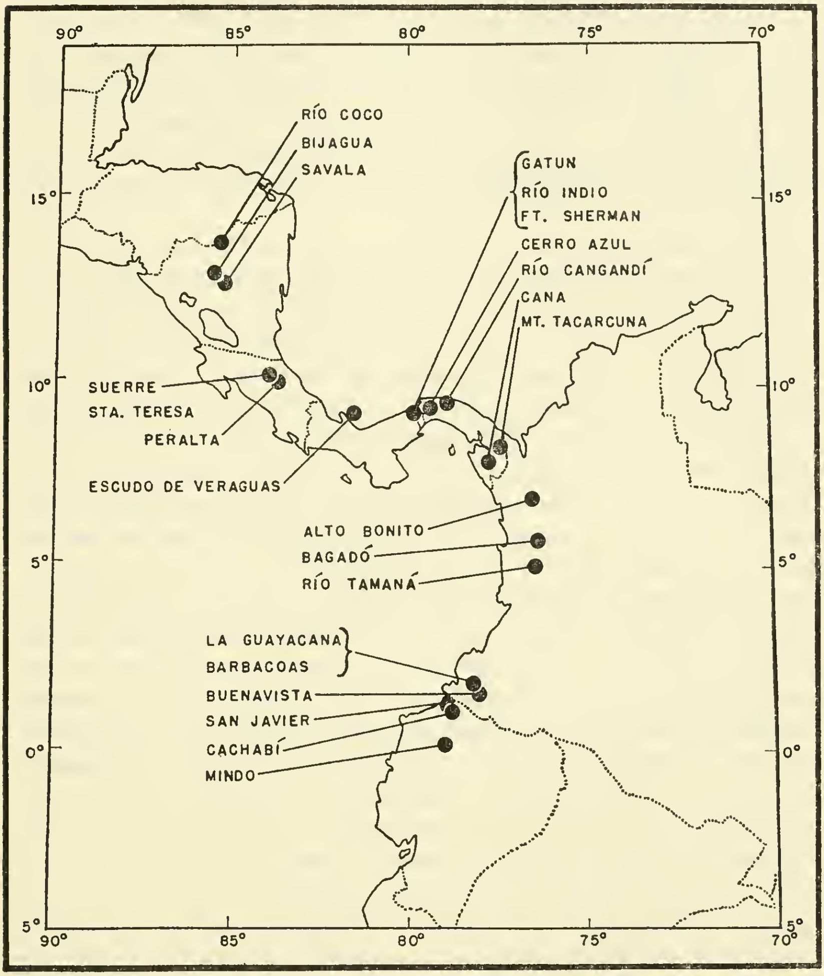

FIG. 1.—Distribution of *Hoplomys gymnurus.* All known specimen localities are indicated.

of individual variation in the genus. Eleven specimens from Darién and nine from the Canal Zone, are also helpful. In addition, random series of up to 75 specimens per sample of the closely related *Proechimys semispinosus* have been used to evaluate the variations seen in the smaller series of *Hoplomys.*

Size, flatness, and ridging of the skull increase with advancing age in *Hoplomys* and *Proechimys.* Tooth wear appears to be a reliable criterion of age. Full adult pelage usually is attained after M3 appears and before it becomes functional. Only juvenile and adult pelages have been distinguished. Specimens in which all cheek teeth are functional are considered to be adults. Generally, the largest, flattest, most heavily ridged skulls have the most worn teeth. Apparently these rodents continue to grow after all teeth are functional. Thus, there is considerable size spread among adult skulls. For this reason only maximum and minimum figures are given in the table of measurements (p. 6).

Body sizes appear to be uniform throughout the mainland range of the species, but larger on Escudo de Veraguas. The skull is narrow in the south—Ecuador, Colombia, and Darién—somewhat broader in central Panamá, Costa Rica, and Nicaragua, and broadest of all on Escudo de Veraguas. Likewise the nasals and cheek teeth are smaller in the southern populations. Size of the auditory bullae increases northward from Ecuador to Nicaragua, but the bullae are largest and most inflated anterolaterally in the Escudo specimen. Several features of the zygomatic arches vary geographically. The maxillary roots of the zygomata flare less widely and less perpendicularly from the longitudinal axis of the skull (so that the zygomata are more convergent anteriorly) from the Canal Zone southward than they do in the north. From Cerro Azul southward the maxillary roots tend to flare up, away from the ventral plane of the skull, rather than paralleling that plane as they do in the north. The jugal has a hooklike posteroventral process in most Canal Zone and Cerru Azul specimens, but not in others. Most of the specimens from Ecuador, Colombia, and Darién, and a smaller percentage of the central Panamanian specimens have a small conical projection on the dorsal edge of the zygoma at the jugal-squamosal suture. I failed to check this character in the Costa Rican and Nicaraguan specimens. There is hardly a trace of it in the Escudo individual. The nasals, broad and posteriorly truncate in the island specimen, are usually narrower and posteriorly acute in mainland populations.

Among mainland populations of *Hoplomys* flatness and ridging of the skulls of mature individuals are similar to these features in mature individuals of *Proechimys semispinosus.* None of the available *Hoplomys* or *Proechimys* closely approaches the Escudo specimen in flatness or ridging, despite the fact that the island specimen, judged by tooth wear, is a prime adult, not as old as many individuals with which it was compared. The degree of reduction of dorsal doming and ventral depression of the brain case of the Escudo specimen is reflected in the convergence of greatest and condylobasal lengths of the skull, and in the more posteriorly oriented (as opposed to ventrally oriented) foramen magnum.

The thick spines that distinguish *Hoplomys* are longest and strongest just behind the shoulders on the upper midback, from which point they diminish in size in all directions. The spines possibly vary geographically in size. They appear to be longer and stronger toward the southern part of the range of *Hoplomys*. The Escudo specimen, although it is larger than any other, has the smallest and weakest spines. Maximum spine length varies as follows (mean, followed by extremes): 6 Ecuador 29 mm. (28-31), 4 Darién 30 (28-33), 11 Cerro Azul 28 (26-29), 5 Canal Zone 28 (27-30), 1 Escudo de Veraguas 26.

Coloration of the spines is individually variable. All specimens have all spines proximally white and distally colored. The tips of those of the dorsum are always black, but the flank spines usually are tinged with orange or banded with orange and black distally. Occasionally the flank spines are colored like the dorsal spines.

Coloration of the soft hairs of the dorsum is geographically variable. At the southern extreme they are reddish orange, especially on the shoulders. The soft hairs of the Escudo specimen are similar but darker and brighter. Costa Rican and Nicaraguan examples have the hairs more orange, and those from Panamá and northern Colombia are more yellowish on the average. The presence or absence of black ocular and crown areas appears to be individually variable throughout the range of *Hoplomys*, but only the Escudo specimen has the soft hairs blackened to form a distinct middorsal stripe from snout to base of tail.

All populations have the underparts dominantly white, and all have some individuals that show encroachment of agouti hairs of the side neck onto the throat, suggesting an incipient collar. This is well marked in the Escudo specimen; one from Río Indio, Canal Zone, has a complete collar. Nine of the 14 Cerro Azul specimens have clear orange collars, and several of them have a band of clear orange hairs separating the agouti hairs of the flanks from the white hair of the belly. Neither of these features is seen in samples of other populations. Coloration of the forefeet (usually white on the inner side, colored on the outer, occasionally colored throughout), and coloration of the cheeks (clear orange, buff, gray, or agouti) are individually variable.

Table 1.—*External and cranial measurements of adult* Hoplomys gymnurus

The minimum and maximum measurements are given in millimeters.

	Total length	Head and body length	Tail vertebrae	Hind foot (c.u., dry)	Ear (from notch)	Greatest length of skull	Condylobasal length
Escudo de Veraguas, Panamá							
1 male	498	313	185	58	23	67.2	62.0
Bijagua, Nicaragua							
1 male	—	270	—	55	—	62.1	55.0
1 female	440	240	200	52	—	60.5	54.2
Sta. Teresa Peralta, Costa Rica							
1 male	—	275	—	61	24	66.1	58.9
Canal Zone, Panamá							
3 males	454–529	221–285	200–244	59–62	24	59.7	53.0
2 females	434	259–260	174	51–59	21	61.1–63.7	54.0–56.0
Cerro Azul, Panamá							
5 males	403–530	218–275	185–255	54–61	22–30	60.6–66.3	52.7–58.3
2 females	423	233–235	188	54–57	23–25	59.6–61.3	52.6–54.2
Darién, Panamá							
6 males	443–519	224–285	184–234	51–60	—	59.5–65.7	52.7–57.6
2 females	439	243–256	196	50–51	—	58.1–62.8	51.3–54.8
S. W. Colombia and N. W. Ecuador							
3 males (only 1 skull)	392–450	243–270	149–180	51–54	22–24	58.4	50.9
4 females (only 1 skull)	396–450	238–265	158–185	50–58	21–27	60.4+	54.5+

TABLE 1.—*Continued.*

	Zygomatic breadth	Interorbital breadth	Mastoidal breadth	Nasal length	Maxillary tooth row *	Incisive foramen length	Palate breadth †
Escudo de Veraguas, Panamá							
1 male	32.3	15.2	24.1	25.6	10.1	6.1	8.6
Bijagua, Nicaragua							
1 male	28.7	14.0	—	23.5	9.5	4.7	7.2
1 female	28.3	13.3	20.8	22.5	9.1	4.7	7.4
Sta. Teresa Peralta, Costa Rica							
1 male	30.1	14.1	22.3	22.1	9.8	5.6	8.3
Canal Zone, Panamá							
3 males	28.4–30.0	13.6–13.8	21.1–22.8	21.9–26.2	8.9–9.5	4.6–5.0	7.2–7.8
2 females	29.4–29.8	13.1–13.1	21.6–21.6	22.0–25.1	9.1–9.6	4.8–.58	7.3–7.4
Cerro Azul, Panamá							
5 males	28.7–30.9	13.5–14.1	21.0–22.7	21.4–25.0	9.0–10.2	4.5–5.6	7.5–8.3
2 females	28.3–29.1	13.4–13.4	20.6–21.4	21.1–22.5	9.5–10.0	4.2–5.2	7.5–8.3
Darien, Panamá							
6 males	26.8–28.6	13.1–13.7	20.8–22.4	20.9–23.5	8.6–9.6	4.2–4.6	7.1–8.2
2 females	27.4–28.4	12.7–13.4	20.3–21.1	19.7–23.0	8.3–8.9	4.0–5.0	7.4–7.5
S. W. Colombia and N. W. Ecuador							
1 male	28.0	12.7	20.8	20.4	8.9	4.3	7.5
1 female	28.7	10.4	21.6	20.9+	8.6	5.1	8.0

* Alveolar length.
† Between outer margins of alveoli of P^4.

The large size of the Escudo specimen, the massiveness, broadness, and heavy ridging of its skull, the inflation of its auditory bullae, and its distinctive coloration all seem to be beyond the possibility of individual variation. This suggests that the Escudo animal is taxonomically distinct from mainland populations. That it is conspecific with them is indicated by its alignment with some of the morphological clines observed in the mainland populations. Wetmore (*op. cit.*) has named three birds (a wren, a manakin, and a tanager) collected on Escudo de Veraguas that differ from their mainland counterparts in greater size, in addition to differences in color.

Classification.—The genus *Hoplomys* is represented by one species, which includes four subspecies:

HOPLOMYS GYMNURUS GOETHALSI Goldman

1912. *Hoplomys goethalsi* Goldman, Smithsonian Misc. Coll., vol. 56, No. 36, p. 10 (Río Indio, near Gatun, Canal Zone, Panamá).

Characters.—Size medium; skull of medium width and ridged; brain case domed and slightly depressed; foramen magnum ventrally oriented; cheek teeth large; auditory bullae medium; zygomata converging conspicuously anteriorly, and maxillary root tending to flare up slightly from ventral plane of skull; jugal with hooklike posteroventral process and small conical posterodorsal projection; nasals long, narrow, and posteriorly acute; dorsal spines long and strong; soft hairs of dorsum appear uniform yellowish orange in mass effect.

Specimens examined.—Panamá: Cana, 2,000 ft., 5 US; Cerro Azul, 2,100 ft., 14 US; Ft. Sherman, 4 US; Gatun, 3 (2 AMNH, 1 US); Cerro Tacarcuna, 2,650 ft., 6 AMNH; Río Cangandí, 200 ft., 1 US; Río Indio, 2 US. Colombia: Alto Bonito, Antioquia, 1,500 ft., 1 AMNH; Bagadó, Chocó, 600 ft., 2 AMNH.

Additional published records.—Colombia: Río Tamaná, branch of the Río San Juan, Chocó (J. A. Allen, Bull. Amer. Mus. Nat. Hist., vol. 35, p. 207, 1916).

HOPLOMYS GYMNURUS GYMNURUS Thomas

1897. *Echimys gymnurus* Thomas, Ann. Mag. Nat. Hist., ser. 6, vol. 20, p. 550 (Cachabí, N. Ecuador, alt. 560 ft.).

Characters.—Size medium or small; skull narrow and ridged; brain case domed and slightly depressed; foramen magnum ventrally oriented; cheek teeth small; auditory bullae small; zygomata converging conspicuously anteriorly, and maxillary root flaring up from ventral plane of skull; jugal lacking posteroventral process, but with prominent conical posterodorsal projection; nasals short, narrow, and posteriorly acute; dorsal spines long and strong; soft hairs of dorsum giving reddish-orange mass effect, slightly darkened on shoulders.

Specimens examined.—Colombia: Barbacoas, Nariño [75 ft.], 8 AMNH; Buenavista, Nariño [1,200 ft.], 1 AMNH; La Guayacana, Nariño, 800 ft., 2 US. Ecuador: Mindo, Río Blanco [4,000 ft.], 1 AMNH; San Javier, 60 ft., 7 (1 AMNH, 6 US).

Additional published records.—Ecuador: Cachabí, 560 ft. (Thomas, *op. cit.*, p. 551).

HOPLOMYS GYMNURUS TRUEI J. A. Allen

1896. *Echimys semispinosus* Alfaro (not Tomes, 1860, Proc. Zool. Soc. London, p. 265), Primera Exposición Centroamericana de Guatemala, Museo Nacional, San José, p. 41 (Suerre, Costa Rica).

1908. *Hoplomys truei* J. A. Allen, Bull. Amer. Mus. Nat. Hist., vol. 24, p. 650 (Savala, Matagalpa Prov., Nicaragua).

Characters.—Size medium; skull of medium width and ridged; brain case domed and slightly depressed; foramen magnum ventrally oriented; cheek teeth large; auditory bullae large; zygomata converging less anteriorly than in *goethalsi,* and maxillary root in plane of ventral surface of skull; jugal without hooklike posteroventral process; nasals long, narrow, and posteriorly acute; dorsal spines relatively short and weak; soft hairs of dorsum giving uniform dark orange mass effect.

Specimens examined.—Nicaragua: Lavala [=Savala, 800 ft., along the inner border of the low east coast region], 2 AMNH; Río Coco [800 ft.], 2 AMNH; Vijagua [=Bijagua, probably 1,500 to 2,000 ft., on eastern slope of highlands in Matagalpa Prov.], 3 AMNH. Costa Rica: Santa Teresa Peralta [3,100 ft.], 1 AMNH; Suerre, 1,500 ft. [near Jiménez], 1 AMNH.

Additional published records.—Tate (Bull. Amer. Mus. Nat. Hist., vol. 68, p. 401, 1935) supposed that True's record (Proc. U. S. Nat. Mus., vol. 11, p. 467, 1889) of *Echinomys semispinosus* in Nicaragua was the first published reference to a *Hoplomys.* The specimens, still in the U. S. National Museum, however, are *Proechimys.*

HOPLOMYS GYMNURUS WETMOREI subsp. nov.

Holotype.—U.S.N.M. No. 307057; adult male, skin and skull; collected March 1, 1958, by Alexander Wetmore; Isla Escudo de Veraguas, Prov. Bocas del Toro, Panamá; original No. 1479.

Characters.—Size large; skull broad and heavily ridged; brain case flattened dorsally and ventrally; foramen magnum posteriorly oriented; cheek teeth large; auditory bullae large and inflated anterolaterally; zygomata converging less anteriorly than in *goethalsi,* and maxillary root in plane of ventral surface of skull; jugal without hook-like posteroventral process, or conical posterodorsal projection; nasals long, broad, and posteriorly truncate; dorsal spines relatively short and weak; and soft hairs of dorsum giving dark reddish-orange mass effect (between Burnt Sienna and Sanford's Brown of Ridgway, 1912, Color Standards and Color Nomenclature), with black middorsal stripe from snout to base of tail. For measurements see table 1.

Specimen examined.—The holotype.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 5

Charles D. and Mary Vaux Walcott
Research Fund

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(With 22 Plates)

By
G. ARTHUR COOPER
Head Curator, Department of Geology
United States National Museum
Smithsonian Institution

(Publication 4382)

CITY OF WASHINGTON
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THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

CONTENTS

	Page
Introduction	1
Acknowledgments	2
Rhynchonelloid morphology	3
Beak characters	3
Interior characters of the pedicle valve	4
Interior characters of the brachial valve	5
Cardinal process	5
Hinge plates	6
Crura	6
Median ridges, median septa, and camerae	9
Exterior characters	10
Ornamentation	10
Folding	11
Rhynchonelloid classification	12
Family and generic arrangement and characters	14
Family Cryptoporidae	17
Cryptopora	17
Mannia	22
Family Basiliolidae	25
Subfamily Basiliolinae	25
Basiliola	25
Eohemithyris	30
Neohemithyris	34
Neorhynchia	34
Rhytirhynchia	35
Probolarina	37
Streptaria	38
Subfamily Aphelesiinae	41
Aphelesia	41
Subfamily Aetheiinae	42
Aetheia	42
Patagorhynchia	44
Family Hemithyridae	45
Hemithyris	45
Notosaria	48
Tegulorhynchia	50
Plicirhynchia	52
Family Frieleiidae	53
Frieleia	53
Compsothyris	56
Grammetaria	58
Family Hispanirhynchiidae	59
Hispanirhynchia	59
Sphenarina	62
Family Erymnariidae	64
Erymnaria	64
Unplaced species	66
References	67
Explanation of plates	73

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INTRODUCTION

For several years the writer has been studying the few brachiopods known from the Tertiary formations in the eastern United States. Most of the species are terebratuloids but a few rhynchonelloids appear in the collection. The Palmer collection of Cretaceous and Tertiary brachiopods from Cuba was also made available. This collection, too, contains a few rhynchonelloids. This group of brachiopods seems to be unusual in Tertiary deposits and the same is true of the rhynchonelloids of modern seas. In the study of the Tertiary forms it proved necessary to compare them with modern representatives. In making these comparisons it became evident that modern rhynchonelloids have been well described in only a few instances and very few of them have ever been adequately illustrated. Inasmuch as the collection of Recent brachiopods in the National Museum contains a good representation of modern rhynchonelloids, the opportunity presented itself to correct the deficiencies outlined above.

In addition to the American Tertiary rhynchonelloids, some species from outside North America are also included. The National collections do not contain many representatives from foreign Tertiary deposits but some good specimens are available from the Mediterranean region and elsewhere. These made possible the figuring and description of some new or little-known genera.

Although this monograph adds considerably to our knowledge of Recent and Tertiary genera of rhynchonelloids it does not include all the known species or all the possible genera. A number of species are known from European deposits but the interior details have never been described, nor were specimens available to use in this study. Consequently it is possible to assign to their proper genera only some of the known species. It is also known that the interior of a number of species differs from that of any of the genera discussed herein, but these species are represented by too few specimens to make generic description possible. Much therefore still remains to be done in the study of the Tertiary and Recent rhynchonelloids.

Possibly the biggest handicap in the study of modern and Tertiary rhynchonelloids is the fact that, except in a few instances, the specimens are quite rare. Several of the Recent species are known from one or two specimens only, yet their morphological details are unique or sufficiently different from known genera to make it impossible to include them in any of the established categories.

Some of the Tertiary species are sufficiently numerous for good descriptive work but their describers seldom made any effort to obtain interior details. Davidson (1870) did not describe the interior of any of the Italian Tertiary rhynchonelloids, probably because emphasis in his day was on description of the species. Later authors seemed to be content to assign many of the modern species to *Hemithyris* regardless of whether or not the interior or exterior details were in accordance with the generic characters of the type species. In present times emphasis is now placed on interior details because it is on them that the family and frequently the generic characters are based.

ACKNOWLEDGMENTS

In any study of this sort it is necessary to ask help of one's colleagues. I am grateful to all the scientists listed below for their help. Dr. Helen M. Muir-Wood, Deputy Keeper, Department of Palaeontology, in charge of the brachiopods in the British Museum (Natural History), furnished a specimen of *Compsothyris,* photographs of *Rhynchonella grayi* Woodward, photographs of serial sections of *R. polymorpha* (Massalongo) and *R. bipartita* (Brocchi), and casts of the specimens serially sectioned. Dr. A. Vandercammen, Subdirector of the Laboratory, Royal Institute of Natural Sciences, Belgium, furnished a specimen of *Mannia nysti* Davidson, a rare Belgian species.

Mrs. Ellen J. Trumbull of the U. S. Geological Survey made available specimens of west coast Tertiary species. Dr. J. H. Peck, Senior Museum Paleontologist of the Museum of Paleontology, University of California, made available a fine suite of topotypes of *Eohemithyris* which made possible preparations of the inner details of that interest-

ing genus described and illustrated herein. Dr. L. G. Hertlein, University of California at Los Angeles, lent paratypes of *Eohemithyris*. Dr. E. Montanaro Gallitelli, University of Modena, Italy, presented the National Museum with specimens of *Rhynchonella polymorpha* (Massalongo) that made it possible to prepare the interior details of the cardinalia described and figured in this monograph.

RHYNCHONELLOID MORPHOLOGY

Throughout geological time the rhynchonelloids have been characterized by triangular to subpentagonal form, with prominent beak and a strong median fold on one valve, usually the brachial valve, and a deep sulcus on the other. Nearly all the genera are provided with a conspicuous beak having a foramen modified by deltidial plates. In some genera, especially a few of the Recent, Tertiary, or Mesozoic ones, the deltidial plates are elaborately auriculate, a feature unusual in other brachiopods. The rhynchonelloid shell is commonly costate; smooth forms are usual in Recent, Tertiary, and Mesozoic families but rare in Paleozoic representatives. The distinctive feature of the rhynchonelloid interior is the more or less long curved crura and hinge plates which characterize the cardinalia. Details of these latter features have long been neglected.

BEAK CHARACTERS

It is not here the intention to discuss these characters for all the rhynchonelloid brachiopods but to point out the significant features shown by the genera discussed herein. Of modern and Tertiary rhynchonelloids only *Cryptopora* and *Mannia* do not have a small round or elongate-oval foramen. In the two genera mentioned the foramen is elongate-triangular and is restricted only slightly by attenuated deltidial plates, which, unlike most other modern and Tertiary genera, form an elevated rim on the sides of the delthyrium.

The nature and completeness of the deltidial plates usually define the form of the foramen. In some genera the deltidial plates are *disjunct,* that is, they do not meet on the anterior side of the foramen. In such cases the foramen is said to be incomplete. An excellent example of this type is *Hemithyris*. When the deltidial plates meet on the anterior side of the foramen, they are spoken of as *conjunct* and the foramen is completely enclosed. Examples are *Basiliola, Aphelesia,* and *Aetheia*. These two conditions of the deltidial plates, disjunct or conjunct, are given considerable weight in genus making by some workers. Yabe and Hatai (1934), for example, distinguished their genus *Neohemithyris* (=*Basiliola*) from *Hemithyris* chiefly on this basis.

Another feature given importance in the study of the rhynchonelloids is the position of the foramen in relation to the beak. A common condition is one in which the entire foramen is surrounded by the deltidial plates and is called a *hypothyrid* foramen. In other genera the foramen has migrated posteriorly because of pedicle pressure and has thus resorbed or worn away the portion of the deltidial plates on its posterior side. In this condition, which is called submesothyrid, the foramen is bounded posteriorly by the beak and anteriorly by the deltidial plates. A further condition is called *mesothyrid* and results from continued posterior migration of the foramen, which has resorbed part of the beak and is bounded posteriorly by part of the curving umbo and the deltidial plates anteriorly. This condition is rare in modern and Tertiary rhynchonelloids.

One of the most characteristic rhynchonelloid features is the rims or winglike extensions that adorn the deltidial plates of some genera. Perhaps the most exaggerated modern examples are those of *Grammetaria* and some species of *Cryptopora* in which the deltidial plates bear prominent lateral extensions. The more common condition is that of *Basiliola* in which the lateral and anterior margins of the deltidial plates in contact with the foramen are reflected dorsally in the direction of the brachial valve and form a conspicuous lip around the foramen. This may have helped, in conjunction with the pedicle collar, to form a tube which strengthened the hold of the valve on the pedicle.

INTERIOR CHARACTERS OF THE PEDICLE VALVE

Most of the Recent and Tertiary rhynchonelloids have the beak and pedicle regions strengthened by a pedicle collar. An elaborate collar is developed in *Basiliola*. The deltidial plates are conjunct and auriculate. Their inner margin grows laterally along the sides of the delthyrial cavity to meet on the floor of the valve. In *B. pompholyx* (U.S.N.M. 274135) the anterior margin of the collar protrudes anterior to the edge of the deltidial plates and is elevated above the valve floor (pl. 12, figs. 9, 10). In *B. beecheri* the anterior ends of the deltidial plates are thickened and expanded inward to form a flat area that rides over the umbo of the brachial valve when the valves are opened and closed (pl. 14, A, fig. 2).

Hemithyris possesses a pedicle collar but it is not complete because the deltidial plates are disjunct. The inner edges of the deltidial plates are extended ventrally to the valve floor where they join to form the collar, but this is never closed at the anterior end. In genera with disjunct deltidial plates the collar is seldom prominently developed. In some instances as in *Frieleia* it forms a callosity at the posterior apex against which the pedicle rests. It is suggestive of the pedicle callist of the Orthoidea in the Paleozoic. In *Cryptopora* no pedicle collar is developed, but a small apical plate elevated above the valve floor serves the same purpose, the pedicle evidently lying against it.

The dental plates are another part of the apical region of the rhynchonelloid of importance in classification and generic definition. Dental plates are generally present in rhynchonelloids from the time of their origin. They are present in all but two of the Recent and Tertiary members discussed herein. Usually they are strong and erect plates which define narrow but distinct umbonal cavities. In a few genera such as *Rhytirhynchia, Aetheia,* and *Patagorhynchia* the dental plates are reduced to mere vestiges or are absent. The only specimen of *Patagorhynchia* available for dissection, that figured on plate 6, A, failed to show any trace of dental plates. *Aetheia* which is usually described as lacking these structures seems to have vestiges of them. *Rhytirhynchia* has fairly distinct dental plates in the Okinawa Pliocene species but they are mere vestiges in the Recent *R. sladeni* (Dall) from the Indian Ocean.

INTERIOR CHARACTERS OF THE BRACHIAL VALVE

The definitive family characters of the brachiopods are in the brachial valve. This is the more conservative of the two valves and thus retains its diagnostic features while parts of the pedicle valve which is fixed to some solid object may be evolving. The most important characters of this valve are the cardinalia which embrace the cardinal process, the hinge plates, crura, and septa. Except for Thomson's (1927) work, no attempt has been made to apply the features of the cardinalia to the classification of Recent and Tertiary rhynchonelloids. Parts of the cardinalia have been used in defining families and subfamilies of the Paleozoic rhynchonelloid genera. These attempts have been based on the presence or absence of a cardinal process. The type of crura and hinge plates, however, have not been used even though they offer the greatest possibilities.

Cardinal process.—In the modern and Tertiary brachiopods this structure does not attain a high state of development and makes little impress on the classification. In some Paleozoic genera the cardinal process is a simple vertical blade, suggesting inheritance from an orthoid ancestor. In the Devonian the cardinal process of some genera, especially the robust forms that have passed under the name *Uncinulus* (=*Sphaerirhynchia*), have elaborate cardinal processes. Some of these appear to be secondary characters and difficult to evaluate in the present meager state of our knowledge. The cardinal process is not highly developed in the few Mesozoic forms, the interiors of which have been described. In modern and Tertiary forms the most prominent cardinal process is that of *Plicirhynchia,* a robust and thick shell.

The cardinal process of several genera such as *Notosaria* (pl. 6, B, fig. 16) and *Hemithyris* (pl. 4, E, fig. 9) appears as a triangular roughened area at the apex. In the younger shells it is scarcely visible but it is fairly prominent in old or obese specimens. The majority of the modern and Tertiary forms have no cardinal process, the diductor muscles being inserted in a pit under the apex. The presence of a cardinal process in rhynchonelloids of this age is thus a ready means of distinction.

Hinge plates.—These structures are an important part of the cardinalia and the combination of them with various kinds of crura makes recognizable patterns. The sockets, which are corrugated in nearly all of the genera discussed herein, are defined by a prominent ridge that curves anterolaterally from the apex or the cardinal process to form a narrow cup defining the socket. This ridge may be high or low, thick or thin, and to its inner side is attached the outer hinge plate or the crus, depending on the genus. The outer hinge plate may not exist in some genera or it may be a fairly broad plate between the socket ridge and the crus. To it are attached the muscles that rotate the animal on its pedicle. The outer hinge plates are especially well developed in *Basiliola* (pl. 12, fig. 15) and *Neorhynchia,* but not present in *Aphelesia.*

The inner hinge plates are seldom well developed but appear in several genera. These are extensions medially from the inside edge of the crura. They are best developed in *Frieleia* (pl. 15, A, fig. 10) where they are so strong that they unite in the middle of the valve to create a small apical chamber somewhat reminiscent of the septalium (or cruralium?) of certain Paleozoic and Mesozoic genera. The inner hinge plates are also developed in exaggerated form in *Aetheia* but in a way different from *Frieleia.* In *Aetheia* they are not flat or slightly concave plates but are great swellings that extend medially from the crura and plug the whole apical region. The degree of development of either of these hinge plates may play a role in genus definition.

Crura.—The crura are the most distinctive part of the rhynchonelloid shell and are usually moderately long, somewhat curved plates extending into the body cavity. To them the body wall is attached and the brachia are attached to the anterior body wall at their extremity. Among the Mesozoic rhynchonelloids several distinctive types of crura have been named. The five types distinguished do not cover the possibilities among the Rhynchonelloidea because the crura of many of the Paleozoic genera have not yet been described and illustrated. Furthermore all these types are not recognizable in the Recent and Tertiary forms.

Rothpletz (1886, p. 86) was the first to name types of crura. He distinguished the following (translated from the German):

1. Radulifer type.—Generally consisting of two dental plates in the larger [pedicle] valve, a median septum in the small [brachial] valve, two hinge plates joined at the beak of the small [brachial] valve, and two narrow crura curved toward the large [pedicle] valve, which at their free lower ends are provided with barbs. One can compare these crura with the radula [Schabeisen] of the Greek athletes and I therefore name rhynchonellas with such crura *radulifer*. (Rothpletz, pl. 11, figs. 20 and 21.)

2. Falcifer type.—The crura, with otherwise like structures, rarely have the form, as with *lacunosa* according to Quenstedt's researches, the form of broad, sharp septa which are extended parallel with the plane of symmetry of the shell and possess a sickle shape (*Rhynchonellae falciferae*). (Rothpeltz, pl. 11, fig. 19.)

3. Septifer type.—There can be, however, such sickle-shaped crura so broad they make contact with the edge directed toward the small [brachial] valve, are grown with it and consequently appear like actual septa extending from the shell (*Rhynchonellae septiferae*). (Pl. 8, figs. 46-48.)

Thirty-four groups or "Sippe" of rhynchonelloids were recognized by Rothpletz but the interior details of 19 of them were unknown at this time. Of the remaining 15 Sippe, 3 belong to the falcifer group (Trilobita, Lacunosa, and Varians), 2 belong to the septifer type (Inversa and Trigona), and 10 are placed in the radulifer group (Amalthei, Variabilis, Concinna, Plicatissima, Tetraëdra, Inconstans, Difformis, Plicatella, Psittacea, and Spinosa). Some of these Sippe have been made into genera but generally little relationship exists between the interior details of many of the species placed in each group.

Wisniewska (1932, p. 6), in her fine work on rhynchonelloids from the Jurassic of Poland, more clearly defines these types and adds a fourth, as follows:

1. Radulifer type.—Crura narrow, recurved toward the ventral valve, widening gradually toward their extremity. This type, characterizing the genera *Septaliphoria, Rhynchonella,* and *Cyclothyris,* was given the name "radulifer" by Rothpletz.

2. Falcifer type.—Crura with a large suspended crural plate, touching the bottom of the valve only near its summit. This is the "falcifer" type of Rothpletz characterizing the genus *Lacunosella.*

3. Septifer type.—Crura short with the crural plates supported at the bottom of the valve and extending for about one-third the valve length. This is the "septifer" type of Rothpletz affirmed by us only in the genus *Septocrurella.*

4. Arcuifer type.—Crura with large bases separated from each other and curved so as to turn their concave sides toward the middle, the extremity turned toward the ventral valve and terminated by a sort of small crural plate in the form of a hammer. This type of crura, seen in the genus *Monticlarella,* may be called "arcuifer."

Muir-Wood (1934, p. 526; 1936, p. 14) added a fifth type as a result of her work on Mesozoic brachiopods:

Calcarifer crura.—". . . The crura consist of two flattened, curved, posteriorly concave laminae which project from the hinge-plate into the cavity of the pedicle valve. These laminae each unite with a second curved lamina which appears to be suspended from it and projects dorsally like a spur. A ventral extension of the second lamina terminates in a hook-shaped process, the apex of which is directed medianly." *Kallirhynchia* and *Rhynchonelloidella* possess this type.

Among the Tertiary rhynchonelloids considered herein five types of crura are distinguishable, three of which have been identified among Mesozoic genera and have been named. Two types have not been named or described among the Mesozoic genera.

Of the three named types *Hemithyris* belongs to the group having radulifer crura. These are long, slender, and curved but have a horizontally flattened, bluntly pointed distal extremity. The *Hemithyris* crus is strengthened by a narrow ridge on the anterior side. The radulifer type of crus is not common among Recent and modern genera.

The second type of crus known in the Mesozoic and present among modern and Tertiary genera is that characteristic of the Basiliolidae and named falcifer type. The Basiliolidae are all characterized by having broad-bladed, gently curved crura that are convex outward and gently concave inward. This crus is generally attached to the hinge plate by its convex side and may or may not be separated from the socket ridge by outer hinge plates.

The third type of named crus is that characterizing the Erymnariidae and called septifer type. This is an extremely rare type of crura known in a few genera only.

A fourth type of crus is recognized in the Cryptoporidae. The crura are long and slender and appear to be continuous with the distal end of the socket ridge. The distal extremity of the crus is commonly flattened, expanded, and serrate or digitate, some examples suggesting a tiny hand with outspread fingers. The name "*maniculifer*" is proposed for this type.

The fifth type of crus in the modern and Tertiary genera is generally shorter than the others, laterally compressed, somewhat flat in section and attached to the hinge plate or socket ridge so that the short direction is nearly vertical or slightly oblique. This type is best seen in *Frieleia,* but *Grammetaria, Hispanirhynchia,* and *Compsothyris* have similar crura. This type is here designated as "*spinulifer.*"

Median ridges, median septa and camerae.—A conspicuous feature of many rhynchonelloid stocks is the median septum. Some groups however, such as the Basiliolinae, are devoid of septa in the brachial valve. The most conspicuous septum in any modern rhynchonelloid is that of *Cryptopora* in which, although short, it is so elevated that it almost touches the inner surface of the opposite valve. The septum of *Frieleia* is also considerably elevated.

In the descriptions below a distinction is made between median septa and median ridges. The term septum is reserved for the thin blades, like those of *Cryptopora* or *Frieleia* that stand boldly and abruptly above the inner valve surface. These are in contrast to the ridges such as that of *Aetheia,* which is low, short, and stout, and that of *Aphelesia* which is low, long, and slender. Dorsally aseptate rhynchonelloids are commonly provided with low and inconspicuous median ridges, some in the form of a myophragm but others buttressing the cardinalia.

In a few genera of Recent and Tertiary, *Frieleia* for example, the median septum joins folds from the inside of the crural bases to form a small chamber at the posterior. In some instances the chamber remains open but it is frequently closed by deposit of shell material on its inner walls to form a thick apical callosity. All degrees occur in *Frieleia* from the open chamber to the solid callosity between the hinge plates. These do not seem to constitute a *septalium* in the true sense of the word as defined by Leidhold (1928, p. 11) who says that the median septum divides to produce the chamber. Wisniewska (1932, p. 6), on the other hand, states that the septalium of the Mesozoic rhynchonelloids is formed by internal inflection of the hinge plate to meet the median septum. This seems to be the method of formation of this structure in *Frieleia* rather than division of the median septum.

The method suggested by Wisniewska seems certainly to be the case in *Septaliphoria* in which it is possible in some specimens to see the median septum between the lateral walls of the apical chamber. The specimen illustrated (pl. 21, C, fig. 6) shows the plates converging to the median septum and bounding a small chamber. In other specimens the plates bounding the chamber meet the floor of the valve rather than the median septum (see Wisniewska, 1932, p. 26, fig. 6).

In *Camarotoechia* (pl. 4, D, figs. 6-8) the entire structure seems to be different from the Jurassic forms and strongly reminiscent of the orthoids. The sides of the chamber buttress the crura which can be seen buried in excess shell tissue surrounding the plates (Kozlowski, 1929, p. 146, fig. 43, A). Division into hinge plates is difficult. The structures of the modern and Tertiary forms with camera seem more like the Mesozoic species than like the Paleozoic.

EXTERIOR CHARACTERS

It is usually difficult to evaluate the generic characters of the exterior of brachiopods and all workers are not agreed on this evaluation. It is, however, quite clear that ornamentation and folding patterns are generic in character.

Ornamentation.—Buckman (1917) and Rothpletz (1886), who made attempts at the classification of rhynchonelloid brachiopods, mostly used the exterior to make genera or species groups which might ultimately become genera. Both of these classifications fail because ornamentation and folding are repetitious in many unrelated stocks. Buckman attempted to make his genera on the basis of a scheme of ornamentation development: those that are smooth and then develop costae, those that are capillate and develop costae and ornate or spinose forms. These characters were combined with shell outline and anterior folding. Buckman, however, failed to determine the characters of the cardinalia.

Rothpletz (1886) arranged many rhynchonelloid species into groups or "Sippe" having similar external characters. Although he determined the nature of the crura of some species he did not reveal the details of all of them. Consequently he placed many species together which are utterly unlike internally.

In modern and Tertiary rhynchonelloids a smooth exterior is common, a capillate or costellate exterior is also fairly common, but a strongly plicate exterior is unusual, occurring in only a few genera. *Rhytirhynchia* is similar to *Basiliola* but differs exteriorly by its anterior costation. *Notosaria* and *Tegulorhynchia* are the only completely strongly costate modern rhynchonelloids. *Rhynchonella grayi* Woodward, the true generic affinities of which are with the Eocene genus *Eohemithyris,* is partially costate but not so strongly costate as the Patagonian genus *Plicirhynchia.*

Folding.—The anterior commissure of most rhynchonelloids is uniplicate but some of them are sulcate or even more complicated. The production of a fold is thought to be related to the feeding habits of the brachiopod, the median fold helping to channel the excurrent stream at midvalve.

Sulcation, brachial valve with sulcus, pedicle valve with fold, is not a common feature of the brachiopods but crops up again and again in many unrelated stocks, producing confusing heterochronous and isochronus homeomorphs. *Neorhynchia* is the only known Recent sulcate rhynchonelloid, but another modern deep-sea form, *Abyssothyris,* is a terebratuloid having a shape identical to that of *Neorhynchia.* If it were not for the punctae of *Abyssothyris* it would be almost impossible to tell the two genera apart on exterior characters alone. Rhynchonelloids of almost identical form to *Neorhynchia* are known from all the periods of the Mesozoic era and from the Paleozoic back at least as far as the Devonian. It is difficult to suggest any reason for the reversal of folding from the usual uniplicate condition because the two types must have functioned in the same manner. It is a common feature of the young brachiopod to have a more robust pedicle valve more or less prominently folded in the ventral direction and with a somewhat sulcate brachial valve. Perhaps sulcation is merely a retention of youthful shell characters into the adult stages.

Several of the modern and Tertiary brachiopods have rectimarginate anterior commissures. This, too, is a youthful character. Buckman emphasized the folding of brachiopods and used this feature as a major part of his classification. It is evident, however, from the above remarks and known brachiopod history that folding is of value only as a generic character. When combined with ornamentation features as Buckman advocated, valid genera have been established. These however can only be placed in their proper families by determination of their beak and cardinalia characters.

RHYNCHONELLOID CLASSIFICATION

Very few comprehensive works have ever been written on the rhynchonelloids. The first to have attempted a detailed classification of these difficult shells was Rothpletz (1886), who divided them into seven species groups and numerous subdivisions of these groups based on exterior details. Although Rothpletz carefully defined the interior of some of the Jurassic rhynchonelloids, using strictly modern methods, he did not bring the information into his classification. Some of Rothpletz's groups and subdivisions bring together species now known to have nothing in common except exterior form. Besides overlooking details of anatomy in his classification, Rothpletz also composed unlikely assemblages from various parts of the geological column.

Bittner's (1890, 1892) great works on the Triassic brachiopods defined in exquisite detail some of the rare and unusual spiriferoids but neglected interior features of the rhynchonelloids except for a few forms. The Triassic rhynchonelloids are a prolific lot and will amply repay in new information a modern, detailed study. Bittner added only a few genera but left many for the future. He, too, was content to work chiefly on exterior details even though the method of serial sectioning was well known and even used by him in some cases.

Hall and Clarke (1894) described many rhynchonelloid genera but never made a serious attempt at classification. They did, however, show the importance of internal characters and described these details in many Paleozoic genera.

Weller (1910) used the serial-section method to make known the details of many rhynchonelloid genera, but he did not go beyond genus making. His work was important for showing that a combination of interior and exterior details is necessary for the correct elucidation of rhynchonelloid descent. He indicated several genera that had interior details like those of *Camarotoechia* but were quite unlike that genus in exterior details. He had, therefore, no other choice than to create new genera for them.

The greatest strides in the understanding of the rhynchonelloids came in Buckman's classic work on the Jurassic brachiopods of Burma and Great Britain. Buckman also proliferated genera more than anyone before him. In his work he relied almost wholly on exterior characters, first on the kind of ornamentation and then on the type of folding of the anterior commissure. These features were supplemented by some details of the interior such as the septa and the muscle scars which were exhibited by a process of calcining the shells.

Unfortunately most of the interior characters developed by Buckman are of secondary importance compared with the cardinalia, which he did not develop. He made no effort to learn the details of these features by serial sectioning as since used by many British authors.

A necessary task of the future is to determine the cardinalia characters of the Buckman genera and then to sort these genera into families based on these characters. It seems likely that most of Buckman's genera will prove useful because the exterior features of most of them are distinctive. It will probably be found that some of these ornamentation patterns will be repeated in combination with various cardinalia patterns. The result will be a further, but necessary, proliferation of genera, but a considerably better understanding of Jurassic genera will be forthcoming. In this connection the writer has determined the interior features of a number of Jurassic rhynchonelloids by etching the shell from limestone. These show the cardinalia of *Septaliphoria* in combination with exterior characters indicating more than one genus. Another interesting feature is variations of the septaliphore interior that promise to be of great interest. Silicified Mesozoic rhynchonelloids occur in South America, Israel, Africa, and elsewhere, and should be sought and prepared because they offer the best opportunity for understanding interior details.

Leidhold (1921, 1922) wrote several papers elucidating the interior of the rhynchonelloid shell. His work in 1921 defined the interior of *Septaliphoria* and two other genera, but he did not make any strides in classification of these brachiopods.

Schuchert, in Schuchert and LeVene (1929), took a stride forward in rhynchonelloid classification when he separated the Camarotoechiidae from the Rhynchonellidae. Unfortunately, however, he did not define the characters of the family. Even with this family divided into three subfamilies Schuchert has many forms of unlike structure classified together. He states that the "Classification into families [of the Rhynchonellacea = Rhynchonelloidea] is not yet satisfactory." No attempt was made to subdivide the Mesozoic and later forms except to group them according to geological periods, and to recognize the Dimerellidae of Buckman.

Thomson (1927, pp. 145-164) discussed Recent and Tertiary rhynchonelloids in detail and made many interesting observations on them. He also assigned the genera to two families. The peculiar and primitive *Cryptopora* was assigned to the Dimerellidae where it seems very unhappy and the rest of the genera were put in the Rhynchonellidae where they are likewise out of place.

Pettit (1950, 1954), in revising the Cretaceous rhynchonelloids of Great Britain, described some details of their interior but his work is disappointing in this respect. In some instances the interior was described by serial sections when direct preparations should have been less time consuming, easier to make, and far better understood. Owen (1955, p. 369) recently described a method for making serial sections of brachiopods preserved in chalk. In the writer's opinion the serial-section method should be a last resort when all others fail. Chalk brachiopods are easy to prepare directly. The serial-section method is destructive of material and the interior characters may be obscured by old age growth and inner injury. Sectioning is far less satisfactory than direct observation unless it is the only course that can be taken.

Rzhonsnitzkaia (1956, p. 125) presented an abstract and outline of a new classification of the order Rhynchonellida of Moore 1952. This classification is more elaborate and complete than any hitherto published but the families are not defined and the characters on which they are based are not stated. Family splitting of the rhynchonelloids has been so long needed that the characters of some of Rzhonsnitzkaia's new families and subfamilies are quite obvious. For a few, however, they are not so clear. Among the younger rhynchonelloids the only new category introduced is the Hemithyrinae, which will probably receive general acceptance, and is here elevated to family status.

FAMILY AND GENERIC ARRANGEMENT AND CHARACTERS

This brief survey of rhynchonelloid classification indicates that fundamental work is still to be done on the group. These shells are difficult, but they can be made to yield good interiors by simple methods of manual preparation or by serial sectioning. The writer attempts below to group into families the Recent and Tertiary rhynchonelloids on the basis of their interior details combined with features of the exterior. The cardinalia characters in their over-all pattern are, in accordance with his work on the orthoids, triplesioids, pentameroids, and several other groups, regarded as of family rank. Some details of the cardinalia are generic but mostly they help to define families. The generic characters are found in minor interior details combined with ornamentation features and beak characters of the pedicle valve. This is well shown by the number of genera in the Paleozoic that have the internal characters of *Camarotoechia* but vary in external form and ornamentation: *Paraphorynchus, Camarotoechia,* and *Pugnoides* are examples. The principle is well exemplified by the families described below.

Family Cryptoporidae Muir-Wood, 1955.—Primitive rhynchonelloidea having a large deltoid foramen slightly restricted by elongate, triangular, elevated deltidial plates; crura long, maniculifer, continuous with the socket ridges; median septum strongly elevated; cardinal process a lobate thickening between the socket ridges; one pair of nephridia.

Genera: *Cryptopora* and *Mannia.*

Cryptopora.—Triangular in outline, exterior smooth.

Mannia.—Exterior spinose, with spoon-shaped expansion of median septum of brachial valve (validity of genus in question, see text, p. 22).

Basiliolidae Cooper, new family.—Smooth or semicostate rhynchonelloids having conjunct deltidial plates and small auriculate foramen; pedicle valve with dental plates varying from nearly obsolete to strong, pedicle collar well developed; brachial valve with broad falcifer crura supported by outer hinge plates or the socket ridge; no median septum but a median ridge may be present.

Subfamilies: Basiliolinae, Aphelesiinae, and Aetheiinae.

Basiliolinae Cooper, new subfamily.—Basiliolidae with crura attached to broad outer hinge plates; no median septum.

Genera: *Basiliola, Eohemithyris, Neorhynchia, Rhytirhynchia, Probolarina,* and *Streptaria.*

Basiliola.—Brachial valve much deeper than the pedicle valve; pedicle collar elaborate; exterior smooth; anterior commissure strongly uniplicate.

Eohemithyris.—Valves subequal in depth, smooth to semicostate; anterior commissure uniplicate.

Neorhynchia.—Deltidial plates disjunct; exterior smooth but anterior commissure sulcate; incipient inner hinge plates.

Rhytirhynchia.—Outline like that of *Basiliola* but anteriorly costate; anterior commissure sulciplicate.

Probolarina.—Beak elongated; deltidial plates well exposed; anterior half strongly costate; elaborate pedicle collar; anterior commissure uniplicate.

Streptaria.—Exterior smooth to semicostate; anterior with sides twisted; foramen with reflected rim; dental plates reduced; pedicle collar poorly developed.

Aphelesiinae Cooper, new subfamily.—Basiliolidae with crura attached directly to side of socket ridge; thick median ridge present in brachial valve.

Genus: *Aphelesia.*

Aphelesia.—Smooth to anteriorly costate; anterior commissure uniplicate.

Aetheiinae Cooper, new subfamily.—Basiliolidae having a minute foramen, concave deltidial plates, reduced to obsolete dental plates and thick inner hinge plates.

Genera: *Aetheia* and *Patagorhynchia.*

Aetheia.—Elongate triangular in outline and exterior smooth.

Patagorhynchia.—Costellate and anteriorly imbricate.

Family HEMITHYRIDAE Rzhonsnitzkaia, 1956 [proposed as a subfamily].—Rhynchonelloidea with strong, slender, curved radulifer crura attached to small outer hinge plates by their posterodorsal face or to thick socket ridges; crura distally pointed and horizontally flattened.

Genera: *Hemithyris, Notosaria, Tegulorhynchia,* and *Plicirhynchia.*

Hemithyris.—Beak long, surface striate to costellate; deltidial plates disjunct.

Notosaria.—Beak short; exterior costate; nonimbricate; deltidial plates disjunct.

Tegulorhynchia.—Costellate to costate, strongly imbricate to spinose; deltidial plates conjunct?; medium septum reaching apex.

Plicirhynchia.—Long beak, posterior striate to costellate, anterior costate to plicate; deltidial plates conjunct.

FRIELEIIDAE Cooper, new family.—Usually capillate to costellate valves with triangular outline, strong dental plates, and brachial valve with short, straight, laterally compressed spinulifer crura supported by short plates that unite with the median ridge or septum to form a small chamber.

Genera: *Frieleia, Compsothyris, Grammetaria.*

Frieleia.—Elongate shells with the pedicle valve having the greater depth and the brachial valve with a high median septum; anterior commissure rectimarginate to ligate; deltidial plates disjunct; inner hinge plates extravagantly developed.

Compsothyris.—Roundly triangular in outline; valves of subequal depth; median septum only moderately elevated and deltidial plates disjunct; anterior commissure gently uniplicate; inner hinge plates incipiently developed.

Grammetaria.—Elongate, costellate shells with rectimarginate anterior commissure, low, thick median septum, and conjunct, strongly auriculate deltidial plates; inner hinge plates incipient.

HISPANIRHYNCHIIDAE Cooper, new family.—Triangular, capillate rhynchonelloidea having a weak median ridge or no median ridge in the brachial valve; crura spinulifer; anterior commissure rectimarginate to ligate.

Genera: *Hispanirhynchia* and *Sphenarina.*

Hispanirhynchia.—Deltidial plates disjunct and median ridge of brachial valve low and thick; inequivalve, the pedicle valve being the deeper; inner hinge plates strongly developed.

Sphenarina.—Deltidial plates conjunct; subequivalve; brachial valve with no median ridge; slight or no development of inner hinge plates.

ERYMNARIIDAE Cooper, new family.—Rhynchonelloidea having septifer crura.

Genus: *Erymnaria*.

Erymnaria.—Exterior smooth, inequivalve; anterior commissure uniplicate to twisted; deltidial plates conjunct; the brachial valve having the greater depth.

Family CRYPTOPORIDAE Muir-Wood 1955

Genus CRYPTOPORA Jeffreys, 1869

Plates 1, A, B, 2, A, 5, C, 21, D; text figure 1A

Cryptopora Jeffreys, Nature, vol. 1, p. 136, 1869 (inadequately described, not figured); Thomson, Geol. Mag., n. s., dec. 6, vol. 2, pp. 387, 388, 392, 1915; Thomson, New Zealand Board Sci. Art, Manual 7, p. 146, 1927.

Atretia Jeffreys, Proc. Roy. Soc., vol. 18, No. 121, p. 421, 1870 (inadequately described, not figured); Ann. Mag. Nat. Hist., ser. 4, vol. 18, p. 250, 1876; Proc. Zool. Soc. London, p. 412, 1878; Davidson, Trans. Linnaean Soc., ser. 2, vol. 4, pt. 2, p. 173, 1887. Not *Atretium* Cope, 1861.

Neatretia Fischer and Oehlert, Exped. Sci. *Travailleur* et *Talisman*, p. 122, 1891.

Mannia Davidson, Geol. Mag., dec. 2, vol. 1, No. 4, p. 156, 1874(b).

Small, translucent to transparent, subtriangular in outline with the greatest shell width anterior to the middle; subequivalve; anterior commissure rectimarginate to broadly sulcate; surface smooth. Beak of the pedicle valve moderately long, pointed, nearly straight; foramen large, incomplete, not restricted; deltidial plates rudimentary, forming a ridge on the delthyrial edge, auriculate to alate. Shell fiber mosaic coarse.

Pedicle valve interior with small noncorrugated teeth; apex with thickened plate elevated above valve floor; teeth supported by strong, divergent dental plates. Muscle scars not well impressed.

Brachial valve interior with small, smooth or roughened sockets bounded by high socket ridges; socket ridge overlying crural base; crura of maniculifer type, long and slender, slightly curved, expanded distally and commonly with the distal edge deeply digitate. Cardinal process small, bilobed and transverse. Median septum high anteriorly but sloping steeply to the valve floor posteriorly and disappearing anterior to the apex; anterior face of septum steep. Adductor scars lightly impressed. One pair of metanephridia in the fleshy body of the animal.

Type species (by monotypy).—*Atretia gnomon* Jeffreys. Ann. Mag. Nat. Hist., ser. 4, vol. 18, p. 251, 1876.

Comparison.—This is a very distinctive little brachiopod and cannot be confused with any other modern form. It is characterized by a yellowish to white and shiny, transparent to translucent shell having peculiar deltidial plates, long, slender maniculifer crura and a short, high, slender median septum. The only described genus similar to it is *Mannia* which is said to differ in the form of the septum and the possible presence of spines on the exterior. (See *Mannia*.)

Cryptopora has frequently been compared with the Triassic genus *Dimerella* but the two are actually very different. The median septum of the brachial valve of *Dimerella* has a different form, the deltidial region of the Triassic shell is different, and the dental plates are much less strongly developed than those of the modern genus. The exterior of the two genera is also quite different, the Triassic shell being wide with a fairly wide hinge and costellate exterior. The modern genus on the other hand is narrowly triangular and smooth.

Geological horizon.—*Cryptopora* was recorded from the Eocene (Salt Mountain formation) by Toulmin (1940, p. 229). It is also known from the Oligocene of Cuba and Miocene of Europe (see below and *Mannia*).

Thomson (1927, p. 147) cites *Rhynchonella discites* Dreger from Vienna, *R. lovisati* Dreger from Sardinia, and *Hemithyris parvillima* Sacco from Italy, all from the Miocene, as possible fossil examples of *Cryptopora.* Thomson also cites *Terebratella acutirostra* Chapman, a possible synonym of *C. brazeri* from the Miocene of Victoria, Australia, as another fossil species. The geological range is therefore from Eocene to Recent.

Distribution.—In the North Sea and North Atlantic south to Cuba in waters ranging from 75 to 2,200 fathoms. In the Southern Hemisphere it occurs off New South Wales in 17 to 100 fathoms, and on southern Agulhas Bank, South Africa, in 500 to 565 meters or about 275 fathoms.

Assigned species.—The one Eocene form known was not named but species are known from the Miocene and in modern waters:

Atretia gnomon Jeffreys, Recent, North Atlantic.
A. brazeri Davidson, Recent, east Australia.
Cryptopora boettgeri Helmcke, Recent, southern Agulhas Bank, Africa.
C. rectimarginata Cooper, Recent, East coast Florida, Cuba.
? *Rhynchonella discites* Dreger, Miocene, Vienna.
? *R. lovisati* Dreger, Miocene, Sardinia.
? *Terebratella acutirostra* Chapman, Miocene, Australia.
? *Hemithyris parvillima* Sacco, Miocene, Italy.
Mannia nysti Davidson, Miocene, Belgium.

Discussion.—This genus differs strongly from other modern and Tertiary rhynchonelloids except *Mannia* which is discussed below. The form of the median septum and crura are unique and the deltidial plates are formed differently from those of the other rhynchonelloid genera.

The deltidial plates of *Cryptopora* are disjunct throughout life. The foramen is not greatly restricted by these plates because they usually grow at a high angle to the edge of the delthyrium rather than being a continuation of it. The foramen is thus incomplete and not circular but is deltoid and roughly parallel to the delthyrial margins.

The deltidial plates are small and elongate triangular, forming on the delthyrial margin at a high angle and commonly reflected laterally to overhang the dorsolateral slopes of the beak. In *Cryptopora rectimarginata* Cooper, new species, the deltidial plates are strongly alate, the projections being located near the posterior of the plate and narrowly rounded, bluntly pointed or rarely serrated. In the older shells the blunt points disappear.

The apex of the pedicle valve is occupied by a small elevated triangular plate against which the pedicle rests. A plate similar to this appears in other genera, such as *Hemithyris.* Aside from the strong dental plates the pedicle valve reveals no other structures. The shell is so thin that muscle scars cannot be seen easily. A suggestion of a low myophragm appears in some specimens.

The cardinalia of the brachial valve are unusual. The socket plates are small and delicate, appear to be continuous with the crural bases and lie above or posterior to them. The socket plates are attached directly to the shell wall and buttressed for a short distance by a small supporting plate. The crura are long and welded with the crural bases and supporting plates in such a way that they appear to make one plate. The main part of the crura are strong but slender and are bowed outward to a considerable degree in older specimens, less so in the young ones. The distal extremity is flattened laterally and the free end serrated or frayed into a number of small prongs. The whole suggests a tiny hand with outstretched spreading fingers or a flattened fist.

The diductor muscles were attached to a bilobed boss or cardinal process at the posterior apical part. This is somewhat thickened in old shells, the thickening spreading to the base of the crura and uniting with an extension of the median septum.

The most conspicuous feature of the brachial valve is the median septum. It is highest at about midvalve but descends rapidly posteriorly to disappear before reaching the apex in young shells. In old specimens a low extension of the septum extends to the apex where it unites with a thickening from the cardinal process. The septum thus makes a narrow wedge extending ventrally almost to the inner wall of the pedicle valve.

I have not observed the radial striae reported by Dall (1920, p. 293) in young shells.

The fossil species assigned doubtfully to *Cryptopora* may be the young of other species. The gaping foramen and rudimentary deltidial plates are suggestive of young rhynchonelloids. Meznerics (1943, p. 23) points out that Sacco believed *H. parvillima* to be a juvenile of *H. de buchii=Streptaria buchi.*

I have examined a specimen of *Mannia nysti* Davidson from the Miocene of Belgium. As explained in the discussion under *Mannia,* this specimen has the features of *Cryptopora* but does not conform completely with the description given by Davidson. The description of this genus is evidently inaccurate and the two genera are exact synonyms (see discussion under *Mannia*).

CRYPTOPORA RECTIMARGINATA Cooper, new species

Plates 1, B, 2, A

Atretia gnomon Dall (not Jeffreys), Proc. U. S. Nat. Mus., vol. 57, p. 293, 1920 (U.S.N.M. Cat. Nos. 83131, 274138, 274139, 94367, 336894).

Shell small, translucent to white, subtriangular in outline, with the greatest width anterior to the middle; sides gently rounded; anterior margin strongly rounded; valves subequal in depth; anterior commissure rectimarginate; surface smooth.

Pedicle valve slightly deeper than the brachial valve; lateral profile gently convex, most convex in the posterior third and flattened in the anterior third; anterior profile broadly convex, slightly more convex than the brachial valve in this profile. Beak pointed, forming an angle of about 85°, suberect; deltidial plates erect, thickened along their distal margin, commonly extravagantly auriculate, the auriculations directed laterally.

Pedicle valve interior with thick apical plate well elevated above the valve floor; teeth small, wide; dental plates stout, slightly divergent anteriorly, approximately vertical to the valve floor. Muscle field anterior to delthyrial cavity.

Brachial valve with gently convex lateral profile, the maximum convexity located just anterior to the umbo and posterior to the middle;

anterior profile broadly and gently convex; posterolateral slopes moderately steep; anterior slope long and flattened.

Brachial valve interior with long, approximately parallel crura; socket ridges stout, grown together with the cardinal process which forms a thickening between the socket ridges at the apex; median septum stout, short anteroposteriorly, narrow in profile; adductor scars deeply sunk and forming an elongate track on each side of the median septum.

MEASUREMENTS IN MILLIMETERS

	Length	Brachial length	Width	Thickness
Holotype	5.2	4.4	4.4	1.8
Paratype U.S.N.M. 274143d	5.3	4.7	4.6	1.6

Types.—Holotype, U.S.N.M. 274143a; figured paratypes, U.S. N.M. 274143b, c, d, 274168a, 336895a, and 336896a.

Horizon and locality.—Recent, Eolis Station 340, at 209 fathoms off Fowey Light; several other stations off Fowey Light at depths ranging from 85 to 205 fathoms; off Sand Key at 75 to 120 fathoms; off Sambo Reef at 135 fathoms; off Western Dry Docks, at 80 and 90 fathoms; and off Key West at 110 fathoms; all off Florida.

Comparisons.—This species is characterized by its narrowly lenticular profile, the rectimarginate anterior commissure, auriculate deltidial plates, thick cardinalia and short, stout median septum.

Cryptopora rectimarginata differs from *C. gnomon* in several respects. The latter is quite strongly sulcate, whereas the Florida species is rectimarginate; *C. gnomon* is a thicker shell than *C. rectimarginata* and has a longer median septum and does not have the auriculations on the deltidial plates. Helmcke's species *C. boettgeri* likewise does not have the auriculations on the deltidial plates and also has a longer median septum than *C. rectimarginata.* The Australian *C. brazieri* differs from *C. rectimarginata* in having a flattened brachial valve, no auriculations on the deltidial plates, and a longer and more delicate median septum.

A specimen from the Oligocene (Cojinar formation), from Sagua la Grande in Las Villas Province, Cuba (U.S.N.M. 459424a) is strongly suggestive of *C. rectimarginata* because it has auriculate deltidial plates and the form and profile of the Florida species.

Cryptopora rectimarginata appears to be a shallow-water species ranging in depth from 75 to 209 fathoms. *Cryptopora gnomon,* on the other hand, is a deeper-water form. Depth ranges given for specimens in the U. S. National Museum collection are from 650 to 2,200 fathoms. The Australian species is a shallow-water form found in 100 fathoms. *Cryptopora boettgeri* from off Agulhas Bank, South Africa, is from deeper water, 500 meters (275 fathoms).

CRYPTOPORA GNOMON Jeffreys

Plates 5, C, 21, D

Crytopora gnomon Jeffreys, Nature, vol. 1, Dec. 2, p. 136, 1869.
Atretia gnomon Jeffreys, Proc. Roy. Soc., vol. 18, No. 121, p. 421, 1870; Davidson, Trans. Linnaean Soc., ser. 2, vol. 4, pt. 2, p. 173, pl. 25, figs. 6-13, 1887.
Neatretia gnomon (Jeffreys) Fischer and Oehlert, Exped. Sci. *Travailleur* et *Talisman*, p. 122, figs. 11a-c, 1891.

This is a deep-water form that differs markedly from *C. rectimarginata* in its nonalate deltidial plates, more strongly folded anterior commissure, and other details. Figures are introduced for comparison with the Florida species.

Types.—Figured specimens U.S.N.M. 94367, 44911a, c, d.

Horizon and locality.—Recent, 780 fathoms, off Cuba; 1,525 fathoms at U. S. Fish Commission Station 2221, south of Marthas Vineyard, Mass.

Genus MANNIA Davidson, 1874

Plates 1, A, 21, F; text figure 1, B

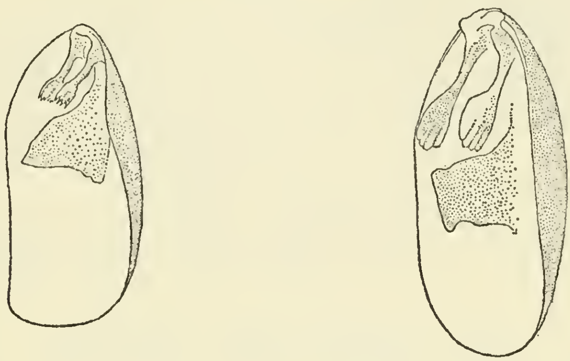
Mannia Dewalque, Prodrome d'une Description Géol. Belg., p. 432, 1868 (not described or figured); Davidson, Geol. Mag., dec. 2, vol. 1, No. 4, p. 156 (extract p. 6), 1874(b); Thomson, New Zealand Board Sci. Art, Manual 7, p. 296, 1927.

This interesting little brachiopod [type species (by monotypy), *Mannia nysti* Davidson, 1874] was described by Davidson who indicates that some points of its anatomy are still to be learned. The affinities of *Mannia,* as well as its anatomy, are not clearly understood because some workers have regarded it as a rhynchonelloid but one of the best informed students of brachiopods, J. Allan Thomson, thought that it is a terebratuloid. Its rhynchonelloid affinities, however, now seem clear and unquestionable. Because of the rarity of this species little is known of it but restudy of a good specimen and photographs of the types now make its features clear.

According to Davidson's description, *Mannia* is similar to *Cryptopora* externally as well as internally. The beak region is elongated and pointed and the pedicle opening is elongate triangular. The pedicle opening is bordered by attenuated, triangular deltidial plates as in

Cryptopora. An external difference between the two, on the other hand, is suggested by Davidson's report on the exterior of *Mannia* of "concentric scaly lines of growth, from which scattered adpressed spinules seem to arise." The specimen figured by Davidson is very small. Its measurements are given in lines: length 2 lines = 4 mm., width $1\frac{1}{2}$ lines = 3 mm.

The pedicle valve interior is not well known, but Davidson (1874b, p. 157) speaks of a "narrow vertical plate" dividing the larger portion of the beak into two parts. However, no indication of a median



A B

FIG. 1.—Partial side views of the brachial valves of A, *Cryptopora,* ca. × 8, and B, *Mannia,* ca. × 16, showing maniculifer crura.

septum can be seen in the beak region in Davidson's figure 10a, plate 7. Inside the brachial valve the cardinal process is medial and the crura are long but the socket plates are small. In one figure the crura are convergent; in the other they are divergent, but in both they are similar to the crura of *Cryptopora.* Davidson reports them as being broken, which is probably the reason why they are illustrated as not flattened and expanded distally.

The median septum of the brachial valve is illustrated by Davidson as like that of *Cryptopora* in being short and very high. Unlike *Cryptopora,* however, its distal extremity is embellished by "two small triangular plates united posteriorly, separate and angular anteriorly." These form a small spoonlike trough which was interpreted by Thomson (1927, p. 297) as a terebratelliform structure. Thomson goes on to state that the shell of *Mannia* will ultimately prove to be punctate, but Davidson said emphatically that it is impunctate and referred it to the Rhynchonellidae.

I am indebted to Dr. A. Vandercammen and the officials of the Institute Royal des Sciences Naturelles de Belgique for a very fine specimen of *Mannia nysti* from the Upper Miocene (Diestien-Sables de Deurne) from Wommelghem, just east of Antwerp, Belgium. When delivered to me the specimen had both valves attached. Its exterior was photographed and then the valves teased apart with only a small fracturing of the anterior margin of the pedicle valve (see pl. 1, A). Inasmuch as this specimen is essentially a topotype and from the only horizon from which the species is known, it gives an authentic check on Davidson's description and figures.

My obligation to Dr. Vandercammen is still greater because he also sent me notes on Davidson's type lot and an enlarged picture of his types. These and the fine little specimen now make it possible to correct Davidson's description and to refigure the genus with unretouched pictures. The combined result of this reevaluation is to demonstrate beyond reasonable doubt that *Mannia* is *Cryptopora*.

The specimen from Wommelghem is small, having a length of 2.5 mm. and a width of 1.8 mm. The outline is elongate triangular, the beak sharply pointed and the deltidial plates strongly elevated. The exterior appears to be completely smooth, without any trace of concentric, scaly lines or "adpressed spinules." The anterior commissure is rectimarginate. The interior shows a coarse mosaic of shell fibers, a distinctly rhynchonelloid character.

The striking feature of the pedicle valve of this specimen is the strong elevation of the deltidial plates and the large size of the apical plate. The interior of the brachial valve is generically exactly like that of modern *Cryptopora* but specific differences may be readily noted, especially in the crura. These are bowed as in the modern species but the distal expansion is greatly exaggerated in its size and flatness. Furthermore the serrations on its distal extremity are numerous and minute (text fig. 1, A).

Of features recorded by Davidson as characteristic of *Mannia* I was unable to confirm the presence of a median septum in the apex of the pedicle valve. The triangular plates on the distal extremity of the median septum of the brachial valve were not confirmed and the details of the exterior are not in accordance with Davidson's description and figures.

The information and data furnished me by Dr. Vandercammen included a photograph of Davidson's type specimens and the label accompanying them. Five specimens are shown, one complete specimen exactly like that from Wommelghem sent to the U. S. National

Museum, three brachial valve interiors, and one pedicle valve interior. The outside and inside of these specimens are exactly like those of the specimen illustrated on plate 1, A, of this monograph except in one instance. Examination of the pictures of the brachial valve interiors under a magnifier failed to show any expansion of the distal end of the median septum. A possible mixture of species has occurred because the median septum of the largest of the three brachial valves extends anterior to midvalve and nearly to the apex in the opposite direction, is not abruptly elevated as typical, and seems to have different crura. This appears to belong to some other genus but it is difficult to say what it is. The other two are quite characteristic of *Cryptopora*. The complete specimen is illustrated from the dorsal side and shows the characteristic large foramen bordered by narrow deltidial plates. I am unable to distinguish the details of the pedicle valve interior from the picture.

Davidson was a keen observer but it is difficult to escape the conclusion that his figures of *Mannia* are a misrepresentation of specimens of *Cryptopora*. I have therefore placed *Mannia* in the synonymy of *Cryptopora*.

BASILIOLIDAE Cooper, new family

Basiliolinae Cooper, new subfamily

Genus BASILIOLA Dall, 1908

Plates 11, B, 12, 13, B, 14, A, C

Basiliola Dall, Bull. Mus. Comp. Zool., Harvard Coll., vol. 43, No. 6, p. 442, 1908; Thomson, New Zealand Board Sci. Art, Manual 7, p. 154, 1927; Jackson and Stiasny, *Siboga*-Exped., Monogr. 27, p. 10, 1937.

Basiola Thomson, Geol. Mag., n. s., dec. 6, vol. 2, p. 390, 1915 (Lapsus calami).

Neohemithyris Yabe and Hatai, Proc. Imp. Acad. Japan, vol. 10, No. 9, p. 587, 1934; Hatai, Sci. Rep. Tôhoku Imp. Univ., ser. 2 (Geology), vol. 20, p. 210, 1940.

Outline elongated subpentagonal to rounded subpentagonal; widest at about midvalve; strongly inequivalve, the brachial valve being greatly swollen but the pedicle valve gently convex; anterior commissure strongly uniplicate but the fold on the brachial valve low and inconspicuous; surface smooth. Beak of pedicle valve small, nearly straight, short; foramen small, complete circular to elongate-elliptical, submesothyrid; deltidial plates small, conjunct, moderately to elaborately auriculate.

Pedicle valve interior with strong and complex pedicle collar; teeth small and corrugated, supported by short receding dental plates which define shallow and narrow umbonal chambers. Muscle field short and narrow, the diductors surrounding the large adductors and with small adjustors in a posterolateral position. Pallial marks strongly impressed, the vascula media extending from the anterolateral end of the muscle field to converge anteriorly on the long tongue. Lateral branches few.

Brachial valve interior with deep corrugated sockets bounded by strong socket ridges; crura of falcifer type, moderately long crescentic in section, scimitarlike and attached to the socket ridges by prominent outer hinge plates. Inner hinge plates absent. Vascula media widely divergent.

Type species (by original designation).—*Hemithyris beecheri* Dall, Proc. U. S. Nat. Mus., vol. 17, p. 717, pl. 31, figs. 1-4, 1895.

Comparison.—*Basiliola* is characterized by its smooth shell, elaborate pedicle collar, conjunct and auriculate deltidial plates, small round to longitudinally elliptical foramen and the broad outer hinge plates of the cardinalia. *Basiliola* differs from *Rhytirhynchia,* which it otherwise resembles, in lack of anterior costation. It differs from *Aetheia* in the nature of the foramen and the lack of inner hinge plates in the cardinalia. *Aphelesia* is similar externally to *Basiliola* and has a similar foramen but its cardinalia are quite distinct in lacking outer hinge plates. *Basiliola* differs from *Probolarina* by its smooth exterior.

Geological horizon.—*Basiliola* is known from Pliocene to Recent.

Distribution.—The known Pliocene species of *Basiliola* are from Okinawa. Yabe and Hatai (1935) identified one Okinawa form as *Neohemithyris lucida* and identified its age as Pleistocene. Cooper (1957) described specimens of this species from the same place as new, and another, not named, in addition. Furthermore, the U. S. Geological Survey now dates the beds producing these specimens as late Pliocene. So far as known these are the only fossil basiliolas known.

Basiliola occurs in modern seas around the Hawaiian Islands, Japan, Fiji, Borneo, Malay Archipelago, the Celebes, and Philippine Islands.

Bathymetric range.—Each of the species assigned here to *Basiliola* has a different bathymetric range and different temperature tolerance. *Basiliola beecheri* ranges in depth from 143 fathoms down to 313 fathoms, and the temperature range is 43.8° F. to 60.8° F. *Basiliola pompholyx* usually occupies deeper water, from about 150 fathoms (275 meters, Jackson and Stiasny, 1937, p. 10) down to 1,105 fathoms, and with a temperature tolerance between 43.3° F. and 52° F. *Basiliola elongata* occurs in 24 fathoms but the temperature is not known.

Another specimen, possibly the same species, is from 153 fathoms. *Basiliola lucida* is from waters of 56 fathoms down to 122 fathoms and the temperature range is from 51° F. to 63° F.

Assigned species.—The following species are assigned to *Basiliola:*

Hemithyris beecheri Dall, Recent, Hawaiian Islands.
Basiliola pompholyx Dall, Recent, Philippines.
Rhynchonella lucida Gould, Recent, Japan.
Basiliola nitida Cooper, Pliocene, Okinawa.
B. elongata Cooper, new species, Recent, Philippines.

Discussion.—*Basiliola* with its strongly unequal valves and small foramen bounded by auriculate deltidial plates is usually easy to recognize. The shells range from hyalescent when living to opaque in the older or dead shells. The color ranges from pale yellow-brown to brownish gray. The anterior commissure is usually strongly folded in the dorsal direction, a long tongue from the pedicle valve fitting into the deeply reentrant brachial valve. Although the anterior uniplication is strong, the fold on the brachial valve is not, as a rule, well defined. Except for the uniplicate commissure the valves are not otherwise plicated, nor do they have any radial markings.

Aside from the smooth shell and uniplication the only other distinctive exterior feature of *Basiliola* is the beak. This is generally not much elongated but is bluntly pointed. The foramen is usually small circular, longitudinally oval, or elongated elliptical. The anterior side of the foramen is usually bounded in all the species by a moderate to elaborate flange or auriculation. In *B. beecheri* and *lucida* this is present but not as exceptionally developed as in *B. pompholyx.*

The deltidial plates are conjunct and often so tightly joined as to approximate a symphytium. The anterior margin of the deltidial plates commonly rests on the umbo of the brachial valve. In old shells the movement of the umbo against the anterior margin of the deltidial plates leaves a smooth area. In some specimens an extension grows anteriorly from the anterior margin of the deltidial plates along the surface of the umbonal slope of the brachial valve. This usually is part of the pedicle collar.

The chief character on which Dall based his genus is the pedicle collar and which is elaborate in many specimens. It is best seen in *B. pompholyx* (pl. 12, fig. 10) although it is well developed in the other species. The collar is built as a plate from the anterior edge of the deltidial plates as mentioned above and extends around the inside of the apex. The collar in many specimens is clear of the valve floor but in others shell substance has been added under the free anteroventral edge.

The muscle field of the pedicle valve is generally small in all species but it is also deeply excavated into the shell. The individual scars are usually strongly impressed. The diductor scars are small for such large shells, are somewhat rectangular in form, and surround the moderately large adductor patch. The adjustor scars are small and are located just anterior to the front edge of the dental lamellae. Posterior to the main part of the muscle field and within the delthyrial cavity the floor of the valve is considerably thickened. Here two small scars, the accessory diductors, are located.

The genital area is small and is situated on the sloping sides of the shell just anterior to the dental plates. The teeth are small, corrugated, and are supported by thin dental plates that are nearly obliterated in some specimens by thickening of the inside of the shell and filling of the umbonal cavities.

A prominent feature of *Basiliola* is the strong development of the pallial markings. One main pair of pallial trunks, the vascula media, originates between the diductor and adjustor muscles. A subsidiary pair of trunks, the vascula genitalia, originates at the same place but extends posterolaterally to surround the genital area. The vascula media extend slightly anterolaterally to just beyond midvalve where they branch. The main vascula media then extend slightly antero-medially to terminate on the outside of the tongue. The other branches at midvalve extend laterally where they divide. One branch swings posteriorly near the valve margin to die out just before reaching the teeth. The other branch extends anterolaterally. Short vascula terminalia are given off from the outside anterior part of the vascula media and their lateral branch, the vascula arcuaria.

The cardinalia of the brachial valve are characterized by the wide and flat outer hinge plates to which are attached concave scimitarlike falcifer crura. These are concave inward and are blunt at their distal extremity. The crural blades are slightly oblique or nearly vertical as viewed from the posteroventral side. The distal edge of the crura facing the pedicle valve are usually finely serrate.

No median septum is present but in some specimens the elongated adductor field is divided medially by a faint myophragm. The adductor scars are small and elongated. The posterior pair is much smaller than the anterior pair. The genital area is small like that of the pedicle valve and is surrounded anteriorly and laterally by vascula genitalia that connect with the posterior end of the vascula media. The major trunks in the brachial valve are like those of the pedicle valve. The vascula media originate at the outer ends of the adductor field and extend anteriorly, generally following the outer slope of the median trough formed by the fold. The vascula media branch at midvalve and the branches form a course similar to those of the opposite valve.

The genus *Neohemithyris* as defined by Yabe and Hatai in 1934 is identical to *Basiliola*. The authors of this genus emphasize the conjunct deltidial plates and the nature of the foramen. Specimens of *Rhynchonella lucida* Gould, type species of *Neohemithyris*, have been compared with *B. beecheri* and proved generically identical. In fact the Japanese species suggests immature *B. beecheri*.

Specimens (U.S.N.M. 499321) from Vanua Mbalavu, Lau, Fiji, referred by Ladd and Hoffmeister (1945, pp. 329-330) to *Neohemithyris lucida*, are young forms having the characters of *Basiliola*. The genus *Basiliola* thus proves to have a far wider range in the Pacific than hitherto believed.

BASILIOLA ELONGATA Cooper, new species

Plate 14, C

Not *Basiliola pompholyx* Dall, Proc. U. S. Nat. Mus., vol. 57, p. 292, 1920 (U.S.N.M. 235844 and 300266).

Shell thin, of about medium size, elongate oval in outline; greatest width anterior to the middle; beak acute, forming an angle of about 80°. Anterior margin nearly straight; anterior commissure moderately uniplicate; valves subequal in depth, the brachial valve being slightly deeper than the other; surface marked only by concentric lines of growth.

Pedicle valve gently convex in lateral profile, with the maximum convexity in the posterior half; anterior profile broadly but gently convex; umbonal region moderately and narrowly swollen and with steep lateral slopes; sulcus originating just anterior to the middle, broad and shallow; tongue short and abruptly truncated; flanks gently inflated and with gentle slopes. Foramen elongate-oval, fairly large; deltidial plates conjunct and with a marked lip on the anterior side of the foramen.

Brachial valve fairly evenly and moderately convex in lateral profile; strongly convex in anterior profile; umbonal and median regions inflated; umbonal slopes steep; fold originating at about midvalve, in the anterior third slightly elevated above the surrounding flanks which are moderately swollen and steep sided.

Pedicle valve interior with small teeth and short, inconspicuous dental plates; diductor field moderately large, flabellate not strongly inserted; genital areas narrowly crescentic; pallial marks not strongly impressed. Brachial valve interior with long, stout, slightly curved crura and moderately wide outer hinge plates.

MEASUREMENTS IN MILLIMETERS

	Length	Brachial length	Greatest width	Thickness
Holotype	14.8	13.7	13.4	8.9
Figured paratype	15.8	13.8	13.2	9.0

Types.—Holotype, U.S.N.M. 235844a; figured paratype, U.S.N.M. 235844b.

Locality.—U. S. Bureau of Fisheries Station 5146 at 24 fathoms, off Sulade Island, Tapul Group, southern Philippines.

Discussion.—This pretty little species is listed by Dall (1920, p. 292) as *B. pompholyx* but it is a proportionally much longer shell and with completely different outline. Compared with the growth lines of specimens of *B. pompholyx* corresponding in length to those of *B. elongata* the two species prove to be quite distinct.

Basiliola elongata is intermediate between *B. beecheri* and *B. lucida*. It is larger than the latter but smaller than the former although its outline is similar. The Hawaiian shell is stouter and has somewhat stronger shoulders than *B. elongata*. The Japanese *B. lucida* is also less elongated than the new species.

Inside the brachial valves of these three species *Basiliola elongata* has the longest crura whereas *B. pompholyx* has shorter crura relative to *B. elongata* and *B. beecheri*.

It is interesting to note that the bathymetric range of most of the specimens of *B. pompholyx* listed by Dall (1920) is deeper than 300 fathoms except for the new species and specimen U.S.N.M. 300863 which appears to be referable to *B. elongata*.

The specimen mentioned by Jackson and Stiasny (1937, p. 10) as very small and coming from Kei Island is suggestive of the new species. This is cited by them as a juvenile.

Genus EOHEMITHYRIS[1] Hertlein and Grant, 1944

Plates 5, A, 8, B, 15, B, 20, A, B, 22, A

Eohemithiris Hertlein and Grant, Publ. Univ. California at Los Angeles, Math. and Phys. Sci., vol. 3, p. 55, 1944.

Subpentagonal in outline, thick shelled, coarsely fibrous, translucent to transparent; subequivalved, the brachial valve having a slightly

[1] The spelling of *Eohemithiris* is here corrected to *Eohemithyris* to make it coincide with the corrected spelling of *Hemithyris.* Inasmuch as *Eohemithiris*

greater depth than the pedicle valve; anterior commissure uniplicate, the fold being broad and gentle; beak erect, small, inconspicuous; foramen small, round, slightly auriculate, submesothyrid; deltidial plates conjunct. Surface smooth but with obscure anterior costation in old individuals.

Pedicle valve with narrow delthyrial cavity bounded by short dental plates plastered against the shell wall; vascula media short, prominent.

Brachial valve with short, slender socket ridges bounding narrow corrugated sockets; outer socket plates moderately broad and shallow, attached to long and exceptionally broad falcifer crura; adductor field subcircular, deeply inserted; pallial trunks not impressed.

Type species (by original designation).—*Eohemithiris alexi* Hertlein and Grant, 1944, p. 55.

Comparison.—The entire anatomy of *Eohemithyris* is most like that of *Basiliola* and other members of the Basiliolidae. It differs, however, in being more nearly equivalve, whereas *Basiliola* is strongly inequivalve; the deltidium of *Eohemithyris* is only slightly auriculate and does not have the elaborate development of the pedicle collar seen in *Basiliola.* The pallial marks of *Basiliola* are more strongly developed in all species but those of the type species of *Eohemithyris* are much abbreviated. The outer hinge plates attaching the crura to the socket ridges are narrower in *Eohemithyris* than in *Basiliola.*

Comparison of *Eohemithyris* and *Rhytirhynchia* is essentially the same as that with *Basiliola.* The brachial valve of *Rhytirhynchia* is much deeper than that of *Eohemithyris* but the anterior costation of the former is much stronger than that seen in *Eohemithyris* which seems to be a rare feature.

Eohemithyris is quite suggestive of *Aetheia* in outline and beak characters but differs from it in interior details. No development of inner hinge plates appears to have taken place in *Eohemithyris.*

No other members of the Basiliolidae compare closely with *Eohemithyris.*

Geological horizon.—Eocene (Domengine and Capay formations).

Assigned species.—Four species are assigned to this genus, two fossil and two Recent:

Eohemithiris alexi Hertlein and Grant, Eocene, California.
Eohemithyris? gettysburgensis Cooper, Miocene, California.
Hemithyris colurnus Hedley, Recent, Australia.
Rhynchonella grayi Woodward, Recent, Fiji Islands.

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was thought by its authors to be similar to *Hemithyris* and an early relative of it, the correction of spelling in the latter by Bronn is essential in the former. The spelling of *Eohemithiris* is corrected to *Eohemithyris* in Zoological Record for 1950, p. 21.

Distribution.—The fossil species are from the Eocene and Miocene of California but one Recent form is from off southeastern Australia, and another off the Fiji Islands.

Discussion.—The name chosen for this genus is unfortunate and inappropriate because the interior details now make it clear that it is totally unrelated to *Hemithyris* as its name implies. Relationship to the Basiliolidae seems clear in the broad falcifer crura, the details of the deltidial plates, foramen, and smooth exterior. *Eohemithyris* is the oldest known member of the Basiliolidae but its roots are probably deep in the Cretaceous. It is also interesting that species are living today.

Hemithyris colurnus Hedley is here assigned to this Eocene genus. This Australian species has never been satisfactorily placed and some objections may be raised to assigning it to *Eohemithyris,* an Eocene species now known only from California. In spite of the time gap indicated, close comparison of the California and modern Australian species leaves few anatomical points of difference. The exterior of *H. colurnus* is essentially identical to that of *Eohemithyris alexi.* Both are thick-shelled forms with translucent to almost transparent shells, especially when they are wet. They are both coarsely fibrous. The beak characters of the two are identical. It is not possible to make a comparison of the pedicle collars of the two species because it is very difficult to determine these details in *Eohemithyris.* Actually some uncertainty exists as to whether the fossil species has a pedicle collar, but the area of the beak is so thickened that some sort of tubular arrangement must be present.

Inside the pedicle valve the dental plates of the modern species may be somewhat less prominent than those of the fossil form; dental plates are definitely present in both however. It is to be expected that those of the older species might be better developed than those of the modern form. The delthyrial cavities and muscle areas of the two seem identical; the pallial trunks of the modern form are better impressed but this may be a matter of preservation rather than one of generic distinction.

Inside the brachial valve the crura and hinge plates are almost identical, no features of generic value having been detected. The outer hinge plates are of about the same size, narrower than in *Basiliola* but much wider than in *Aphelesia.* The adductor field of the modern species is deeply impressed as in *Eohemithyris alexi* but the pallial marks of the Recent species are more plainly impressed. The sockets of *H. colurnus* are strongly corrugated but the corrugation of the

Eocene species is not so strong in the specimens examined. This however could hardly be regarded as a generic difference. Other species of *Eohemithyris* can be expected in other Tertiary deposits and should be looked for.

Rhynchonella grayi Woodward is another species that has never been correctly placed generically. Through the kindness of Dr. Helen M. Muir-Wood and the authorities of the British Museum I am able to furnish exterior and interior views of this species. It is clearly very similar to *Hemithyris colurnus* but is more strongly costate in the anterior third. *Eohemithyris alexi* and *colurnus* are both obscurely to definitely costate in the anterior part. Davidson's figures of *R. grayi* greatly exaggerate the plication. The interiors and beak characters of *R. grayi* are clearly identical to those of *E. colurnus* and *E. alexi,* except for the swellings of shell material on the hinge plate, consequently the species is assigned to *Eohemithyris.* The shell profile and beak characters exclude *R. grayi* from assignment either to *Basiliola* or *Rhytirhynchia.* Lack of inner hinge plates separates *R. grayi* from *Aetheia* which, except for the anterior costation, it otherwise resembles in its exterior characters.

EOHEMITHYRIS? GETTYSBURGENSIS Cooper, new species

Plate 8, B

Shell large, subpentagonal in outline, slightly wider than long; sides narrowly rounded; widest slightly anterior to midvalve; anterior commissure strongly uniplicate; surface marked only by concentric lines of growth.

Pedicle valve less deep than the brachial valve, moderately convex in lateral profile and with the strongest convexity in the posterior third; anterior profile nearly flat but with the median region slightly concave; beak low, incurved; umbo moderately swollen; sulcus originating on the umbo, shallow and narrow but deepening and widening anteriorly to occupy slightly more than half the width at the anterior; flanks somewhat flattened and with gentle slopes to the margins; tongue moderately geniculate, moderately long and broadly rounded.

Brachial valve gently and fairly evenly convex in lateral profile; anterior profile moderately strongly domed; fold originating at about midvalve, low, flattened, and prominent only at the anterior; flanks bounding fold slightly depressed, gently rounded. Umbonal region only slightly convex.

Interior.—Strong, short dental plates visible in pedicle valve; small, short socket ridges visible in brachial valve but no trace of a median septum or ridge seen through the moistened shell.

MEASUREMENTS IN MILLIMETERS

	Length	Brachial length	Maximum width	Thickness
Holotype	24.3	22.2	28.0	13.0

Type.—Holotype, U.S.N.M. 549382.

Horizon and locality.—Miocene, Station 69, on coast, 4½ miles west of Gettysburg, Washington.

Discussion.—This is a large and distinctive species unlike any figured by Hertlein and Grant (1944) in their monograph on the Tertiary and Recent brachiopods of the west coast of the United States. Tentative assignment to *Eohemithyris* is made because the exterior is smooth, dental plates are present, but a median septum or ridge is absent. The species differs from *E. alexi* in its greater size and more pronounced fold and sulcus.

Genus NEOHEMITHYRIS Yabe and Hatai 1934

Plate 13, B

Neohemithyris Yabe and Hatai, Proc. Imp. Acad. Japan, vol. 10, No. 9, p. 587, 1934; Hatai, Sci. Rep. Tôhoku Imp. Univ., ser. 2 (Geology). vol. 20, p. 210, 1940.

Yabe and Hatai (1934, p. 587) described their new genus *Neohemithyris* with type species (by original designation) *Rhynchonella lucida* Gould as resembling *Hemithyris* "in shape, folding, beak characters and microstructure" but differing "only in possessing an entire foramen and conjunct deltidial plates in the ventral valve." In the brachial valve a cardinal process is absent and no median ridge is present. Although these characters do distinguish *Neohemithyris* from *Hemithyris* they do not differentiate the Japanese shell from *Basiliola* with which it seems to be identical. Consequently I have placed *Neohemithyris* in the synonymy of *Basiliola.* [For further discussion see under *Basiliola;* see also pl. 13, B, figs. 6-23, for illustrations of *Rhynchonella lucida* Gould type species of *Neohemithyris* (=*Basiliola*).]

Genus NEORHYNCHIA Thomson, 1915

Plate 2, B

Neorhynchia Thomson, Geol. Mag., n. s., dec. 6, vol. 2, p. 388, 1915; Dall, Proc. U. S. Nat. Mus., vol. 57, p. 290, 1920; Thomson, New Zealand Board Sci. Art, Manual 7, p. 149, 1927; Hertlein and Grant, Publ. Univ. California, Math. and Phys. Sci., vol. 3, p. 57, 1944.

Pentagonal in outline, with the greatest width at midvalve; valves unequal in depth, the pedicle valve having the greater depth; anterior commissure deeply sulcate; surface smooth. Beak of pedicle valve short, nearly straight, and bluntly pointed; foramen of moderate size, hypothyrid; deltidial plates disjunct.

Pedicle valve interior with small corrugated teeth supported by short dental plates which define a small delthyrial chamber; muscle area small.

Brachial valve interior with corrugated sockets bounded by overhanging socket ridges; crura short, falcifer type, crescentic in section, attached to socket ridges by broad outer hinge plates. Inner hinge plates small and inconspicuous. Median ridge short and reaching the apex. Adductor field small.

Type species (by original designation).—*Hemithyris strebeli* Dall, Bull. Mus. Comp. Zool., Harvard Coll., vol. 43, p. 441, 1908.

Comparison and *discussion*.—The important and striking difference between *Neorhynchia* and all known Recent and Tertiary rhynchonelloid genera is the sulcation of the anterior commissure. Rhynchonelloids of similar habit are known from the Mesozoic. They are also known from the Devonian, Mississippian, and Permian as well. Sulcation is a folding tendency that has appeared many times in different stocks of the rhynchonelloids.

Neorhynchia is most closely related to *Basiliola* in the presence of the wide outer hinge plates and falcifer crura having a crescentic section. The presence of incipient inner hinge plates in *Neorhynchia* is another difference between the two genera.

Assigned species.—Only one species is so far known in this genus:

Hemithyris strebeli Dall, Recent, Pacific.

Distribution.—The known specimens of this species are all from great depths: 2,084 fathoms at 35.1° F. in mid-Pacific and 2,035 fathoms at 35.3° F. off the Galápagos Islands, both on *Globigerina* ooze.

Genus RHYTIRHYNCHIA Cooper, 1957

Plate 11, A

Rhytirhynchia Cooper, U. S. Geol. Surv. Prof. Pap. 314-A, p. 8, 1957.

Subcircular to suboval in outline and with the maximum width at midvalve; strongly inequivalve, the brachial valve being swollen and deep; anterior commissure sulciplicate, surface smooth except anterior which is paucicostate. Beak small, rounded, inconspicuous; foramen rounded, submesothyrid to mesothyrid; deltidial plates short, conjunct.

Pedicle valve with thick, coarsely corrugated teeth and moderately developed to remnantal dental plates; pedicle collar well formed;

muscle field short and narrow, somewhat longitudinally rectangular in outline; diductor scars small; adductor scars large and surrounded anteriorly by the diductors. Vascula media strong, converging anteriorly on the tongue.

Brachial valve interior with deep sockets bordered by overhanging socket ridges; crura attached to socket ridges by narrow outer hinge plates; crura falcifer, long crescentic in section, convex outward; inner hinge plates incipient, forming a slight thickening on the inside of the crura near their proximal end; median ridge or septum absent; adductor field small, rounded in outline with large anterior scars and small posterior ones; vascula media prominent, diverging widely at the anterior end of the adductor field.

Type species (by original designation).—*Hemithyris sladeni* Dall, Trans. Linnaean Soc. London, ser. 2, Zool., vol 13, pt. 3, p. 440, pl. 26, figs. 7-12, 1910.

Comparisons.—This genus is most like *Basiliola* in form and outline but differs in having anterior costation. Inside the pedicle valve the dental plates are reduced to remnants or are wanting in the modern species. In the brachial valve the development of outer hinge plates in *Basiliola* is usually greater than that in *Rhytirhynchia* but otherwise the details of the valves are the same. Incipient inner hinge plates appear in *Rhytirhynchia.*

Rhytirhynchia in its anterior costation suggests *Eohemithyris* which likewise has anterior costation in old adults. In the latter this seems to be a rare feature but the two genera are not likely to be confused because their lateral profiles are different, that of *Rhytirhynchia* having an extremely deep brachial valve, whereas *Eohemithyris* has both valves nearly equal.

Geological range.—Pliocene to Recent.

Distribution.—*Rhytirhynchia* occurs as a fossil in the Pliocene of Okinawa and today lives in the Indian Ocean south of the Saya de Malha banks.

Assigned species.—Two species are now assigned to this genus, one living and one fossil:

Hemithyris sladeni Dall, Recent, Indian Ocean.
Rhytirhynchia hataiana Cooper, Pliocene, Okinawa.

Discussion.—This genus is essentially a semicostate *Basiliola.* In the one modern species the dental plates are remnantal but in *R. hataiana* from the Pliocene of Okinawa the dental plates are moderately developed. This is a small and delicate form in which internal thickening of the shell is not great. The degrees of development of the dental plates are, in this case, not regarded as generic in character.

PROBOLARINA Cooper, new genus

(Gr. *probolos,* projection)

Plate 17, A, B

Subpentagonal to subtriangular in outline, with the greatest width at or near the middle; inequivalve, the brachial valve having the greater depth and convexity; anterior commissure uniplicate; surface semicostate, the posterior third to half smooth, anterior half to two-thirds costate. Beak moderately long, pointed, nearly straight; foramen small, longitudinally elliptical, hypothyrid to submesothyrid and with strongly auriculate margins. Deltidial plates prominent, wholly visible, conjunct throughout their length and anteriorly resting on the umbo of the brachial valve.

Pedicle valve interior with strong pedicle collar, small teeth supported by vertical dental plates separated from the side wall by narrow umbonal chambers. Details of the musculature not available.

Brachial valve interior with narrow sockets bounded by erect but not greatly thickened socket ridges; crural bases attached to socket ridge by a prominent, flat outer hinge plate; crura falcifer, long, scimitarlike, crescentic in section and convex outward. No cardinal process. Muscle and pallial marks not visible in available material.

Type species.—*Rhynchonella holmesii* Dall, Trans. Wagner Free Inst. Sci., vol. 3, pt. 6, p. 1536, pl. 58, figs. 10, 12 (not 11), 1903.

Comparisons.—This genus is most like *Rhytirhynchia* in its exterior characters but differs importantly in the interiors as well as in details of the exterior. *Rhytirhynchia* has almost nude valves except for the costation at the very anterior margin. In *Probolarina* on the other hand the costation affects more than two-thirds of the valve, only the umbones being free of costation. The deltidial plates of the two genera are conjunct and both are auriculate but those of *Probolarina* are more developed and more elaborately auriculate than those of *Rhytirhynchia.*

Inside the pedicle valve of *Probolarina* a strong pedicle collar strengthens the beak and strong but thin dental plates buttress the teeth. In *Rhytirhynchia* on the other hand the dental plates are rudimentary in the type species and can be seen only as a trace on the sides of the shell. In *R. hataiana* Cooper from the Pliocene of Japan moderately developed dental plates are present but they are not to be compared with the strong and vertical plates of *Probolarina.*

The cardinalia of the brachial valves of the two genera are very similar and a median septum or ridge is lacking from both of them. The crura of both genera are of the same falcifer type and the outer hinge plates are developed to about the same degree.

Assigned species.—At present two species only are assigned to this genus:

Rhynchonella salpinx Dall.
R. holmesii Dall.

Distribution.—Eocene (Castle Hayne), North Carolina.

Discussion.—Tertiary brachiopods are a rarity in the United States and that is especially true of the genus *Probolarina.* The two species of this genus are represented by a few specimens only. They are also quite different in form but the beak characters and the cardinalia of the two appear to be identical. It is interesting that the cardinalia of *Probolarina* are so like those of *Rhytirhynchia,* a modern inhabitant of the Indian Ocean and represented in the fossil state in Okinawa.

PROBOLARINA HOLMESII (Dall)

Plate 17, B

Rhynchonella holmesii Dall, Trans. Wagner Free Inst. Sci., vol. 3, pt. 6, p. 1536, pl. 58, figs. 10, 12 (not 11), 1903.

In Dall's description of this species it is stated that one of the figured specimens is a young individual. The other specimen figured is somewhat fragmentary, probably belonging to a different and undescribed species. I here select the smaller of the two specimens as the type of *R. holmesii,* U.S.N.M. 109298a. This specimen is clearly a young form of those figured on plate 17, B. Specimen U.S.N.M. 549359 is a well-preserved adult of *R. holmesii.*

STREPTARIA Cooper, new genus

(Gr. *streptos,* twisted)

Plate 19, B, C

Pentagonal in outline with the greatest thickness near midvalve; valves unequal in depth, the brachial valve having the greater depth; anterior commissure uniplicate to twisted, either right or left; surface marked only by concentric lines of growth, occasionally with obscure marginal costae. Beak short, deltidial plates conjunct, foramen hypothyrid to submesothyrid, small and usually with prominent elevated rim.

Pedicle valve interior with remnantal dental plates and strong corrugated teeth. Other details not yet known.

Brachial valve with deep corrugated sockets, long falciform crura attached to fairly broad outer hinge plates; inner marginal rim present on crura but no inner hinge plates; socket ridges thick and curved. No median septum. Other details not yet known.

Type species.—*Terebratula De Buchii* Michelotti, Cenn. Brach., Acefali foss. Italia, p. 4, 1938.

Comparison and discussion.—This genus is characterized by its smooth exterior, small, short beak, twisted to uniplicate anterior commissure, nearly obsolete dental plates, and long falciform crura attached to broad outer hinge plates. In the latter character and the smooth, uniplicate shell *Streptaria* is like *Basiliola* but it differs in beak characters, lack of a pedicle collar, and the small development of the dental plates of the pedicle valve.

Specimens of this genus are similar to *Erymnaria* in the smooth exterior, beak characters, and the twisted anterior margin, but the latter genus possesses two strong, diverging septa in the brachial valve—a character unlike any other known rhynchonelloid from Tertiary rocks or Recent seas.

Assigned species.—This genus is known in Mediterranean and West Indian rocks.

Terebratula De Buchii Michelotti, Miocene, Italy.
Rhynchonella deformis Seguenza, Miocene, Italy.
R. eocomplanata Sacco and var., Eocene, Italy.
Streptaria streptimorpha Cooper, new species, Eocene, Cuba.

Distribution.—The known species of this genus are from the Tertiary of Italy, southern Europe, northern Africa, and Cuba.

Discussion.—One of the interesting features of *Streptaria* is the twisted anterior margin. This character occurs in rhynchonelloid stocks from Paleozoic to Tertiary times. It has been seen in many different stocks and undoubtedly is an aberration of the anteriorly produced folding that facilitates the passage of nourishing currents into the valve and their elimination with waste from the valves. *Streptaria* and *Erymnaria* form isochronous homeomorphs in this respect. The Ordovician genus *Streptis* is like *Streptaria* in having shells twisted to right and left but also has normally uniplicate individuals or species.

Cuba has produced another species of *Streptaria* which is not described because of insufficient material. Three specimens of this undescribed shell are known from the Eocene of Camaguey Province in which the valves are normally folded (uniplicate), but a third specimen has a wider sulcus on the pedicle valve which shows a definite twist. This species has abbreviated dental plates and the same cardinalia as the Italian forms and *S. streptimorpha*.

STREPTARIA STREPTIMORPHA Cooper, new species

Plate 19, B

Of medium size for a rhynchonelloid, subcircular in outline; sides narrowly rounded; greatest width at the middle; anterior commissure twisted. Surface marked only by concentric growth lines.

Pedicle valve gently convex in lateral profile; broadly and slightly convex in anterior profile; depth less than that of the brachial valve; umbonal and median regions slightly swollen; sulcus indefinite, shallow; beak short, blunt, forming an obtuse angle (about 110°). Foramen hypothyrid, small, oval; deltidial plates forming low rim around foramen.

Brachial valve deeper than the pedicle valve, moderately convex in lateral profile but strongly domed in anterior profile; umbonal region somewhat flattened; median region and flanks strongly swollen; fold ill defined because of twisted commissure.

Interior.—Pedicle valve with remnantal deltidial plates and no pedicle collar. Brachial valve with long falciform crura attached to the socket ridges by fairly broad outer hinge plates. Median septum absent. Other details not yet known.

MEASUREMENTS IN MILLIMETERS

	Length	Brachial length	Width	Thickness
Holotype	17.0	15.2	18.0	10.6

Types.—Holotype, U.S.N.M. 549386a; figured paratype, U.S.N.M. 549386b.

Horizon and locality.—Eocene, deep cut north of Grua 9, Ramal Juan Criollo, Camaguey Province, Cuba (Palmer locality 1640).

Discussion.—This species is characterized by its rounded form, small foramen, and broadly twisted anterior commissure. It is suggestive of *Streptaria de buchii* (Michelotti) from the Mediterranean region but differs in its rounded form, less narrow twist to the anterior commissure, smaller foramen, and lesser development of the foraminal lip.

Aphelesiinae Cooper, new subfamily

APHELESIA Cooper, new genus

(Gr. *apheles,* smooth)

Plates 7, B, 8, C, 22, D

Outline subtriangular to subpentagonal; widest anterior to the middle; strongly inequivalve, the brachial valve being deep and swollen, the pedicle valve gently convex; anterior commissure strongly uniplicate but fold of brachial valve defined only at the anterior; smooth on most of the surface but the anterior with incipient costation. Beak of pedicle valve moderately elongated, nearly straight to suberect, pointed; foramen complete, elongate-oval, small hypothyrid; deltidial plates thick, conjunct, moderately auriculate; beak apex thickened internally.

Pedicle valve interior with elongated, corrugated teeth supported by thick dental plates. Muscular field large and flabellate, extending to about midvalve with the diductor scars surrounding the adductors; adjustor scars small and laterally disposed.

Brachial valve interior with deep corrugated sockets bounded by strong overhanging socket ridges; crura of falcifer type, long, crescentic in section, broad, scimitarlike and cemented directly to the socket ridges with no outer hinge plates developed; inner hinge plates lacking; crural supporting plates thick. Median ridge low and thick; adductor field narrow and elongated. Pallial trunks not deeply impressed.

Type species.—Anomia bipartita Brocchi, Conch. Foss. Subapp., vol. 2, p. 469, pl. 10, fig. 7, 1814.

Comparisons.—This species is generally referred to *Hemithyris* but it actually does not have either the exterior or interior features of this genus. *Aphelesia* is completely smooth or with slight and very obscure costation. It does not have the numerous and regular subdued costellae or striae of *Hemithyris.* Furthermore the foramen of *Aphelesia* is small and the deltidial plates are conjunct. The foramen of *Hemithyris* is large and not enclosed anteriorly because the deltidial plates are disjunct.

The interior of the pedicle valve of each of these genera is quite similar except for the fact that the dental plates of *Hemithyris* are somewhat more prominently developed and with deeper umbonal chambers than those of *Aphelesia.* Important differences appear on the inside of the brachial valves where the cardinalia of the two genera are quite distinctive. In *Hemithyris* the crura are of radulifer type, long and slender and with only a slight development of outer hinge plates. The crura however are flattened horizontally as one observes them from the posteroventral side and the distal extremities are quite thin. In *Aphelesia* the crura are long, broad, of falcifer type, and the bases attached to the socket ridges with no development of outer hinge plates. The distal ends of the crura, unlike *Hemithyris* are scimitarlike, are laterally compressed and their distal extremities serrate. In cross section these crura are crescentic and the convex surface faces laterally. The crural blades are broad and thick and thus quite unlike those of *Hemithyris*.

The crura of *Aphelesia* are like those of *Rhytirhynchia, Neorhynchia,* and *Basiliola* but differ from all of them in the absence of outer hinge plates which are so prominent in the other genera. *Aphelesia* differs from these genera also in other important respects.

Geological horizon.—Eocene through Pliocene.

Geographic distribution.—Mediterranean region.

Assigned species.—At present it is difficult to assign the several species of Mediterranean Tertiary rhynchonelloids to their proper genus because the interiors are poorly known or completely unknown.

Anomia bipartita Brocchi, Pliocene, Italy.
Terebratula plico-dentata Costa, Miocene-Pliocene, Italy.
Rhynchonella (Hemithyris) saccoi Patané, Pleistocene, Sicily.
Hemithyris acuta Meznerics, Miocene, Hungary.
Rhynchonella bipartita pseudobipartita Patané, Pleistocene, Sicily.

Discussion.—These species have been assigned to *Hemithyris* at one time or another but the exterior characters preclude such a placement. The little that is known of the interior also excludes these shells from assignment to *Hemithyris*. The beak characters and cardinalia of *Aphelesia* as shown by *A. bipartita* are quite unlike the same features of *Hemithyris*. The exterior of most of these shells is smooth or nearly so. Some exhibit anterior costation but it is generally not regularly developed. None of them have the fine striate exterior of *Hemithyris*. The latter, too, has disjunct deltidial plates and an elongate beak, whereas the beaks of the Italian species are short and the deltidial plates conjunct. The crura of *Hemithyris* are long, curved, and slender, quite different from the broad-bladed *Aphelesia bipartita*.

AETHEIINAE Cooper, new subfamily

Genus AETHEIA Thomson, 1915

Plates 4, A, 9, B

Aetheia Thomson, Geol. Mag., n. s., dec. 6, vol. 2, p. 389, 1915; Thomson, New Zealand Board Sci. Art, Manual 7, p. 156, 1927.

Thomsonica Cossmann, Rev. Crit. Pal., vol. 24, No. 3, p. 137, 1920; Finlay, Trans. New Zealand Inst., vol. 57, p. 532, 1927.

Outline elongate-oval to triangular with the greatest width at the front; inequivalve, the brachial valve having the greater depth; anterior commissure broadly uniplicate, the brachial fold low and inconspicuous. Surface marked by concentric lines of growth only. Beak small, erect; foramen minute, submesothyrid; deltidial plates conjunct, forming a concave plate.

Pedicle valve interior with thick teeth attached directly to the shell wall; dental plates absent; muscle field short and narrow, the diductors small but surrounding the adductor scars. Vascula media strong, branching about two-thirds the shell length from the beak.

Brachial valve interior with deep corrugated sockets bounded by long vertical socket ridges to which the long crura are cemented; crura of falcifer type, crescentic in section, convex outward; inner hinge plates thick and filling the intercrural space. Cardinal process small and transversely triangular. Median ridge short and low, but thick, united with the cardinalia. Adductor field large, with large anterior scars.

Type species (by original designation).—*Waldheimia* (?) *sinuata* Hutton, Catalogue of the Tertiary Mollusca and Echinodermata of New Zealand in the collection of the Colonial Museum, p. 36, 1873 = ?*Terebratula gualteri* Morris, Quart. Journ. Geol. Soc., London, vol. 6, p. 329, pl. 28, figs. 2, 3, 1850.

Comparisons.—This interesting genus has exterior and interior features that set it aside from nearly all other rhynchonelloids. It is unlike all other known Tertiary and modern rhynchonelloids except *Patagorhynchia* in the extremely small pedicle foramen and concave deltidial plates. It differs from *Patagorhynchia* in being smooth rather than marked by squamose costellae. Internally it differs from all other known Tertiary and Recent rhynchonelloids except *Frieleia* in the great development of the inner hinge plates which grow and swell between the crural bases to plug the entire posterior.

Geological horizon.—Upper Cretaceous to Miocene.

Distribution.—New Zealand.

Assigned species:

Terebratula gualteri Morris.
Waldheimia ? sinuata Hutton.

Discussion.—This genus presents some peculiarities not seen in most of the Tertiary and Recent rhynchonelloids. The small foramen is submesothyrid, an unusual position for this group of animals. The deltidial plates are conjunct but they do not overlie the umbo of the brachial valve as in *Hemithyris* and several other genera. They are concave and lie ventrally to the umbo of the brachial valve.

The teeth are large, corrugated and not buttressed by dental plates. Instead of dental plates a thickening extends posteroventrally but does not meet the floor. I have never seen immature specimens and therefore cannot say whether or not dental plates existed in the young as in some other genera.

The pallial marks of the pedicle valve are like those of *Hispanirhynchia* and *Basiliola*. In the one specimen showing these marks the course of the sinuses appears as an elevated ridge rather than a depression. This bifurcates near midvalve as in the genera mentioned.

The great thickening of the apical region of the brachial valve obscures many of the details of the cardinalia that can only be cleared up by a study of young specimens. These are not available in the National collections. The true nature of the crural bases is not known, whether they attach to the median ridge or to the valve floor or whether they have supports that extend dorsally.

Thomson (1927, p. 157) assigned *Hemithyris colurnus* Hedley and *H. sladeni* Dall to his genus *Aetheia* even though they differed to some extent from the fossil genus. Because of its anterior costation and the bulbous brachial valve the latter of these two species is here placed in *Rhytirhynchia,* and the former, because of its nearly equally deep valves, among other characters, is placed in *Eohemithyris.*

In their correction of brachiopod homonyms in 1951, Cooper and Muir-Wood suggested that *Thomsonica* Cossmann, 1920, should be substituted for *Aetheia* because the latter name is preoccupied by *Aethia* Merrem 1788 (Aves). It is now the sense of the Zoological Commission as outlined in the Copenhagen Proceedings (Hemming 1953, Article 34, paragraph 153, p. 78), that these two names are not in conflict. It is therefore necessary to return to *Aetheia* and reject *Thomsonica* as Thomson did in 1927 (p. 156).

Genus **PATAGORHYNCHIA** Allan, 1938

Plates 6, A, 21, B

Patagorhynchia Allan, Rec. Canterbury (N.Z.) Mus., vol. 4, No. 4, p. 199, 1938.

Subcircular to subpentagonal in outline; inequivalve, the brachial valve having the greater depth; anterior commissure uniplicate, the fold of the brachial valve being moderately strong. Surface costellate, lamellose to imbricate. Beak short, nearly straight, bluntly pointed; foramen minute, submesothyrid, deltidial plates conjunct and forming a concave plate.

Pedicle valve interior without dental plates. Other details not known.

Brachial valve interior with short crura and with the inner hinge plates thickened and filling the intercrural space.

Type species (by original designation).—*Rhynchonella patagonica* von Ihering, Anal. Mus. Nac. Buenos Aires, ser. 3, vol. 9, t. 2, p. 334, pl. 3, figs. 11a, b, 1903.

Comparisons.—*Patagorhynchia* is comparable to two genera from the Southern Hemisphere: *Tegulorhynchia* and *Aetheia.* The first genus is ornamented like *Patagorhynchia* but there the similarity ends because the South American genus has completely different beak characters and the interiors are wholly unlike. Close comparison is possible with *Aetheia* on the inside and in beak characters but *Aetheia* is a smooth shell and externally not to be confused with *Patagorhynchia.* The Argentine shell has the minute foramen and concave deltidial plates like the New Zealand shell. Inside the pedicle valve no dental plates were observed in *Patagorhynchia.* The interior of the brachial valve is not well known and the published illustration of it is poor. It does indicate, however, cardinalia with moderately long crura, concave inward, probably of falcifer type and a thickening of the inner hinge plates to fill the posterior space between them with shell substance. The illustration indicates a condition even more extreme than that seen in *Aetheia.*

Geological horizon.—Eocene (Patagonian).

Distribution.—Argentina and Chile.

Assigned species.—Only one species, the type of the genus, is known.

Discussion.—Allan (1938) discussed the interior details of *Patagorhynchia,* especially those of the pedicle valve. Specimens of pedicle valves in the Canterbury Museum enabled him to determine some characteristics not before seen, such as the strong concavity of the deltidial plates and the fact that they do not exhibit the suture line. He also described the great thickening formed by coalescence of the deltidial plates with a platform made by a thickening at the base of the teeth.

Family HEMITHYRIDAE Rzhonsnitzkaia 1956

Genus HEMITHYRIS d'Orbigny, 1947

Plates 3, A, B, 4, E

Hemithiris d'Orbigny, Paléont. France Ter. Crét., vol. 4, p. 342, 1847; Hertlein and Grant, Publ. Univ. California at Los Angeles, Math. and Phys. Sci., vol. 3, p. 41, 1944.

Hemithyris d'Orbigny, Bronn, Neues Jahrb. Min., Geog., Geol. u. Petrefaktenk, p. 246, 1848; Thomson, Geol. Mag., dec. 6, vol. 2, p. 387, 1915; Thomson, New Zealand Board Sci. Art, Manual 7, p. 149, 1927; Grabau, Sci. Quart. Nat. Univ. Peking, vol. 3, No. 2, p. 112, 1932; Hatai, Sci. Rep. Tôhoku Imp. Univ., ser. 2 (Geology), vol. 20, p. 194, 1940.

Outline triangular, greatest width at or anterior to the middle; inequivalve, the brachial valve having the greater depth and convexity; anterior commissure broadly to narrowly uniplicate; surface obscurely to moderately costellate, the costellae broad and separated by fine striae. Beak of pedicle valve prominent, elongate, and suberect. Foramen incompletely hypothyrid; deltidial plates disjunct; apical region thickened and buttressed by a short median ridge.

Pedicle interior with strong, somewhat elongated, corrugated teeth; dental plates vertical and strong, the umbonal cavities becoming partially filled by adventitious deposit in old specimens. Delthyrial cavity occupied by the pedicle. Apical plate thick, commonly somewhat elevated. Muscle field anterior to the delthyrial cavity, subflabellate, the diductor scars surrounding the adductors. Adjustor scars lateral to the diductors. Lateral areas bounding muscle field pitted; pallial marks obscure.

Brachial valve with deep, corrugated sockets defined by strong crural supporting plates; socket ridges prominent; crura of radulifer type, long, slender, curved, forming horizontally flat blades distally, widening posteriorly to form a narrow hinge plate and strengthened anteriorly by an oblique ridge running from the outside of the tip to the inside of the hinge plate; crural supporting plates buttressing hinge plate; inner hinge plate absent or incipient. Cardinal process absent, the diductor muscles being attached to an apical, roughened pit. Median ridge low, defined chiefly at midvalve and disappearing posteriorly in the umbonal chamber. Adductor field small consisting of a large pair of triangular anterior scars and a pair of small, elongate, subrhomboidal scars situated on the outside posterior to the anterior set.

Type species (by subsequent designation, d'Orbigny, 1847).—*Anomia psittacea* Gmelin, Syst. Nat., vol. 2, p. 3348, 1790.

Comparisons.—The exterior and interior details of *Hemithyris* are distinctive and have no known close counterparts among the Tertiary and Recent brachiopods. The genera nearest like *Hemithyris* are *Aphelesia* and *Notosaria*. The former differs from *Hemithyris* in being exteriorly smooth and in having broad, concave, falcifer crura. The external form of *Notosaria* is suggestive and the beak characters are similar but that genus has well-marked costae and the crura are shorter.

Geological horizon.—Miocene to Recent.

Distribution.—All of the northern seas from the Arctic south to Japan in the Pacific and south to the coast of Maine in the Atlantic.

Assigned species.—The following species, fossil and Recent are placed in *Hemithyris:*

Anomia psittacea Gmelin, Pleistocene to Recent, Northern Hemisphere.
Hemithyris psittacea alaskana Dall, Recent, Alaska.
Rhynchonella woodwardi (A. Adams), Recent, Japan.
H. braunsi Hayasaka, 1928, Pliocene to Recent, Japan.
H. peculiaris Nomura and Hatai, 1936, Recent, Japan.

Discussion.—The most distinctive features of *Hemithyris* are the ornamentation and cardinalia. The type species is strongly marked but other species assigned here are very delicately or obscurely ornamented. *Hemithyris* is really better described as striate rather than costellate. The surface is marked by radial grooves or impressed lines, fairly uniform in *H. psittacea* but discontinuous and irregular in *H. woodwardi.* The spaces intervening between the lines are flat and broad and thus simulate costellae. In *H. woodwardi* the impressed lines are very delicate and so irregular that broad, smooth patches of shell are separated by the striae. These cannot be construed as costellae. This type of ornamentation was seen in this study in only one other rhynchonelloid, *Plicirhynchia.* In this Argentinian genus the region around the umbones is marked as in *Hemithyris* but the striae do not extend to the costate portion of the valves.

The crura are unusual because they are long and slender and are usually flattened in a dorsoventral direction rather than laterally as in most of the other genera. They are thus unlike the crura of any other modern rhynchonelloid. The flat blade is attached to the outer hinge plate on its posteroventral surface. In side view the edge of the outer hinge plate forms an oblique ridge and the crus lies at angle under it. The distal end of the crus is usually pointed, the point being on the inside of the plate. This type of crura is generally classified as belonging to the "radulifer" group.

The cardinal process is seldom conspicuous. It is a triangular area at the apex, roughened horizontally and usually divided by the cleft in the hinge plate which extends to the apex. It is quite like that of several other genera such as *Notosaria.*

Median septa or ridges are never well developed in *Hemithyris,* even in old and obese specimens. This makes a ready distinction and helps to show that septate specimens from the West Coast Tertiary of the United States are not referable to *Hemithyris* where some of them have been placed.

The name *Hemithyris* has been applied to many Tertiary and modern species without regard to geographic realm or biological considerations. Many smooth species have been referred here and some plicated species have also been given this name. The ornament of the genus is so distinctive that confusion with other genera should not occur. *Hemithyris* as now defined appears to be confined to the Northern Hemisphere. Most of the species assigned to this genus from the Southern Hemisphere clearly belong to other genera. As explained above it is difficult to place the rhynchonelloid species generically from descriptions which do not include the interior details. It has thus proved impossible to reassign many of the species now described as *Hemithyris* or placed in that genus.

NOTOSARIA Cooper, new genus

(Gr. *notos,* south)

Plates 6, B, 22, C

Subpentagonal in outline, usually widest at the middle; inequivalve, the brachial valve having the greater depth and convexity; anterior commissure uniplicate; brachial valve fold usually low. Surface costellate; costellae crossed by growth lines and growth varices only. Beak short to moderately long, nearly straight to suberect; foramen large, incomplete, hypothyrid; deltidial plates vestigial to prominent, disjunct; beak with thick, transversely striated apical plate.

Pedicle valve interior with large corrugated teeth supported by short receding dental plates; muscle field large, wide and flabellate, lobate anteriorly and leaving adductor scars open to the anterior. Pallial marks consisting of numerous anteriorly directed channels.

Brachial valve interior with deep, coarsely corrugated sockets and overhanging, thick socket ridges; crura of radulifer type moderately long, horizontally flattened and attached to socket ridges without outer hinge plates. No inner hinge plates. Pallial marks as in the pedicle valve. Cardinal process transversely widely triangular, thickened and somewhat elevated. Median ridge short, low, not reaching the apex.

Type species.—Terebratula nigricans Sowerby, Proc. Zool. Soc., p. 91, 1846.

Comparisons.—This genus was hitherto placed under *Tegulorhynchia* and was generally regarded as the reference species for that genus because it is a Recent as well as fossil form, the interior details of which are well known. Significant differences between this and the type species of *Tegulorhynchia* make it impossible to keep the two in intimate association. The exterior ornamentation of the two is quite distinct, *Tegulorhynchia* having the strongly squamose or spinose exterior whereas *Notosaria* is costellate but with only fine growth lines.

Another exterior difference of importance is the presence in *Notosaria* of disjunct deltidial plates. *Tegulorhynchia* has conjunct deltidial plates and an entire foramen. Inside the pedicle valve the pedicle collar of the modern form is not well developed. A major difference appears inside the brachial valve of *Tegulorhynchia*. In that genus the median septum extends posteriorly to unite with extensions from the crural base to form a thickened plate at the posterior. This is illustrated by Chapman and Crespin (1923) for *T. coelata,* plate 12, figure 17. In shells of modern *Notosaria* the median septum is not extended to the apex.

Geological horizon.—Miocene to Recent.

Distribution.—New Zealand and Kerguelen Island; Belgium.

Assigned species:

Rhynchonella nigricans Sowerby, Miocene to Recent, New Zealand.
R. nigricans pyxidata Davidson, Recent, Kerguelen Island.
R. nysti Davidson, Pliocene, Belgium.
Hemithyris sublaevis Thomson, Miocene, New Zealand.

Discussion.—It may come as a surprise that the group of shells so long associated under the generic name of *Tegulorhynchia* could be separated, but the differences in ornamentation, beak characters, and cardinalia are sufficient. The interior differences of significance are in the pallial markings and cardinalia.

As indicated on plate 6, B, figures 12 and 14, the pallial markings in both valves of *Notosaria* are entirely different from those figured by Leidhold (1922, pl. 11) for *Tegulorhynchia döderleini* (this monograph pl. 22, C, figs. 16 and 17). In *Notosaria* the vascula media cannot be easily distinguished on the inner shell surface and the pallial marks make numerous short trunks extending anteriorly and anterolaterally from the muscle and ovarian fields. The latter is also not distinctly impressed but seems to be a quite narrow crescent in the pedicle valve but somewhat wider in the brachial valve. The pallial trunks of *Tegulorhynchia* as figured by Leidhold are like those common to many other genera illustrated herein.

The cardinalia of the two genera are similar except for the median ridge. In *Notosaria* the median ridge is short and thick and is usually on a small callosity between the posterior adductors. The ridge does not extend to the apex which is generally smooth. In *Tegulorhynchia* on the other hand the median septum is short but extends to the apex where it meets short extensions from the crural bases which form a small apical callosity. The cardinal process of *Notosaria* is well developed but that of *Tegulorhynchia* can scarcely be distinguished.

Rhynchonella nysti Davidson from the Pliocene of Belgium was referred by Thomson (1927, p. 154) to *Tegulorhynchia* with the remark that Davidson (1874a, p. 7) had compared the species to *Tegulorhynchia nigricans.* Comparison of the interior and exterior details corroborates this assignment and comparison. The beak characters of a pedicle valve in the national collection (U.S.N.M. 549417a) has the characteristic foramen and deltidial plates of *Notosaria.* The cardinalia, too, are like those of *Notosaria* as shown by a brachial valve (U.S.N.M. 549417b). The sockets are large and the socket plates broad and strong. The cardinal process is a thickened triangular callosity like that of the New Zealand species. These features combined with the exterior ornament clinch the assignment. *Rhynchonella nysti* is costate and the costae bifurcate at places on the valve as in the New Zealand shell, a feature unusual in the Rhynchonelloidea. This occurrence, as Thomson remarks, leads to interesting speculation on the paleogeographic distribution of *Notosaria.* It is possible that the Austral members of the genus originated in European waters and thus constitute a clearly distinct stock from *Tegulorhynchia* as its anatomy suggests.

Genus TEGULORHYNCHIA Chapman and Crespin, 1923

Plates 5, D, 21, E

Tegulorhynchia Chapman and Crespin, Proc. Roy. Soc. Victoria, n. s., vol. 35, pt. 2, p. 175, 1923; Thomson, New Zealand Board Sci. Art, Manual 7, p. 152, 1927.

Transversely triangular to subpentagonal in outline; inequivalve, the brachial valve having the greater depth; anterior commissure rectimarginate, the brachial valve having a moderately well-defined fold; surface costellate and lamellose, the lamellae being produced into hollow spines in some species. Beak of pedicle valve long and pointed; foramen complete in the type of the genus (Allan, 1940, p. 279). large, hypothyrid; deltidial plates usually conjunct.

Pedicle valve interior with strong corrugated teeth supported by short, receding dental plates; muscle field large, located anterior to the delthyrial cavity; diductor scars of moderate size, surrounding the large adductor scars; adjustor scars large; pallial sinuses sparse, with the vascula media short and branching near midvalve, one branch continuing anteromedially, the other laterally and posteriorly (pl. 21, E, fig. 15).

Brachial valve interior with small cardinalia having strong and elevated socket ridges, no outer hinge plates and no inner hinge plates; crura short, of radulifer type, stout, curved; median septum short, low, and meeting the crural bases at the apex; diductor attachments a pit at the apex. Adductor field small.

Type species (by original designation).—*Rhynchonella squamosa* Hutton, Cat. Tertiary Mollusca and Echinodermata of New Zealand, p. 37, 1873.

Comparison.—The squamose to spiny ornamentation of this genus makes it one of the most conspicuous of modern and Tertiary shells. The distinctive ornamentation is, however, only one means of differentiation from other genera. Interior differences also exist in the form of the moderately short crura and apical callosity formed by the crural bases. This and the difference in the pallial markings are means of distinction from *Notosaria* which is most like *Tegulorhynchia.*

Geological horizon.—The type species and most other species of *Tegulorhynchia* are found in the fossil state. The genus ranges from Oligocene into the Recent where it is represented by *T. döderleini* (Davidson).

Distribution.—The fossil species occur chiefly in the Southern Hemisphere in the southern part of Australia and New Zealand. One fossil form, identified as *T. döderleini* occurs in the Pliocene of Okinawa.

The geographic range of the one living species *T. döderleini* is from Japan south to Borneo.

Assigned species.—The species of *Tegulorhynchia* are:

Rhynchonella squamosa Hutton, Miocene, New Zealand.
R. tubulifera Tate, Miocene, Australia.
R. döderleini Davidson, Recent, Japan to Borneo.
Hemithyris antipoda Thomson, Miocene, New Zealand.
? H. *depressa* Thomson, Miocene, New Zealand.
H. squamosa Buckman (not Hutton), Miocene-Oligocene, Antarctic.
H. imbricata Buckman, Miocene-Oligocene, Antarctic.
Tegulorhynchia thomsoni Chapman and Crespin, Miocene, Tasmania.
T. coelospina Chapman and Crespin, Miocene, Tasmania.

T. coelata (Tension-Woods), Oligocene to Miocene, Tasmania and Australia.
T. masoni Allan, Miocene, New Zealand.

Discussion.—As here limited, the name *Tegulorhynchia* is applied only to imbricate species with cardinalia and hinge characters like those of *T. squamosa.*

Genus PLICIRHYNCHIA Allan, 1947

Plate 7, A

Plicirhynchia Allan, Journ. Paleont., vol. 21, No. 5, p. 493, 1947.

Subtriangular to subpentagonal in outline with the maximum width near the middle; inequivalve, the brachial valve having the greater depth; anterior commissure uniplicate, the fold of the brachial valve being conspicuous and fairly long; surface ornate, the posterior half being marked by fine radial lines and striae, the anterior half strongly costate. Beak of the pedicle valve long, narrowly pointed, and nearly straight; foramen complete, large, longitudinally oval, hypothyrid; deltidial plates thick and conjunct.

Pedicle valve interior with thick corrugated teeth supported by long, stout dental plates; pedicle collar long; muscle field large and flabellate, enclosing the adductor scars.

Brachial valve interior with corrugated sockets bounded by thick overhanging socket ridges; crural bases attached directly to the socket ridges; crura of radulifer type, long, horizontally flattened; inner hinge plates strongly developed. Cardinal process thick and bilobed. Median ridge small.

Type species (by original designation).—*Rhynchonella plicigera* von Ihering, Rev. Mus. Paulista, vol. 2, p. 270, text fig. 7, 1897.

Comparisons.—This genus is characterized by its peculiar exterior ornament, the posterior and umbonal regions being finely costellate but the anterior half strongly costate. The only other semicostate genus marked like this is *Probolarina,* but from that genus it differs in beak characters, cardinalia, and the presence of a cardinal process.

Geological horizon.—*Plicirhynchia* occurs in the Eocene (Patagonian) of Argentina.

Assigned species.—Only one species is assigned here with assurance:

Rhynchonella plicigera von Ihering.
? *Hemithyris plicigera* Buckman, not von Ihering.

Distribution.—Known only from Argentina and possibly from the Antarctic.

Discussion.—The exterior characters of this genus, except for the anterior costation, are most like *Hemithyris.* The general form of the shell, the obscure, fine costellation of the umbonal region, and the large foramen are suggestive of the northern genus. The deltidial plates are conjunct, however, and there the resemblance ends.

The specimens available for study of the interior are not good because the muscle marks are obscure and the cardinalia partially broken. Nevertheless some important details can be distinguished. Inside the pedicle valve the pedicle collar is fairly long and slightly elevated above the valve floor. The dental plates are solid but of the receding type. They are separated from the valve walls by moderately deep and wide umbonal cavities. The muscle field is large and reaches to about midvalve, possibly somewhat beyond in old specimens.

Inside the brachial valve the cardinalia are stout and thick. The cardinal process is a thick, bilobed boss at the apex. The socket ridges are thick and the crura are long, slender, and flattened horizontally. These features are well shown in specimen U.S.N.M. 549423a. The crural bases are attached directly to the socket ridges without outer socket plates. An inner thickening along the edge of the crural bases suggests some development of inner hinge plates. Median ridge small and inconspicuous. The cardinalia appear to be related to those of *Hemithyris, Notosaria,* and *Tegulorhynchia.*

According to Jaanusson (1951, p. 196) the shell referred by Buckman (1910, p. 12) to *Hemithyris plicigera* should be referred to *Plicirhynchia.* Jaanusson also points out in connection with *Hemithyris dibblei* and *H. reagani,* both of Hertlein and Grant (1944), that these do not belong to *Hemithyris* but, because of their anterior costation, may be assigned to *Plicirhynchia.* Unfortunately the interior details of these two species are unknown and the suggested assignment can only be tentative (see discussion of *Hemithyris*).

FRIELEIIDAE Cooper, new family

Genus FRIELEIA Dall, 1895

Plates 4, B, 14, B, 15, A, 21, A

Frieleia Dall, Proc. U. S. Nat. Mus., vol. 17, p. 713, 1895; Thomson, Geol. Mag., n. s., dec. 6, vol. 2, pp. 389, 392, 1915; Jackson, British Antarctic ("Terra Nova") Exped., 1910, Nat. Hist. Rep., Zool., vol. 2, No. 8, pp. 192, 193, 1918; Thomson, New Zealand Board Sci. Art, Manual 7, p. 157, 1927; Hatai, Sci. Rep. Tôhoku Imp. Univ., ser. 2 (Geology), vol. 20, p. 219, 1940; Hertlein and Grant, Publ. Univ. California at Los Angeles, Math. and Phys. Sci., vol. 3, p. 57, 1944.

Elongate oval to subtriangular in outline, with the greatest width at or anterior to the middle; thin shelled; inequivalved, the pedicle valve having the greater depth and convexity; rectimarginate to ligate; surface smooth to obscurely and minutely costellate. Beak of pedicle valve short, nearly straight to suberect; foramen incomplete, elongate oval, hypothyrid; deltidial plates thick, disjunct but nearly united; apex marked by a small triangular plate elevated above the valve floor.

Pedicle valve interior with long, curved, corrugated teeth buttressed by prominent and strong dental plates; muscle and pallial marks lightly impressed; diductor field subquadrate, small, surrounding adductors; vascula media branching at about midvalve, the branches diverging anteromedially and anterolaterally.

Brachial valve interior with deep corrugated sockets margined by thick overhanging socket ridges; crura, of spinulifer type, thin, long, divergent, attached directly to the socket ridges; inner hinge plates small, rounded, disjunct or coalesced at the posterior to form a central bilobed plate; median septum long, slender, elevating posteriorly and united to the inner hinge plates to form a small V-shaped chamber which may be filled by callus in old specimens. Median septum rising to a crest just anterior to the apex; cardinal process a small, triangular, transversely striated pit at the apex; adductor scars long and narrow, posteriorly situated.

Type species.—*Frieleia halli* Dall, Proc. U. S. Nat. Mus., vol. 17, p. 714, pl. 24, figs. 6, 9-13, 1895.

Comparisons.—This is a thin-shelled, fragile brachiopod with both valves somewhat sulcate in the Recent species and characterized by a great development of inner hinge plates and a camerate apex in the brachial valve. It is unlike all other described genera in these respects.

Geological horizon.—Possibly Miocene to Recent. Species from the California Tertiary now referred to *Hemithyris* or other genera may belong here.

Assigned species:

Frieleia halli Dall, Recent, West Coast North America, Japan.
? *Terebratula nitens* Conrad = *Hemithyris astoriana* Dall, Miocene, Oregon.
Hemithyris pellucida Yabe and Hatai, Recent, Japan.

Distribution.—Known from Alaska to California, Japan, and Kamchatka in waters ranging from 21 to 1,059 fathoms.

Discussion.—The important exterior features of this genus are the obscurely costellate surface, the rectimarginate anterior commissure, and the disjunct deltidial plates. In most specimens the median portion of one or both valves is marked by a depressed line or flattening that produces an emargination of the anterior. The deltidial plates are usually strongly developed but have not been observed to meet.

In the apex of the pedicle valve a small triangular plate appears which is elevated above the valve floor. This forms a partial sheath for the pedicle which rests against it. The teeth, as in most modern rhynchonelloids, are corrugated and are supported by well-developed, erect dental plates defined by deep umbonal cavities. The muscle field is small, with a large subquadrate flabellate diductor field surrounding the adductors anteriorly. The adjustor scars are small and are located just anterior to the front of the dental plates. Faint pallial marks preserved in one specimen show the vascula media as in *Hispanirhynchia.*

The most interesting parts of *Frieleia* are the cardinalia. The diductor muscles are attached in a small, triangular, horizontally striated pit at the apex. In some specimens this is much thickened to form a cardinal callus. The socket ridges are strong and curved. To them are attached small triangular outer hinge plates. The hinge plates bear the crural bases and crura. The crural bases are further strengthened by inner hinge plates that extend dorsally to unite with the median septum to form a small chamber. I am unable to detect any substantial resemblance of this structure to that of *Camarotoechia* or even to the camerate Mesozoic rhynchonelloids.

The median septum in *Frieleia* is a narrow, strong, elevated plate that is a myophragm and a crural buttress. It is interesting to note that the inner hinge plates, in decking over the space between the crural bases, do not form a septal chamber as in *Camarotoechia* but fill in the space solid. In some specimens the inner hinge plates coalesce in such a way as to form an undivided but concave hinge plate.

The adductor field is divided by the median septum and is long and slender. The anterior scars are elongate, tear shaped in outline. The posterior pair is smaller and lies posterolateral to the anterior pair.

Frieleia has not yet been definitely identified in the Tertiary of California or Japan. It has distinctive characters and is one of the few modern or Tertiary brachiopods having a prominent median septum. Several species occurring on the Pacific Coast of the United States may be referable to *Frieleia,* especially if the definition were to be broadened to some extent. The so-called *Hemithyris astoriana*

Dall (=*Terebratula nitens* Conrad) has interior characters strongly suggesting *Frieleia,* especially the strong median septum in the brachial valve. The species is fairly strongly uniplicate, however, which is not in accordance with the current definition of *Frieleia.* All the specimens of *H. astoriana* available for study, including the type specimen, are badly exfoliated. The exterior is therefore not yet wholly known. The exfoliated shells have fairly strong radial costellae, but these may be only a feature of the exfoliated shell. A cross section of the beak of the brachial valve reveals a small triangular chamber. No modern specimens of *Frieleia* are uniplicate. The specimens of *H. astoriana* are here referred to *Frieleia* with a query. They are nearer that genus than they are to *Hemithyris.* Ultimately it may be necessary to erect a new genus for uniplicate *Frieleia* if specimens good enough for detailed description are brought to light.

Genus COMPSOTHYRIS Jackson, 1910

Plate 16

Compsothyris Jackson, British Antarctic ("Terra Nova") Exped., 1910, Nat. Hist. Rep., Zool., vol. 2, No. 8, p. 188, 1918; Thomson, New Zealand Board Sci. Art, Manual 7, p. 161, 1927.

Rounded triangular in outline with the greatest width at about the middle; valves subequal in depth, the pedicle valve having a greater depth than the brachial valve; anterior commissure broadly and gently uniplicate, the brachial fold inconspicuous. Surface marked by fine radial costellae. Beak of pedicle valve nearly straight to suberect, bluntly pointed; foramen incomplete, of moderate size, elongate elliptical, hypothyrid (permesothyrid according to Jackson, 1918); deltidial plates disjunct.

Pedicle valve interior with small teeth supported by strong dental plates; muscle field located well anterior to the delthyrial cavity, small; diductor scars small, surrounding the adductor pair. Pallial marks not impressed.

Brachial valve interior with narrow corrugated sockets bounded by strongly overhanging socket ridges; crura of spinulifer type, short, attached to the socket ridges by narrow hinge plates. Inner hinge plates incipiently developed. Median ridge or myophragm slender, moderately elevated and reaching the apex where it is divided and supports the proximal ends of the crural bases. Adductors closely crowded against the myophragm, the right and left pairs being tear shaped in outline.

Type species (by original designation).—*Rhynchonella racovitzae*

Joubin, Résultats voyage S. Y. *Belgica,* 1897-1898-1899, Zool., Rapt. Sci. Commiss. *Belgica,* p. 5, pl. 1, figs. 1-4, 1901.

Comparisons.—The genera to which *Compsothyris* can profitably be compared are: *Frieleia, Hispanirhynchia,* and *Grammetaria.* The differences between *Compsothyris* and *Frieleia* are chiefly exterior characters but the cardinalia also vary importantly. *Frieleia* is not so strongly and evenly costellate as *Compsothyris* and the shape and folding of the two are quite different. In *Frieleia* it is common for both valves to have a sulcus and for the front to be emarginate. *Compsothyris* is faintly uniplicate. Furthermore, *Frieleia* is much more triangular than *Compsothyris* and has a great development of inner hinge plates in the cardinalia of the brachial valve, a feature not shared by the Antarctic shell.

Hispanirhynchia differs in shape from *Compsothyris,* having a compressed profile and strongly triangular outline. The two genera are similarly marked on the exterior however. Inside the brachial valve only a slight development of inner hinge plates appears in *Compsothyris,* and the small chamber at the apex is not obliterated by shell growth in the adults as it is in *Hispanirhynchia.*

Compsothyris differs from *Grammetaria* in the form of the valves and in the less elaborate deltidial plates. *Compsothyris* is nearly circular in outline whereas *Grammetaria* is strongly triangular. The deltidial plates of *Grammetaria* are elaborately auriculate but those of the Antarctic genus are small and not auriculated. Inside the brachial valve no inner hinge plates are developed by *Grammetaria* but the small apical chamber present in the young is sealed off in the adult by the sides growing shut. In adult *Compsothyris* this chamber remains open.

Geological horizon.—Not known in the fossil state.

Distribution.—Ross Sea area and western Antarctic in depths ranging from 45 to 300 fathoms.

Assigned species.—So far only one species can be definitely assigned here but two others may belong:

Rhynhonella racovitzae Joubin, Recent, Antarctic.
? *Hemithyris striata* Thomson, Recent, Antarctic.
? *Rhynchonella valdiviae* Helmcke, Recent, Indian Ocean.

Discussion.—Jackson (1918, p. 193) expressed interest over the fact that the features of *Compsothyris* and *Frieleia* were suggestive of certain Paleozoic genera, especially *Camarotoechia.* Comparison with interiors of *Camarotoechia* (see pl. 4, D, figs. 6-8), however, show the relationship to be quite remote because the structures in the two genera, which look similar, actually are developed differently. In the Paleozoic genus the median septum is strong and high and supports a V-shaped chamber having strong walls. This is in turn covered by a flat plate connecting the crural bases. This plate is apparently built, at least in part, posteriorly because it does not generally close the chamber but leaves a small round cavity at the apical end. This chamber of *Camarotoechia* is more like the structure in *Septaliphoria*. The chamber of this Jurassic shell is, however, also different from that of *Camarotoechia*, although the two look alike. The chamber of *Compsothyris* is a much more delicate affair and, it seems to me, not related to any Paleozoic form.

GRAMMETARIA Cooper, new genus

(Gr. *gramme*, line)

Plates 4, C, 9, A

Outline elongate triangular with the maximum width at the anterior; valves subequal in depth, the pedicle valve having a slightly greater depth; anterior commissure rectimarginate; surface marked by fine costellae. Beak small, bluntly pointed, suberect; foramen incomplete, rounded, hypothyrid; deltidial plates auriculate, conjunct.

Pedicle valve interior with small corrugated teeth, supported by strong vertical dental plates. Muscle field small and subcircular; diductor scars small; adjustor scars large, posterolaterally placed.

Brachial valve interior with corrugated sockets bounded by strong, thick socket ridges; crura short, of spinulifer type, triangular in section but laterally flattened distally, attached to the socket ridges by very narrow, inconspicuous outer hinge plates; median ridge thick, not quite reaching the apex in the adult, but in the young forming a low, wide V-shaped chamber with the crural bases; V-shaped chamber covered by shell substance in the adult. Adductor field elongate triangular, the anterior and posterior scars on each side of the median ridge tear shaped in outline; posterior set of adductors located outside the anterior set.

Type species.—*Hemithyris bartschi* Dall, Proc. U. S. Nat. Mus., vol. 57, p. 289, 1920.

Comparison.—This genus is most suggestive of *Frieleia* and *Compsothyris* among described genera, but it has important differences from both of them. In the first place, *Frieleia* has a strong tendency to ligation while *Compsothyris* is broadly uniplicate. *Grammetaria,* on the other hand, is rectimarginate. The deltidial plates of the pedicle valve of *Grammetaria* are elaborately auriculate but such features have not been seen in the other two genera. The deltidial plates of *Grammetaria* are conjunct but those of the other two genera are disjunct. However, those of *Frieleia* nearly meet.

The interior of the brachial valve is the significant part of each of these genera. In *Frieleia* the crural bases are attached to the median septum but in addition a strong development of inner hinge plates may create a small chamber at the apex. In *Compsothyris* the crural bases are likewise supported by the median septum but no comparable development of the inner hinge plates is known. In *Grammetaria* the very young are similar to *Compsothyris* in having the crural bases united to the median septum but the apical V-shaped chamber thus formed is much broader and shallower than that of *Compsothyris*. In the adult of *Grammetaria* the spaces between the septum, shell wall, and the broad chamber are filled to form a thick apical callosity between the crura. Thus the low septum ends in a callosity at the rear of the adult shell.

Assigned species.—At present only *Hemithyris bartschi* Dall is known in this genus.

Distribution.—*Hemithyris bartschi* is known only from Philippine waters from depths of 161 and 298 fathoms.

Discussion.—Only two specimens of this genus are known but they indicate a brachiopod having several unusual characters. Although the deltidial plates of the adult specimen are broken, probably in separating the valves, those of the young specimen are quite definitely conjunct even though broken slightly at their line of junction. This is one feature that distinguishes this genus from *Frieleia* and *Compsothyris*. Another feature of considerable interest is the development of the brachial interior from a camerate brachial valve to one having only a callosity at the posterior. The small camera of the young is buried in callus as the valve grows and is completely obliterated. This takes place to a lesser extent in *Hispanirhynchia*. The crura of *Grammetaria* are more like those of *Frieleia* in not having prominent outer hinge plates developed. In *Compsothyris* modest but definite outer hinge plates are present, making the crura more suggestive of *Basiliola* than of *Frieleia*.

HISPANIRHYNCHIIDAE Cooper, new family

Genus HISPANIRHYNCHIA Thomson, 1927

Plates 10, 13, A, 21, G

Hispanirhynchia Thomson, New Zealand Board Sci. Art, Manual 7, p. 159, 1927.

Outline elongate triangular with the greatest width in the anterior third; inequivalve, the pedicle valve being deeper than the brachial valve; anterior commissure rectimarginate to ligate to slightly uniplicate; surface marked by concentric lines of growth and fine obscure radial costellae; beak of the pedicle valve short, suberect; foramen incomplete, large, hypothyrid; deltidial plates small, disjunct.

Pedicle valve interior with well-developed but incomplete pedicle collar and thick teeth supported by small, somewhat receding dental plates; muscle field small, rounded, with small diductor scars surrounding large adductor scars. Vascula media prominent, originating between diductor and adjustor scars, extending anteriorly to branch about one-third the length from the front margin.

Brachial valve interior with corrugated sockets and overhanging socket ridge to which the short, bladelike, spinulifer crura are attached by small and narrow outer hinge plates. Inner hinge plates small and narrow. Median ridge low, thick, extending to the apex. Adductor field small, divided by a low median ridge; anterior adductors rounded, posterior pair elongated. Vascula media widely divergent.

Type species (by original designation).—*Rhynchonella cornea* Fischer, *in* Davidson, Trans. Linnaean Soc., ser. 2, vol. 4, Zool., pt. 2, p. 171, pl. 25, figs. 2-4, 1887.

Comparisons.—This is one of several triangular or nearly triangular genera with faint radial ornamentation. It differs from *Frieleia* and *Compsothyris* in not having a strongly camerate apex in the brachial valve of the adult. It differs from *Grammetaria* in its less prominent radial markings, nonalate deltidial plates, and the development of the cardinalia which are camerate in the young of *Grammetaria*. *Aetheia* can be readily distinguished from *Hispanirhynchia* by its small foramen, concave deltidial plates and the great development of inner hinge plates on the interior.

Distribution.—In modern seas *Hispanirhynchia* is known from off the coasts of Morocco, the Sudan, and the Canary Islands. It is also known from west of Cape Finistere, northwestern Spain. It is generally found in deep water, from 577½ fathoms [2] off Cape St. Vincent, Portugal, to below 1,000 fathoms off the coast of Spain. One species, *H. ?craneana* (Dall) doubtfully assigned, taken off Cocos Island, Panama, came from 117 fathoms.

Geological horizon.—Possibly present in the Eocene of Cuba.

Assigned species.—Two Recent species are assigned to this genus:

Rhynchonella cornea Fischer, Recent, North Atlantic.
? *Hemithyris craneana* Dall, off Panama, Pacific Ocean.
Hispanirhynchia sp., Eocene, Cuba.

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[2] See note by Jackson (1918, p. 192, footnote).

Discussion.—External features of importance in this genus are the beak characters, the ornamentation, and the anterior commissure. In the type species the deltidial plates are well developed and disjunct but in some specimens approach each other very closely. Dall describes the deltidial plates of *H. ?craneana* as "obsolete" but the specimen has definitely been damaged in the beak region. In some old specimens of *H. cornea* these plates are also lacking, possibly due to abrasion.

The shell of young specimens of *Hispanirhynchia* is generally translucent and a pale brown. Adults are opaque and a deeper brown in color. The surface is minutely costellate, the costellae extremely fine and very closely crowded.

Specimens of *H. cornea* are generally rectimarginate but Thomson (1927, p. 159) speaks of some as being ligate, that is, with a gentle depression in each valve which will produce an emarginate anterior. The anterior commissure of *H. ?craneana,* on the other hand, has a slight wave in it toward the pedicle valve, thus producing a faint sulcation.

The interior of the pedicle valve of the mature to old shells usually shows the details to perfection because the muscles and pallial marks are deeply impressed. The pedicle collar is well developed and may be elevated above the valve floor. The teeth are strong and corrugated. The dental plates are strong and separated from the lateral shell wall by deep cavities. In old shells these tend to become nearly obliterated by deposition of shell substance inside the cavities.

The muscle field is small. The flabellate diductor scars are small and surround a fairly large adductor patch anteriorly. The adjusttor scars are deeply impressed at the anterior edge of the dental plates. Accessory diductor scars are not visible in the delthyrial cavity. The vascula media take off anterior to the adjustor scars and along the outside of the diductor scars. The main trunk branches at about midvalve, one branch extending laterally, the other anteromedially. Both of these branches bifurcate again to produce distributaries anteriorly and laterally.

The genital area is small and located on the shell wall just anterior to the dental plates. This area is smaller than that in *Basiliola* and *Rhytirhynchia.*

The cardinalia of this genus are interesting because the young show features that are buried by excess shell in the adult. The insertion of the diductor muscles appears as a small, triangular, horizontally striated pit at the apex. No swollen cardinal process is present as in

Plicirhynchia. The socket ridges are thick and curved; the crura are attached to them by small, triangular outer hinge plates. The crura are laterally compressed blades, not concave in section and their distal end is serrated. Prominent inner hinge plates are formed at the apical end of the shell which attach to the floor of the valve. With the septum they form a poorly defined chamber but in old specimens the inner plates become thickened at the apex and fuse to form a thick callus. In such cases the extensions of the inner plates to the valve floor are obscured.

The adductor field is small and elongated. The anterior pair of scars is the larger and the posterior pair more elongated, at least in the old shells. The field is divided medially by a short, thick median ridge which extends no farther than the anterior end of the adductor field. At the anterior end of the ridge a small scar appears in old specimens. The genital areas are small like those of the pedicle valve. The vascula media originate at the inside ends of the anterior adductors and surround the small scar mentioned above. These pallial trunks divide near midvalve in a manner similar to that of the pedicle valve.

Comparison of *Hispanirhynchia ?craneana* with middle-aged specimens of *H. cornea* show slight differences but they do not appear to be great enough to exclude the species from *Hispanirhynchia.* The outer hinge plates of the brachial valve appear slightly wider than those of the Atlantic shells and the inner hinge plates are not so well developed, but they are there.

Rhynchonella sicula Seguenza, here made the type of the genus *Sphenarina,* was early identified with *H. cornea,* but examination of the interior of the Sicilian shell makes it clear that the two have little in common but shape and ornament. *Sphenarina* has no median septum and its beak characters are different from those of *Hispanirhynchia.*

SPHENARINA Cooper, new genus

(Gr. *sphenos,* wedge)

Plates 5, B, 8, A

Shell triangular in outline, with the greatest width in the anterior third; subequivalve, the pedicle valve having a slightly greater depth than the brachial valve; anterior commissure rectimarginate; surface marked by minute radial lines. Beak long, suberect; foramen small, circular, hypothyrid; deltidial plates conjunct, elaborately auriculate.

Pedicle valve interior with short pedicle collar and well-developed dental plates with wide umbonal cavities.

Brachial valve interior with prominent socket ridge to which the short crural bases are attached without outer hinge plates. Crura moderately long, of spinulifer type, nearly straight, compressed to slightly crescentic in section and with distal extremities flattened; no inner hinge plates. Posterior of crural bases attached to floor of valve by short plates; cavity between plates occupied by callus, thus making the apex solid. Median ridge or septum absent; adductor field elongate.

Type species.—*Rhynchonella sicula* Seguenza, *in* Davidson, Geol. Mag., vol. 7, No. 76, p. 461, pl. 20, fig. 6, 1870.

Comparisons.—This is a wedge-shaped form with fine radial ornamentation comparable to *Hispanirhynchia, Grammetaria,* and *Compsothyris*. It differs from all these in the nature of the cardinalia. On the inside of the brachial valve the cardinalia of *Sephenarina* differ from all three in the almost total absence of a median ridge or septum and in the fact that the plates supporting the crural bases at the apex meet the floor of the valve directly.

Geological horizon.—Pliocene of the Mediterranean region.

Assigned species.—The following species are placed in this genus:

Rhynchonella sicula Seguenza.
R. soricina Defrance = *R. sicula* Seguenza.
? *Hemithyris eotrigona* Sacco and variety *obliquatella* Sacco.

Discussion.—This species has commonly been referred to *Hispanirhynchia* because of the close similarity of form and ornamentation. In fact Jeffreys (1878, p. 413) identified dredged specimens of the latter as identical with the Italian species. Examination of the beak and brachial valve interior of *R. sicula* will dispel the idea of identity almost immediately.

The material of *S. sicula* showing interior details is scanty. The two specimens in the National Museum from which the above description was drawn were prepared by needles, a delicate operation considering the thin shell of the species and the fragile nature of the cardinalia. The length of the crura is moderate and the ends are flattened laterally, strongly suggesting the crura of *Frieleia*.

The cardinalia of *Sphenarina* are suggestive of those of *Hispanirhynchia* but the median septum is lacking. The plates supporting the crural bases thus rest directly on the valve floor rather than on the median septum. A young specimen dissected shows no trace of a septum and no evidence of supporting plates for the crural bases.

ERYMNARIIDAE Cooper, new family

ERYMNARIA Cooper, new genus

(Gr. *erymnos,* fenced)

Plates 18, A, B, 19, A, 22, B

Outline irregular triangular to rounded pentagonal, usually with the greatest width at or anterior to the middle; inequivalve, the brachial valve having the greater depth; anterior commissure irregular, twisted or regularly uniplicate; surface smooth or marked by concentric growth lines and short, irregular costae occupying the anterior third or half. Beak of pedicle valve short, deltidial plates conjunct, slightly auriculate; foramen small to moderately large, oval, hypothyrid.

Pedicle valve with short dental plates defining a deep delthyrial cavity; muscle field small, with small adductor scars surrounded by subflabellate diductor scars. Vascula media short.

Brachial valve with large, deep, corrugated sockets; socket ridges elevated and strong; outer hinge plate broad; crura of septifer type, curved, supported by two long septa that extend along the valve floor for about one-fifth the valve length. Vascula media thin, moderately long.

Type species.—*Terebratula polymorpha* Massalongo, Schizzo geognostico sulla valle del Progno o Torrente D'Illasi, con un saggio sopra la flora primordiale del M. Bolca, Verona, pp. 18, 19, 1850.

The septifer type of crura are not well known but have been recognized in the Jurassic. Rothpletz recognized two groups or Sippe having septifer crura. One of these is the Inversa-Sippe in which the species have a sulcate anterior commissure and are smooth or semicostate; the other group is the Trigona-Sippe in which the shells are rectimarginate to uniplicate and are wholly costate.

Septocrurella of Wisniewska is a paucicostate genus having a sulcate anterior commissure and the septifer type of crura. *Rhynchonella deluxa* Oppel, which is similar exteriorly to *Septocrurella sanctaclarae* Wisniewska, also has the septifer type of crura.

No Cretaceous rhynchonelloids having this structure are now known to me, but the fact that septifer genera appear in the Jurassic and Eocene indicate the strong likelihood that specimens with this structure occur in the Cretaceous. It is interesting to note that the known Eocene septifer genus is smooth pauciplicate but is uniplicate rather than sulcate.

Comparison.—The exterior form of two species of *Erymnaria* is like that of *Streptaria* in having the strongly twisted anterior commissure, but there the similarity ends. The interior of *Erymnaria* is so unlike that of *Streptaria* that confusion of the two is not possible.

Geological horizon.—Eocene of Italy and Cuba.

Distribution.—Two species of this genus are known in the Eocene of northeastern Italy and one at the same horizon in Cuba. Only one specimen is known from the latter occurrence but the interior details visible through the shell make the identification with this genus quite certain.

Assigned species.—Three species of this genus are now known:

Terebratula bolcensis Massalongo, Eocene, Italy.
T. polymorpha Massalongo, Eocene, Italy.
Erymnaria cubensis Cooper, new species, Eocene, Cuba.

Discussion.—The genus is characterized by having strong supporting plates buttressing the crura and constituting the septifer type of Rothpletz. It is the only Tertiary genus known to me having this peculiar structure. The supporting plates of the crura make two long, dark suture lines diverging from the beak. In several specimens the socket plates are also visible as dark lines on the inner filling of the shell. In such cases the socket plates occupy the outside and are shorter than the crural supports.

ERYMNARIA CUBENSIS Cooper, new species

Plate 19, A

Shell of about median size for a rhynchonelloid, slightly wider than long; subpentagonal in outline; widest at midvalve; sides narrowly rounded; beak forming an angle of 100°; anterior margin truncated. Anterior commissure strongly uniplicate; surface marked only by concentric growth lines.

Pedicle valve evenly and gently convex in lateral profile; nearly flat in anterior profile with margins abruptly bent dorsally; umbo somewhat narrowly swollen; median region flattened; sulcus originating at about midvalve, broad and shallow; tongue moderately long, narrowly rounded, and bent nearly at right angles to the lateral commissure; flanks bounding sulcus narrow, gently convex, and moderately steep. Beak small, rounded; beak ridges not prominent; deltidial plates conjunct; foramen moderately large, longitudinally elliptical, and with the anterior margin having a small lip.

Brachial valve deeper than the pedicle valve; gently convex in lateral profile but narrowly domed in anterior profile, the sides long and steep. Umbo and median region swollen; fold originating anterior to midvalve, low and gently rounded, scarcely protruding beyond the flanks; sides steep, gently inflated.

MEASUREMENTS IN MILLIMETERS

	Length	Brachial length	Width	Thickness
Holotype	14.1	12.8	15.0	10.0

Types.—Holotype, U.S.N.M. 549385.

Horizon and locality.—Eocene, 80 meters northeast of school, Chucho Machin, Matanzas Province, Cuba.

Discussion.—Only a single complete specimen is known of this interesting species, but it is well preserved and some of the interior details are visible through the transluscent shell. It is most like *T. bolcensis* (Massalongo) in its symmetrical form and folding, but differs in having a broader and less narrowly folded anterior commissure, a larger foramen, and the crural supporting plates seem to be somewhat shorter than those of the Italian species.

That this species belongs to the Italian genus seems certain because the crural supporting plates and socket ridges are clearly visible through the thick but transluscent shell as narrowly divergent septa. Visibility was made better by washing the beak and umbo of the brachial valve with dilute acid to thin the shell.

UNPLACED SPECIES

Rhynchonella lamothei Dautzenberg (1909, p. 271). This is a completely costate (16 costae) species from the Pliocene of Algeria. It has a sulcus on the pedicle valve with 7 costae and a prominent fold with 6 costae. No details of the hinge or interior were described. It is unlike any other Tertiary rhynchonelloid.

R. (*Hemithyris*) *vinassai* Boni (1933, p. 86). Miocene, Monte Vallassa, Italy. This is a semicostate form suggestive of *Aphelesia bipartita* but the interior details are not figured.

Rhynchonella washingtoniana Weaver (1912, p. 55). Weaver's figures of this species indicate a brachiopod with a type of ornamentation never seen in rhynchonelloids. Examination of specimens from the Cowlitz River proves the shell to be punctate and the ornamentation to be that of the genus *Terebratulina*. The species is thus not a rhynchonelloid.

Rhynchonella meneghiniana Davidson (1870, p. 463). This is a small completely costate species from the Eocene of Bolca, Italy. It is quite distinct from any other Tertiary species but nothing is known of its beak characters and interiors. It may be related to *R. polymorpha* (=*Erymnaria*) which may be strongly costate.

Hemithiris dibbleei Hertlein and Grant (1944, p. 46). Eocene of California. No details of the interior of this species are given but it is semicostate. In exterior view it accords with *Plicirhynchia* but this is a much younger genus located in a completely different faunal realm.

Hemithiris reagani Hertlein and Grant, (1944, p. 54). Oligocene, California. This species is also semicostate like that above and might be referable to *Plicirhynchia,* but no details of the interior are known.

"Rhynchonella" supraoligocaenica Görges (1952, p. 5). This species is from the upper Oligocene of Germany. It is a large, smooth form suggestive of *Aphelesia bipartita.* The interior is, however, unknown and the species cannot be assigned with confidence.

"Rhynchonella" valdiviae Helmcke (1940, p. 290). This species is found near New Amsterdam in the south-central part of the Indian Ocean. It resembles *Compsothyris* in form, ornamentation, and beak characters. The color is brownish gray and the shell transparent as in *Compsothyris.* Dental plates are present in the pedicle valve. The cardinalia consist of spoon-shaped, curved crura truncated at the end. The brachial valve is provided with a "very weak median-septum, the front end of which is about even with the ends of the crura. The septum is highest in the middle." The figure given by Helmcke (fig. 37) does not show the septum clearly. The species strongly suggests *Compsothyris,* but it is not possible to be sure until better details of the interior are known.

This species also suggests *Hemithyris striata* Thomson from off Shackleton Glacier, Davis Sea, Antarctica, by its rounded outlines and fine costellae. These two species are assigned to *Compsothyris* with a query.

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EXPLANATION OF PLATES

Plate 1

Cryptopora

Page

A. *Mannia nysti* Davidson = *Cryptopora nysti* (Davidson).............. 22

Figs. 1-14. 1, Dorsal view of a complete specimen showing triangular outline, × 10, hypotype U.S.N.M. 549422a. 2, Same view as preceding, × 20, showing strongly elevated deltidial plates and large triangular foramen. 3-5, Respectively partial side, side, and ventral views of the same specimen showing the profile and large deltidial plates, × 10. 6, Interior of the pedicle valve of the same specimen showing teeth and deltidial plates, × 10. 7, Interior of the brachial valve of the same individual showing high, narrow median septum, and crura with flattened distal extremities, × 10. 8-10, Respectively interior, partial side, and side views of the same valve, × 20, showing median septum and details of the cardinalia. 11, 12, Interior and partial side views of another pedicle valve interior, × 10, showing teeth and deltidial plates, hypotype U.S.N.M. 549422b. 13, 14, Partial side and anterior views of the preceding specimen, × 20, showing dental plates, apical plate and deltidial plates.

Upper Miocene (Diestien-Sables de Deurne), Wommelghem, east side of Antwerp, Belgium.

B. *Cryptopora rectimarginata* Cooper, new species....................... 20

Fig. 15. Dorsal view of a complete specimen showing alate deltidial plates and apical plate, × 15, paratype U.S.N.M. 274143d.

Recent, Eolis Station 340, at 209 fathoms, off Fowey Light, Florida.

Fig. 16. Another specimen showing the alate deltidial plates and apical plate, × 15, paratype U.S.N.M. 274168a.

Recent, Eolis Station 320, at 80 fathoms, off Western Dry Docks, Florida.

Figs. 17, 18. Respectively tilted to the side and full views of a specimen showing elaborate alae on the deltidial plates, × 15, paratype U.S.N.M. 336896a.

Recent, Eolis Station 378, at 165 fathoms, off Fowey Light, Florida.

Fig. 19. Interior of a pedicle valve with tooth broken on right side but showing alae with scalloped edges on deltidial plates and the large plate just anterior to the apex, × 15, paratype U.S.N.M. 336895a.

Recent, Eolis Station 377, at 190 fathoms, off Fowey Light, Florida.

Plate 2

Cryptopora and *Neorhynchia*

T. *Cryptopora rectimarginata* Cooper, new species....................... 20

Figs. 1-11. 1-3, Respectively dorsal, side, and anterior views of a complete specimen, × 6, showing rectimarginate commissure, holotype

Page

U.S.N.M. 274143a. 4, Partial side view of another individual showing the alate deltidial plates, × 6, paratype U.S.N.M. 274143b. 5, Posterior of the specimen shown in figure 4, illustrating the alate deltidial plates, × 8. 6, 7, Respectively anterior and full views of the interior of the pedicle valve, × 6, showing strong dental plates, paratype U.S.N.M. 274143c. 8-11, Respectively partial side, full, anterior, and posterior views of the brachial interior of the preceding, showing the long slender maniculifer crura, the short, strongly elevated median septum and the bilobed cardinal process, × 8, paratype U.S.N.M. 274143c.

Recent, Eolis Station 340, 209 fathoms, off Fowey Light, Florida.

B. *Neorhynchia strebeli* Dall 34

Figs. 12-23. 12-15, Respectively ventral, dorsal, anterior, and side views of a complete specimen, × 2, showing the sulcate anterior commissure, paratype U.S.N.M. 110741a. 16, 17, Respectively anterior and full views of the posterior pedicle valve, × 4, showing dental plates, corrugated teeth, and disjunct deltidial plates, holotype U.S.N.M. 110741. 18, 19, 21, 22, Respectively full, posterior, anterior, and partial side views of the posterior of the brachial valve of the holotype, × 4, showing broad outer hinge plates, low median ridge, small inner hinge plates, and falcifer crura. 20, 23, Partial anterior and partial side views of the paratype showing socket ridges and short crura, × 6.

Recent, U. S. Fish Commission Station 4721, 2,084 fathoms in *Globigerina* ooze, 35.1° F., mid-Pacific.

Plate 3

Hemithyris

A. *Hemithyris woodwardi* (Davidson) 47

Figs. 1-11. 1-3, Respectively side, anterior, and dorsal views of a complete specimen, × 1, hypotype U.S.N.M. 111083a. 4, Dorsal view of the same specimen, × 2, showing fine radial striae. 5, Beak of a pedicle valve, × 3, showing large foramen and discrete deltidial plates, hypotype U.S.N.M. 111083b. 6, Interior of the same pedicle valve tilted to show the vertical dental plates, × 2. 7, 8, Respectively anterior and full views of a brachial valve showing cardinalia, inconspicuous median ridge and muscle scars, × 2, U.S.N.M. 111083c. 9, Posterior view of the same brachial valve showing socket ridges, outer hinge plates, and radulifer crura, × 4. 10, Partial side view of the same brachial valve showing the long slender crura, × 4. 11, Posterior view of another brachial valve showing the cardinalia and the scars of the diductor muscles at the apex, × 4, hypotype U.S.N.M. 111083d.

Recent, Hakodate, southern Hokkaido, Japan.

B. *Hemithyris psittacea* (Gmelin) 45

Figs. 12-21. 12-14, Respectively anterior, side, and dorsal views of a complete specimen showing the long beak, × 1, hypotype U.S.N.M. 111004a. 15, Dorsal view of the preceding specimen, × 2, showing

Page

the closely crowded costellae separated by narrow, shallow striae. 16, Interior of the pedicle valve of another specimen tilted to show apical and dental plates, × 2, hypotype U.S.N.M. 111004b. 17, Posterior of the preceding pedicle valve, × 3, showing large, incomplete foramen, large teeth, and small disjunct deltidial plates. 18, 19, Respectively anterior and full views of the brachial valve interior showing cardinalia, myophragm, and muscle scars, × 2, hypotype U.S.N.M. 111004b. 20, Posterior of the preceding specimen tilted to show socket ridge, corrugated socket, and long, slender, curved, radulifer crura with the strengthening ridge on their under or dorsal surface, × 3. 21, Posterior view of the cardinalia of the same specimen showing socket ridge, small outer hinge plates, and distally flattened crura, × 3.

Recent, Coal Harbor, Unga Island, Shumagins, Alaska.

Plate 4

Aetheia, Frieleia, Grammetaria, Camarotoechia, and *Hemithyris*

A. *Aetheia gualteri* (Morris) 42

Fig. 1. Rubber impression of a pedicle valve interior prepared to show the muscle scars and pallial marks, × 2, hypotype U.S.N.M. 369298a (see pl. 9, B).

Miocene (Duntroon greensand), Otago, New Zealand.

B. *Frieleia halli* Dall 53

Figs. 2, 3. 2, Posterior of a brachial valve, × 6, showing the hinge plates surrounding a plug of the median septum, and the inner hinge plates engulfing the septum, hypotype U.S.N.M. 111021a. 3, Posterior of another brachial valve interior, × 6, with well-preserved cardinalia and elongate adductor scars, and showing inner hinge plates not yet coalesced, hypotype U.S.N.M. 111021b.

Recent, 559 fathoms, in ooze, 38.4° F., U. S. Fish Commission Station 2871, off the coast of Washington.

C. *Grammetaria bartschi* (Dall) 58

Figs. 4, 5. 4, Dorsal view of a young but imperfect specimen, × 6 above and × 10 below, showing elaborate auriculations on the deltidial plates, paratype U.S.N.M. 274134. 5, Same specimen with brachial valve tilted to show cardinalia and dental plates, × 6, and also showing septum united with hinge plates and long curved crura.

Recent, at 161 fathoms, 57.4° F., on sand, U. S. Bureau of Fisheries Station 5735, off Jolo, Philippine Islands.

D. *Camarotoechia* species 10

Figs. 6-8. 6, 7, Two views of the posterior part of a silicified brachial valve, × 4, showing crura and median hinge plate welding them together, figured specimen U.S.N.M. 134812e. 8, The same specimen tilted to show apical chamber (septalium?) and crural plates, × 4 (see p. 10).

Devonian (Norway Point formation), junction French and Truckey roads, SW1/4SW1/4 sec. 4, T. 31 N., R. 8 E., Alpena County, Michigan.

Page

E. *Hemithyris psittacea* (Gmelin) 45

Figs. 9, 10. 9, Posterior of a large brachial valve showing cardinalia with the narrow outer hinge plates and slender radulifer crura with the transverse cardinal process at the apex, × 3, hypotype U.S.N.M. 111013. 10, Same specimen, × 3, tilted to the side to show the slender radulifer crura with their flattened distal extremity and strengthening ridge on dorsal side.

Recent, 13 fathoms, Upernavik Harbor, east coast of Greenland.

Figs. 11, 12. 11, Posterior of another brachial valve, × 3, tilted to show the long, slender crura and slight development of outer hinge plates, hypotype U.S.N.M. 549379. 12, Side view of the pedicle valve interior belonging to the preceding and showing the inner face of the dental plate and tooth with its corrugations, × 2.

Recent, north end of Nunivak Island, Alaska.

Plate 5

Eohemithyris, Sphenarina, Cryptopora, and *Tegulorhynchia*

A. *Eohemithyris alexis* Hertlein and Grant.......................... 30

Figs. 1-5. Respectively anterior, posterior, side, dorsal, and ventral views of a somewhat crushed paratype cracked at the beaks, × 1, U.C.L.A. 7257.

Eocene (Domengine formation), from section line, 2,600 feet south of the northeast corner of sec. 20, T. 28 S., R. 19 E., M. D. B. and M., near headwaters of west branch of Agua Media Creek, McKittrick Quadrangle, Temblor Range, California.

B. *Sphenarina sicula* (Seguenza)....................................... 62

Figs. 6-15. 6-10, Respectively dorsal, posterior, ventral, side, and anterior views of a well-preserved complete specimen, × 1, showing the strongly triangular outline, hypotype U.S.N.M. 549353a. 11, Dorsal view of the preceding showing the foramen and obscure radial lines, × 2. 12, Posterior of the same specimen, × 4, showing alate conjunct deltidial plates. 13, 14, Two views of the interior of another specimen showing the cardinalia, × 4, with their small outer hinge plates, dental plates and lack of a median ridge or septum in the brachial valve, hypotype U.S.N.M. 549353c. 15, Enlargement of the shell surface, × 6, showing the delicate radial lines, hypotype U.S.N.M. 549353b.

Pliocene, Milasso, Messina, Sicily.

C. *Cryptopora gnomon* (Jeffreys).. 22

Fig. 16. Brachial valve tilted to the side, × 8, to show the high median septum and the long maniculifer crura with the distal end handlike and with fingers extended, paratype U.S.N.M. 94367.

Recent, 780 fathoms, off Cuba.

D. *Tegulorhynchia.*

Tegulorhynchia squamosa (Hutton).................................. 50

Figs. 17-24. 17-20, Respectively ventral, dorsal, anterior, and side views of a complete specimen, × 1, hypotype U.S.N.M. 89855a. 21-23, Respectively dorsal, anterior, and side views of the preceding speci-

Page

men, × 2, showing the imbricating ornament. 24, A partially exfoliated pedicle valve showing the impression of the muscle scars, × 2, hypotype U.S.N.M. 89855b.

Miocene (Ototaran), Broken River, Trelissick Basin, Canterbury, New Zealand.

Tegulorhynchia döderleini (Davidson) 51

Figs. 25-31. 25, Dorsal view of a complete but small specimen, × 2, showing imbricate ornament, hypotype U.S.N.M. 549317b. 26, 27, Tilted and full views of the interior of the pedicle valve showing the muscle field and dental plates, × 2, hypotype U.S.N.M. 549317d. 28, Beak and teeth of the pedicle valve, × 4, showing nearly conjunct deltidial plates, hypotype U.S.N.M. 549317f. 29-31, Respectively full view of the cardinalia, lateral view, and with shell tilted to show short median ridge and hinge plates, × 4, hypotype U.S.N.M. 549317c. The crural points have been broken off.

Miocene or Pliocene (Shinzato tuff), high road cut along Highway 64, about 0.1 mile west of sharp bend in road about 0.3 mile east of Yashitomi, Okinawa, Ryûkyû Islands.

Plate 6

Patagorhynchia and *Notosaria*

A. *Patagorhynchia patagonica* (von Ihering) 44

Figs. 1-4. Respectively dorsal, posterior, side, and anterior views of a complete but imperfect specimen showing imbricated ornamentation, × 1, hypotype Princeton University.

Eocene (Patagonian), Lake Pueyrredon, Argentina.

Figs. 5, 6. Interior of the pedicle and brachial valves, × 1, showing concave deltidial plates and thickened cardinalia. (After von Ihering, 1903, pl. 3, figs. 11a, 11b.)

Eocene (lower Patagonian), north of Seco River and San Julián, Argentina.

B. *Notosaria nigricans* (Sowerby) 48

Figs. 7-17. 7-9, Respectively side, dorsal, and anterior views of a complete specimen showing commissure and folding, × 1, hypotype U.S.N.M. 111018b. 10, The beak of the preceding specimen enlarged, × 3, to show apical plate, small disjunct deltidial plates, and large, incomplete foramen. 11, 12, Interior of pedicle valve respectively tilted and in full view, × 2, to show apical plate, teeth, muscle scars, dental plates, deltidial plates, and numerous pallial sinuses, hypotype U.S.N.M. 111018a. 13, Posterior of same, × 3, showing foramen, small disjunct deltidial plates, and large teeth. 14, 15, Brachial valve in full and tilted views to show cardinalia, transverse cardinal process, inconspicuous median ridge, muscle scars, and numerous pallial sinuses, × 2, hypotype U.S.N.M. 111018a. 16, Posterior of same, × 4, showing cardinal process and curved crura. 17, Same tilted to show crura in side view, × 4.

Recent, Stewart Island, New Zealand.

Plate 7

Plicirhynchia and *Aphelesia*

Page

A. *Plicirhynchia plicigera* (von Ihering) 52

Figs. 1-11. 1-3, Respectively anterior, side, and dorsal views of a complete specimen showing the long beak and anterior costation, × 1, hypotype U.S.N.M. 549346a. 4, Exterior of the dorsal side of the same specimen showing the posterior obscure striation and the strong anterior costation, × 2. 5, Posterior of the same specimen, × 4, showing the large foramen, conjunct deltidial plates, and the fine striae on the umbo of the brachial valve. 6, 7, Full and tilted views of interior of a pedicle valve showing the deltidial plates and strong vertical dental plates, × 2, hypotype U.S.N.M. 549346b. 8, 9, Full and tilted views of a fragmentary brachial valve showing cardinal process and incomplete crura, × 2, hypotype U.S.N.M. 549346c. 10, 11, Full and partial side views of the cardinalia of the same brachial valve showing the radulifer crura, thick socket plates, and cardinal process, × 4.

Eocene (Patagonian), Mazaredo, Patagonia, Argentina.

B. *Aphelesia bipartita* (Brocchi) 41

Figs. 12-22. 12-14, Respectively side, anterior, and dorsal views of a complete specimen showing small beak, small foramen, and anterior fold, × 1, hypotype U.S.N.M. 549349a. 15, 16, Interior of a pedicle valve in full view and tilted to show the small teeth, small dental plates, oval foramen, conjunct deltidial plates, and muscle field, × 2, hypotype U.S.N.M. 549349b. 17, Posterior of the same pedicle valve, × 4, showing the oval foramen and conjunct deltidial plates. 18-20, Respectively partial side, anterior, and full views of the brachial valve belonging to the preceding specimen (pedicle valve), × 2, showing the cardinalia. 21, 22, Respectively side and posterior views of another brachial valve, × 3, showing the broad falcifer crura, hypotype U.S.N.M. 549380.

Pliocene, Messina, Sicily.

Plate 8

Sphenarina, *Aphelesia*, and *Eohemithyris*

A. *Sphenarina sicula* (Seguenza) 62

Figs. 1-7. 1-5, Respectively dorsal, ventral, anterior, side, and posterior views of a complete and nearly perfect specimen, × 1, showing triangular form, rectimarginate anterior commissure, and nearly erect beak, hypotype U.S.N.M. 173728. 6, The same specimen enlarged, × 2. 7, Interior of another specimen showing cardinalia, × 10, with their long, slender, spinulifer crura, narrow outer hinge plates, and narrow, elevated socket ridges, hypotype U.S.N.M. 549381a.

B. *Eohemithyris*? *gettysburgensis* Cooper, new species 33

Pliocene, Messina, Sicily.

Figs. 8-12. Respectively anterior, posterior, side, dorsal, and ventral views of a large and complete specimen, × 1, holotype U.S.N.M. 549382.

Miocene, on coast 4½ miles west of Gettysburg, Washington.

Page

C. *Aphelesia bipartita* (Brocchi) 41

Figs. 13-18. 13, Imperfect brachial valve showing falcifer cardinalia, lack of outer hinge plates, deeply entrenched muscle scars, and short median ridge (myophragm) in full view, × 3, hypotype U.S.N.M. 549380a. 14, Same tilted slightly toward the observer to demonstrate absence of outer hinge plates, × 3. 15, Same in side view, showing the serrated edge and convex outer surface of the falciform crus, × 4. 16, Same in side view, × 3, showing falcifer crura and socket. 17, Same tilted to show posterior face of cardinalia with the short socket ridges, lack of outer hinge plates and falcifer crura, × 3. 18, Same tilted to show cardinalia and serrated distal extremity of crus, × 3.

Pliocene, Messina, Sicily.

Plate 9

Grammetaria and *Aetheia*

A. *Grammetaria bartschi* (Dall) 58

Figs. 1-12. 1-4, Respectively dorsal, side, anterior, and posterior views of the holotype U.S.N.M. 239269, × 1, showing the rectimarginate commissure. 5, 6, Ventral and dorsal views of the holotype, × 2, showing the fine radial costellae. 7, Posterior of the pedicle valve of the holotype showing the corrugated teeth, large foramen, and auriclate but broken deltidial plates, × 4. 8, Anterior view of the same pedicle valve showing the vertical dental plates, × 2. 9, 10, Full and slightly tilted views of the interior of the brachial valve of the holotype showing the cardinalia with their spinulifer crura, × 2. 11, Partial side view of the cardinalia of the preceding brachial valve showing the strong socket ridge, corrugated socket, and short, slender spinulifer crura, × 4. 12, Posterior view of the same, brachial interior, × 4, showing socket ridges, small inner hinge plates, and plug closing apical chamber.

Recent, U. S. Bureau of Fisheries Station 5621, off Jolo Island, Philippines; 298 fathoms, in Mollucca Pass off Makyan Island.

B. *Aetheia gualteri* (Morris) 42

Figs. 13-22. 13-15, Respectively dorsal, side, and anterior views of a complete specimen, × 1, hypotype U.S.N.M. 89828a. 16, Dorsal view of the preceding specimen, × 2. 17, Posterior of the preceding, × 3, showing the minute foramen and concave deltidial plates. 18, 19, Respectively full and anterior views of the pedicle valve interior of another specimen showing deeply impressed muscle field, × 2, hypotype U.S.N.M. 369298a. Note absence of dental plates. 20, Interior of an imperfect brachial valve, hypotype U.S.N.M. 89828b, × 2, 21, Full view of the preceding specimen showing the thick socket ridges, corrugated sockets and thick coalesced inner hinge plates, and long falcifer crura, × 4. 22, Same as preceding, × 4, but tilted to show the slender bladelike falcifer crura, socket ridge, and corrugated socket.

Miocene (Duntroon greensand), 1 mile north of Kakanui, north of Otago, New Zealand.

PLATE 10

Hispanirhynchia

Page

Hispanirhynchia cornea (Fischer) 59

Figs. 1-21. 1-3, Respectively dorsal, anterior, and side views of a complete specimen, × 1, hypotype U.S.N.M. 130327a. 9, Pedicle valve interior of same tilted to show small dental plates, × 2. 4, Exterior of preceding hypotype showing fine costellae, × 2. 5, Anterior of pedicle valve of another specimen, × 3, showing fine, subdued costellae, U.S.N.M. 130327b. 6, 8, Two views of the interior of the preceding pedicle valve, × 2, showing teeth, dental plates, small muscle field, and pallial marks. 7, Interior view of another pedicle valve showing teeth and pallial marks, × 2, hypotype U.S.N.M. 130327c. 10, Beak of preceding, × 4, showing teeth, foramen, and remnantal deltidial plates. 11, Interior of the brachial valve of a young specimen showing strong development of inner hinge plates, × 2, hypotype U.S.N.M. 130327d. 13, Same, × 6, showing inner hinge plates in great detail. 12, Same specimen as preceding, × 4, tilted to the side to show the spinulifer laterally flattened crus with serrated distal extremity, the inner hinge plates, and corrugated socket. 14, Same as preceding tilted to show junction of septum and inner hinge plates, × 4. 15, Posterior of an old specimen showing deeply impressed adductor field, × 3, hypotype U.S.N.M. 130327c. 16, Same, ca. × 6, tilted to show inner hinge plates and median ridge. 17, Interior of another brachial valve showing pallial sinuses, small genital areas, and cardinalia, × 2, hypotype U.S.N.M. 130327a. 19, Same tilted to show direct view of cardinalia and septum, × 2. 18, 20, Same specimen, respectively side view showing bladelike spinulifer crura and view showing strong socket ridges and inner hinge plates, ca. × 6. 21, Interior of another brachial valve tilted to show socket ridges, inner hinge plates and rostral chamber, × 3, hypotype U.S.N.M. 130327e.

Recent, 240 fathoms off the coast of Mogador, Morocco.

PLATE 11

Rhytirhynchia and *Basiliola*

A. *Rhytirhynchia sladeni* (Dall) 35

Figs. 1-11. 1-3, Respectively anterior, side, and dorsal views of a complete specimen showing anterior costation, × 1, lectotype U.S.N.M 111086. 4, 5, Respectively full and tilted views of the interior of the pedicle valve showing pallial sinuses, small conjunct deltidial plates, deeply incised muscle scars, and pedicle collar, × 2. 6, Posterior of the pedicle valve of the lectotype, × 3, showing small foramen, conjunct deltidial plates, and corrugated teeth. 7-9, Respectively anterior, full, and partial side views of the interior of the brachial valve showing cardinalia, deeply impressed adductor field, and pallial sinuses, × 2. 10, Partial side view of the falcifer crura showing serrate distal extremity and corrugated socket, × 4. 11, Posterior view of the same

Page

brachial valve, × 4, showing curved socket ridges, modestly developed outer hinge plates, incipient inner hinge plates, and falcifer crura.

Recent, *Sealark* Expedition, 1905, Station Cl, 123 to 158 fathoms, south of the Saya de Malha Banks, Indian Ocean.

B. *Basiliola beecheri* (Dall) 25

Figs. 12-16. 12-14, Respectively side, anterior, and dorsal views of a complete specimen showing the smooth exterior fold, × 1, hypotype U.S.N.M. 334678. 15, Dorsal view of the same specimen, × 2. 16, Posterior of the preceding specimen showing conjunct, auriculate deltidial plates, × 3.

Recent, U. S. Bureau of Fisheries Station 4130, 283 to 309 fathoms, 46.1° F., near Kauai Island, Hawaiian group.

Figs. 17-23. 17, 18, Respectively tilted and full views of the pedicle interior of another specimen showing deeply impressed muscle scars and pallial sinuses, × 2, hypotype U.S.N.M. 334679. 19, Posterior of the preceding pedicle valve, × 4, showing corrugated teeth, conjunct and auriculate deltidial plates. 20, 21, Respectively full and anterior views of the brachial valve of the preceding pedicle valve showing the cardinalia and pallial marks, × 2. 22, Posterior view of the cardinalia of the preceding specimen showing socket ridges, corrugated sockets, broad outer hinge plates, and falcifer crural plates, × 4. 23, Side view of the preceding specimen showing the broad, distally serrate, falcifer crura and the corrugated sockets, × 4.

Recent, 147 to 198 fathoms, 49° F., off west coast of Hawaii.

Plate 12

Basiliola

Basiliola pompholyx Dall 27

Figs. 1-6. 1-5, Respectively dorsal, posterior, anterior, ventral, and side views of the lectotype, × 1, showing robust form, smooth exterior and strong dorsal fold, U.S.N.M. 229301b. 6, Beak of the preceding specimen, × 3, showing small round foramen and auriculate deltidial plates.

Recent, U. S. Bureau of Fisheries Station 5592, 305 fathoms, 43.3° F., gravel and mud bottom, Sibuko Bay, south of Silungan Island, Borneo.

Figs. 7-15. 7, Posterior of the pedicle valve of another specimen, × 4, showing corrugated teeth, and conjunct and auriculate deltidial plates, hypotype U.S.N.M. 274135. 8, 9, Respectively full and tilted views of the preceding pedicle valve, × 2, showing dental plates, muscle area and pallial sinuses. 10, Interior of the apex of the preceding pedicle valve, × 4, showing pedicle collar, auriculation of deltidial plates, corrugated teeth, and small genital areas. 11, 12, Tilted and full views of the interior of the brachial valve of the preceding specimen showing cardinalia, pallial sinuses, and muscle scars, × 2. 13, 14, Two views of the apex of the preceding brachial valve tilted to show the cardinalia in partial side and partial anterior position, the strongly corrugated sockets, and the broad outer hinge plates, × 4. 15, Poste-

Page

rior view of the cardinalia of the same brachial valve as the preceding, × 4, showing the broad and flat outer hinge plates. The crura are shorter than normal because of slight breakage at the distal extremity.

U. S. Bureau of Fisheries Station 5487, 585 fathoms, 52° F., on mud, off Panaon Island, Philippines.

PLATE 13

Hispanirhynchia? and *Neohemithyris* (=*Basiliola*)

A. *Hispanirhynchia?* species 60

Figs. 1-5. 1-3, Respectively ventral, dorsal, and anterior views of a somewhat crushed specimen, × 1, figured specimen U.S.N.M. 549361. 4, Dorsal view of the preceding specimen, × 2, showing foramen. 5, Beak of the preceding, × 4, showing foramen and disjunct deltidial plates.

Eocene (lower), 200 meters south of the south side of the Riverside Yacht Club, west side Almendares River, in Reparto Kohly, Habana Province, Cuba.

B. *Basiliola lucida* (Gould) 34

Figs. 6-23. 6-10, Respectively posterior, anterior, dorsal, side, and ventral views of a complete specimen, × 1, showing small size, rounded form, and nearly smooth exterior, hypotype U.S.N.M. 110826a. 11-13, Respectively anterior, side, and dorsal views, × 2, of the preceding specimen showing the same features. 14, Interior of the pedicle valve, × 2, showing pallial marks indistinctly, hypotype U.S.N.M. 110826b. 15, Apex of same specimen, × 4, showing corrugated tooth and conjunct deltidial plates. 16, The same specimen tilted to show the pedicle collar and dental plates, × 4. 17, 18, Interior and tilted views of another pedicle valve showing the pallial marks, foramen, teeth, and deltidial plates, × 4, hypotype U.S.N.M. 110826c. 19, Interior of the brachial valve, × 2, hypotype U.S.N.M. 110826b. 20, Posterior part of the same specimen showing the cardinalia with the long falcifer crura, × 4. 21-23, Respectively side, tilted anterior, and full views of another brachial valve, × 4, showing the long falcifer crura, the small elevated inner hinge plates, corrugated sockets, small genital areas, and pallial marks, hypotype U.S.N.M. 110826c.

Recent, U. S. Fish Commission Station 4936, rocky bottom at 103 fathoms, Kagashima Gulf, Kyushu, Japan.

PLATE 14

Basiliola and *Frieleia*

A. *Basiliola beecheri* (Hall) 25

Fig. 1. Interior of the pedicle valve of an obese specimen, × 2, showing thickened marginal rim and pallial marks, hypotype U.S.N.M. 334667.

Recent, U. S. Fish Commission Station 3864, 163 to 198 fathoms, 55.9° F., Pailolo Channel, Hawaiian Islands.

Fig. 2. Dorsal view of the apex of a pedicle valve showing the deltidial plates with their reflected rim and the anterior smooth area of the

Page

pedicle collar which slides over the umbo of the dorsal valve, × 4, hypotype U.S.N.M. 274136.

Recent, U. S. Fish Commission Station 3811, 238 to 252 fathoms, 70.5° F.?, south coast of Oahu, Hawaiian Islands.

B. *Frieleia? nitens* (Conrad) = *F.? astoriana* (Dall)..................... 55

Figs. 3-6. 3-5, Respectively side, dorsal, and ventral views of the holotype, U.S.N.M. 3487. 6, Ventral view of another specimen showing broad sulcus and radial lines on exfoliated shell, × 1, paratype U.S.N.M. 3487a.

Miocene, Astoria, Clatsop County, northwest Oregon.

C. *Basiliola elongata* Cooper, new species................................ 29

Figs. 7-21. 7-11, Respectively dorsal, anterior, ventral, posterior, and side views of the holotype, × 1, U.S.N.M. 235844a. 12-14, Respectively dorsal, side, and anterior views of the holotype, × 2, showing smooth surface, elongate form, and growth lines. 15, Interior of the pedicle valve of the paratype U.S.N.M. 235844b, × 2. 16, Beak region of the same pedicle valve, × 4, showing the fused deltidial plates and the reflected rim around the foramen. 17, Same pedicle valve, × 3, tilted to show the pedicle collar, dental plates, and small genital region. 18, Interior of the brachial valve of the same paratype, × 2, showing elongated falcifer crura. 19, 20, Side and anterior views of the preceding showing the broad falcifer crura, concave inward, and with serrate distal extremity, the small reflected inner hinge plates, and the broad outer hinge plates, × 4. 21, Interior of the apex of the same brachial valve, × 6, showing the falcifer crura, broad outer hinge plates, small inner plates, and corrugated sockets.

Recent, U. S. Bureau of Fisheries Station 5146, 24 fathoms on coral sand, Sulade Island, Tapul Group, Philippines.

Plate 15

Frieleia and *Eohemithyris*

A. *Frieleia halli* Dall 53

Figs. 1-5, 12-14. 1-3, Respectively anterior, brachial, and side views, × 1, of a complete specimen showing the narrow sulcus in each valve and the rectimarginate anterior commissure, hypotype U.S.N.M. 110830a. 4, Interior of the pedicle valve tilted to show the strong dental plates and small teeth, × 2, hypotype U.S.N.M. 110830b. 5, Apical region of the preceding, × 4, showing the disjunct deltidial plates and incomplete foramen. 12, Brachial valve tilted to show apical chamber of the cardinalia, × 2, hypotype U.S.N.M. 110830c. 13, Another brachial valve tilted to show the apical chamber, × 2, hypotype U.S.N.M. 110830b. 14, The same, × 4, showing the apical chamber and cardinal process.

Recent, U. S. Fish Commission Station 4797, 682 fathoms, off Avacha Bay, Kamchatka.

Figs. 6-11. 6-8, Respectively full, partial side, and tilted views of a brachial valve showing cardinalia and median septum, × 2, hypotype U.S.N.M. 549348a. 9, 11, Apical part of another brachial valve in full

Page

and anterior views showing the cardinalia, ×2, hypotype U.S.N.M. 549348b. 10, The same, ×4, showing the large inner hinge plates covering the apical chamber and the small transverse cardinal process.

Recent, U. S. Fish Commission Station 2923, 522 fathoms, off San Diego, California.

B. *Eohemithyris colurnus* (Hedley) 32

Figs. 15-26. 15-17, Respectively brachial, anterior, and side views of a complete specimen showing the anterior costation and uniplicate anterior commissure, ×1, hypotype U.S.N.M. 333012b. 18, Enlargement, ×2, of the beak of the preceding specimen showing the small submesothyrid foramen and conjunct deltidial plates. 19, 20, Two views of the interior of a pedicle valve, ×2, one in full view, the other anteriorly tilted to show the minute dental plates, small genital areas, and pallial sinuses, hypotype U.S.N.M. 333012a. 21, Apical part of the preceding specimen showing beak, foramen, and conjunct deltidial plates, ×4. 22, 23, Full view and slightly tilted view of the brachial valve of the preceding specimen showing the cardinalia, pallial sinuses, and genital areas, ×2. 24, 25, Partial side and full views of the cardinalia showing the distally serrate, falcifer crus, corrugated sockets, and thickening over the crural bases, ×4. 26, Posterior part of the preceding tilted to show the concave ends of the crura, the small genital areas, and the interior thickening, ×4.

Recent, 115-135 fathoms, off Gabo Island, Victoria, Australia.

Plate 16

Compsothyris

A. *Compsothyris racovitzae* (Joubin) 56

Figs. 1-17. 1-4, Respectively anterior, dorsal, ventral, and side views of a complete individual, showing faintly uniplicate commissure, ×1, hypotype U.S.N.M. 549343. 5, Dorsal view of the preceding specimen showing fine closely crowded costellae, ×2. 6, 7, Interior of the pedicle valve of the same specimen, ×2, showing small foramen and small dental plates. 8, Beak of the preceding valve, ×4, showing small corrugated teeth and small disjunct deltidial plates. 9-11, Respectively full, slightly tilted, and strongly tilted views of the brachial interior of the same specimen showing cardinalia, median septum, and muscle scars, ×2. 12, Same brachial interior tilted to show the socket ridges and distally serrate spinulifer crura, ×4. 13-15, Three views of the cardinalia variously tilted to show socket ridges, narrow outer hinge plates, and crura, ×4. 16, Same brachial valve strongly tilted to show junction of crural supporting plates with median septum, ×4. 17, Exterior of the pedicle valve, ×6, showing the very fine radial costellae.

Recent, British Antarctic Expedition 1910, Station 316 of Terra Nova, 190 to 250 fathoms, 30.5° F., off Glacier Tongue, 8 miles north of Hut Point, McMurdo Sound, Antarctic.

Plate 17

Probolarina

Page

A. *Probolarina salpinx* (Dall) 38

Figs. 1-19. 1-5, Respectively, posterior, ventral, side, dorsal, and anterior views of a small but complete individual, × 2, hypotype U.S.N.M. 549357a. 6, 7, Dorsal and ventral views of another hypotype showing variation of costation, × 1, U.S.N.M. 549355. 8-10, Respectively dorsal, ventral, and anterior views of a specimen larger and more strongly costate than the two preceding ones, × 1, hypotype U.S.N.M. 549357b. 11-14, Respectively side, anterior, ventral, and dorsal views of a small specimen with few costae, × 3, holotype U.S.N.M. 109293a. 15, Apical portion of a large specimen showing the small submesothyrid foramen, conjunct and auriculate deltidial plates, × 4, hypotype U.S.N.M. 549354a. 16, Interior of a brachial valve, × 3, showing cardinalia, hypotype U.S.N.M. 549356d. 17, 18, Partial side and full views of the apical part of the same specimen, × 6, showing the concave falcifer crura and large outer hinge plates. 19, The same tilted anteriorly to show the concave crura and lack of median ridge, × 6.

Eocene (Castle Hayne formation), at the city quarry near the cemetery, Wilmington, North Carolina.

B. *Probolarina holmesii* (Dall) 38

Figs. 20-36. 20-24, Respectively posterior, anterior, dorsal, ventral, and side views of a complete specimen, × 2, hypotype U.S.N.M. 549359a. 25, The same, × 3, showing the ornamentation and long beak. 26, 27, Beak of the same specimen, × 5, showing conjunct and strongly auriculate deltidial plates. 28, Small specimen showing foramen and conjunct deltidial plates, × 4, hypotype U.S.N.M. 549359b. 29, 30, Apical part of another specimen showing conjunct and auriculate deltidial plates, × 6, and the same tilted to show the dental plates and pedicle collar, × 6, hypotype U.S.N.M. 549359e. 31, The same tilted to the side to show the pedicle collar, × 4. 32, Apex of another pedicle valve showing strongly auriculate deltidial plates, × 6, hypotype U.S.N.M. 549359f. 33, Interior of the brachial valve, × 3, showing cardinalia and absence of median ridge, hypotype U.S.N.M. 549359g. 34, 35, Apical part of the preceding tilted to show concave falcifer crura, × 6. 36, Same in full view to show the outer hinge plates, × 6.

Horizon and locality same as above.

Plate 18

Erymnaria

A. *Erymnaria bolcensis* (Massalongo) 64

Figs. 1-17. 1-5, Respectively dorsal, side, posterior, anterior, and ventral views of a decorticated specimen showing symmetrical form, × 1, U.S.N.M. 549383b. 6, Posterior view of preceding, × 3, to show dorsal umbo, trace of the crural supporting plates, and the shorter socket ridges outside of them (photographed under water). 7, Anterior of same specimen, × 2, showing symmetrical fold on brachial valve.

Page

8-12, Respectively posterior, anterior, side, dorsal, and ventral views of another symmetrical specimen, × 1, hypotype U.S.N.M. 549383a. 13-15, Respectively dorsal, anterior, and side views of the preceding, × 2. 16, 17, Two views of cross sections of the beak of the brachial valve U.S.N.M. 549383c, ca. × 8, respectively 2.6 mm. and ca. 6.0 mm. anterior to the beak, showing crura, crural supports, and socket ridges (see pl. 22, fig. 9, and explanation).

Lower Eocene (Spilecciano), Spilecco, Verona, Italy.

B. *Erymnaria polymorpha* (Massalongo) 64

Figs. 18-25, 31-34. 18-22, Respectively ventral, dorsal, side, anterior, and posterior views of a large but imperfect specimen showing twisted anterior commissure and traces of pallial marks, × 1, hypotype U.S.N.M. 75888a. 23, 24, Dorsal and anterior views of the same specimen, × 2, showing trace of vascula media and twisted anterior commissure. 25, Dorsal view of the same specimen taken under water and tilted away from the observer to show the long crural supporting plates as black lines and the shorter socket ridges, × 3. 31-33, Respectively side, anterior, and dorsal views of the preceding specimen, × 2, showing costae along the anterior margin. 34, Another specimen tilted away from the observer and taken under water to show the trace of the long crural supporting plates and the shorter socket ridges diverging widely from the beak, × 4, hypotype U.S.N.M. 75888b.

Lower Eocene, Spilecco, Verona, Italy.

Figs. 26-30, 35, 36. 26-30, Respectively anterior, ventral, side, posterior, and dorsal views of another specimen, not decorticated like the preceding, and showing, in addition to the twisted commissure, short radial costae, × 1, hypotype U.S.N.M. 549384a. 35, Posterior of a brachial valve excavated to show cardinalia and crural supporting plates, × 6, hypotype U.S.N.M. 549384b. 36, Another brachial valve interior showing cardinalia with their fairly broad outer hinge plates, and crural supporting plates, × 6, hypotype U.S.N.M. 549384c.

Lower Eocene (Spilecciano), Spilecco, 400 meters southwest of Purga di Bolca, Monti Lessini, Verona, Italy.

Plate 19

Erymnaria and *Streptaria*

A. *Erymnaria cubensis* Cooper 65

Figs. 1-10. 1-5, Respectively dorsal, anterior, ventral, posterior, and side views of the holotype, × 1, U.S.N.M. 549385. 6-8, Respectively side, dorsal, and anterior views of the same specimen, × 2, showing folding. 9, Posterior of holotype, × 3, showing conjunct deltidial plates and foramen. 10, Holotype tilted and photographed under water to show crural supporting plates and the shorter, more widely divergent socket ridges, × 3.

Eocene, 80 meters northeast of school, Chucho Machin, Matanzas Province, Cuba.

B. *Streptaria streptimorpha* Cooper, new species 40

Figs. 11-21. 11-15, Respectively anterior, ventral, side, dorsal, and pos-

Page

terior views of the holotype, × 1, showing twisted anterior commissure, U.S.N.M. 549386a. 16, Dorsal view of the holotype showing smooth exterior, × 1½. 17, 18, Side and anterior views of the holotype, × 2, showing twisted commissure. 19, Posterior of the holotype, × 3, showing deltidial plates and foramen. 20, 21, Posterior of another specimen, × 4, showing short dental plates and cardinalia with falcifer crura (see discussion), paratype U.S.N.M. 549386b.

Eocene, deep cut north of Grua 9, Ramal Juan Criollo, Camaguey Province, Cuba.

C. *Streptaria buchi* (Michelotti) 38

Figs. 22-31. 22-26, Respectively ventral, dorsal, anterior, side, and posterior views of a complete specimen showing twisted anterior commissure, × 1, hypotype U.S.N.M. 549352a. 27-29, Respectively anterior, dorsal, and side views of the preceding specimen, × 2, showing twisted commissure. 30, Posterior of the same specimen, × 3, showing large foramen with elevated rim. 31, Posterior of the brachial valve of another specimen prepared to show the strong socket ridges, wide outer hinge plates, and falcifer crura with thickened ventral edge, × 6, hypotype U.S.N.M. 549352b.

Middle Miocene, Messina, Sicily.

Plate 20

Eohemithyris

A. *Eohemithyris alexi* Hertlein and Grant 30

Figs. 1-16. 1-5, Respectively dorsal, posterior, ventral, side, and anterior views of a complete and undistorted specimen, showing form and true profile of valves, × 1, hypotype U.C.M.P. 15524. 6-9, Respectively, anterior, ventral, dorsal, and side views of the same specimen, × 2. 10, Dorsal view of another nearly perfect specimen showing rounded outlines and low fold, × 1, hypotype U.C.M.P. 15526. 11, Posterior of the same specimen, × 3, showing small foramen. 12, Posterior of another specimen, × 3, showing small foramen and conjunct deltidial plates, hypotype U.C.M.P. 15541. 13, 14, Dorsal and ventral views of a specimen from which the shell has been scraped to show the muscle fields, × 2, hypotype U.C.M.P. 15542. 15, 16, Full view and partial side view of the cardinalia, × 6, showing narrow outer hinge plates and broad, long falcifer crura, hypotype U.C.M.P. 15545.

Eocene (Domengine formation), from just below the 1/4 section marker toward the top of the 25-foot last sandstone "reef" on the ridge on the east side of the North Fork of Media Agua Creek, grid. coord. 142001-139004, McKittrick (15′) Quadrangle, Kern County, California (see text for further information).

B. *Eohemithyris grayi* (Woodward) 33

Figs. 17-23. 17, Dorsal view of the exterior, ca. × 2, showing anterior costae and minute foramen, holotype British Museum (Nat. Hist.) ZB280. Specimen coated by ammonium chloride. 18-20, Respectively

Page

side, dorsal, and anterior views of the same specimen, ca. × 2. 21, Posterior of the same specimen (coated) showing small foramen, ca. × 2½. 22, Interior of the pedicle valve of the holotype, ca. × 2½, showing small foramen, muscle field, and pallial marks. 23, Interior of the brachial valve of the holotype showing cardinalia with falcifer crura, thickened inner edges of crural bases, muscle field, and pallial marks, ca. × 4.

Recent, Fiji Islands.

Photographs by permission of the Trustees of the British Museum (Natural History) through Dr. H. M. Muir-Wood Deputy Keeper, Department of Palaeontology.

PLATE 21

Frieleia, Patagorhynchia, Septaliphoria, Cryptopora, Tegulorhynchia, Mannia, and *Hispanirhynchia?*

A. *Hemithyris astoriana* Dall = *Frieleia* ? *nitens* Conrad................. 56

. Fig. 1. Section of the apex of the brachial valve showing the small chamber and median septum, × 8, paratype U.S.N.M. 3487a.

Miocene, Astoria, Clatsop County, Oregon.

B. *Patagorhynchia patagonica* (Ihering)................................ 44

Figs. 2-5. Respectively anterior, dorsal, side, and ventral views of a fairly well-preserved specimen showing costellate ornamentation, × 1, figured specimen U.S.N.M. 549387.

Eocene, 1 to 2 miles southwest of Ancha Terriza, Rio de los Ciervos, Provincia de Magallones, Chile.

C. *Septaliphoria* species 10

Fig. 6. Interior of the dorsal valve tilted to show septalium and median septum, × 2, figured specimen U.S.N.M. 129896a.

Jurassic (Lower Callovian), in the railroad cut 300 meters east of the station at Chatillon-sur-Seine, Department of Côte d'Or, France.

D. *Cryptopora gnomon* (Jeffreys)..................................... 22

Figs. 7-14. 7-9, Respectively anterior, side, and ventral views of a complete specimen, × 6, hypotype U.S.N.M. 44911a. 10, Anterior of another specimen, × 6, showing the sulcate anterior margin, hypotype U.S.N.M. 44911c. 11, Dorsal view of the preceding, × 8, showing the nonauriculate deltidial plates. 12, Posterior of the pedicle valve, × 8, showing deltidial plates, apical plate, and teeth, hypotype U.S.N.M. 44911d. 13, 14, Full and partial side views of the brachial valve of the preceding interior showing median septum and maniculifer crura.

Recent, U. S. Fish Commission Station 2221, 1,525 fathoms, 36.9° F., south of Marthas Vineyard, Massachusetts, in gray ooze.

E. *Tegulorhynchia döderleini* (Davidson)............................ 51

Fig. 15. Interior of the pedicle valve, × 1, showing pallial sinuses, after Leidhold, Neues Jahrb. Min., Geol., Paläont., BB. 45, pl. 11, fig. 1b [here reduced 1/2], 1922. Original in Institute of Zoology, Strasburg University.

Recent, Sagami Bay, Honshu, Japan.

Page

F. *Mannia nysti* Davidson.. 22

Figs. 16-20. 16, Drawing of the dorsal side, ca. × 1. 17, Exterior of the dorsal side, ca. × 7, showing large foramen and long, elevated deltidial plates. 18, 19, Interior of two brachial valves showing septum with spoonlike plate and long maniculifer crura. 20, Cross section through a complete individual showing relationship of valves, median septum, spoonlike plate, and crura. All from Davidson, Geol. Mag., dec. 2, vol. 1, No. 4, pl. 7, 10-13, 1874.

Miocene (Diestien), 3 miles east of Antwerp, Belgium.

G. *Hispanirhynchia ? craneana* (Dall) 61

Figs. 21-26. 21-23, Respectively dorsal, anterior, and side views of the holotype showing gently sulcate anterior commissure, × 1, U.S.N.M. 122861. 24, The holotype, × 2, showing the beak area. 25, The beak region of the holotype, × 4, showing teeth (the deltidial plates probably have been broken away). 26, Posterior of the brachial valve showing spinulifer crura and small outer hinge plate (these structures have been damaged).

Recent, U. S. Fish Commission Station 3362, mud at 117 fathoms and 36.8° F., off Cocos Island, Pacific Ocean off Panama.

Plate 22

Eohemithyris, Erymnaria, Notosaria, Aphelesia

A. *Eohemithyris alexi* Hertlein and Grant.............................. 30

Figs. 1-3. 1, 2, Full and partial side views of the cardinalia to show broad, falcifer crura, ca. × 5, hypotype U.C.M.P. 15545. 3, Drawing of the posterior of a pedicle valve, ca. × 4, showing the conjunct deltidial plates and small, round foramen, hypotype U.C.M.P. 15524.

Horizon and locality as in plate 20, figures 1-16.

B. *Erymnaria polymorpha* (Massalongo)................................ 64

Figs. 4-9. Sections through a slightly distorted individual, ca. × 4, hypotype U.S.N.M. 549384e. Sections measured from pedicle beak respectively: (4) ca. 1 mm., (5) 1.7 mm., (6) 1.95 mm., (7) 2.25 mm., (8) 2.6 mm., and (9) ca. 4.0 mm.

Lower Eocene (Spilecciano), 400 meters southwest of Purga di Bolca, Monti Lessini, Verona, Italy.

Figs. 10-15. Sections through another individual showing long crural supporting plates, ca. × 4, British Museum (Natural History) B 8088. Sections respectively 0.3 mm. apart except figure 13 which is 0.4 mm. from figure 12.

Eocene, Castelvecchio, Vicentin, Italy.

C. *Tegulorhynchia* (= *Notosaria*) *nigricans* (Sowerby)................ 48

Figs. 16, 17. Diagram of the interior of the pedicle and brachial valves of the adult showing pallial sinuses, ca. × 1.5, after Williams (1956, fig. 7, No. (4) on p. 276).

Recent, New Zealand.

Page

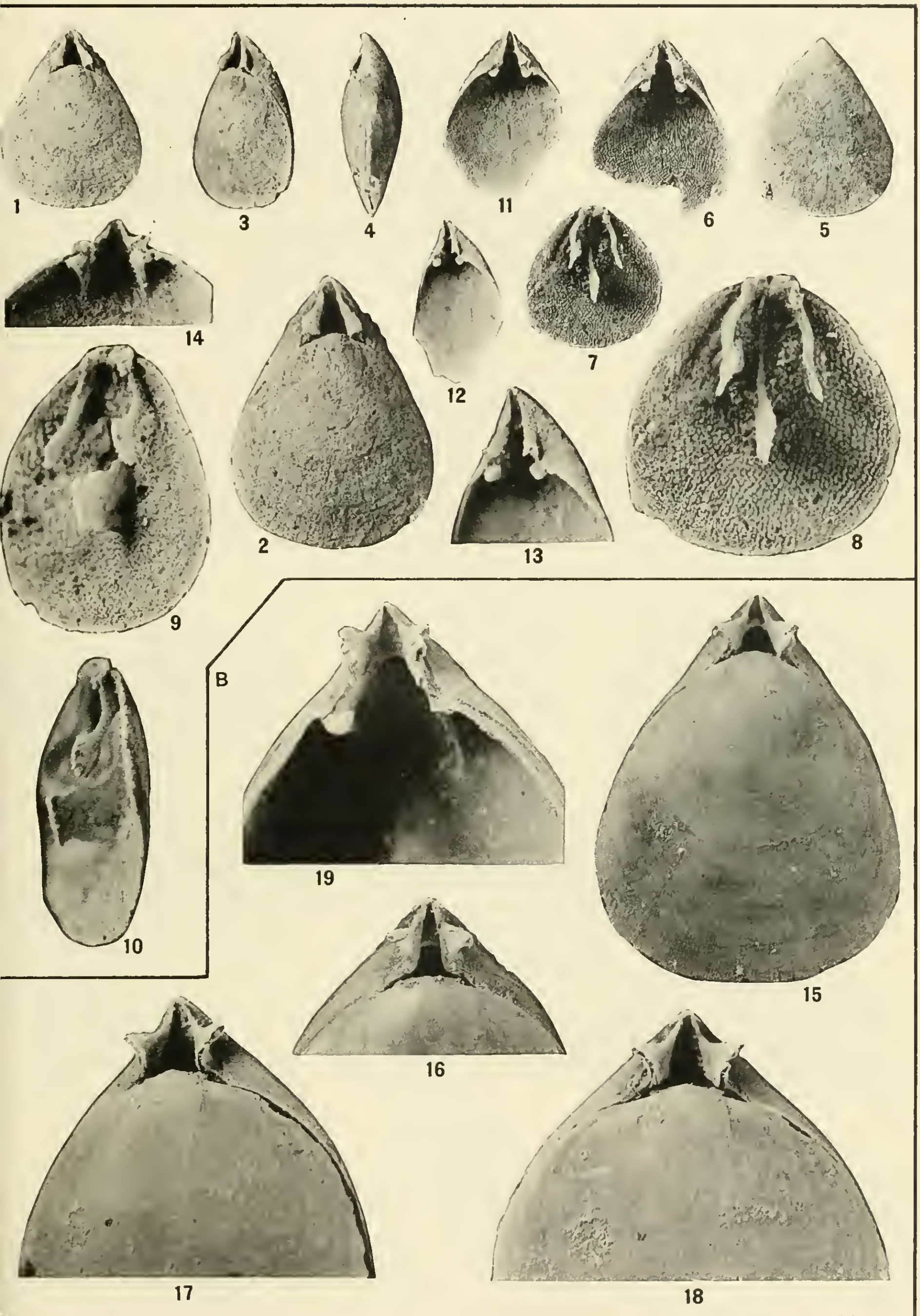
D. *Aphelesia bipartita* (Brocchi) 41

Figs. 18-25. Sections through the valves of a full-grown adult, × 2, British Museum (Natural History) not numbered, showing sockets and teeth. Sections respectively from the beak of the pedicle valve: (18) 1.0 mm., (19) 1.6 mm., (20) 2.0 mm., (21) 2.6 mm., (22) 2.8 mm., (23) 3.2 mm., (24) 3.6 mm., and (25) 4.0 mm.

Miocene, St. Lorenzo, Tuscany, Italy.

Photographs of figures 10-15 and 18-25 by permission of the Trustees of the British Museum (Natural History) through Dr. H. M. Muir-Wood, Deputy Keeper, Department of Palaeontology.

PLATES



CRYPTOPORA

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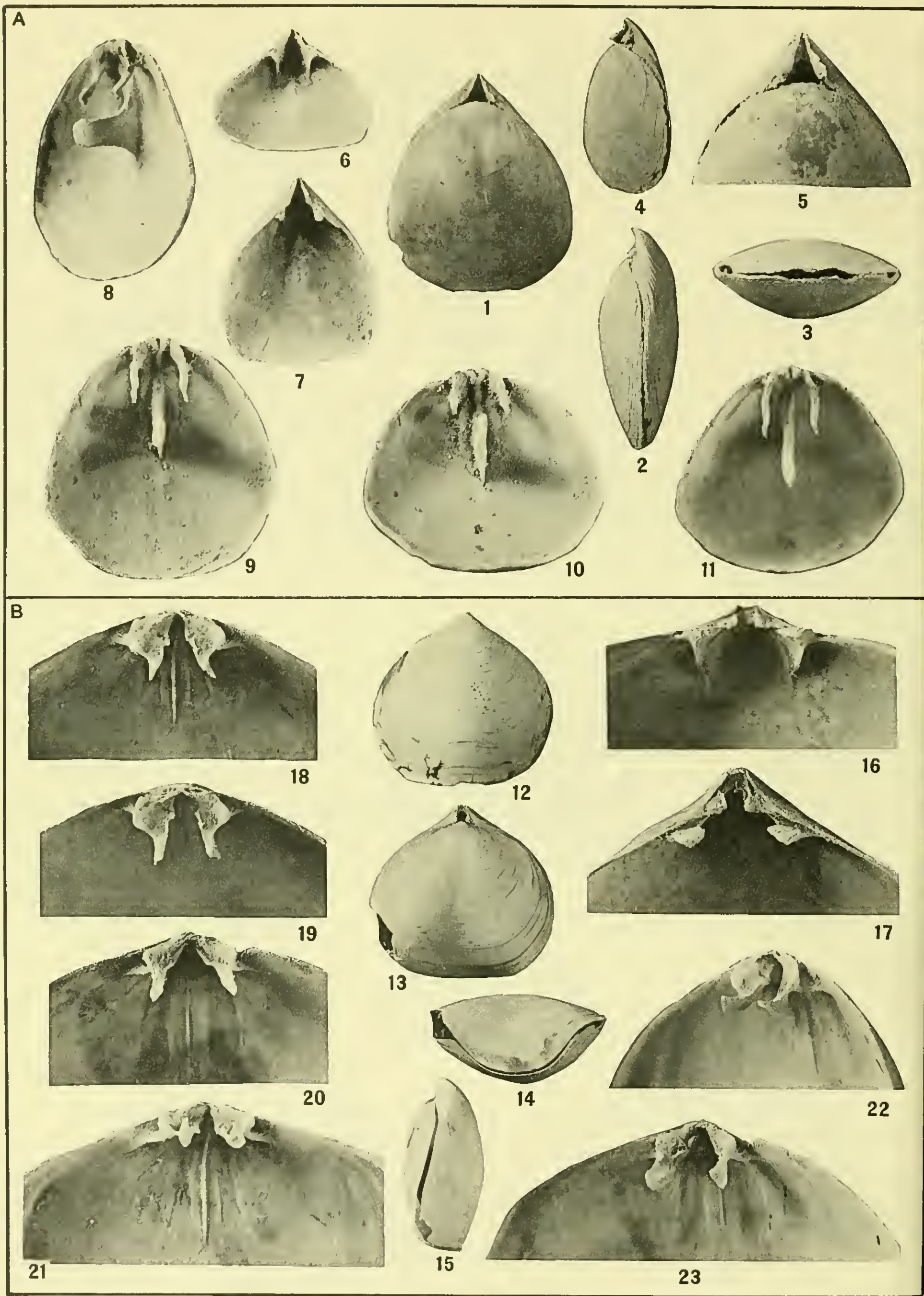

CRYPTOPORA AND NEORHYNCHIA

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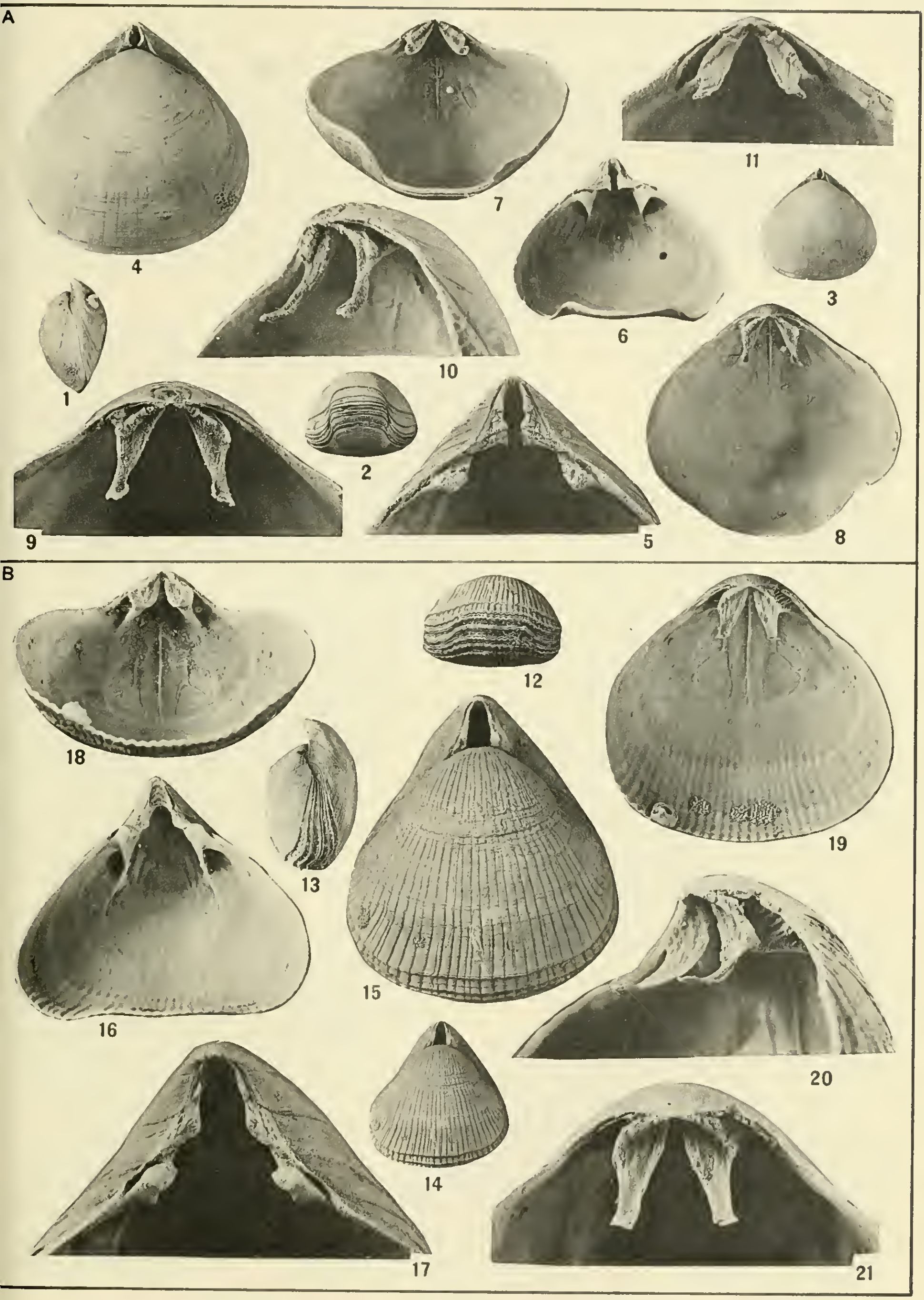

HEMITHYRIS

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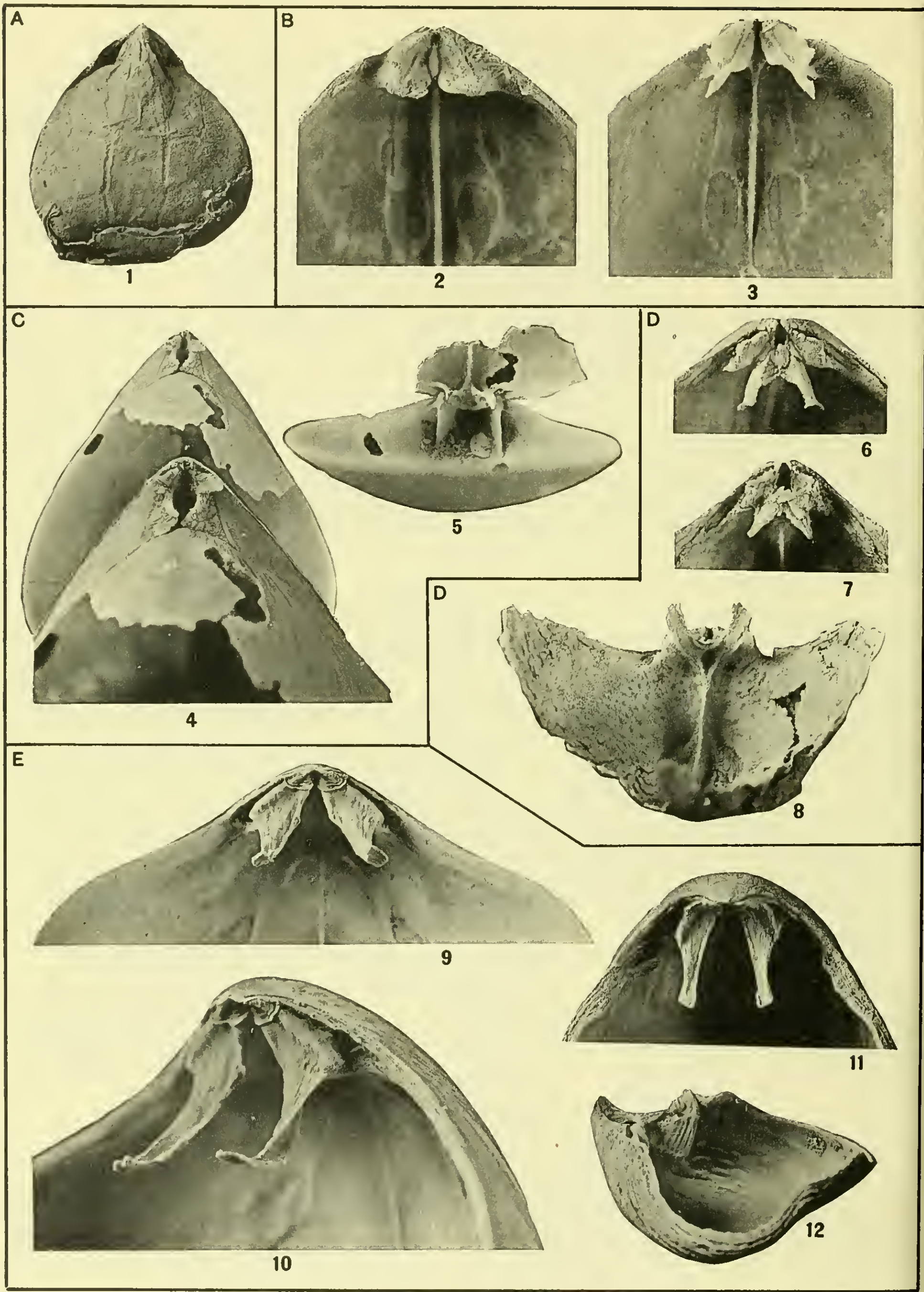

AETHEIA, FRIELEIA, GRAMMETARIA, CAMAROTOECHIA, AND HEMITHYRIS

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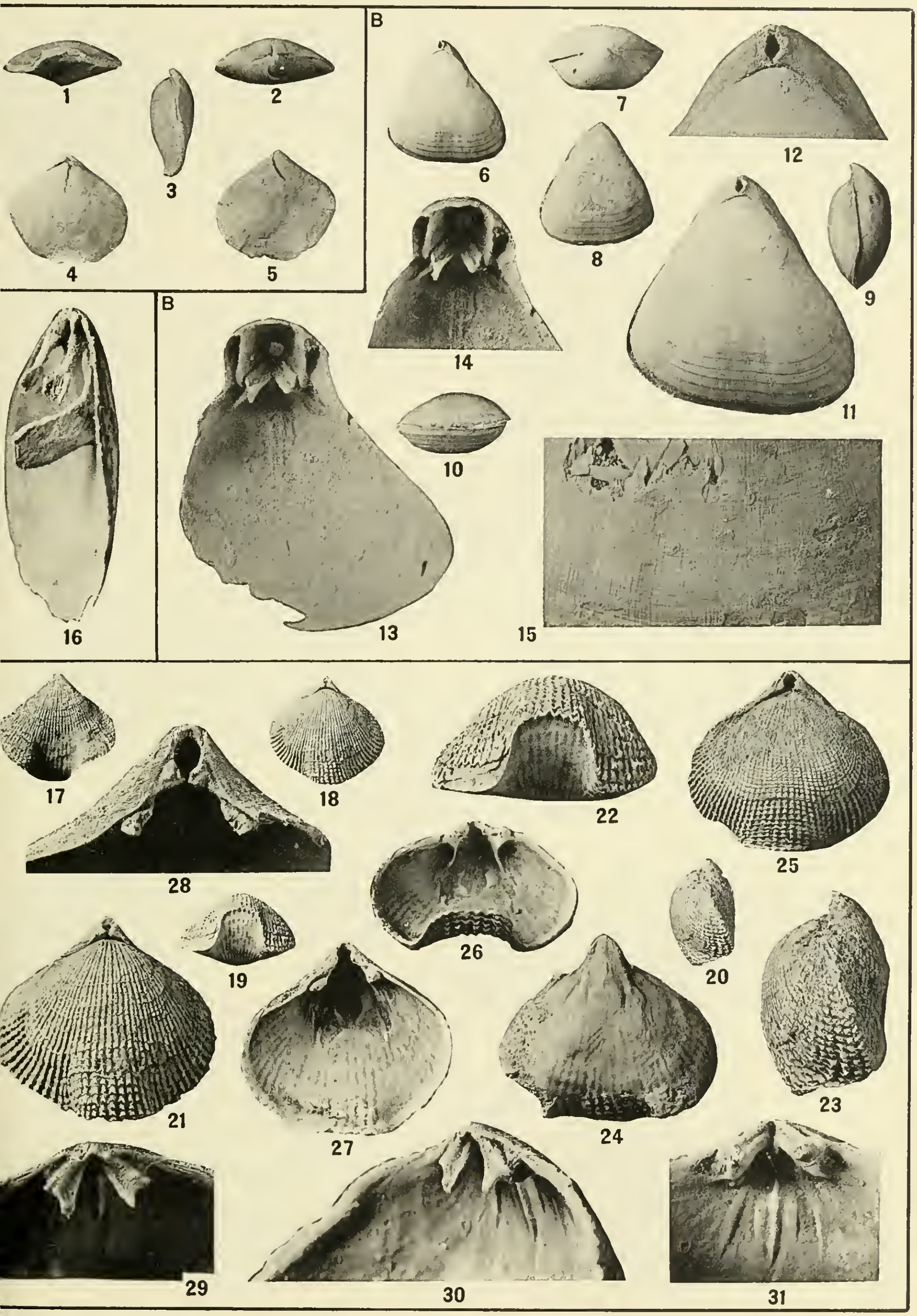

EOHEMITHYRIS, SPHENARINA, CRYPTOPORA, AND TEGULORHYNCHIA

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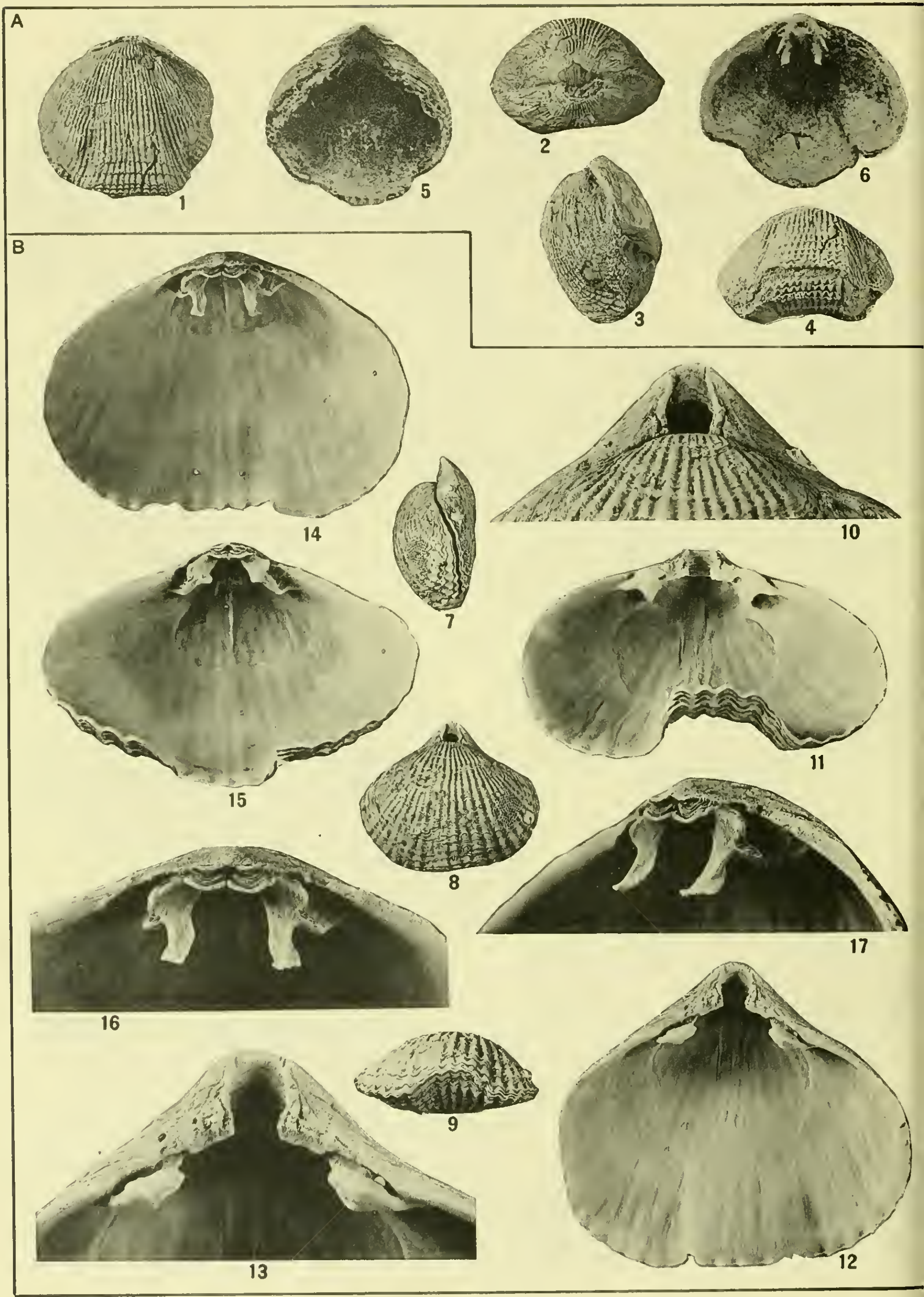

PATAGORHYNCHIA AND NOTOSARIA

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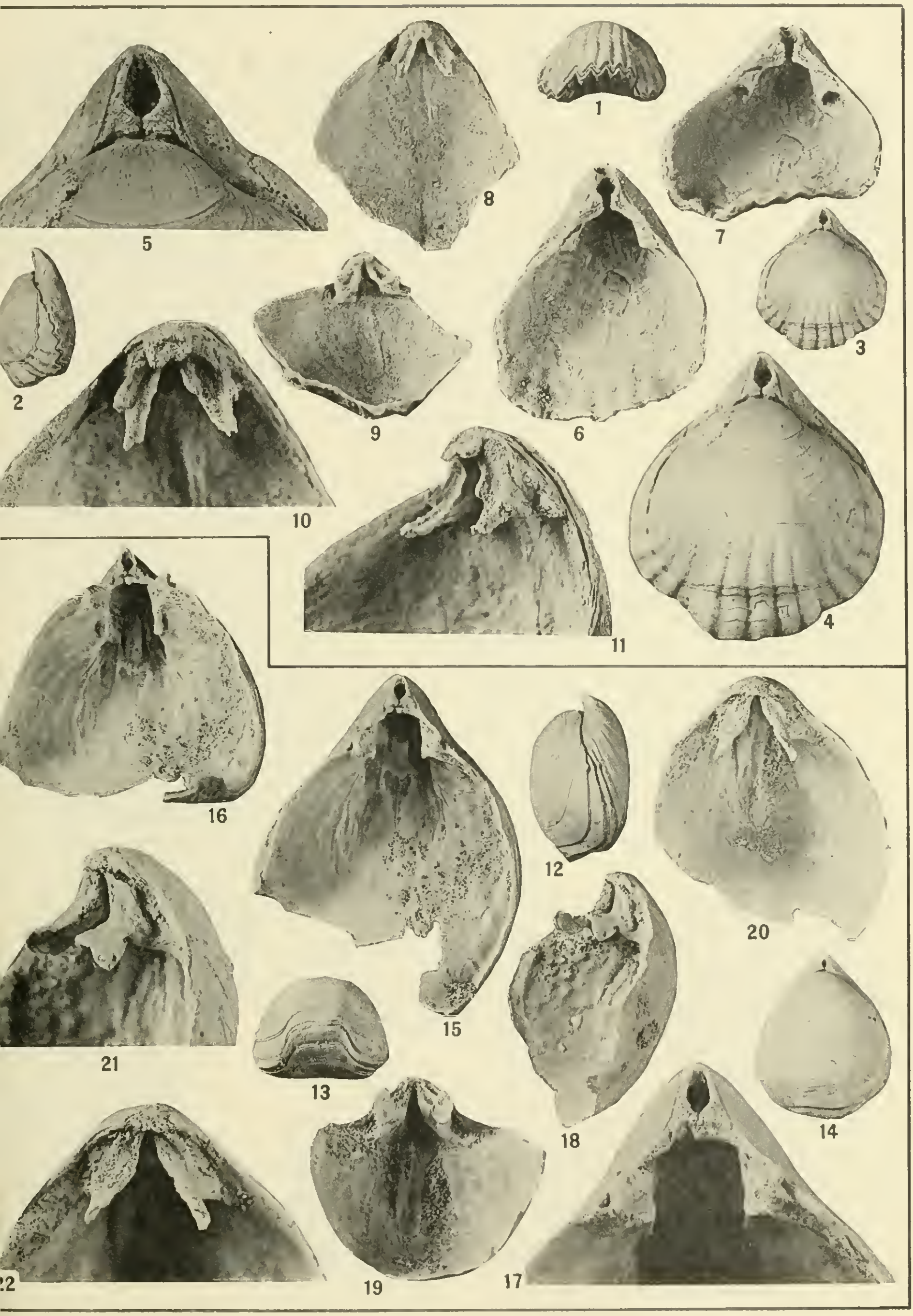

PLICIRHYNCHIA AND APHELESIA

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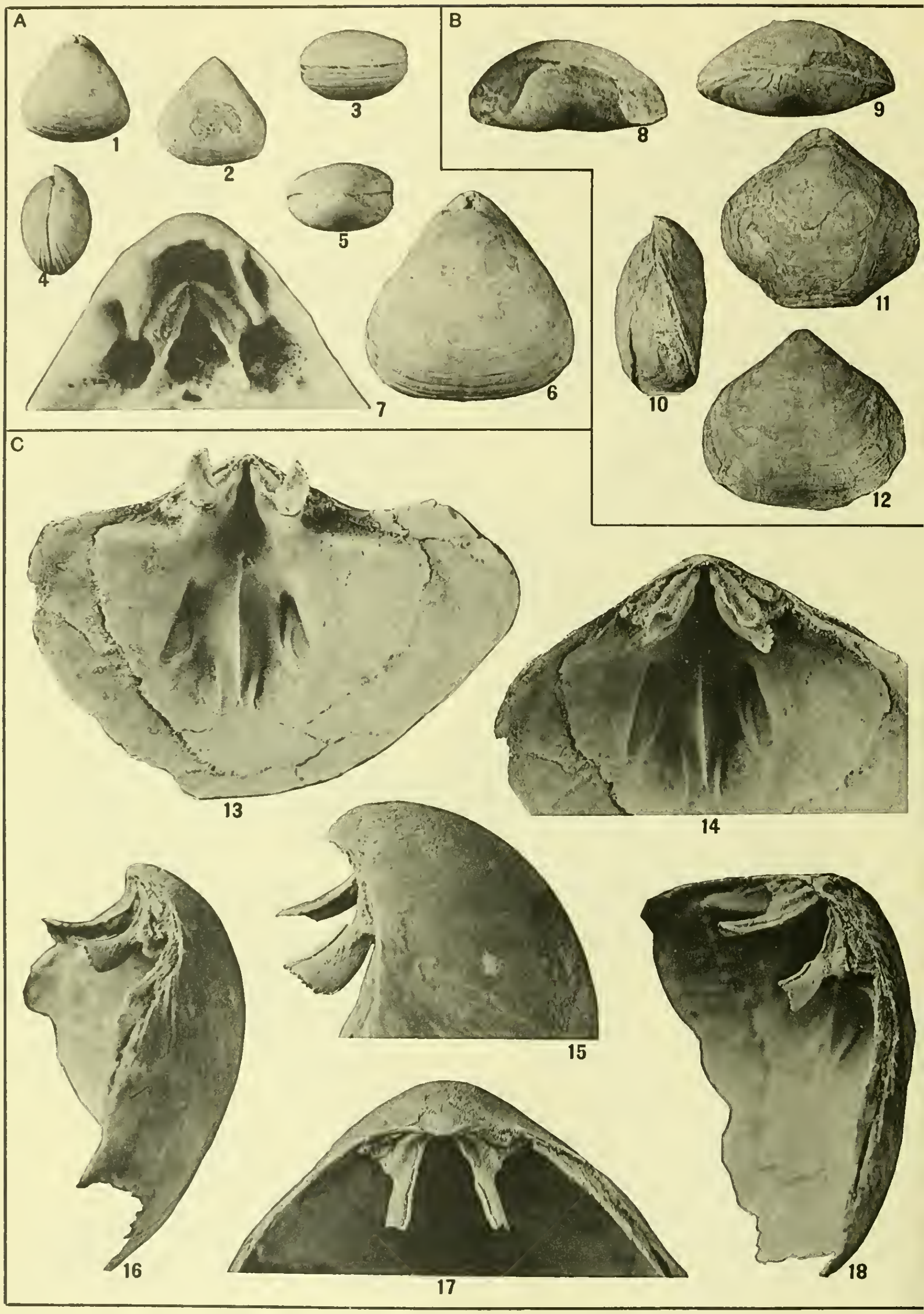

SPHENARINA, APHELESIA, AND EOHEMITHYRIS?

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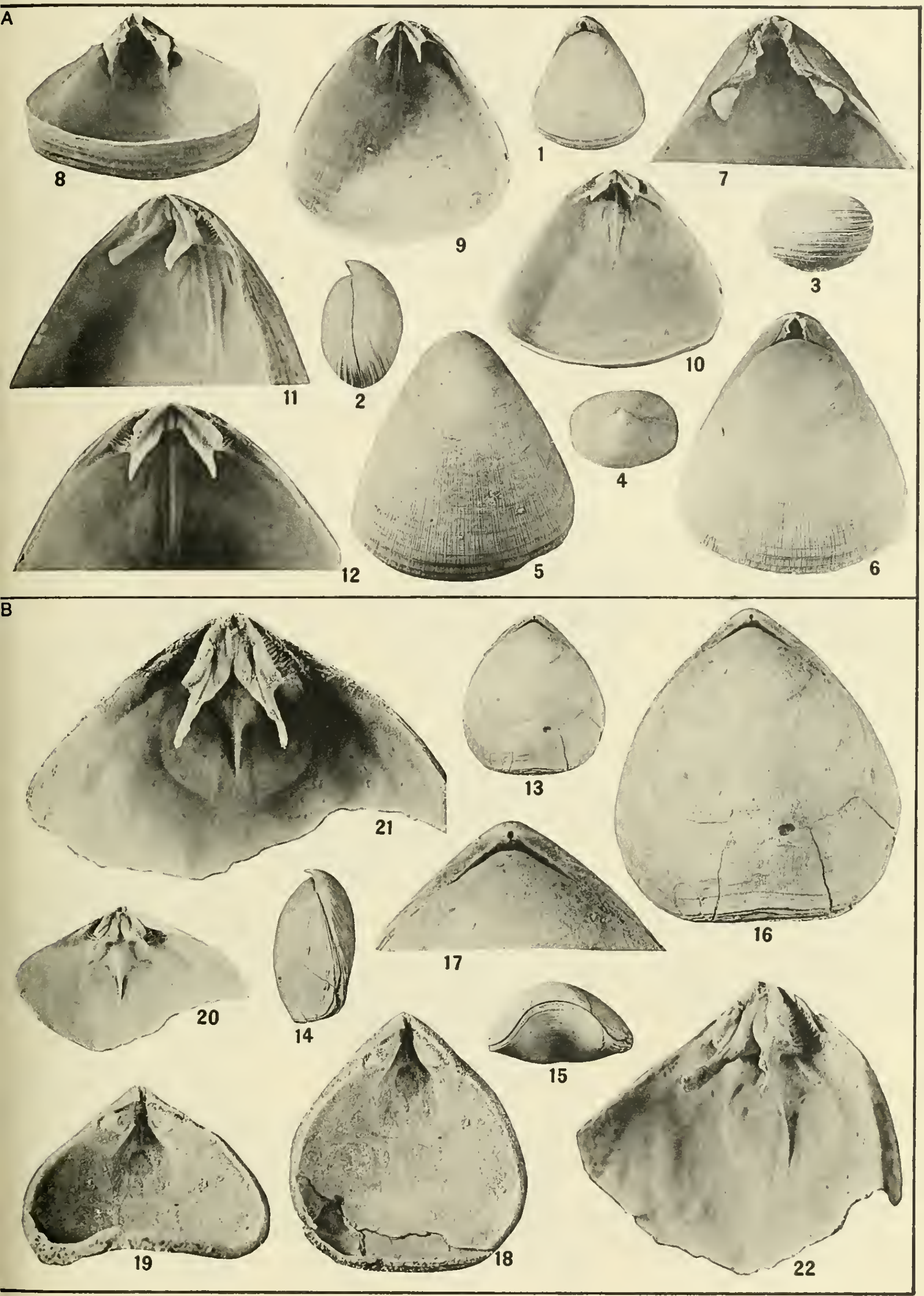

GRAMMETARIA AND AETHEIA

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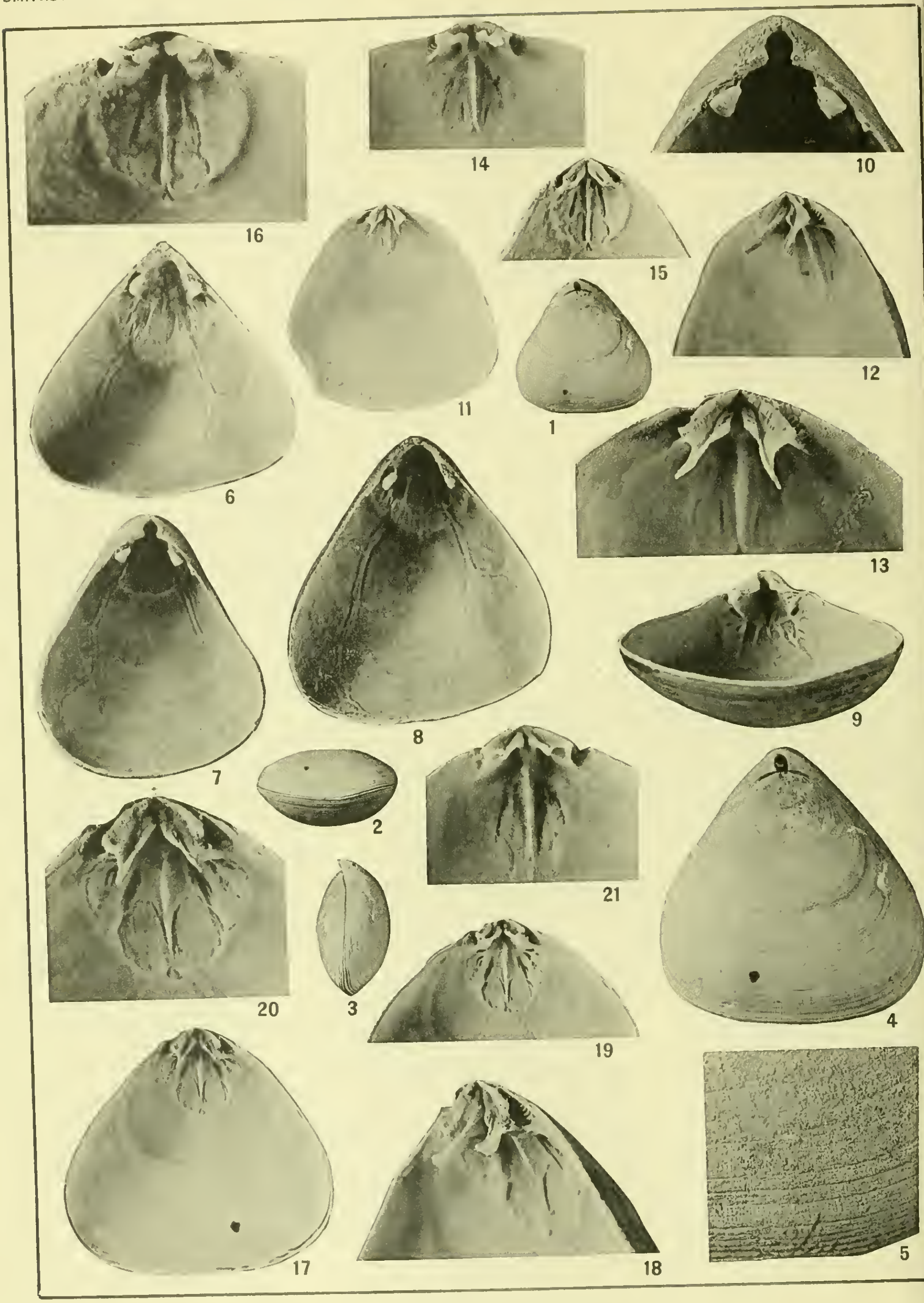

HISPANIRHYNCHIA

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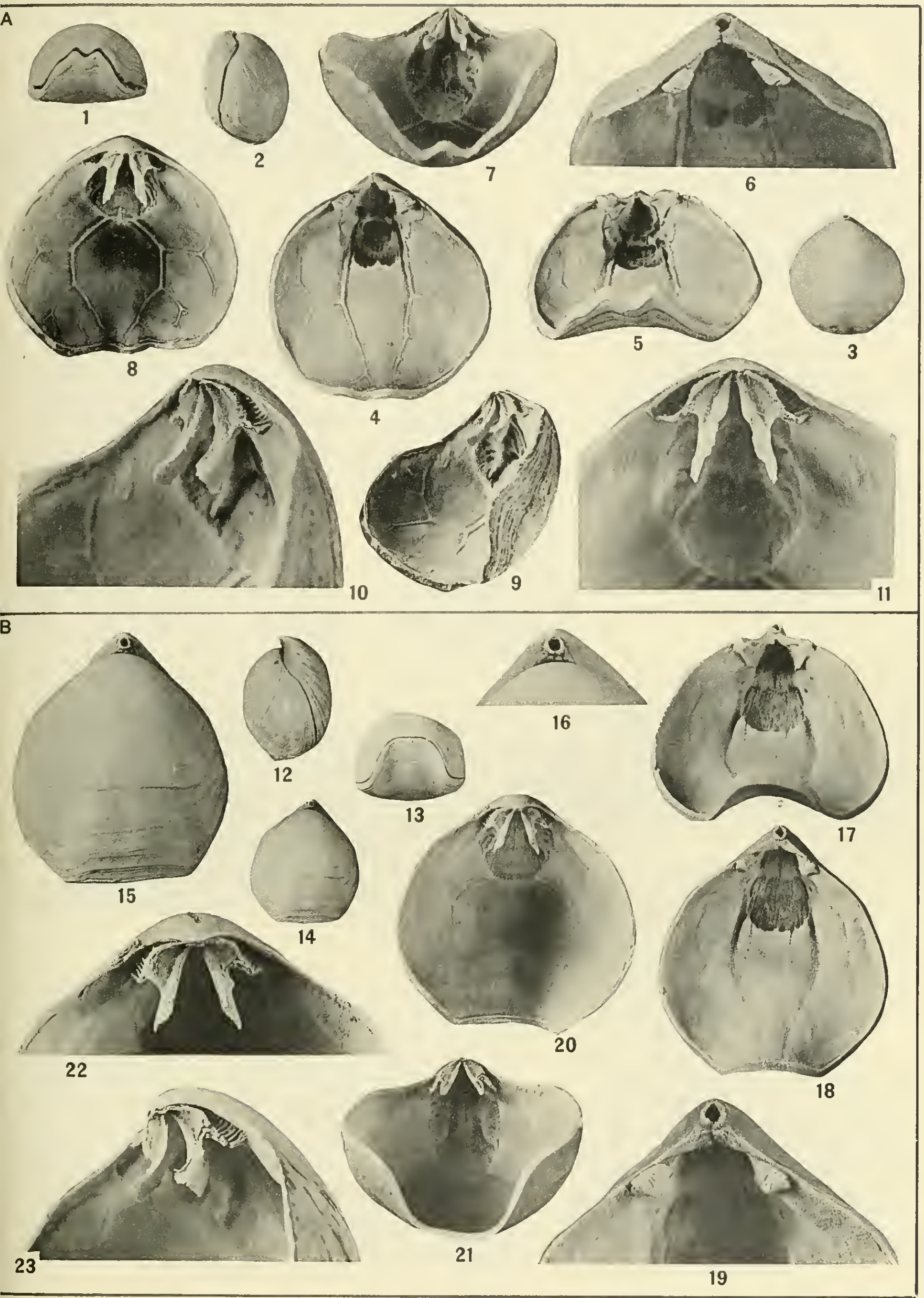

RHYTIRHYNCHIA AND BASILIOLA

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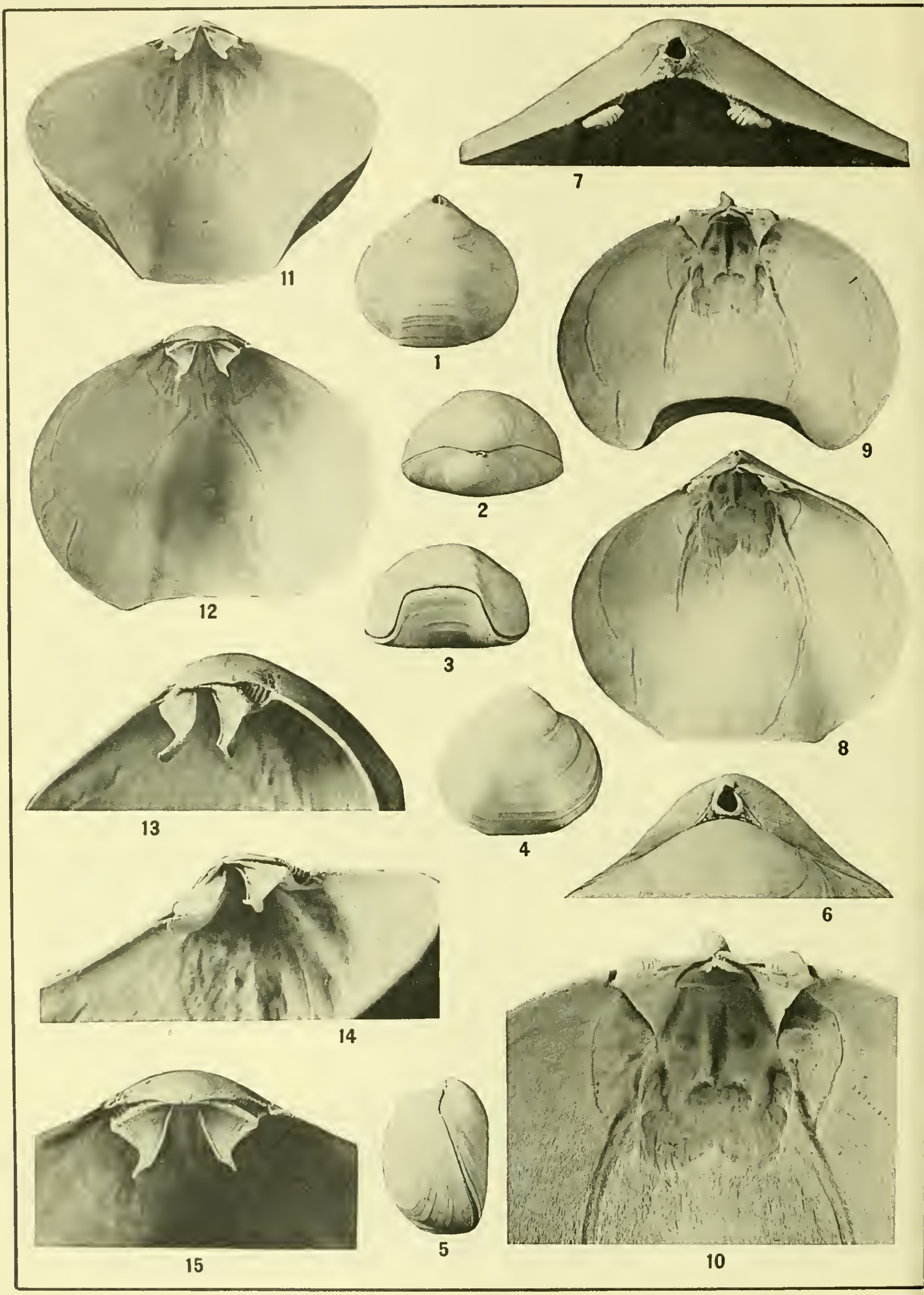

BASILIOLA

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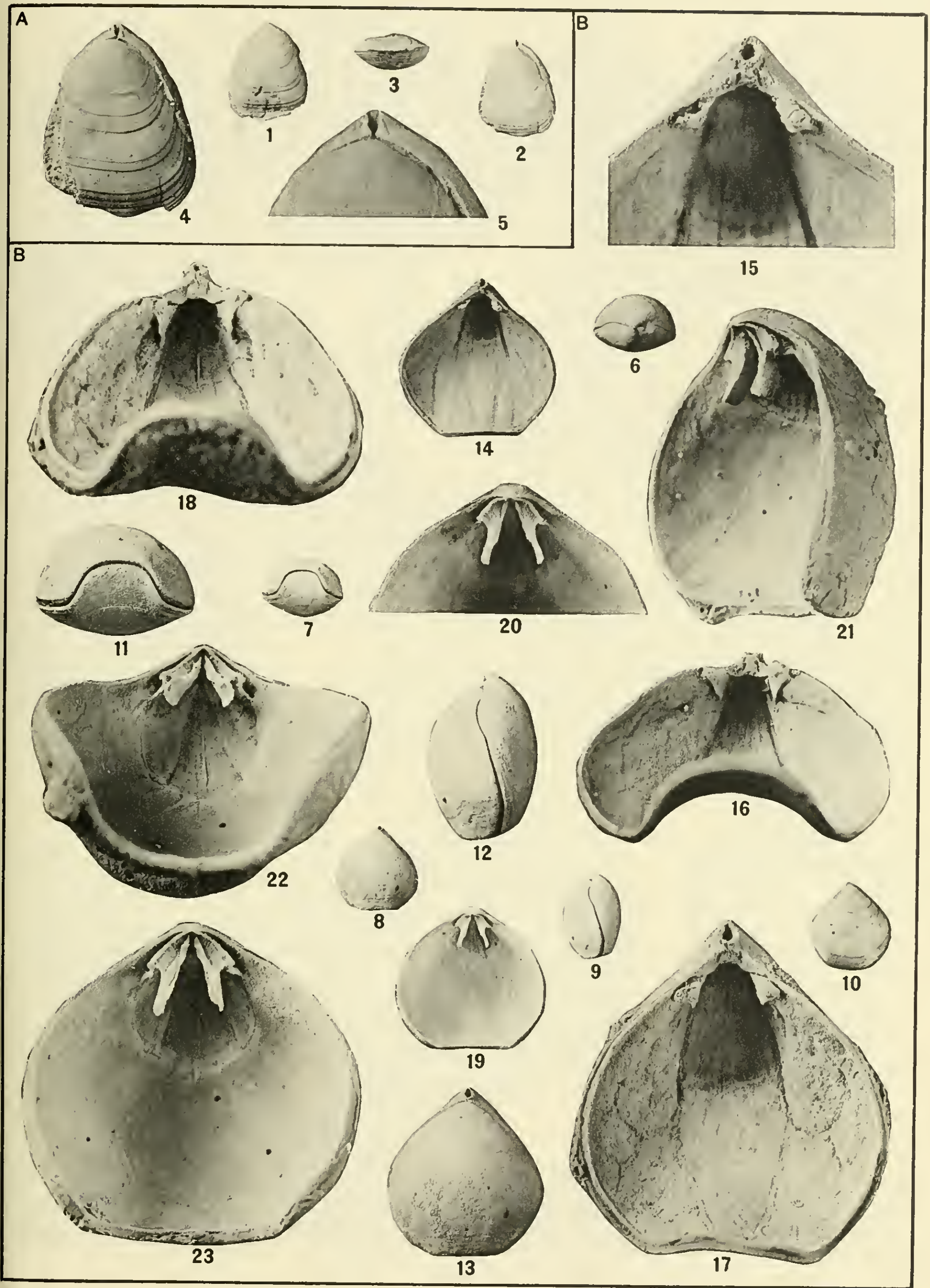

HISPANIRHYNCHIA? AND NEOHEMITHYRIS = BASILIOLA

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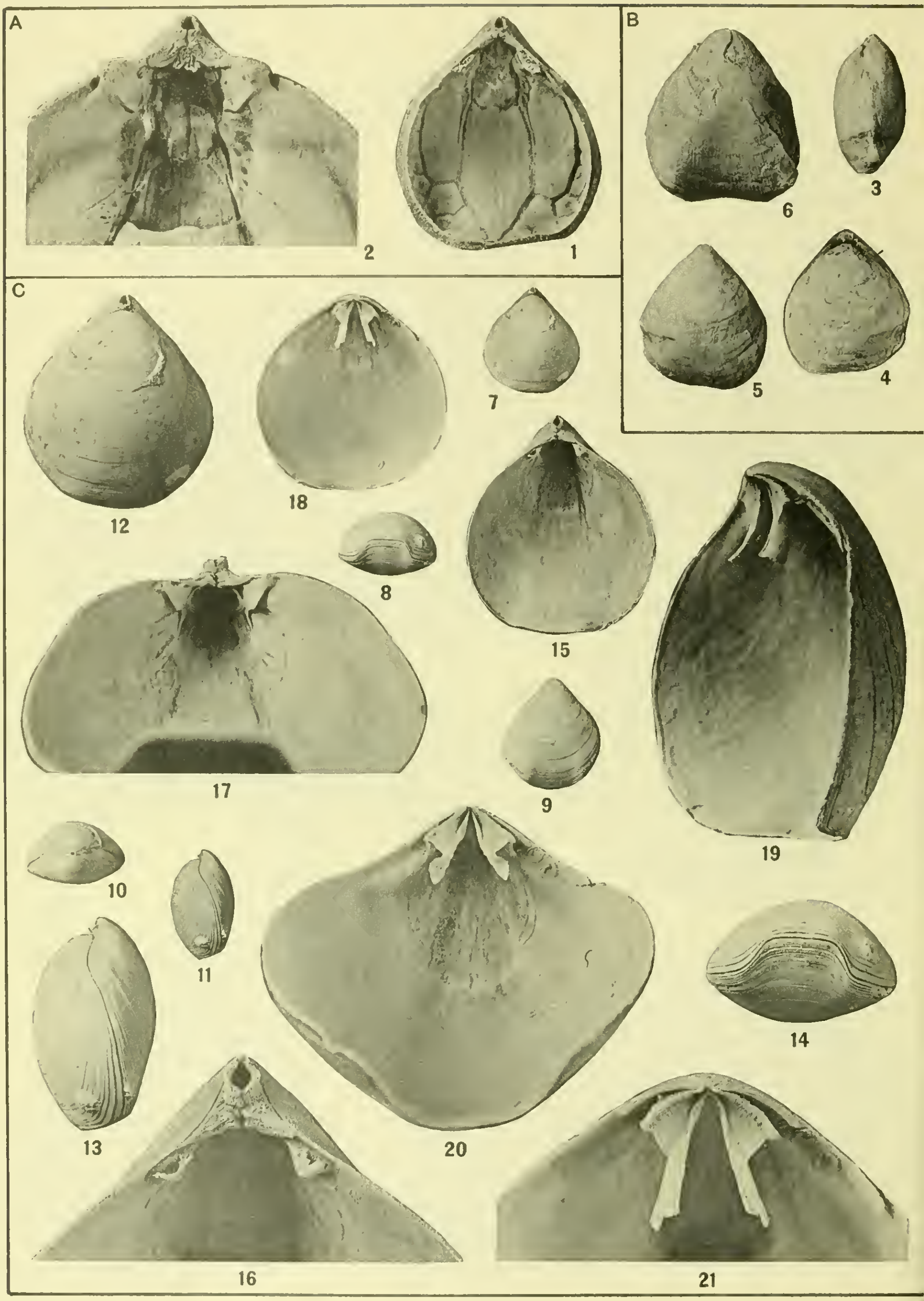

BASILIOLA AND FRIELEIA

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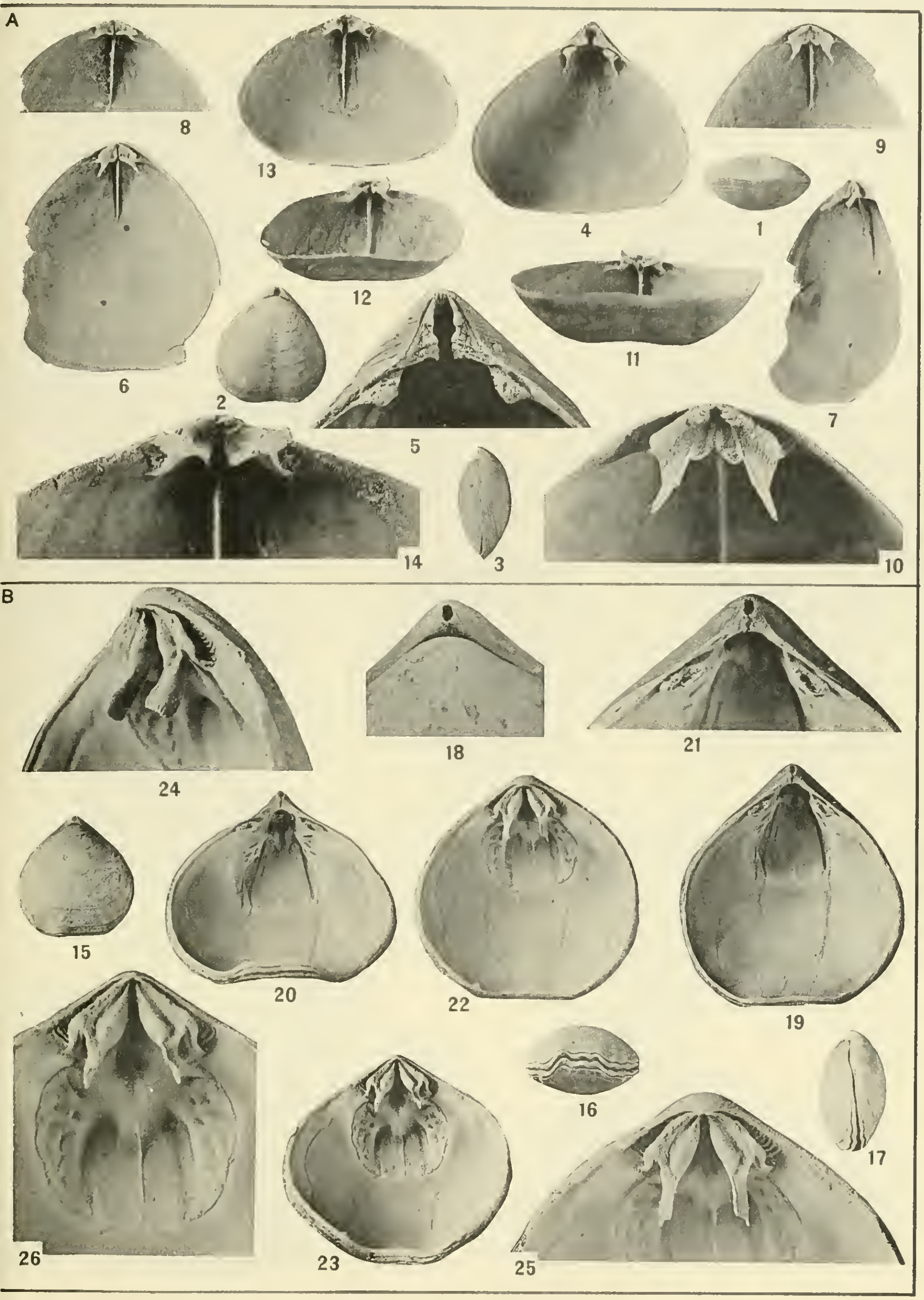

FRIELEIA AND EOHEMITHIRIS

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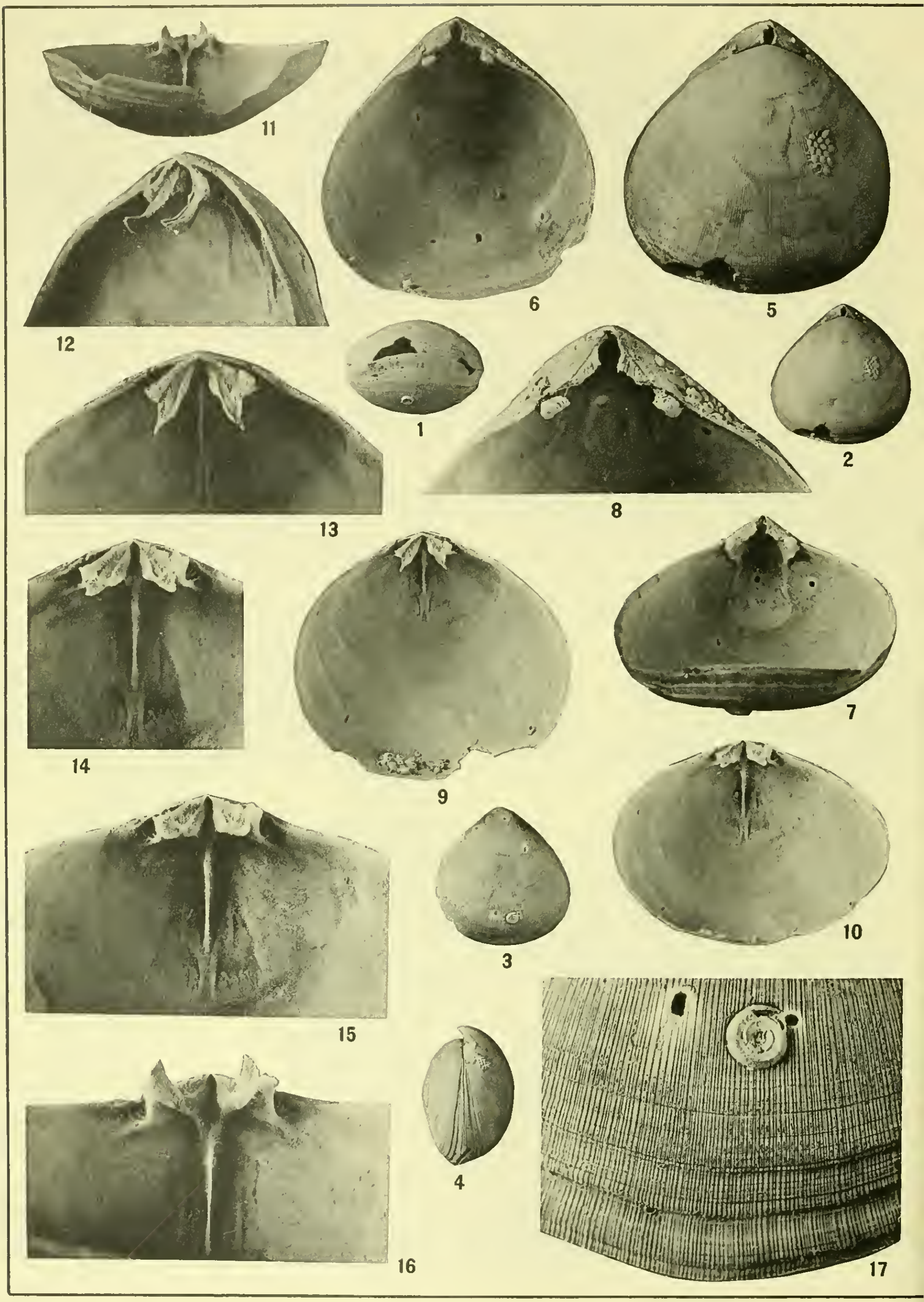

COMPSOTHYRIS

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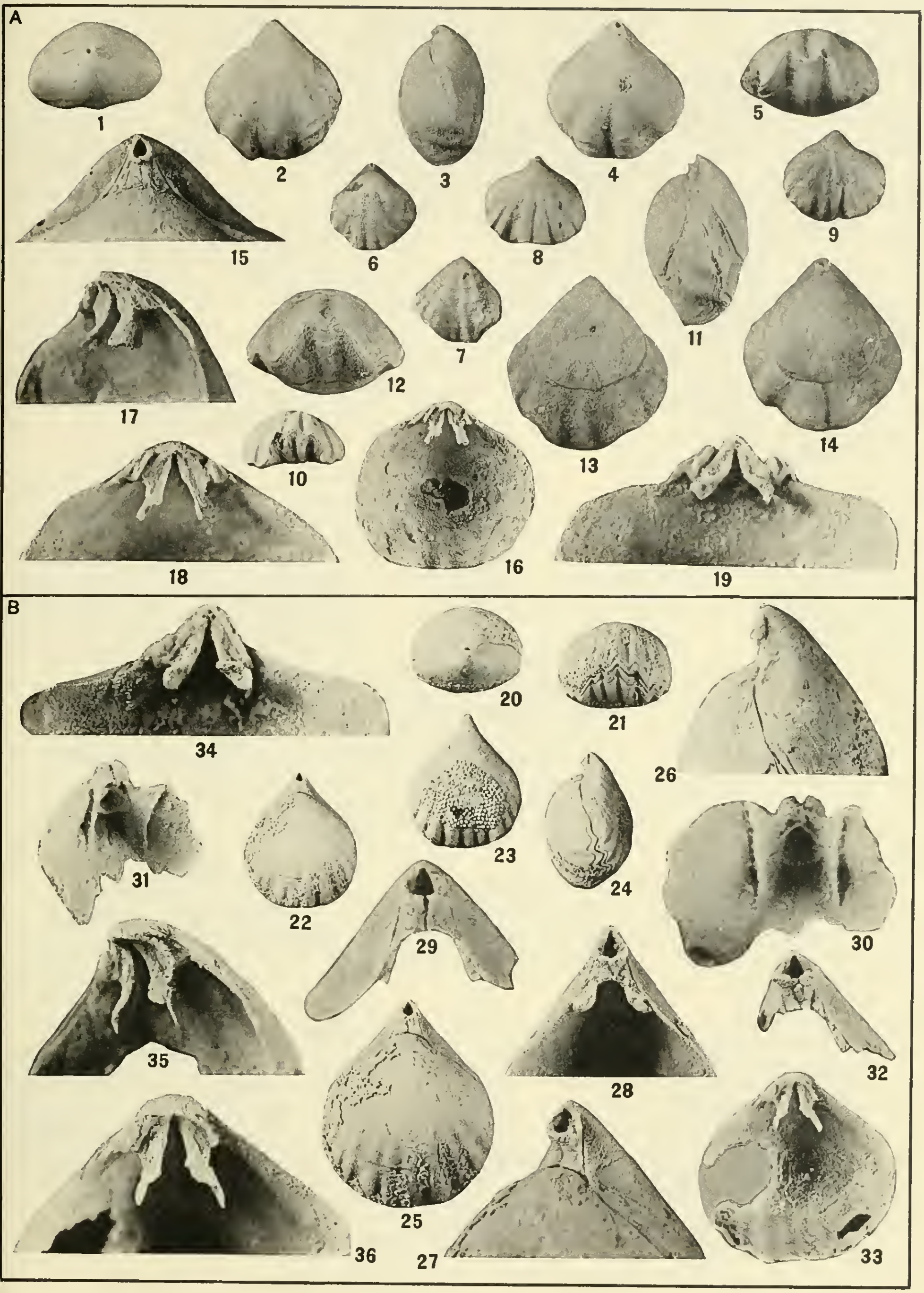

PROBOLARINA

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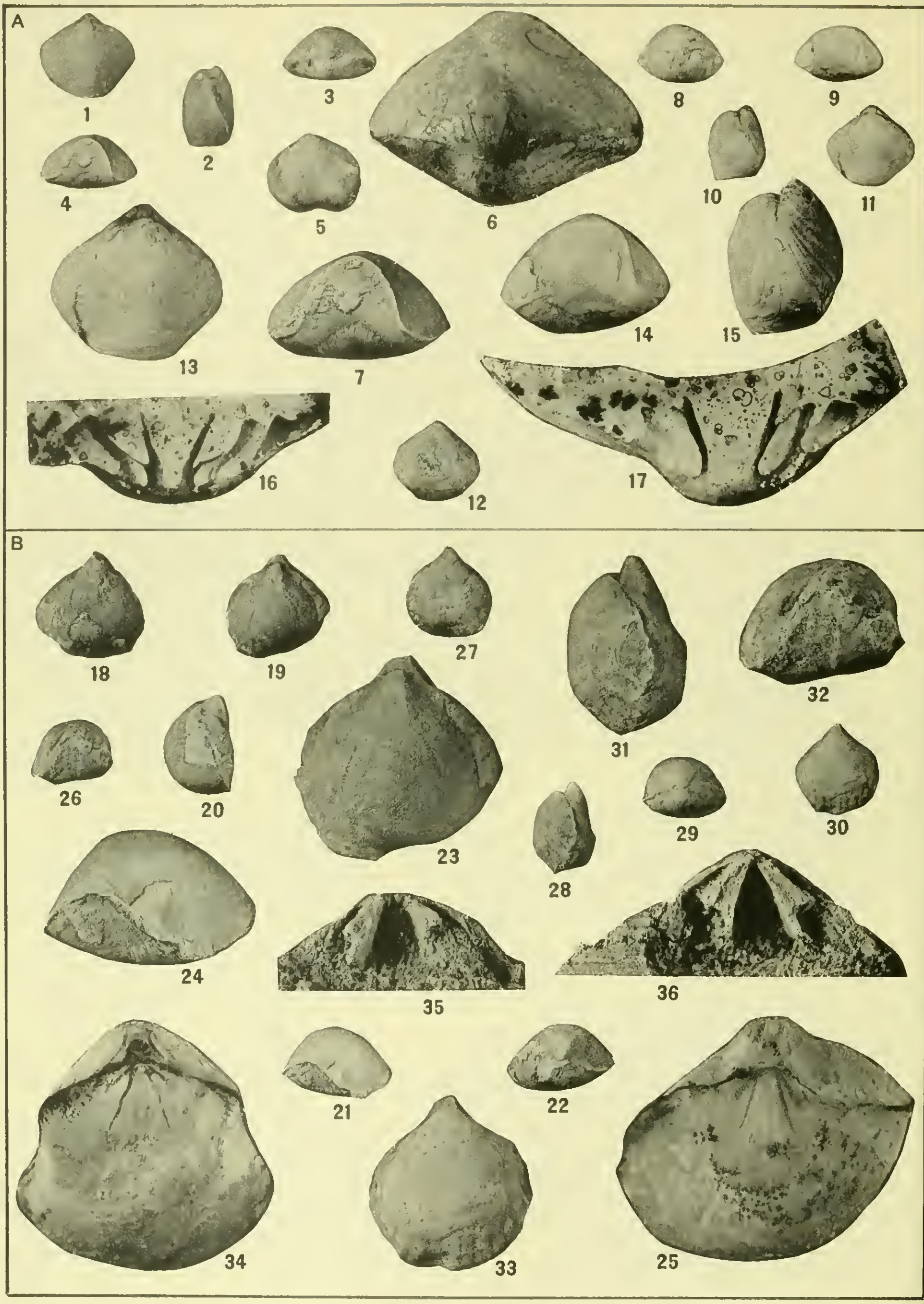

ERYMNARIA

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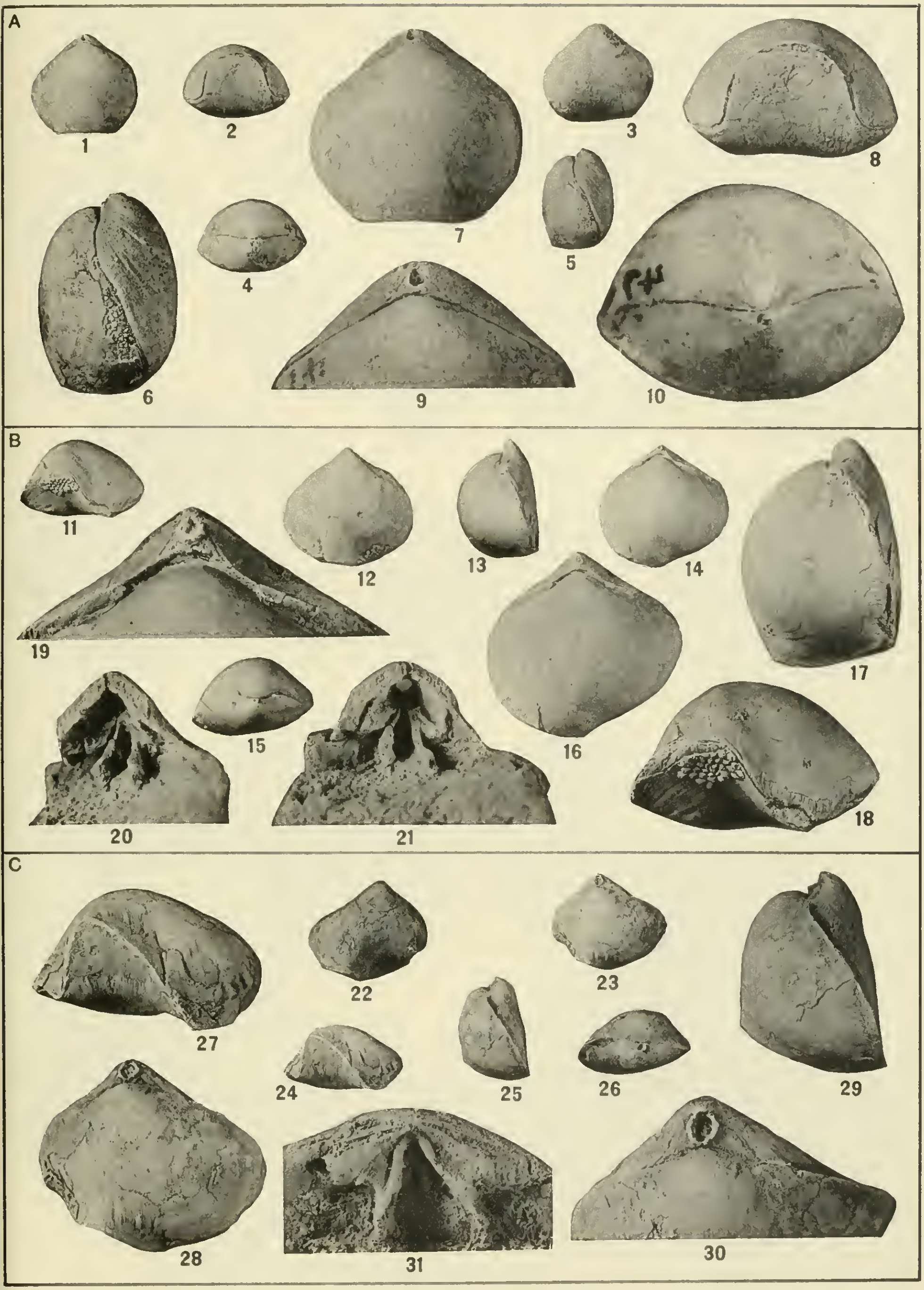

ERYMNARIA AND STREPTARIA

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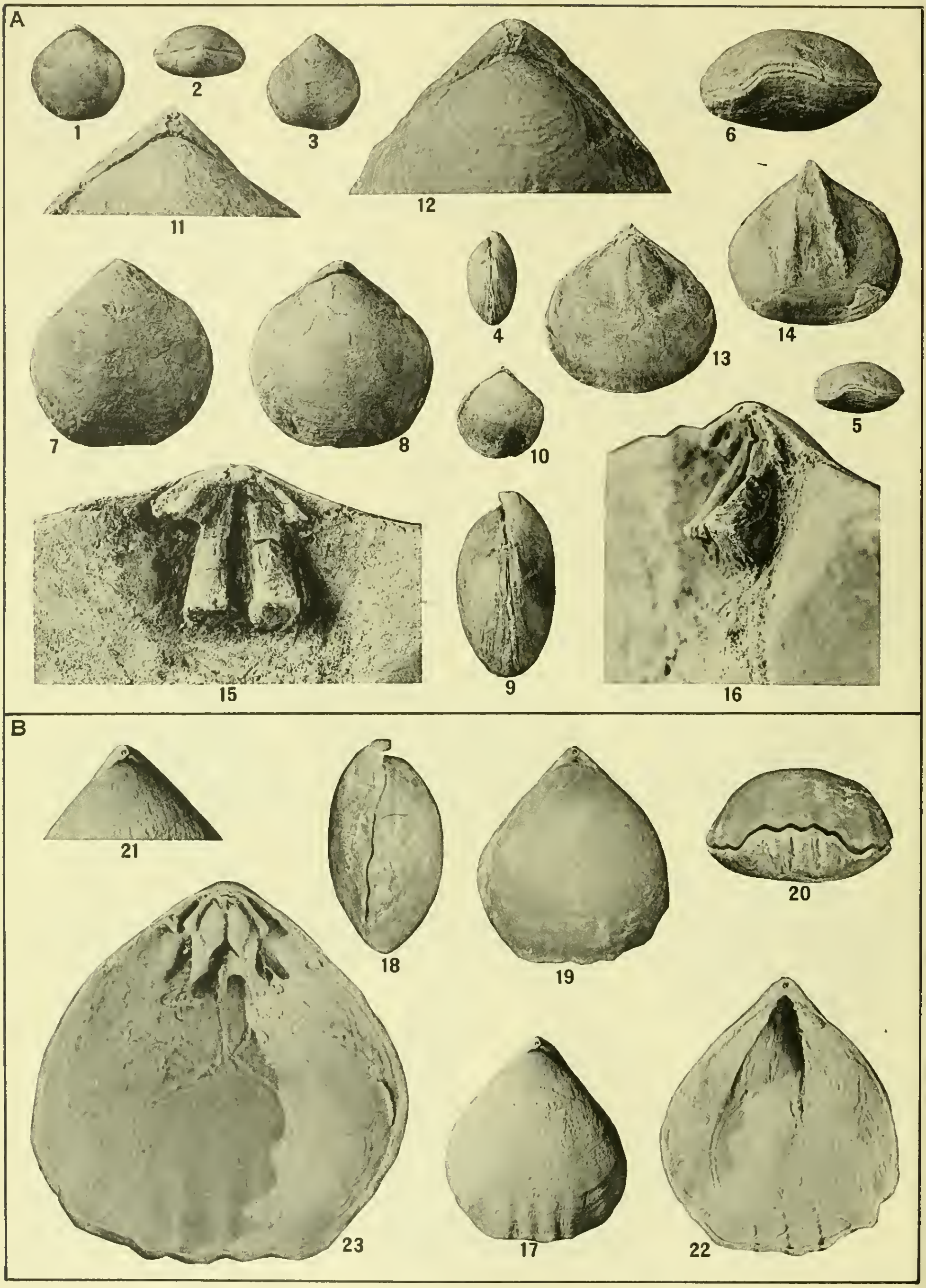

EOHEMITHYRIS

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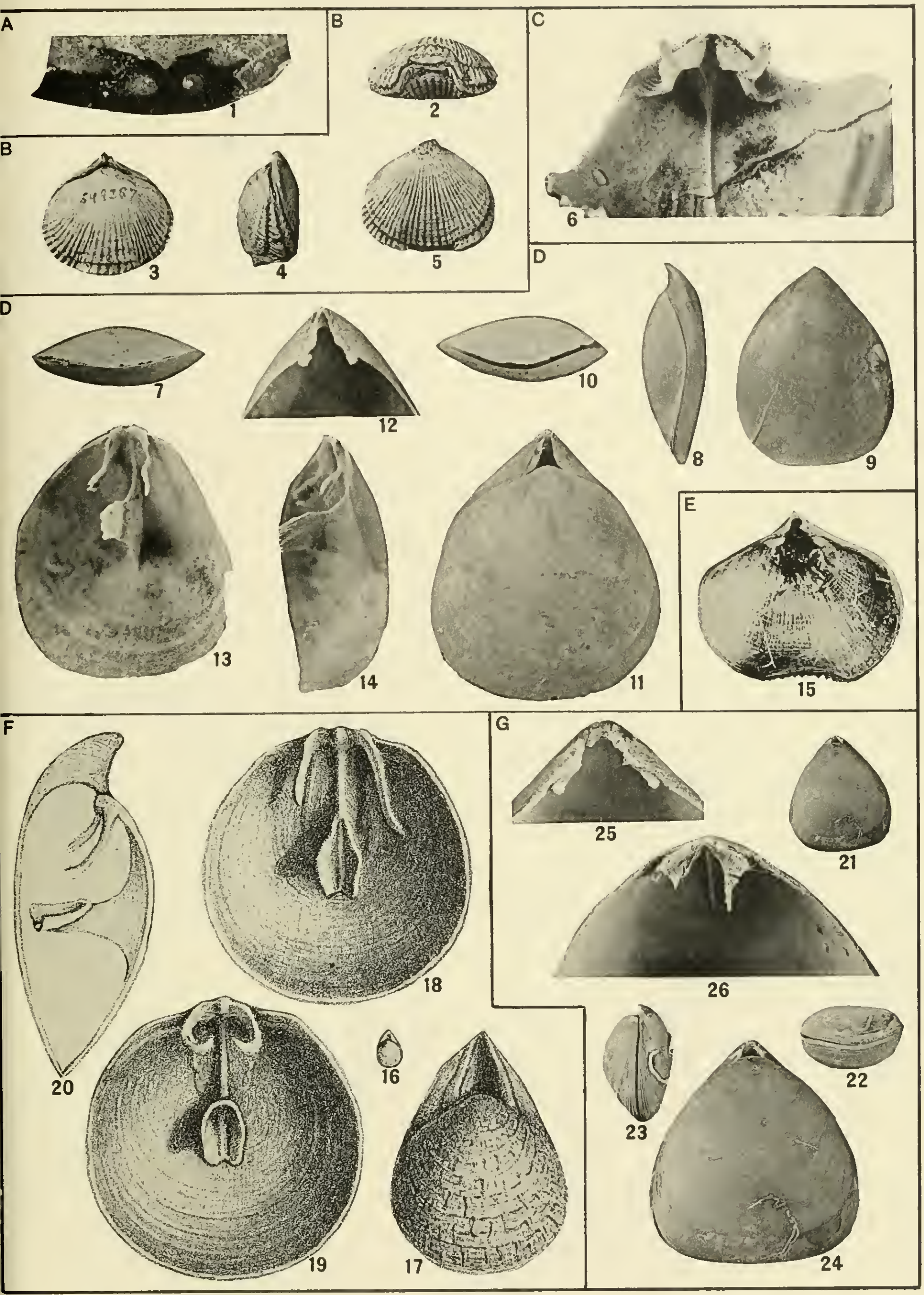

FRIELEIA, PATAGORHYNCHIA, SEPTALIPHORIA, CRYPTOPORA, TEGULORHYNCHIA, MANNIA, AND HISPANIRHYNCHIA?

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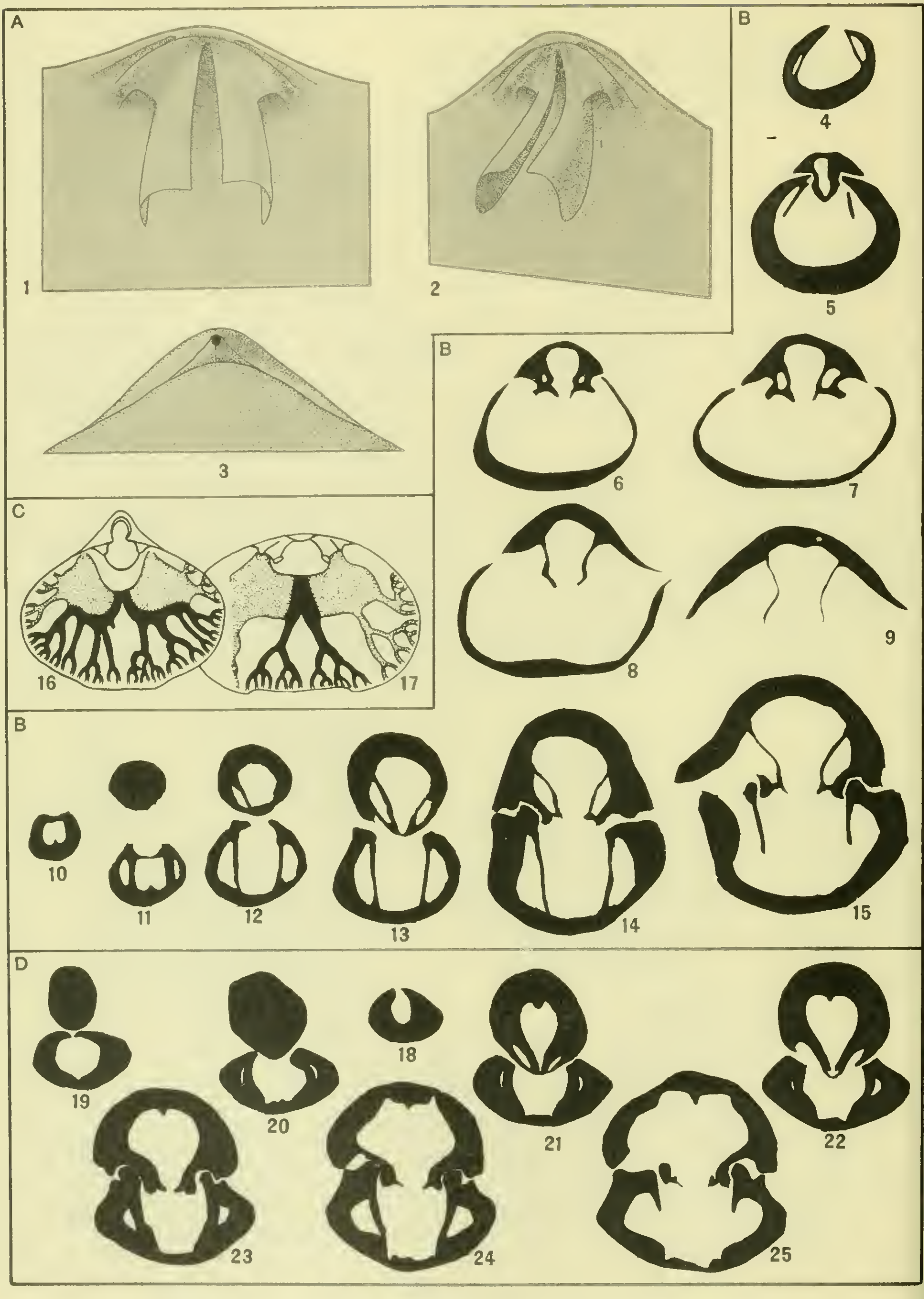

EOHEMITHYRIS, ERYMNARIA, NOTOSARIA, AND APHELESIA

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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 6

Charles D. and Mary Vaux Walcott Research Fund

A REVISION OF THE SILURIAN BRYOZOAN GENUS TREMATOPORA

(With 2 Plates)

By
RICHARD S. BOARDMAN
Associate Curator of Geology
United States National Museum
Smithsonian Institution

(Publication 4383)

CITY OF WASHINGTON
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INTRODUCTION

The genus *Trematopora* Hall, 1851, is placed in the order Trepostomata of the Bryozoa and is the type genus of the family Trematoporidae Ulrich in Miller, 1889. The type species of *Trematopora* is *T. tuberculosa* Hall, 1852, from the Rochester shale in New York (type by subsequent designation, Ulrich, 1882, p. 241).

The name *Trematopora* was established in an article by the editors of the American Journal of Science and Arts (Hall, 1851, p. 400) in which parts of Hall's manuscript for volume 2 of the Paleontology of New York (1852) were quoted. The species of *Trematopora* listed following the diagnosis of the genus were *nomina nuda* and were not published by Hall until the next year in volume 2.

The development of the generic concept of *Trematopora* has been controlled partly by the study and preparation techniques employed by the various authors, each advance in technique adding refinements to the original very generalized description. All the work of Hall and Hall and Simpson (1851-1887) was done on external characters without the use of thin sections. In fact, Hall's primary types of the type species were sectioned for the first time for the present paper. Owing in part to the external homeomorphy common in the Trepostomata, Hall included in the genus many forms now placed in other genera, families, and orders. At various times Hall considered such diverse genera as *Trematella* Hall, *Orthopora* Hall, *Chaetetes* Fischer (part), and *Callopora* Hall (part), as subgenera of *Trematopora*.

Ulrich (1883, p. 257) was the first to section some "authentic specimens of *Trematopora tuberculosa* Hall." These sections are in the

U. S. National Museum collections and are conspecific with Hall's primary types of the species. After seeing the sections, Ulrich greatly restricted the concept of the genus and indicated the great range of forms that Hall had included in the genus. The concept established by Ulrich in 1883 has remained essentially unchanged to the present time and was the type-genus concept for the family Trematoporidae in 1889. Under Ulrich's definition of the genus, 12 species and subspecies have been assigned to *Trematopora,* ranging in age from Middle Ordovician through Middle Silurian.

The primary type specimens were made available for sectioning and study by N. D. Newell of the American Museum of Natural History. Helpful suggestions were made by Helen Duncan and W. A. Oliver, Jr., of the U. S. Geological Survey, and N. Spjeldnaes, of the University of Oslo. Thin sections were prepared by T. M. Robison of the U. S. Geological Survey. Photography was done by J. Scott, and the text figure was drawn by L. B. Isham, both of the Department of Geology of the U. S. National Museum.

INTERPRETATION OF SKELETAL MICROSTRUCTURE

The skeletal structures of most trepostomatous Bryozoa are composed of finely laminated calcite (fig. 1 and pl. 2). These laminae are assumed to have been deposited parallel to the surface of the secreting tissue (Cumings and Galloway, 1915, p. 361). Therefore, trends of the laminae within skeletal structures such as walls and diaphragms are considered to reveal something of the disposition of the original secreting tissue and the mode of growth of the skeletal structures.

In longitudinal thin sections of *T. tuberculosa,* laminae are commonly oriented parallel to the zooecial walls (fig. 1) in the endozone (immature or axial region of authors) and to the thinner walls and mesopore diaphragms in the inner region of the exozone (mature region of authors). This type of microstructure is here designated longitudinally laminated structure. Such an orientation of laminae is assumed to indicate that the depositing tissue was parallel to the walls and diaphragms, but it does not indicate whether the laminae were deposited on one or both sides of the structures.

Another type of structure is characterized by laminae that are curved or angled transversely to the walls and diaphragms as seen in longitudinal sections. The transverse laminae form V- or U-shaped patterns with apices pointing distally and aligned along the median line of a wall or diaphragm. This type of microstructure is here designated transversely laminated structure. In *T. tuberculosa,* this structure is found in the walls of zooecia and mesopores in the outer region of the exozone, and in the inner region in some of the thicker mesopore walls and in the vicinity of central pores in the mesopore diaphragms (fig. 1).

Assuming that secreting tissue was oriented parallel to the laminae, transversely laminated structure indicates that the tissue must have been wrapped around the growing edges of walls and diaphragms

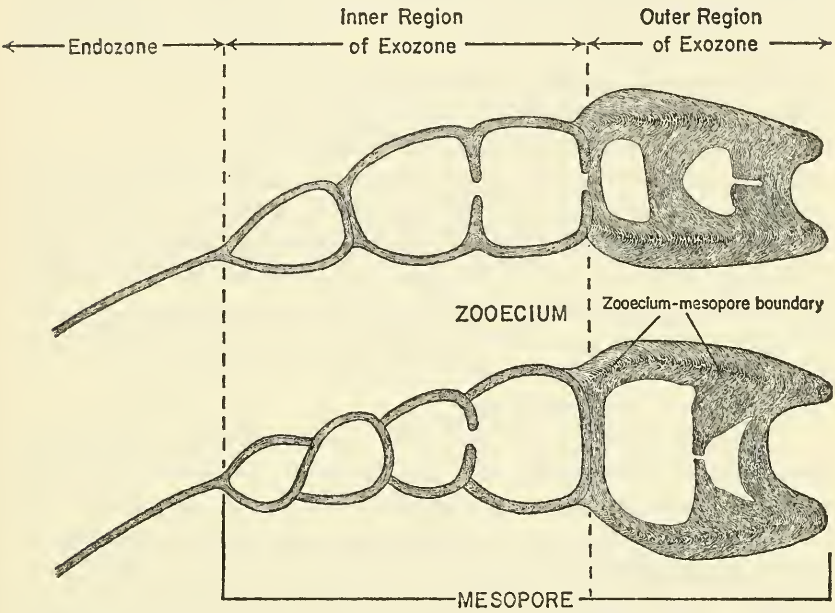

FIG. 1.—Idealized diagram of *T. tuberculosa* in longitudinal view illustrating the variety of laminated structures commonly occurring in the species. Two mesopores and an intervening zooecium are shown in profile. Few central pores of the mesopore diaphragms are intersected in a longitudinal section.

on both sides of the median lines. Thus, transversely laminated structure presumably indicates deposition from both sides of a wall or diaphragm.

Such interpretations applied to the skeletal laminae of *T. tuberculosa* and correlated with other morphologic characteristics of the species suggest that the exozone is divisible into two parts, an inner and an outer region (fig. 1) based on fundamentally different modes of growth of the mesopores. The physiologic significance of the two modes of growth is a matter for speculation. The taxonomic significance of these characters must await comparable studies in related genera.

In the inner region of the exozone, the mesopores are beaded (series of rounded chambers). This beading is produced by the mesopore walls curving transversely to the axis of the mesopore to form a diaphragm. The succession of longitudinally and transversely laminated structures along the walls and diaphragms is interpreted to indicate deposition from both sides of longitudinal as well as transverse structure throughout the inner region. Thus, at least a part of the depositing tissue of the mesopore remained behind the diaphragm and within the chamber being formed. The pore in the center of the mesopore diaphragm presumably would be necessary to allow the soft parts within the chamber to communicate with the outside environment. There is no indication as to whether the soft parts in the mesopores during the formation of the inner region consisted of anything more than a depositing tissue or mantle, but the distal diaphragm would have acted, temporarily at least, as a covering for any soft parts within the last chamber. Continuity of laminae from the distal side of a diaphragm to the wall of the succeeding mesopore chamber implies that at least the proximal part of the chamber was formed as the diaphragm developed (see middle diaphragm of the inner region in the upper mesopore of figure 1). For a more complete discussion of figure 1 see species description.

The thick-walled outer region of the exozone contains transversely laminated structure in the walls of zooecia and mesopores and longitudinally laminated structure in the thick diaphragms. The mesopores in this region are not beaded. The pattern of continuity of the laminae of walls and adjoining diaphragms (fig. 1) indicates deposition was limited to the outer surface of the walls and diaphragms, contemporaneous deposition of laminae taking place on the outermost surfaces of the zooecial wall, around the median line or boundary to the mesopore wall, and back to the distal side of the diaphragm. There is no evidence that deposition occurred on the proximal side of the diaphragm within the mesopore chamber.

The formation of the diaphragms in the inner and outer regions of the exozone is quite different. Diaphragms in the inner region were formed by continued distal growth of mesopore walls that merely curved through an angle of 90 degrees to form transverse structures. Diaphragms in the outer region were formed by an additional, transversely oriented sheet of depositing tissue that was continuous with at least the depositing tissue of the mesopore side of the walls and actively deposited calcite at the same time that the mesopore walls were being formed. This transverse sheet of tissue apparently had no counterpart in the inner region of the exozone.

Evidence concerning the position of the soft parts in the outer region of the mesopore is inadequate. Configurations of the laminae give no indications of deposition behind the distalmost diaphragm. The common occurrence of single, centrally located pores that either partly or completely penetrate the thick outer diaphragms suggest some activity within outer chambers. The majority of these central pores appear to have been cut through the laminae of the diaphragms. Their termination within outermost diaphragms suggests that activity within the outermost chambers might have been choked off by the growth of the thickened diaphragms.

SYSTEMATIC DESCRIPTION

Genus TREMATOPORA Hall, 1851

1851. *Trematopora* Hall, Amer. Journ. Sci. and Arts, ser. 2, vol. 11, p. 400.
1852. *Trematopora* Hall, Paleontology of New York, vol. 2, p. 149.
1881. *Trematopora* Hall, Nicholson, Genus *Monticulipora*, pp. 232-234.
1882. *Trematopora* Hall, Ulrich, Journ. Cincinnati Soc. Nat. Hist., vol. 5, p. 241.
1883. *Trematopora* Hall, Ulrich, Journ. Cincinnati Soc. Nat Hist., vol. 6, p. 257.
1887. *Trematopora* Hall, Hall and Simpson, Paleontology of New York, vol. 6, p. xiv.
1893. *Trematopora* Hall, Ulrich, Geol. Minnesota, vol. 3, pt. 1, p. 308.
1911. *Trematopora* Hall, Bassler, U. S. Nat. Mus. Bull. 77, pp. 267, 268.
1882. [non] *Trematopora* Hall, Ulrich, Journ. Cincinnati Soc. Nat. Hist., vol. 5, p. 153.

Type species.—Trematopora tuberculosa Hall, 1852.

Emended definition.—Zoaria are ramose, conspecific overgrowth is common, and monticules range from level to tuberculated. Externally, zooecia are elliptical to subcircular in cross section and walls are slightly elevated above intervening mesopores. Mesopores form shallow, subpolygonal depressions between zooecia.

The exozone is divided into an inner thin-walled region containing the earliest chambers of the mesopores and an outer thick-walled region. In the inner region, both mesopores and zooecia are polygonal to subpolygonal in cross section and mesopores are beaded and contain diaphragms with single central pores. In the outer region of the exozone, zooecia become elliptical to subcircular in cross section and the mesopores contain thickened diaphragms and are not beaded. Diaphragms are thin and few in zooecia.

In the outer region of the exozone, walls of adjacent zooecia are divided by sharply defined zooecial boundaries, as seen in longitudinal sections. Laminae on either side of a boundary converge to form a

V-shaped pattern that has extremely long limbs trending nearly parallel to the boundary and curving very slightly just before the boundary is intersected. Laminae of walls of zooecia and adjacent mesopores are more broadly curved approaching the median boundary and form a broad U-shaped pattern having limbs of varying lengths. Acanthopores are common in the zooecial walls.

Discussion.—Based on an examination of thin sections of primary types of species previously assigned to *Trematopora* now in the U. S. National Museum collections, the following species are considered correctly assigned to the genus:

T. halli Ulrich 1883, Niagaran group, Waldron, Ind.
T. whitfieldi Ulrich 1883, Niagaran group, Waldron, Ind.

The holotype section of *T. spiculata* Miller 1877, Niagaran group, Waldron, Ind., is not adequate to determine generic affinities. This species is retained in the genus until a more detailed study of additional material can be made.

The following species originally placed in *Trematopora* do not satisfy the generic definition proposed here and are not considered to belong to the genus. Their proper generic assignments must await restudy of both the species themselves and the available genera.

calloporoides Ulrich 1890, Cincinnati group, Alexander County, Ill.

cystata Bassler 1911, Kuckers shale (C2), Reval, Esthonia. This species is the type of *Aostipora* Vinassa 1920).

debilis Ulrich 1890, Girardeau limestone, Alexander County, Ill.

kukersiana Bassler 1911, Kuckers shale (C2), Reval, Esthonia.

primigenia Ulrich 1886, Decorah shale, Minneapolis, Minn.

primigenia var. *ornata* Ulrich 1886, Decorah shale, Minneapolis, Minn.

None of the Ordovician species investigated displayed the two regions of the exozone or pores in the mesopore diaphragms. Thus, the genus is limited presently to the Middle Silurian.

A close taxonomic relationship seems to exist between *Trematopora* and some or all of the Silurian and Devonian species that have been placed in the genus *Leioclema* Ulrich. These species of *Leioclema* are largely incrusting and possess many of the morphologic characters now defining *Trematopora*. In general they have elliptical zooecia with few thin diaphragms, abundant mesopores with closely spaced thicker diaphragms and an irregularly discontinuous inner region of the exozone containing beaded mesopores. Pores in the diaphragms of the mesopores are rare but do definitely occur in the following species.

Leioclema asperum (Hall) 1852, Rochester shale, Lockport, N. Y. (Only Bassler's plesiotypes of 1906 available.)
L. confertiporum (Hall) 1883, Hamilton group, New York.
L. decipiens (Hall) 1883, Hamilton group, New York.
L. passitabulatum Duncan 1939, Traverse group, Michigan.

The region now considered to be the inner region of the exozone in species of *Leioclema* from the Hamilton group of New York was interpreted as the outer part of the endozone (Boardman, in press) and diaphragm pores were overlooked.

TREMATOPORA TUBERCULOSA Hall

Pl. 1, figs. 1-4; pl. 2, figs. 1-3

1852. *Trematopora tuberculosa* Hall, Paleontology of New York, vol. 2, p. 149, pl. 40A, figs. 1a-g.
1883. *Trematopora tuberculosa* Hall, Ulrich, Journ. Cincinnati Soc. Nat. Hist., vol. 6, p. 259, pl. 13, figs. 2, 2a, 2b.
1906. *Trematopora tuberculosa* Hall, Bassler, U. S. Geol. Surv. Bull. No. 292, p. 43, pl. 13, figs. 15, 16; pl. 17, figs. 1-3; pl. 25, fig. 8.

TYPE DATA

Lectotype (Hall, 1852, pl. 40A, fig. 1a) and the two paratype zoaria from syntype suite No. 1747, American Museum of Natural History.

MATERIAL STUDIED

In addition to the primary types, 55 fragmentary topotype zoaria were studied. The topotypes are from U. S. National Museum collection No. 2998 and cat. No. 43618 collected by E. O. Ulrich. U. S. National Museum catalogue numbers of illustrated topotypes are 137847 to 137850.

OCCURRENCE

Rochester shale member of the Clinton formation, Lockport, N. Y.

DESCRIPTION

Zoaria.—Zoaria are ramose and branches are circular to elliptical in cross section. Branch arrangement was affected by branches rising from conspecific secondary growth superimposed on the normal bifurcating pattern. Branches of secondary growth produced irregularities in branch arrangement, commonly causing branches to anastomose and form erratic and confused zooecial growth at surfaces of contact. These irregularities in branch arrangement were formed by random bends at ramose extensions of overgrowths beyond the distal tips of primary branches, and irregular branch angles in lateral secondary branches. The zoaria were further complicated by repetitions of thin- and thick-walled growth in the outer region of the exozone (mature region) without the formation of intervening basal laminae. This apparently rejuvenated growth formed localized swellings on the zoaria, and combined with adjacent patches of overgrowth to form some of the secondary branches.

Monticules.—Monticules are prominent tubercles. The apertures of some monticular zooecia are restricted or closed by a distal thickening of the walls, and the walls and outer diaphragms of monticular mesopores are somewhat thicker than those of surrounding mesopores. Monticular mesopores generally contain one to several more diaphragms than intermonticular mesopores.

Longitudinal View: *Endozone.*—In the endozone (immature or axial region), zooecial walls are longitudinally laminated and do not show the dark granularity that is common in the Trepostomata. The zooecial walls range from undeviating to irregularly undulating. In a few specimens the endozone is interrupted by a zone arching distally across the branch that is marked by variable thickening of the zooecial walls. Normal thin-walled zooecial growth generally continues distally from the thickened walls of the arched zones with some bifurcating but without other break. At apparently random levels within a colony, some or all of the zooecia within the endozone have been eroded and the tubes filled with mud. Subsequent growth was initiated from adjacent zooecia and the eroded areas were covered by a basal lamination of the overgrowth that continued the colony distally.

Exozone: Inner region of mesopores.—The boundary between the endozone and exozone is defined by the points of origin of the mesopores. The inner region of the exozone extends distally for one to several mesopore diaphragms, but generally not more than four. The mesopores begin proximally with walls and diaphragms that are slightly thicker than the zooecial walls of the endozone. Mesopore walls curve broadly through 90 degrees into transverse positions relative to the length of the mesopores, thereby forming diaphragms. The broad curving results in constrictions of the mesopores at the positions of the diaphragms to form cystlike chambers. In this inner region of the exozone, mesopore walls commonly are longitudinally laminated, but many, especially the thicker ones, develop transversely laminated structure, either intermittently or throughout their length.

In the inner region, mesopore diaphragms regularly display centrally located single pores that penetrate the diaphragms at right angles. In longitudinal thin sections that pass through these pores, diaphragms display transversely curved laminae that continue uninterrupted to the pores. The curved laminae immediately adjacent to the pores define the rounded boundaries of the pores.

If walls of adjacent mesopore chambers are longitudinally laminated, generally the wall of the earlier chamber is connected directly with the curved laminae on the proximal side of the intervening diaphragm and the wall of the later chamber is connected with the distal side of the diaphragm. If walls of adjacent mesopore chambers are formed by transversely curved laminae, the diaphragm and adjacent walls will appear to be a continuous unit, or the diaphragm is a direct continuation of the proximal wall and the wall of the distal chamber is discordantly joined to the distal side of the diaphragm. Rare, isolated mesopore diaphragms display complete continuity with the walls of distal chambers.

In longitudinal thin sections, mesopore diaphragms in which the pores were not intersected appear longitudinally laminated. Commonly the diaphragms are compound; the proximal half of a diaphragm is continuous with the wall of the preceding mesopore chamber, the distal half is continuous with the wall of the succeeding chamber. Other variations in diaphragm-wall relationships are less common; the two parts of the compound diaphragm can be unequal in thickness, or in extreme development a diaphragm loses its compound appearance and is wholly continuous with the preceding or very rarely the succeeding chamber walls throughout or at either end.

Outer region of mesopores.—In the outer region of the exozone, mesopores are not beaded and the walls and diaphragms display extreme thickening. This greatly thickened skeletal growth can begin on the distal side of the last thin diaphragm, the laminae covering the central pore of the thinner diaphragm and curving distally into the mesopore walls, or it can begin by an abrupt thickening of the mesopore walls. Diaphragms in this outer region are extremely variable in thickness and spacing. A single diaphragm, greater in thickness than the diameter of the enclosing mesopore, can correspond in thickness and position with a series of irregularly and closely spaced diaphragms in adjacent mesopores. Most diaphragms are planar, but a few are strongly curved and join adjacent diaphragms before reaching the mesopore wall. The last diaphragms that were formed are in the distal ends of the mesopores so that in external view the walls and diaphragms of the mesopores combine to form the very shallow polygonal depressions between the zooecia.

Many of the thick diaphragms also display centrally located pores that do not penetrate through to the distal sides of most of the thickest diaphragms. Laminae of the diaphragms generally stop abruptly at the pores without changing direction or flexing, so that the pores have no lining or apparent influence on the structure of the diaphragms. In other thick diaphragms the laminae trend in a proximal direction in varying amounts and there is a noticeable decrease in diaphragm thickness approaching the pore. The pores in the outer region also differ from the central pores of the inner region of the exozone by being consistently smaller in diameter. In addition to the pores, mesopore diaphragms and walls in the outer region contain small, dark, subspherical to elongated cavities formed by the concentric arrangement of laminae about imaginary centers. These cavities seem to be arranged at random in the walls and diaphragms.

Zooecia.—In the outer region of the exozone, undistorted wall structure of adjacent zooecia is rarely seen because of intervening mesopores and acanthopores. Zooecial boundaries are well defined, dark, slightly serrated lines or zones in two dimensions, formed by the abutting ends of laminae from adjacent zooecia. In walls formed by a zooecium and adjacent mesopore, or by adjacent mesopores, boundaries are more coarsely serrated and are commonly discontinuous along their length.

Diaphragms are not present in most zooecia and not more than two were seen in any one zooecium. If present, diaphragms are very thin, planar to slightly curved, and extend distally into the zooecial wall. Single, hollow, subspherical cystlike structures occur in the zooecial voids of a very few zooecia, more commonly in the monticules. The cyst walls are thick and are constructed of laminae that merge with the laminae of the zooecial walls. Irregular spinelike processes are common in the zooecial walls in the thick-walled outer region. These mural spines have their origins at or very near the zooecial boundaries and trend in general toward the zooecial voids at a high angle to undisturbed laminae in the walls. Zooecial wall laminae surrounding the spines are flexed about the spines in a series of irregular superposed cones and some of the laminae are pierced. The spines extend far enough to cause inflection of the walls but none were observed to break through the wall laminae and stand in relief in the zooecial voids. The cores of the spines appear structureless or hollow.

Tangential View.—In tangential sections passing through the outer region of the exozone, zooecia range from irregularly elliptical to subcircular to petaloid in cross section. Major axes of the ellipses are approximately parallel to branch length. The rare petaloid appearance is caused by extreme inflection of zooecial walls by adjacent acanthopores and mural spines. Acanthopores are large, laminated, possess well-defined central tubes, and are generally located at points of closest proximity of adjacent zooecia. Mural spines appear to begin outside the broad band of striated-appearing tissue lining each zooecium and project inwardly toward the zooecial void, strongly inflecting the laminated tissue but not breaking through to the void. Mesopores are numerous, subpolygonal to subcircular. In very shallow sections that pass through the outermost and thickest diaphragms, mesopore boundaries are concealed and interspaces between zooecia appear solid. Many of these solid interspaces do not show the smaller central pores that are the rule in sections that pass through earlier parts of the outer region.

In deeper tangential sections that pass through the inner region of the exozone, zooecia are polygonal to subpolygonal and approximately equidimensional. Mesopores are also polygonal to subpolygonal and have fewer sides than the zooecia, merely appearing to fill the spaces between zooecia. Pores in mesopore diaphragms here are several times larger in diameter than those in the outer region. Acanthopores are considerably smaller in diameter than they are in the outer region.

QUANTITATIVE DATA

The following tables are based on sections of two fragments from the lectotype, three fragments from the two paratype zoaria, and 49 fragments from 33 topotype zoaria. Sections from 55 zoaria of *Trematopora tuberculosa* were examined. All measurements are in millimeters. The axial ratio is the ratio of the diameter of the endozone to the corresponding branch diameter.

TABLE 1.—*General measurements*

	Lectotype AMNH 1747		Paratypes and topotypes	
	Frag. A.	Frag. B.	Minimum	Maximum
Diameter of zoarium	6.5	4.9	3.0	7.2
Width of endozone	5.3	3.3	2.3	5.6
No. zooecia in 2 mm. (longitudinal direction)	5½	6½	6	8
Average major axis of zooecial void per fragment	0.14	0.15	0.14	0.22
Average minor axis of zooecial void per fragment	0.12	0.12	0.09	0.14
Acanthopores per zooecium	0.73	0.63	0.50	0.5
Mesopores per zooecium	1.6	—	1.1	2.0

TABLE 2.—*Ontogeny*

	Average No. diaphragms in mesopores	Width of exozone	Axial ratio
	2	0.3-0.6	0.87-0.92
	3	0.5-1.0	0.74-0.90
Frag. A. lectotype..............	4	1.2	0.82
	4	0.9-1.4	0.71-0.86
	5	1.0-1.4	0.66-0.82
	6	1.4-1.8	0.75
Frag. B. lectotype..............	7	1.6	0.67
	7	1.1-1.6	0.68-0.70

DISCUSSION

The number of mesopore diaphragms and the width of the exozone are not particularly sensitive indicators for ontogenetic development of the mesopores and zooecia in *T. tuberculosa.* The variation in diaphragm counts and in width of exozone within a longitudinal thin section is unusually large because of a marked variation in the number of chambers developed in adjacent mesopores in the inner region. Also, the unusual variation in thickness and spacing of mesopore diaphragms in the outer region of the exozone makes diaphragm counts less reliable.

T. tuberculosa differs from both *T. halli* and *T. whitfieldi* in having the larger branches, tuberculated mesopores, and a broader exozone in mature specimens. Both *T. halli* and *T. whitfieldi* are smooth, rhomboporoid-sized species.

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EXPLANATION OF PLATES

Plate 1

Figs. 1-4. *Trematopora tuberculosa* Hall.

1. Longitudinal view of paratype, A.M.N.H. 1747, × 5, showing primary branch with growth direction upward and branch from secondary overgrowth with growth direction to lower right.

2a. External view of lectotype zoarium, A.M.N.H. 1747, × 2, showing tuberculated monticules.

2b. Longitudinal view of lectotype, × 20, showing beaded mesopore chambers in inner region of exozone.

2c. Tangential view of lectotype, × 20, showing aspect of both inner and outer regions of exozone. Note thin-walled polygonal tubes of inner region of monticule in upper left.

3. Tangential view of paratype, A.M.N.H. 1747, × 50, showing the smaller central pores in mesopore diaphragms of outer region of exozone.

4. Longitudinal view of topotype, U.S.N.M. 137847, × 5, showing zooecial growth at surface of contact of anastomosing branches. U.S.N.M. collection 2998.

Plate 2

Figs. 1-3. *Trematopora tuberculosa* Hall.

1. Longitudinal view of topotype, U.S.N.M. 137848, × 100, showing laminated structure of a beaded mesopore and two diaphragm pores in the inner region of the exozone.

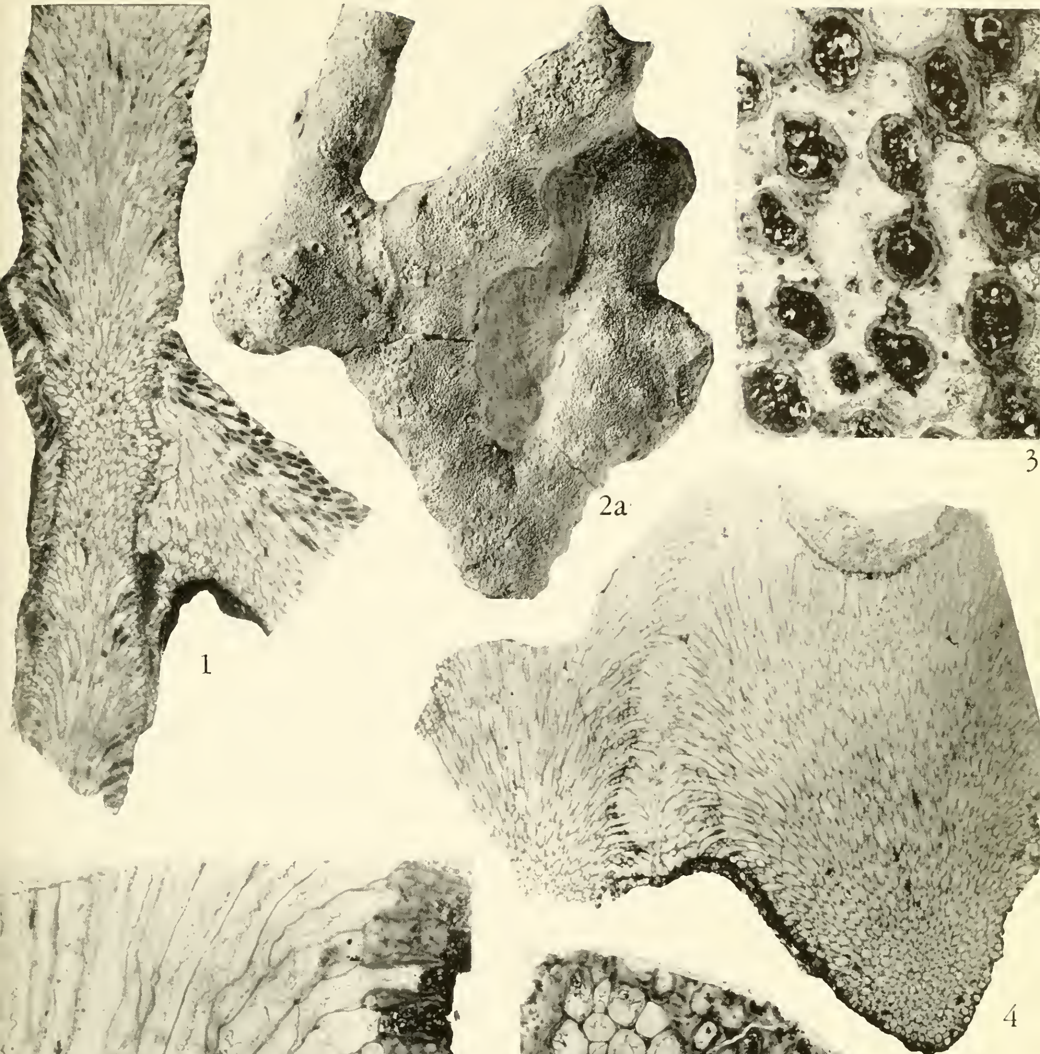
2a. Longitudinal view of topotype, U.S.N.M. 137849, × 100, showing configuration of laminae of mesopores and small diaphragm pore in outer region of exozone.

2b. Longitudinal view of same specimen, × 100, displaying a mesopore with diaphragm pore of inner region covered by first diaphragm laminae of outer region. Note discontinuous and ragged boundary between mesopore wall and zooecial wall above.

3a. Longitudinal view of topotype, U.S.N.M. 137850, × 100, showing first a diaphragm pore and then a compound diaphragm between beaded chambers in the inner region of the mesopore.

3b. Longitudinal view from same zoarium, × 100, illustrating the structure of the wall of adjacent zooecia.

3c. Tangential view from same zoarium, × 100, showing the general aspect of the outer region of the exozone, including acanthopores, mural spines, and a small pore in the center of a diaphragm of a mesopore. The dark intermediately sized spots are the randomly arranged cavities noted in species description.



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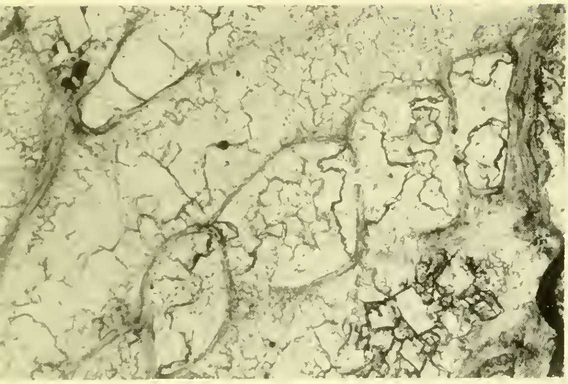
TREMATOPORA TUBERCULOSA

(See explanation of plates at end of text.)



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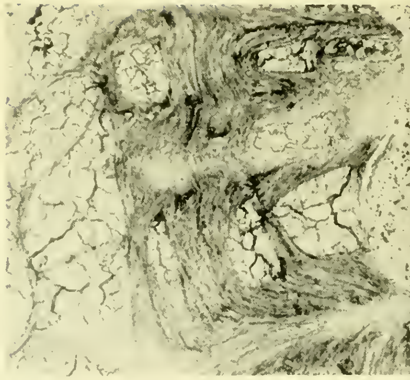

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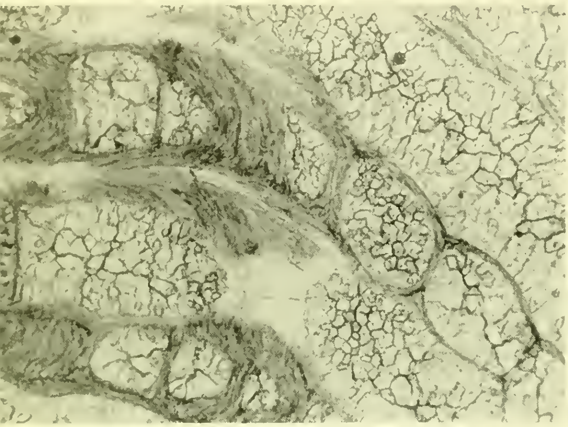

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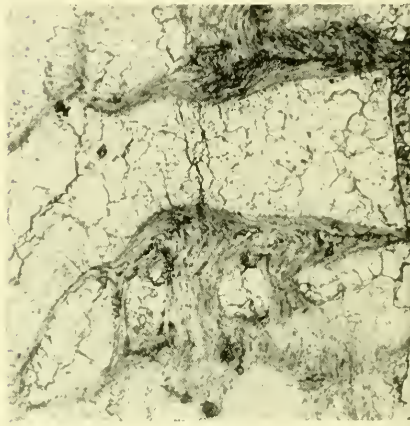

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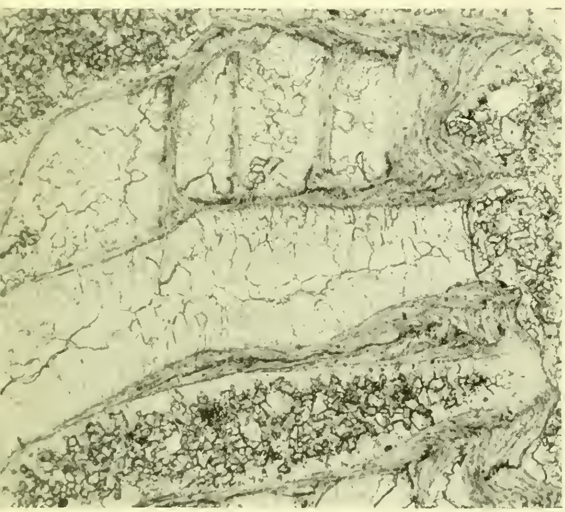

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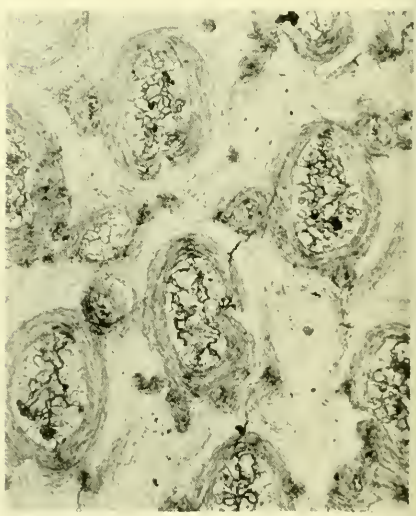

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TREMATOPORA TUBERCULOSA

(See explanation of plates at end of text.)

SMITHSONIAN MISCELLANEOUS COLLECTIONS
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Charles D. and Mary Vaux Walcott
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EARLY TERTIARY APHELISCUS AND PHENACODAPTES AS PANTOLESTID INSECTIVORES

(WITH TWO PLATES)

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Curator, Division of Vertebrate Paleontology
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INTRODUCTION

Examination in 1954 of *Phenacodaptes* material in the Paleocene collections at Princeton University, believed pertinent to a review of Eocene artiodactyls then underway, led to rather inconclusive results. Dr. Jepsen's tentative suggestion (1930, p. 519) of such a relationship may, nevertheless, have merit.[1] More recent studies of the Knight faunas, however, involved certain pantolestids, and comparison of these among a wide range of both Eocene and Paleocene forms has convinced me that Cope's *Apheliscus* and Jepsen's *Phenacodaptes* are closely related and that both are pantolestids, although perhaps somewhat less closely related to the Pantolestinae than to the Pentacodontinae. Their relationships would seem possibly best illustrated by placing them both in the Apheliscinae as a subfamily of the Pantolestidae.

I am indebted to Dr. Glenn L. Jepsen for permitting me to borrow and illustrate specimens of *Phenacodaptes sabulosus* in the Princeton collections, and to Dr. George G. Simpson and Mrs. Rachel H. Nichols for sending me materials of *Apheliscus insidiosus* and *Pentacodon inversus* from the collections of the American Museum. The pencil drawings of specimens shown in the accompanying plates were made by Lawrence B. Isham, scientific illustrator for the Department of Geology in the U. S. National Museum.

PREVIOUS INTERPRETATIONS OF RELATIONSHIP

Apheliscus insidiosus was described by Cope (1874, p. 14) from the lower Eocene San Jose beds in New Mexico. He described it

[1] After this manuscript was submitted for publication, Dr. Jepsen showed me a note that he had placed in the collection drawer some time ago suggesting that *Phenacodaptes* be compared more carefully with *Apheliscus*.

first as a species of *Prototomus* and included it together with "*Prototomus*" *jarrovii* (=*Pelycodus jarrovii*) in the carnivores with *Prototomus* (=*Sinopa*) *viverrinus*. In 1875 (p. 16), however, he proposed the name *Apheliscus*, regarding it as "nearly allied to *Pantolestes*," although at the same time he thought that the molar teeth suggested a relationship to *Anaptomorphus*, noting, nevertheless, that the premolars were "totally different." Cope's statement that the last lower molar lacked a heel would seem highly significant, but, if the meaning is here properly interpreted, it is surely an error, as may be seen from his illustration (1877, pl. 45, fig. 18). In addition to the described condition of the talonid of the third molar, Cope noted as distinctive in comparison with *Pantolestes* only the simplicity of the inner anterior tubercle of the lower molars.

Matthew (1918), in naming the family Apheliscidae, was very dubious as to its affinities, and while referring it to the Insectivora, considered that it might well be condylarthran, primate, or creodont. It should be noted, however, that at the time of his writing, such genera as *Aphronorus*, *Bessoecetor*, and *Phenacodaptes* were not known. Only large and comparatively aberrant *Pentacodon*, which he had recognized as a pantolestid insectivore (1909), and the Eocene members of the Pantolestinae were available for comparison.

Simpson (1937a) demonstrated the most logical arrangement for the pantolestids and pentacodonts, while adding the Paleocene genera *Bessoecetor* and *Aphronorus* to their respective subfamilies. He noted, moreover, the resemblance of *Apheliscus* to the Pentacodontinae in characters of the fourth premolars, but considered, however, that the molar structure was widely different. Nevertheless, his suggestion that *Apheliscus* might be an offshoot of the same stock seems particularly pertinent and certain of the lacking evidence for such an hypothesis may lie in *Phenacodaptes*. The family, however, was retained *incertae sedis*, questionably in the Insectivora in his 1945 classification.

Saban (1954), evidently following Simpson's suggestion, included the Apheliscidae with the Pantolestidae in the superfamily Pantolestoidea. His including Shikama's Endotheriidae, created for the Manchurian Jurassic *Endotherium*, as a subfamily of the Pantolestidae, however, seems surprising. McDowell (1958) rejected certain features of Saban's classification and in discussing the family Apheliscidae regarded it as *incertae sedis*, but noted that the teeth are "reconcilable with those of *Mixodectes*." McKenna, on the other hand, in a field conference guidebook (1955) has the Clark Fork species *Apheliscus nitidus* listed as a condylarth.

Older but more recently described *Phenacodaptes sabulosus* is from the Silver Coulee or Tiffanian horizon of the Polecat Bench formation in the Big Horn Basin. The possibility of a relationship to artiodactyls was tentatively suggested by Jepsen (1930) because of resemblances noted to such genera as *Diacodexis* and *Bunophorus,* evident in certain features of the molars. Simpson, however, in his classification of the mammals (1945) cited *Phenacodaptes* as a condylarth under ?Mioclaeninae *incertae sedis.*

COMPARISON OF *APHELISCUS* AND *PHENACODAPTES*

A lower jaw of *Apheliscus,* referred to *A. insidiosus,* in the National Museum collection (No. 19162) from the Gray Bull beds in the Big Horn Basin, exhibiting P_2-M_1 inclusive (see pl. 1, fig. 1), shows that the form and relative proportions of the lower premolars are strikingly like those in *Phenacodaptes* (see pl. 1, figs. 3, 4). The relatively small size of P_2 and particularly of P_3 in comparison with P_4 is quite alike in the two. P_4 is a little more slender in *Apheliscus* and the distinctive talonid seen in this tooth of *Phenacodaptes* is more sectorial and essentially better developed or exaggerated in *Apheliscus.* Both have a strongly developed primary cusp and only slight evidence of a paraconid. There is no metaconid on P_4 in the known material of *Apheliscus.* It is usually absent, but may be weakly developed in some specimens of *Phenacodaptes.* The lower molars differ noticeably in the anteroposteriorly shorter trigonid and more elongate talonid in *Apheliscus* (see pl. 1, fig. 2); moreover, they are relatively more slender than in *Phenacodaptes.* There is, nevertheless, a rather marked similarity in many details, particularly in form of the cusps and crest surrounding the talonid basin, and in the shape of the basin. The compressed trigonid of *Apheliscus* is rather less like that in *Phenacodaptes,* although the paraconid is absent or very much reduced on the posterior two molars of both forms. In M_1 of *Phenacodaptes,* however, this cusp is moderately well defined as an anterior crest from the protoconid, whereas in *Apheliscus* only a slight median cuspule remains.

The upper cheek teeth of *Apheliscus insidiosus* (see pl. 2, fig. 1) may appear a little less like those of *Phenacodaptes* (see pl. 2, fig. 2) than perhaps do the lower teeth, although both exhibit the comparatively small and subequal second and third upper premolars and enlarged fourth. The more noticeable differences between the two in upper teeth include less development of the cingulum, particularly on P^4, and the transversely narrower molars of *Apheliscus.* Moreover, the hypocone, though distinctive on M_1 and M_2 of *Phenacodaptes,* is weak or absent in Gray Bull *Apheliscus.* It is important to note, however, that the upper teeth seen in Clark Fork *Apheliscus nitidus* seem intermediate in most, if not all, of these respects. A comparison of Matthew's figure (1918, fig. 24) for the Clark Fork specimen, which Simpson (1937b) made the type of *A. nitidus,* with P^4 and M^1 in *Phenacodaptes sabulosus,* here shown in plate 2, figure 2, reveals little to distinguish them. The Sand Coulee lower teeth of *Apheliscus,* figured by Matthew (1918, fig. 24) also seem to show a little less compression of the trigonid than more typical Gray Bull specimens.

The foregoing comparisons strongly suggest that *Phenacodaptes,* or at least a very closely related form, gave rise to *Apheliscus.* The succession may well have been *Phenacodaptes sabulosus–Apheliscus nitidus–Apheliscus insidiosus.* In the course of this postulated development it would seem that the principal tendency was toward the transverse narrowing of the teeth, both upper and lower series; the loss or weakening of the cingulum in the upper series; the increasingly *Pentacodon*-like development of P^4; the relative increase in length of talonid of the lower teeth, P_4 as well as the molars; together with the shortening of the lower molar trigonids.

RELATIONSHIPS OF *APHELISCUS* AND *PHENACODAPTES*

The most nearly comparable development to that illustrated in the *Phenacodaptes–Apheliscus* line would seem to be among the pantolestids. The suggested comparison is perhaps not so close to the *Bessoecetor–Propalaeosinopa–Palaeosinopa–Pantolestes* succession as it is to the middle Paleocene Pentacodontinae. The premolar development would seem rather like that in both *Aphronorus* (see pl. 2, figs. 3 and 4) and *Pentacodon* (see pl. 2, figs. 5 and 6), except that there tends to be no metaconid on P_4 or tritocone (uncertain for *Pentacodon*) on P^4 in the apheliscids. *Aphronorus,* moreover, differs in having somewhat higher crowned, more definitely insectivore teeth. The upper molars of *Aphronorus* show better developed and more laterally directed anteroexternal and posteroexternal styles and the lower molar trigonids are a little higher and show better development of the paraconid.

Much larger *Pentacodon* has a more enlarged fourth premolar, but the upper molars (not previously illustrated) do not show the distinctive outer styles seen in *Aphronorus.* Also the trigonids of the lower molars do not appear to be so elevated, but, like *Aphronorus* and unlike the apheliscids, show a prominent and forward-placed paraconid. The talonid construction, nevertheless, is much alike in the two subfamilies, except for relative length.

The mental foramen, the position of which, as Simpson (1937a, p. 120) notes, has been unduly emphasized, may warrant comment. It exhibits a comparatively small posterior opening somewhat farther forward in the Apheliscinae than in Pentacodontinae or Pantolestinae. It is variable in *Phenacodaptes* and is observed in positions beneath the anterior part of P_4 to the posterior part of P_3. A larger opening is noted beneath P_1 or P_2. In a specimen of *Apheliscus* (U.S.N.M. No. 19162), these foramina were noted beneath posterior portion of P_3 and beneath P_1. In *Aphronorus* the posterior foramen may be small and varies in position from beneath M_1 to the posterior part of P_4. An equally large or larger anterior opening is seen below P_2. In *Bessoecetor* foramina were noted beneath the posterior part of both M_1 and P_2, and in one specimen, U.S.N.M. No. 9442, anterior foramina were observed below the posterior portions of both P_2 and P_3. In Bridger *Pantolestes* I have seen only the well-developed foramen beneath M_1.

Among the Insectivores outside of the Pantolestidae I find a rather more remote relationship to the mixodectids indicated. There would appear to be rather less to suggest affinities with other orders. Among these, however, perhaps the condylarths should be considered. The relatively low trigonids of the lower molars seem indicative of a possible condylarthran relationship, and a form such as *Choeroclaenus* among the mioclaenine hyopsodonts is not too different from *Phenacodaptes* but there is, nevertheless, a more inflated appearance to the molar cusps and the premolars would appear to have little or nothing to recommend them. The possibility that the *Phenacodaptes–Apheliscus* line represents condylarth development rather paralleling that of pentacodonts cannot be entirely disregarded, but the same reasoning might apply equally well were they to be regarded as belonging to such other orders as primates, creodonts, or artiodactyls. Comparison with *Pentacodon* and *Aphronorus* appears rather more pertinent and better accounts for a number of minor details of similarity not easily dismissed.

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EXPLANATION OF PLATES

Plate 1

Apheliscus and *Phenacodaptes* from the early Tertiary of Wyoming

Figs. 1, 2. *Apheliscus insidiosus* Cope: 1, Right ramus of mandible (U.S.N.M. No. 19162), lateral and occlusal views. 2, Left ramus of mandible (A.M. No. 15696), lateral and occlusal views. All four times natural size. Gray Bull lower Eocene, Big Horn Basin, Wyoming.

Figs. 3, 4. *Phenacodaptes sabulosus* Jepsen: 3, Right ramus of mandible (P.U. No. 13926), lateral and occlusal views. 4, Left ramus of mandible (P.U. No. 13391), lateral and occlusal views. All four times natural size. Silver Coulee (Tiffanian) upper Paleocene, Big Horn Basin, Wyoming.

Plate 2

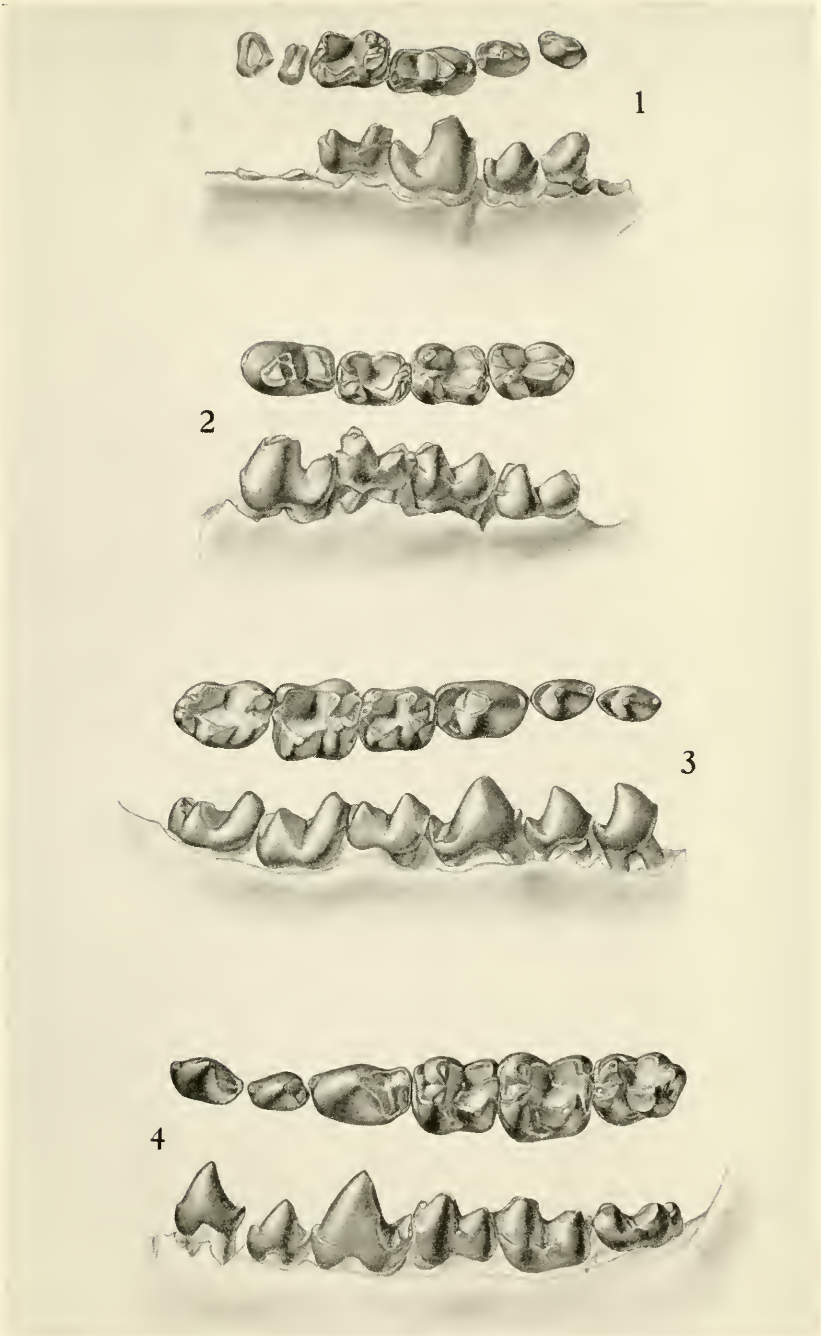
Apheliscinae and Pentacodontinae from the early Tertiary of the Rocky Mountain Region

Fig. 1. *Apheliscus insidiosus* Cope: Left upper cheek teeth (A.M. No. 15696), occlusal view. Four times natural size. Gray Bull lower Eocene, Big Horn Basin, Wyoming.

Fig. 2. *Phenacodaptes sabulosus* Jepsen: Right upper cheek teeth (P.U. No. 13977), occlusal view. Four times natural size. Silver Coulee (Tiffanian) upper Paleocene, Big Horn Basin, Wyoming.

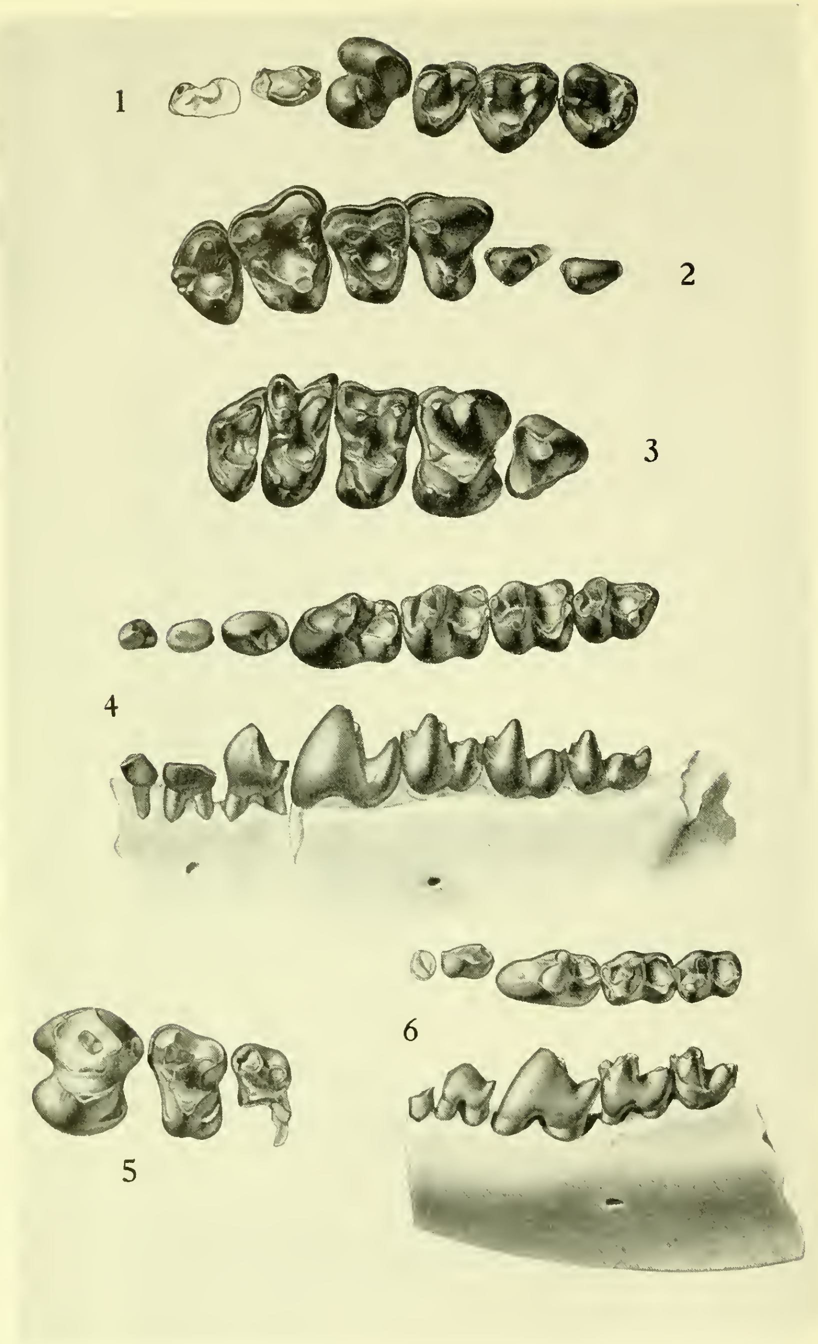
Figs. 3, 4. *Aphronorus fraudator* Simpson: 3, Right upper cheek teeth (U.S.N.M. No. 9561, P_4 from U.S.N.M. No. 9564), occlusal view. 4, Left ramus of mandible (U.S.N.M. No. 6177, type specimen, with molars restored from U.S.N.M. No. 9289, P_1 to P_3 from U.S.N.M. Nos. 9537 and 9291), lateral and occlusal views. All four times natural size. Fort Union middle Paleocene, Crazy Mountain area, Montana.

Figs. 5, 6. *Pentacodon inversus* (Cope): 5, Left upper cheek teeth (U.S.N.M. No. 15502), occlusal view. 6, Left ramus of mandible (A.M. No. 17038), lateral and occlusal views. All twice natural size. Torrejon middle Paleocene, San Juan Basin, New Mexico.



APHELISCUS AND PHENACODAPTES FROM THE EARLY TERTIARY OF WYOMING

(See explanation of plates at end of text.)



APHELISCINAE AND PENTACODONTINAE FROM THE EARLY TERTIARY OF THE ROCKY MOUNTAIN REGION

(See explanation of plates at end of text.)

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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 8

THE ANATOMICAL LIFE OF THE MOSQUITO

By
R. E. SNODGRASS
Research Associate
Smithsonian Institution

(Publication 4388)

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THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

CONTENTS

	Page
Introduction	1
I. The larva	3
The head	4
The feeding organs	11
The labrum	12
The preoral cavity	15
The epipharyngeal apparatus	15
The mandibles	16
The maxillae	17
The labium and hypopharynx	19
The pharynx	21
Larval feeding	22
The thorax	24
The abdomen	26
Internal anatomy	31
The tracheal system	31
The dorsal blood vessel	32
The alimentary canal	32
The Malpighian tubules	33
The salivary glands	33
The nervous system	34
The reproductive organs	34
Food reserves	34
II. The pupa	34
The pupal development	35
The mature pupa	39
General external structure	39
The head and mouth parts	43
The thorax	44
The abdomen	45
The pupal metamorphosis	46
III. The adult	48
The head	51
The organs of feeding	55
The proboscis	55
The cibarial pump	60
The pharyngeal pump	63
The thorax	64
The abdomen	67
Internal anatomy	72
The circulatory organs	73
The alimentary canal	73
The salivary glands	76
The reproductive system	76
References	80

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INTRODUCTION

Mosquitoes are not popular with warm-blooded animals, but from their own standpoint they have been highly successful insects, until recently when they have been attacked with poison sprays and have had their larval habitats drained. Success, however, is always to be admired whether in man or an insect, and it is instructive to see how it has been achieved. The mosquitoes have attained their place in the world by the evolution of highly specialized anatomical characters. A study of their anatomy may help some in our war against them, and it will give a most interesting example of how insects have evolved structures fitting them for particular ways of living and of feeding that have made them so successful in the struggle for existence.

The family name of the mosquitoes is Culicidae, and they belong to the order Diptera, or two-winged flies, which in turn are members of that large group of insects in which the young, or larvae, are very different from their parents in form, structure, and habits, and must undergo a renewed growth to attain the adult state. We are so accustomed to seeing young animals grow up gradually into adults that it seems very remarkable that an animal can completely change its shape and structure in the middle of its life. The young mosquito, for example, hatches from the egg as an active larva having no resemblance to its parents but fully adapted in its structure for living and feeding in the water. During its life the larva sheds its cuticle four times. At each of the first three ecdyses it comes out a little larger than before, but with little change otherwise. On shedding the fourth cuticle, however, a very different creature, the pupa, emerges. The pupa has all the adult organs, though in an incomplete state of development, and is clearly a preliminary adult. With a final moult and ecdysis the completed mosquito appears, equipped for an entirely different life from that of the larva.

It is commonly said that the larva is metamorphosed into the adult during the pupal stage. Actually it simply returns to its parental adult structure after having undergone during its evolutionary history a metamorphosis by which it took on a form and structure suited to a way of living quite different from that of its parents. The embryo, from its very beginning in the egg, develops into a larva. The egg, therefore, contains two distinct hereditary factors, one that first produces the larva, another that later generates the parent adult. When the larva does not differ too much from its parents, the adult may be formed mostly by a new growth of the larval tissues; but as the difference becomes more extreme, the larval tissues go into a state of dissolution and the adult is built up of embryonic cells that multiply but do not become organized during the larval stage. The transformation of the mosquito is intermediate between these two conditions.

Inasmuch as the word *metamorphosis* means simply a "change of form," we may say that the larva in its aberrant evolution has undergone a *divergent* metamorphosis, and that as an individual it resumes the parental form by a *convergent* metamorphosis.

Since the egg has the potentiality of developing into both the larval and the adult form, there must be some influence that allows the larva to develop first. The inhibition of adult development is effected by a hormone, known as the *juvenile,* or *status quo,* hormone. When the larva is mature and has served its purpose in the life of the insect, this hormone ceases to be effective, and the adult development proceeds under the stimulus of another hormone. This at least is the usual story of endocrinal regulation of insect growth and transformation, but, as will be seen, the mosquito does not comply fully with the rules of hormone control in its growth from larva to adult.

Before going on with anatomical descriptions of the larval, pupal, and adult stages of the mosquito, a few terms should be defined as they will be used. An *instar* is the insect between any two consecutive moults. *Moulting* is the physiological process of separating the old cuticle from a new cuticle being formed by the epidermis beneath it. The new instar begins its development when the moult is completed, but remains inside the old cuticle until it is fully formed. Then it breaks the cuticle and comes out. The emergence of the insect is its *ecdysis* (coming out). *Moulting* and *ecdysis,* therefore, refer to two different events, and are not synonymous terms, though many entomologists have not distinguished them as such. In life-history studies the "instar" is usually regarded as the insect between ecdyses, but since development begins inside the old cuticle, an instar is really the insect between moults. The concealed intracuticular period of the instar has been appropriately named by Hinton (1946, 1958a) the *pharate*, or cloaked, stage of development. The pharate stage of the pupa in the larval skin is commonly called the "prepupal stage of the larva," but the larva has already ceased to be a larva, so the expression does not conform with the facts. The mosquito will demonstrate a number of other errors commonly made by entomologists.

The problem of explaining how an animal in its evolution has become adapted structurally to its environment and a special way of living is complicated in an insect such as the mosquito that lives two entirely different lives. If adaptation affects two or more organs separately, the matter is relatively simple, but when it involves coadaptation in all parts of the animal, it is hard to understand how evolution by means of natural selection has brought it about. On the other hand, the technique of "special creation" is entirely incomprehensible.

The writer began this work on a very meager acquaintance with the anatomy of mosquitoes, especially of the larva and pupa. For its completion he is deeply in debt to others, in particular to Dr. Alan Stone and Dr. Richard H. Foote at the U. S. National Museum for literature and the identification of species; to Dr. Paul Woke of the National Institutes of Health at Bethesda, Md., for an abundance of live larvae; to Dr. Ernestine B. Thurman, also of the Institutes of Health, and Dr. Jack Colvard Jones of the University of Maryland for much supplementary information and a critical reading of the manuscript; to various authors for copied drawings; and to Mrs. R. E. Snodgrass for the typing. For morphological interpretations the writer assumes entire responsibility.

I. THE LARVA

Mosquito larvae hardly need an introduction. They are the familiar aquatic "wrigglers" or "wigglers" that everybody knows turn into mosquitoes. Anatomically the most specialized parts of them are the head, the feeding organs, and the respiratory system. A number of good papers have been written on the larval anatomy, and the facts of structure have been well-enough described, but the writers, particularly on the head and feeding organs, mostly disagree as to the homologies of the parts, and consequently the different terminologies used must be very confusing to students. Hence, in the following text, the larval head and organs of feeding are given a disproportionate amount of space in an effort to arrive at reasonable interpretations and an acceptable terminology. Otherwise than in the head and feeding apparatus, the principal specialization of the larva pertains to the respiratory system. The only functional respiratory apertures are a pair of dorsal spiracles near the end of the abdomen, the lateral spiracles being closed except at ecdysis when the tracheal linings are partly pulled out through them.

THE HEAD

The head of a mosquito larva projects forward from the thorax in line with the axis of the body, bringing the mouth parts to an anterior position. In most adult insects the head hangs downward on the thorax, so that the face is anterior and the mouth parts ventral. In the prognathous mosquito larva the face becomes dorsal and the mouth parts anterior. In going from adult to larva, therefore, instead of reversing the meaning of "dorsal" and "ventral," it will be better to speak of the *upper* and *lower* surfaces of the larval head, though "anterior" and "posterior" in either larva or adult will be directions relative to the axis of the body.

The typical shape of the mosquito larval head is oval or ovate, whether seen from above (fig. 1 A,B,C) or from the side (E), but the upper surface is more rounded than the lower. In some species, however, the head is almost rectangular in form (D). Anteriorly the head bears laterally a pair of large mustachelike brushes, and usually between them a small median brush, the three being supported by the labrum. Shortly behind the lateral brushes arise the slender, tapering, unsegmented antennae (E, *Ant*). Posteriorly on each side of the head is a large dark spot (*E*) varying in size with the age of the larva. These spots are the pigmented compound eyes of the adult developing in the epidermis beneath the larval cuticle. Behind or below each compound eye is a small, simple, presumably functional larval eye (*O*). The lateral area of the head between the antenna and the eye is the *gena* (*Ge*), that behind and below the eye the *postgena* (*Pge*). Posteriorly the head abruptly narrows to the occipital foramen, which is rimmed by a darkly sclerotized band, the *postocciput,* set off by a *postoccipital sulcus.* The membranous neck is usually cylindrical (fig. 1 A), but in *Anopheles* (fig. 3 C) it is narrowed where it joins the thorax, evidently to facilitate the turning of the head upside down while feeding.

The upper surface of the head (fig. 1) is differentiated into a large, shieldlike central area, narrow lateral areas bearing the antennae and the eyes, and a slender transverse anterior sclerite at the bases of the brushes. This sclerite (A,B, *Lm*) is the dorsal wall of the *labrum,* as contended by Cook (1944a), though some writers have regarded it as a "preclypeus." The groove behind it (A, *cls*) then is the *clypeolabral sulcus.* The large central area of the head is bounded by lateral lines (*CL*) that diverge forward from a very short occipital cleft and become continuous with the clypeolabral sulcus. These lines, commonly called "frontal sutures," are merely lines of weakness

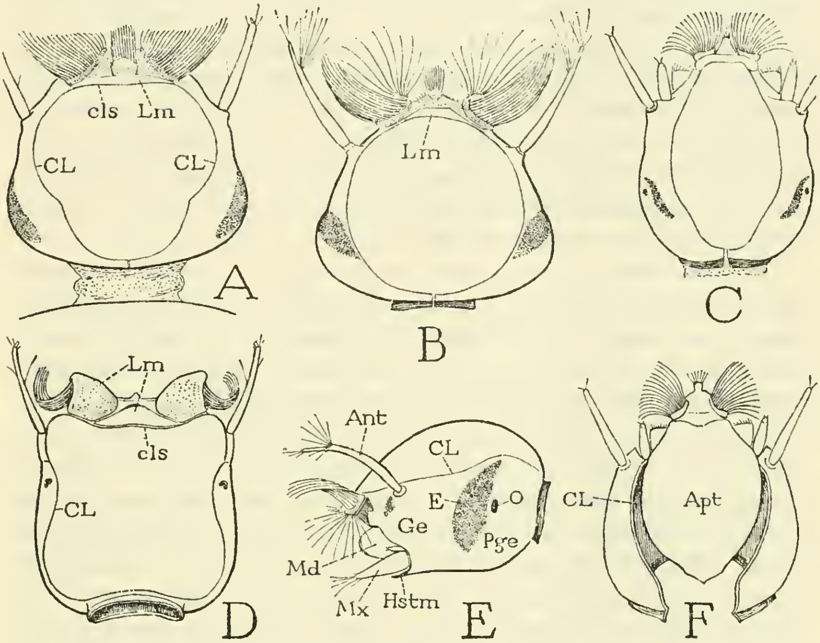

FIG. 1.—The larval head, dorsal and lateral.

A, *Aedes aegypti.* B, *Culex* sp. C, *Anopheles quadrimaculatus.* D, *Toxorhynchites rutilus.* E, *Culex* sp., lateral. F, *Anopheles farauti,* head exuviae. *Ant,* antenna; *Apt,* cephalic apotome; *CL,* cleavage line; *cls,* clypeolabral sulcus; *E,* compound eye; *Ge,* gena; *Hstm,* hypostomium; *Lm,* labrum; *Md,* mandible; *Mx,* maxilla; *O,* group of larval simple eyes; *Pge,* postgena.

in the cuticle where the latter will split at ecdysis (F, *CL*) to allow the emergence of the next instar, and are best termed the *cephalic cleavage lines.* In most young insects the cleavage lines take the form of a Y, which has been known as the "epicranial suture." In the mosquito larva the stem of the Y is the short occipital cleft. The frontal arms follow such very different courses in different insects that they can have no morphological significance (see DuPorte, 1946; Snodgrass, 1947), and hence do not define any specific part of the head. The part of the head wall cut out at ecdysis may be termed the *cephalic apotome* (F, *Apt*).

The space between the arms of the cleavage lines and the clypeolabral sulcus in the mosquito larva has been variously called the "frons," the "clypeus," and the "frontoclypeus." The respective areas of the frons and the clypeus may be identified in other insects by specific groups of muscles that arise on them. In the mosquito larva the clypeal muscles arise anteriorly, the frontal muscles posteriorly on the central head area, but there is no external demarcation between the two regions. This area, therefore, is frontoclypeal in a limited sense, but it is not the entire clypeus or the entire frons. Ordinarily the clypeus extends laterally to the bases of the mandible, and in adult insects the frons is the facial area between the antennae and the eyes. The whole aspect of the mosquito head is changed at the transformation to the pupa and the adult.

The larval antennae are slender, unsegmented shafts bearing variously distributed spines and tufts of long hairs. Each terminates in a small apical papilla. The antenna of the pupa, being eventually much larger than the larval organ, does not develop within the latter but in a pocket extending posteriorly from the base of the larval antenna.

The eyes of the larva are each a group of simple lateral eyes; their structure in *Culex pipiens* has been described by Constantineanu (1930) and by Satô (1951b). According to Satô each eye consists of three parts, each with its own retinular cells. One part is central and has three retinulae, a second part is dorsal and has a single retinula of eight cells, the third part is a long band of about 40 cells surrounding the other two parts dorsally, anteriorly, and ventrally. Constantineanu, on the other hand, describes five parts in the eye of *Culex*, as in some other nematocerous larva. Probably the three retinulae of Satô's "central part" are regarded as three eyes. The larval eyes have no lenses, the ordinary head cuticle being continuous over them. They are present from the beginning of the larval stage and persist into the pupa, or even into the adult.

The presence of large, darkly pigmented compound eyes visible on the surface of the head gives the mosquito larva, as also the corethrid larva, a very unusual appearance. The compound eyes of other related Nematocera are developed likewise in the larva, but, because of the absence of pigment until the pupa stage, they are not apparent externally.

The undersurface of the larval head (fig. 3 C,D,E,F) is more difficult to understand than the upper surface. The mandibles and maxillae are articulated on a transverse margin between the bases of the antennae. The long ventral cranial wall behind them is sclerotically closed by the union of the postgenae (C, *Pge*) along an incomplete median suture (C,D,E, *ms*). This same condition occurs in certain other insects, and to understand how it has come about we shall have to digress on some comparative studies.

The hypognathous position of the insect head in which the mouth parts are ventral (fig. 2 A) is clearly primitive, because the mouth parts, being modified legs, thus hang down from the head in the position of the thoracic legs. The prognathous condition has been attained in some cases by a mere turning forward of the head on the neck, involving a ventral elongation of the occipital foramen on the underside of the head (fig. 3 B). More commonly, however, the foramen remains in the vertical plane, as in the mosquito larva (fig. 1 E), and the underside of the head is lengthened by a ventral elongation of the postgenae (*Pge*).

With the elongation of the postgenae the entire labium, as in some beetles (fig. 2 B), may be simply enclosed between them, with a gular addition (*Gu*) to the submentum. This condition, however, does not occur in the larval mosquito, though some writers have so interpreted the mosquito head structure. More commonly, the postgenae come together medially and displace the labium. A primary stage of this transformation is seen at C, which might represent the head of a caterpillar or an adult honey bee, in which lobes of the hypostomal margins of the postgenae are intruded between the occipital foramen and the base of the labium. In other cases the lobes become united (D), forming a bridge between the foramen and the labium. An elongation of the bridge then produces the condition seen in the beetle larva at E, in which the labium is still fully exposed. Finally, as in the larvae of Chironomidae (F), the labium has become greatly reduced and is hidden from below by a median hypostomal lobe (*Hstm*) of the united postgenae.

This same process of closure and elongation of the postgenae and the reduction of the labium can be traced among nematocerous fly larvae. For example, in the primitive rhyphid larva of *Olbiogaster* (fig. 3 A) described by Anthon (1943b), a pair of small postgenal lobes are approximated behind the submentum (*Smt*) of the labium. In others, as in *Trichocera* and *Philosepedon* figured by Anthon (1943a, figs. 7, 10) the postgenal lobes are united in a bridge; the labium, though much reduced, is still mostly exposed. In the mosquito larva (fig. 3 C) the united postgenae form the long underwall of the cranium and the greatly reduced labium is concealed above a median postgenal lobe (*Hstm*) between the maxillae (*Mx*).

The darkly sclerotized dentate lobe between the maxillae has commonly been regarded as a part of the labium, "mentum" or "submen-

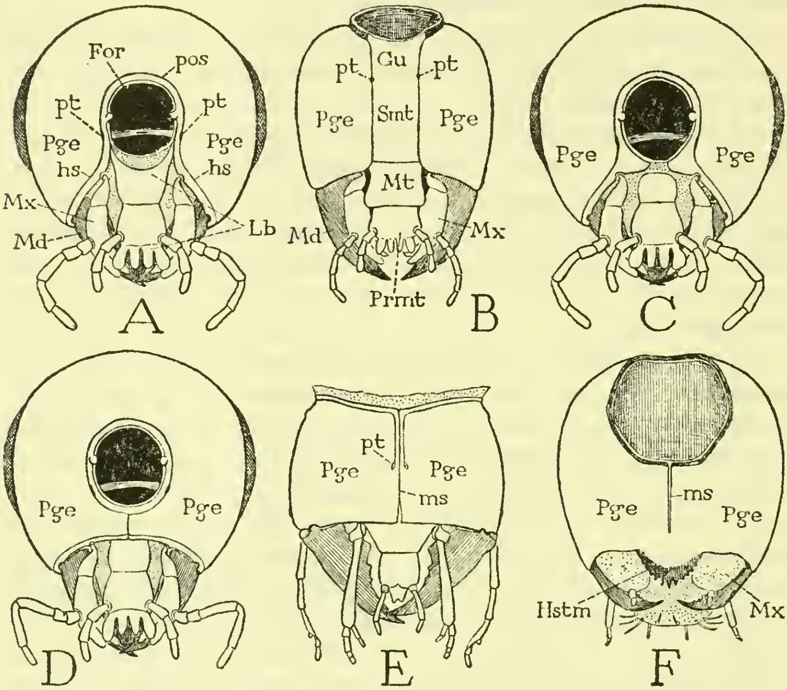

Fig. 2.—Structure of the posterior or ventral wall of the head in different insects, mostly diagrammatic.

A, Generalized structure of the posterior head wall and the mouth part attachments. B, The labium enclosed between the postgenae. C, The labium separated from the occipital foramen by intruding hypostomal lobes of the postgenae. D, The labium entirely separated from the foramen by union of postgenal lobes forming a postgenal bridge. E, Postgenal bridge lengthened. F, Larval head of *Chironomus,* postgenal bridge produced in a toothed lobe, labium displaced dorsally.

For, occipital foramen; *Gu,* gula; *hs,* hypostomal sulcus; *Hstm,* hypostomium, hypochilum; *Lb,* labium; *Md,* mandible; *ms,* median postgenal suture; *Mt,* mentum; *Mx,* maxilla; *Pge,* postgena; *pos,* postoccipital sulcus; *Prmt,* prementum; *pt,* posterior tentorial pit; *Smt,* submentum.

tum." To cut a long argument short, however, we have only to look at a tipulid larva (fig. 3 B) to see that the lobe is formed by the union of two processes extended forward from the anterior median angles of the postgenae, which themselves are not united in the tipulid. Above this lobe are the united labium and hypopharynx (fig. 7 A, *Lb, Hphy*). We may, therefore, following Anthon (1943a), Hennig (1948, 1950), and Lawson (1951), appropriately call this lobe the *hypostomium* (*Hstm*), as it is termed also by Chiswell (1955) in the tipulid larva. Though Schremmer (1949) called it "mentum" in the mosquito larva, he later (1950) expressed doubt of the correctness of this designation, concluding that the lobe is rather a part of the cranial wall. More recently, Gouin (1959) has termed the dentate lobe the *hypochilum* (underlip).

From the base of the hypostomium there arises in some species a thin fold bearing a fringe of pectinate hairs or blunt teeth (fig. 15 A, *Aul*). The fold is the *aulaeum* (curtain) of Cook (1944a), but it has been variously named. Shalaby calls it the "glossa" on the assumption that it is formed by the union of a pair of labial glossae, a highly improbable interpretation since the hypostomium itself is no part of the labium. However, Shalaby has given detailed illustrations of the pectinate hairs of the lobe in *Aedes aegypti* (1957a) and *Culex quinquefasciatus* (1957b), and its armature of eight blunt teeth in *Anopheles quadrimaculatus* (1956). In *Psorophora ciliata* (1957c) he says the fold is absent.

In most mosquito larvae two dark lines in the ventral wall of the head diverge posteriorly from the basal angles of the hypostomium. In some species the lines are short (fig. 3 C,D, *r*), in others (E,F) they extend back to the posterior tentorial pits (*pt*); in *Chironomus* (fig. 2 F) they are absent. These lines when present are the external marks of internal ridges; their variable development suggests that the ridges are secondarily formed to strengthen the head wall. The surface area between the lines, however, has commonly been regarded as the basal part of the labium, probably because the structural pattern they produce resembles that of the head shown at B of figure 2. It has been suggested even that the median suture is the line where the two original labial appendages have united! Cook (1944a), for some obscure theoretical reason, calls the area in question the "maxillary segment," though the maxillae have no relation to it. That the ventral closure of the head results entirely from the union of the lateral cranial walls is clearly indicated in illustrations by Hennig (1948, figs. 31-37) of larval heads of Sciophilidae, in which are shown various degrees of approximation and union of the postgenal margins.

In most adult insects the lower edges of the cranium are reinforced by submarginal internal ridges formed by external grooves known as the *subgenal sulci*. The part of each groove on the postgena behind the mandible is distinguished as the *hypostomal sulcus* (fig. 2 A, *hs*). Posteriorly these grooves become continuous with the postoccipital sulcus (*pos*) that surrounds the occipital foramen. In the mosquito larva the lower ends of the postoccipital sulcus have extended forward in the postgenal region carrying with them the minute rudiments of the posterior tentorial arms, the position of which is marked externally by a pair of pits (fig. 3 E,F, *pt*). The anterior tentorial arms are extremely slender bars arising from the cranial margins mesad of

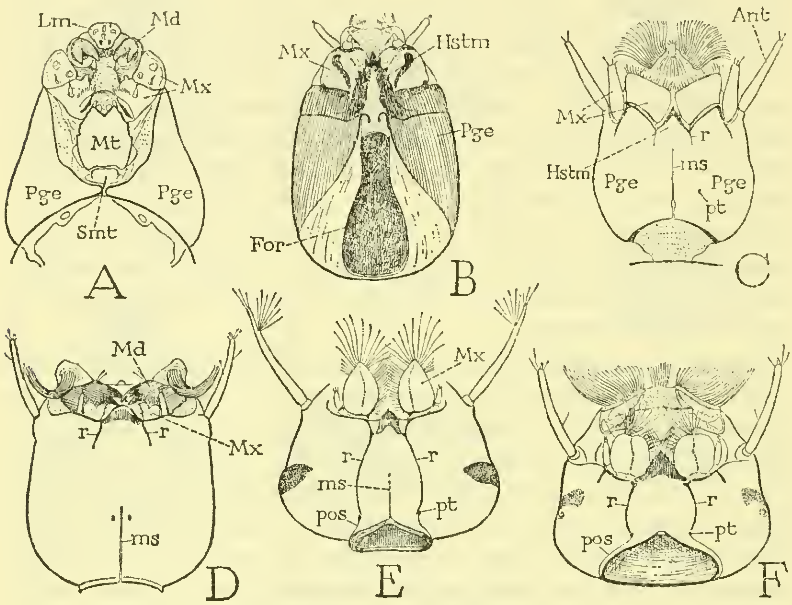

FIG. 3.—The larval head, undersurface.

A, *Olbiogaster* sp., Rhyphidae (from Anthon, 1943b). B, *Tipula* sp. C, *Anopheles quadrimaculatus*. D, *Toxorhynchites rutilus*. E, *Culex* sp. F, *Aedes aegypti*.

r, r, grooves in lower head wall. Other lettering as on figure 2.

the antennae that extend back to the posterior arms. Possibly it is the great lengthening of the postgenal regions of the head that has brought the posterior arms to their forward position.

The postgenal bridge is known also as the hypostomal bridge because it is the hypostomal margins of the postgenae that come together to form it. Lawson (1951) contends that the sclerotized ventral wall of the head behind the mouth parts cannot be derived from the postgenae because, he says, "the hypostomal sutures form the ventral boundaries of the postgenae." This is clearly making anatomy conform with definitions. The lower parts of the postgenae are mechanically strengthened by ridges formed by the submarginal hypostomal grooves. The narrow strips below the grooves, therefore, are simply the marginal parts of the postgenae, so it is immaterial whether we call the bridge resulting from their union hypostomal or postgenal. The grooves are sometimes absent, and the ridges may be marginal on the postgenae. In the mosquito larva the anterior edge of the ventral cranial wall on which the mandibles and maxillae are articulated is the united hypostomal margins of the confluent postgenae.

From the free cranial margins just mesad of the antennal bases, a slender bar on each side (fig. 7 B, *hb*) extends mesally, downward, and somewhat posteriorly through the preoral epipharyngeal wall to the base of the hypopharynx (*Hphy*). Each bar runs close before the mandible of the same side and goes below the narrow lower lip of the mouth (*Mth*). In *Dixa,* as shown by Schremmer (1950), similar structures are present but are much wider than in the mosquito larva. The mandibles have their anterior articulation on these rods, a very unusual condition, since the anterior mandibular hinges are typically on the basal angles of the clypeus. The rods have been called "cibarial bars," but there is no defined cibarium in the culicid larva. Since the rods appear to serve principally as suspensoria of the hypopharynx, they are here termed *hypopharyngeal bars.* They are the *Verbindungsleisten* of Schremmer (1949). Since the hypopharyngeal bars carry the anterior articulations of the mandibles, Menees (1958b) reasonably argues that the parts of the bars laterad of the articulation are extensions of the clypeus. His identification of the posterior parts with the "hypopharyngeal suspensorial bars of generalized insects," however, is less convincing, since these bars enter the mouth angles and give attachment to the hypopharyngeal muscles, though each may have a lateral preoral branch.

THE FEEDING ORGANS

One of the remarkable things about insects is the way their feeding organs are variously adapted to feeding in different ways on different kinds of food. Nothing comparable occurs among the vertebrates, their only adaptation to the nature of their food is in the size, strength, and dentition of their jaws or in the length of the neck. Yet the feeding organs of all insects are made up of the same fundamental parts. There is an upper lip known as the *labrum,* a pair of *mandibles,* a median tonguelike *hypopharynx,* a pair of *maxillae,* and a lower lip, or *labium,* composed of a united pair of second maxillae. The mandibles, maxillae, and labium, furthermore, have been fashioned from three pairs of legs, since the original arthropods had no other organs for feeding than their legs. The insect mouth parts, therefore, are all *outside* the mouth; the space between them may be termed the *preoral food cavity,* but by a long-perpetuated error it has commonly been called the "pharynx." For want of a revised nomenclature we still speak of the upper wall of the preoral cavity as the *epipharyngeal surface,* and call the tonguelike lobe that projects below the mouth the *hypopharynx.* This is just a part of our heritage from the early insect anatomists, who had only vertebrate names to draw from, and applied them to insects on a functional rather than a morphological basis. The true *pharynx* is a part of the stomodaeal section of the alimentary canal behind the mouth.

The labrum.—The labrum of the mosquito larva includes the small transverse sclerite on the dorsal wall of the head before the clypeus (fig. 1 A, *Lm*), and a larger membranous undersurface that bears laterally the two vibratory feeding brushes (fig. 4 B), and usually a small median brush. The median brush is the "palatum" of mosquito students, another example of misuse of a borrowed vertebrate name, which in this case properly refers to the roof of the mouth cavity.

The lateral brushes of the labrum are the organs by which those larvae that feed on particles create currents in the water directed toward the head, and drive a stream of water back to the mouth along the epipharyngeal surface. The individual hairs of the brushes are finely pectinate and serve also as combs for retaining particles filtered from the water.

The vibratory movement of the brushes is produced by a pair of strongly musculated sclerites on the under side of the labrum. Similar sclerites are present in the larvae of Chironomidae (fig. 4 G, *Tor*), which have no brushes, but the posterior ends of the sclerite are produced into strong pointed processes (*Mes*) projecting freely from the epipharyngeal surface. These toothed sclerites were therefore called by most earlier writers "premandibles." Chaudonneret (1951), however, has shown that this term is entirely inappropriate. Cook (1944b) named the sclerites "messores" (harvesters) and carried the term over to the mosquito larvae, in which he has been followed by several recent writers, though the culicid sclerites are unarmed.

It must be noted that the insect labrum is commonly equipped with four muscles, one pair dorsal, the other ventral, all of which arise on the frons. The ventral muscles are usually attached on a pair of sclerites in the lower labral wall known as the *tormae.* In a tipulid larva (fig. 4 A) the tormae (*Tor*) are simple sclerites, each giving attachment to a long muscle (*mcl*) from the frons. There is, therefore, no apparent reason why the similarly musculated sclerites of the mosquito larval labrum (C,D, *Tor*) should not be the tormae. On the other hand, Cook (1944b) has contended that the sclerites are

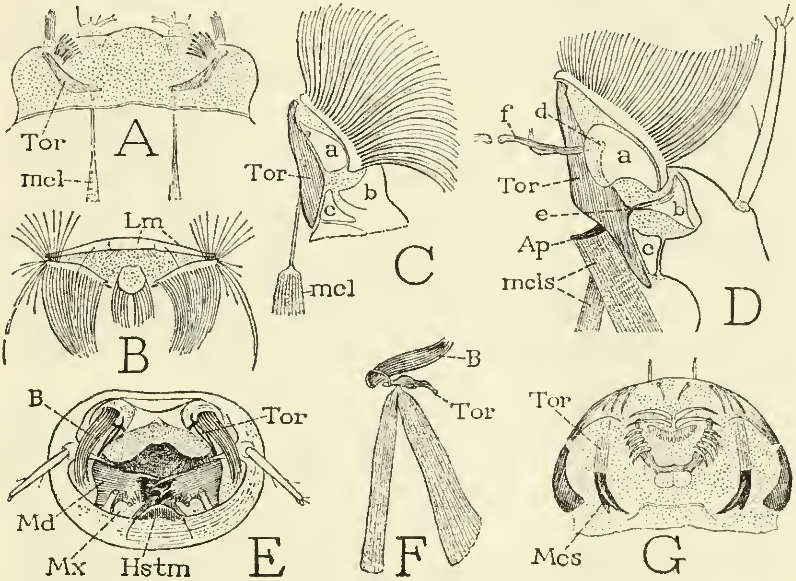

FIG. 4.—The larval labrum and tormae.

A, *Tipula* sp., underside of larval labrum. B, *Culex* sp., labrum of young larva, anterior. C, *Anopheles quadrimaculatus,* left labral brush and torma, undersurface. D, *Aedes aegypti,* same. E, *Toxorhynchites rutilus,* anterior view of larval head. F, Same, labral brush with torma and muscles. G, *Chironomus plumosus,* underside of larval labrum.

Ap, tormal apodeme; *B,* labral brush; *Hstm,* hypostomium; *Lm,* labrum; *mcl, mcls,* tormal muscle or muscles; *Md,* mandible; *Mcs,* messorial teeth of torma; *Mx,* maxilla; *Tor,* torma.

a, connective sclerite between torma and brush; *b, c,* detached sclerites of cranial wall; *d, e,* anterior and posterior articulations of torma; *f,* epipharyngeal bar.

not the tormae because he finds in chironomid larvae another pair of muscles attached more dorsally and laterally on the labrum, which he insists are the true tormal muscles. These muscles, however, would appear to be the usual dorsal muscles of the labrum, which may have a lateral position. Furthermore, Cook adds that the ventral muscles are not tormal muscles because they arise on the clypeus, but what he calls "clypeus" is the entire frontoclypeal area of the upper head wall between the cleavage lines. The sclerites in question, being in the ventral wall of the labrum and giving attachment to the ventral labral muscles, practically identify themselves as the tormae, and they have been regarded as such by Anthon (1943a), Schremmer (1949, 1950), and Menees (1958b). If it is desirable to keep the term "messor," it might be restricted to the free prongs of the tormae where they occur (fig. 4 G, *Mes*).

The tormae of an *Anopheles* larva (fig. 4 C, *Tor*) are elongate sclerites lying mesad of the brushes. Each torma is connected by its tapering anterior end with the base of the corresponding brush; posteriorly it is hinged to a small sclerite (*c*) in the cranial margin. A connective plate (*a*) lies between the torma and the base of the brush. A single muscle (*mcl*) from the frontal region is attached by a long tendon to a small point anteriorly on the lateral margin of the torma. Cook (1944a) ascribes a second posterior muscle to the torma of *Anopheles,* but this muscle, as shown by Farnsworth (1947) and by Schremmer (1949), belongs to a V-shaped sclerite of the epipharyngeal wall between the posterior ends of the tormae.

In the culicine mosquitoes the tormal apparatus is somewhat more complex than in *Anopheles.* In *Aedes aegypti* (fig. 4 D) the tormae have the same relation to the brushes and the cranial margin as in *Anopheles,* but each torma is specifically hinged posteriorly (*e*) to a detached triangular plate (*b*) of the cranial wall, and anteriorly (*d*) to the end of a transverse epipharyngeal bar (*f*). Since both this bar and the connective plate (*a*) underlap the torma, the anterior part of the latter appears to be sunk into the lower wall of the labrum. Posteriorly a strong apodeme (*Ap*) arises from the dorsal surface of the torma and curves mesally. On this apodeme are attached two large muscles (*mcls*) from the frontal region of the head. Contraction of the muscles evidently rocks the torma mesally on its articular points and thus gives a backward and mesal stroke to the connected brush. The reverse movement of the brush, as other writers have noted, results from the elasticity of its basal connections. According to Cook (1944a) in specimens of *Theobaldia* [*Culiseta*] killed and fixed with the brushes retracted, on cutting the muscles the brushes quickly spring back to the expanded condition.

The *Aedes* tormal mechanism is probably characteristic of the Culicinae. The same structure and musculature is shown to be present in *Culex* by Thompson (1905) and by Chaudonneret (1951), and in species of *Theobaldia* [*Culiseta*], *Lutzia,* and *Armigeres* by Cook (1944a).

In the predaceous larvae of *Toxorhynchites* the brushes are supported on prominently projecting lateral lobes of the labrum (figs. 1 D, 4 E). The brushes are narrow, stiff, and falciform, and appear to be grasping organs, but as observed by Breland (1949) and by Horsfall (1955) they are not used for obtaining prey. Just mesad of the base of each brush is a small, slender sclerite (fig. 4 E, *Tor*). Dissection reveals that this sclerite has a connection with the base of the brush (F) and gives attachment to two large muscles, leaving no doubt that it is the torma.

The preoral cavity.—The undersurface of the labrum is continuous with the so-called epipharyngeal surface below the clypeal region, which extends back to the mouth. In most adult insects the part of the preoral cavity above the base of the hypopharynx becomes a special food pocket, the *cibarium,* opening directly into the mouth. In the mosquito larva the shortness of both the labium and the hypopharynx leaves the entire preoral cavity open below, but still it serves as a channel for water carrying food particles to the mouth. In the tipulid larva, however, there is a short cibarial pocket (fig. 7 A, *Cb*) above the hypopharyngiolabial lobe just in front of the mouth. In the adult mosquito and other sucking insects the closed cibarium becomes a preoral sucking pump. In the mosquito larva the pharynx assumes the sucking function.

The epipharyngeal apparatus.—Lying in the epipharyngeal surface between the posterior ends of the tormae is a structure that serves to comb food particles from brushes on the mandibles. Since it is musculated, and hence functions actively instead of passively, this instrument has been termed by Schremmer (1949) the *Epipharynx-apparat.* Other writers have called it the "palatal bar," the "epipharynx," and the "epipharyngeal armature." It includes a transverse bar and groups of setae or other structures arising in front of the bar. The crossbar is usually bow-shaped or V-shaped with the arms diverging forward to the posterior ends of the labral tormae. The setal accompaniment of the bar is quite different in different species.

In *Aedes* (fig. 8 A) the epipharyngeal apparatus is relatively simple. The bar is slender, gently curved forward, and its ends appear to be connected with the tormal apodemes. Arising in front of the bar are two large brushes of stiff hairs that converge posteriorly beneath the bar. At the sides of the brushes arise a pair of large, tapering, hair-bearing processes directed posteriorly, and at the base of each are two small clawlike structures. In *Culex* (B) the bar is strongly developed and angulated, its ends, as in *Aedes,* appear to be attached to the apodemes of the tormae. In front of the bar are two large oval masses of setae curving inward and posteriorly. From above these setal masses two brushes of long hairs project posteriorly. Medially there arise two pairs of short tapering processes that project beneath the bar, and from each angle of the bar a slender, bladelike, sharp-pointed process extends posteriorly.

The epipharyngeal apparatus of *Anopheles* as described by Schremmer (1949) is again quite different from that of either *Aedes* or *Culex*. The bar is V-shaped with an acute angle. Several brushes arise in front of the bar, but particularly developed are two long, wide combs of flattened, sharp-pointed bristles that extend posteriorly from a pair of triangular sclerites in front of the bar. These are the *Klingenborsten* of Schremmer, who says they are used for cleaning the food particles from the combs of the mandibles. In *Anopheles maculipennis,* as shown by Schremmer and by Farnsworth (1947), a large muscle from the clypeal region of the head is attached on each end of the epipharyngeal bar. These muscles the writer has not been able to find in *Aedes* and *Culex,* but the close connection of the bar with the apodemes of the tormae possibly coordinates the movements of the epipharyngeal apparatus with the movements of the labral brushes. In all three genera a pair of very slender, closely adjacent muscles is attached medially on the bar. Contraction of the lateral muscles of *Anopheles,* according to Schremmer, protracts the apparatus from the epipharyngeal wall, the median muscles are retractors. Thompson (1905) makes no mention of lateral muscles attached on the epipharyngeal bar in *Culex,* but he notes the presence of the median retractors.

The mandibles.—Both the mandibles and the maxillae lie on the underside of the head, where they are implanted obliquely in the membranous area that turns upward from the hypostomal margins of the postgenae to the hypopharyngeal bars (fig. 7 B, *Md, Mx*), the mandibles being above the maxillae.

The typical culicine and anopheline mandibles are flattened lobes (fig. 5 D,E,F) with their mesal ends produced into strongly sclerotized toothed processes and a lower seta-bearing lobe. The dorsal margins bear large comblike fringes of long setae directed mesally. The tips of the mandibles on opposite sides do not meet when the mandibles are closed, but come against the hypopharynx, which lies between them (fig. 7 B, *Hphy*). Each mandible has a posterior basal articular point (fig. 5 E,F, *a*) that articulates with a process of the hypostomal margin just laterad of the base of the maxilla (fig. 7 B, *a*). Its anterior articulation (fig. 5 D, *c*) is with the hypopharyngeal bar (fig. 7 B, *hb*). The mandibles move in the transverse plane by strong abductor and adductor muscles. The principal function of mandibles of this type is the collection by their setal combs of food particles from

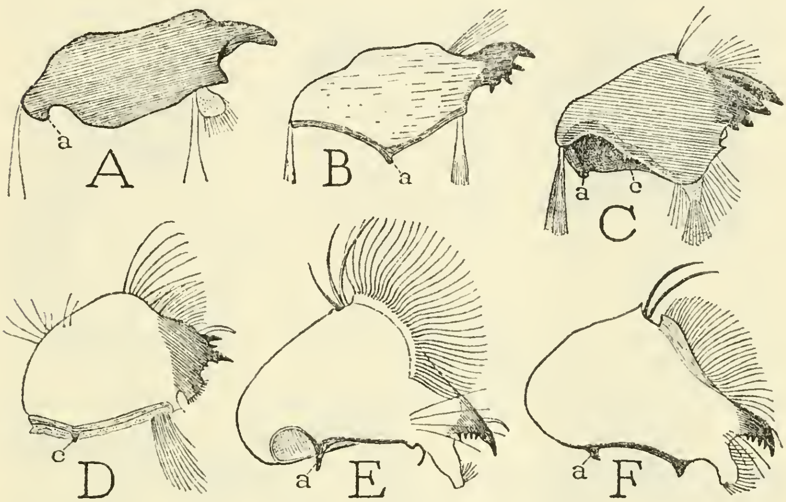

FIG. 5.—Larval mandibles.

A, *Tipula abdominalis,* right, ventral. B, *Lutzia* sp., right, ventral. C, *Toxorhynchites rutilus,* left, dorsal. D, *Anopheles quadrimaculatus,* left, dorsal. E, *Culex,* sp., right, ventral. F, *Aedes aegypti,* right, ventral.
a, posterior (ventral) articulation; *c,* anterior (dorsal) articulation.

the labral brushes, but the incisor points are said to break up larger particles that collect on the hypopharynx.

The mandibles of predaceous larvae, such as *Culex vorax* (fig. 5 B) and *Toxorhynchites* (C), are strongly toothed jaws, the points of which come together in adduction (fig. 4 E). Most larval Nematocera have jawlike mandibles (fig. 5 A), though they present many varieties of structure. *C. vorax* is a culicine mosquito, and its mandible (B) might be derived from the culicine type, but the mandible of *Toxorhynchites* (C) is a typical biting insect jaw.

The maxillae.—The maxillae of the mosquito larva (fig. 6 B-F) are so greatly simplified that they have lost the appearance and structure of an ordinary insect maxilla. They are borne on the transverse hypostomal margins of the postgenae at the sides of the hypostomium, where they lie below the mandibles (fig. 3 C-F, *Mx*). The principal part of each maxilla is a flat lobe (fig. 6 D, *St*) of different shape in different species, bearing brushes of long setae or combs of shorter ones. Laterad of this lobe is a second cylindrical or fusiform lobe regarded as the palpus (*Plp*) varying in size relative to that of the mesal lobe. At the base of the palpus is usually a small sclerite (*x*) in the articular membrane.

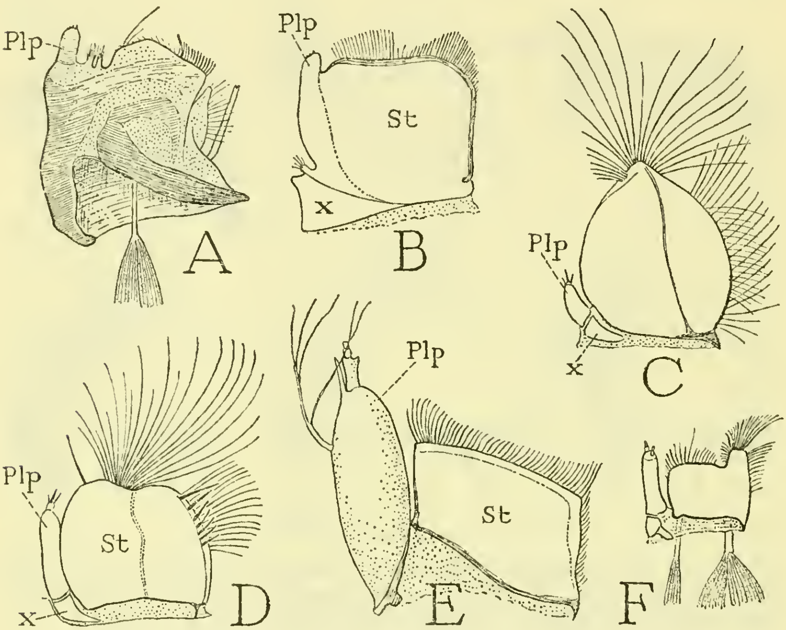

FIG. 6.—Larval maxillae, right, ventral.

A, *Tipula abdominalis*. B, *Culex vorax*. C, *Culex* sp. D, *Aedes aegypti*. E, *Anopheles quadrimaculatus*. F, *Toxorhynchites rutilus*.
Plp, palpus; *St*, stipes; *x*, sclerite at base of palpus.

In other nematocerous larvae, as in *Tipula* (fig. 6 A), the maxillary palpus (*Plp*) is a small lateral appendage of the main maxillary lobe, as it is also in the culicid *Culex vorax* (B). In most mosquito larvae, however, the palpus appears to have somehow become separated from the rest of the maxilla (C-F). The main maxillary lobe in some nematocerous larvae, as shown by Anthon (1943a), may bear on its distal margin mesad of the palpus two variously developed outgrowths, which are identified as the galea and lacinia. The main maxillarly lobe, therefore, appears to be the stipes (*St*). The nature of the small sclerite (*x*) at the base of the palpus is uncertain. Cook

(1944a) calls it the "palpiger," but it might be referred to the cardo, though no muscles are attached on it.

The principal functional features of the culicid larval maxillae are their setal brushes and combs, which serve to collect food particles from the labral brushes. In the predaceous *Toxorhynchites* the maxillae (fig. 6 F) are similar to those of other species, but they are greatly reduced in size (fig. 4 E, *Mx*). The palpi are presumably sensory organs, but their disparity in size, as between *Culex* (fig. 6 C) and *Anopheles* (E), for example, is difficult to explain. The principal movements of the maxillae are in the transverse plane.

The labium and hypopharynx.—In most adult insects the salivary duct opens between the bases of the hypopharynx and the labium. In some larval insects, as in caterpillars and hymenopterous larvae, the labium and hypopharynx are united in a single suboral lobe traversed by the duct of the salivary, or silk, glands, which opens at the tip of the composite lobe. The same is true of some nematocerous fly larvae, as is well seen in the tipulid (fig. 7 A, *SlDct*). In the mosquito larvae the combined labium and hypopharynx are reduced to a flat or somewhat protruding vertical surface between the mouth and the hypostomium, with the salivary duct opening on it. The salivary orifice, therefore, separates the dorsal hypopharyngeal component from the ventral labial component.

The hypopharynx (fig. 7 B, *Hphy*) is supported by the hypopharyngeal bars (*hb*) from the lateral cranial walls; immediately above it is the wide mouth (*Mth*) opening into the pharynx. The labial area below the hypopharynx (D,E, *Lb*) is variously developed, usually strongly sclerotized and armed with spines or teeth. Other writers have well illustrated the details of the labial structure in different mosquito species. Some have attempted to analyze the larval labium into the parts of a typical insect prementum, but their results are not fully convincing. At C of figure 7 is shown the labiohypopharyngeal complex of *Toxorhynchites rutilus* in dorsal view, in which the salivary duct (*SlDct*) is seen opening between the two component parts. Attached laterally on the base of the labium are the tendons of a pair of muscles from the ventral head wall, as in the tipulid larva (A).

Inasmuch as all the cranial muscles of the insect labium are inserted on the prementum, the labium of the mosquito larva is evidently the prementum; the hypostomium and the ventral head wall, as already shown, being no part of the labium. Menees (1958a), however, has argued that the ventral head area behind the hypostomial lobe must be the labial submentum because the labial muscles have their origins on it. He thus assumes that these muscles are the retractors of the prementum. The premental retractors, when present, do arise on the submentum, but they are always median in position. The muscles of the mosquito larval labium are lateral muscles, and therefore should

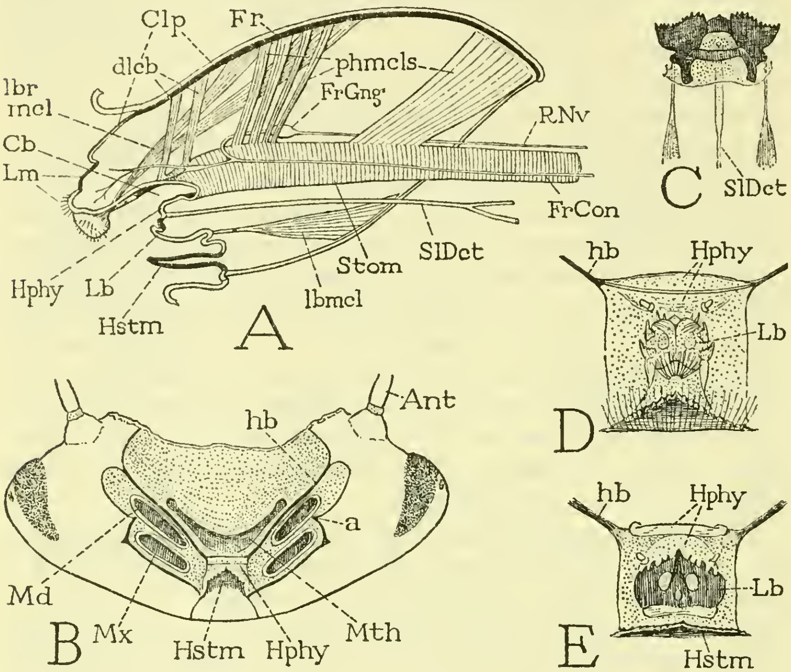

FIG. 7.—Labiohypopharyngeal complex of larvae, and associated structures.

A, *Tipula* sp., section of larval head. B, *Culex* sp., posterior part of head, anterior. C, *Toxorhynchites rutilus*, labiohypopharyngeal complex, dorsal. D, *Aedes aegypti*, same, anterior. E, *Culex* sp., same, anterior

a, posterior articulation of mandible; *Ant*, antenna; *c*, anterior articulation of mandible; *Cb*, cibarium; *Clp*, clypeus; *dlcb*, dilator muscles of cibarium; *Fr*, frons; *FrCon*, brain connective of frontal ganglion; *FrGng*, frontal ganglion; *hb*, hypopharyngeal bar; *Hphy*, hypopharynx; *Hstm*, hypostomium; *Lb*, labium; *lbmcl*, muscle of labium; *lbrmcl*, labral muscle; *Lm*, labrum; *Md*, mandible; *Mth*, mouth; *Mx*, maxilla; *phmcls*, pharyngeal muscles; *RNv*, recurrent nerve; *SlDct*, salivary duct; *Stom*, stomodaeum.

be one pair of the usual two pairs of cranial muscles of the prementum, which in other insects commonly arise on the tentorium. The same muscles in the tipulid larva (fig. 7 A, *lbmcl*) certainly have their origins on the head wall, since there is no sclerotization between the postgenae (fig. 3 B). The labial muscles of the mosquito larva, therefore, do not identify the head area on which they arise as any part of the labium.

The interpretation of these parts has been still further confused by Shalaby (1957d), who regards the median ventral head area as the labial submentum and mentum, the toothed hypostomial lobe as the paraglossa, the fringed lobe below it the glossa, and the entire complex above the toothed lobe the hypopharynx. Comparative studies, as already shown, give no basis for any such interpretation. Moreover, the adult labium is formed entirely from the rudiment beneath the cuticle of the larval labium (figs. 9 F, 15 A, *pLb*) and involves no part of the ventral head wall of the larva.

The larval labiohypopharynx is evidently retractile, but it plays no active part in feeding. Its principal function is said to be that of an "anvil" on which the incisor points of the mandibles strike to break up food particles.

Elaborate studies of the developmental changes in the mouth parts of larval instars of *Anopheles, Aedes, Culex,* and *Psorophora* have been made by Shalaby (1956, 1957a, 1957b, 1957c).

The pharynx.—The pharynx of larvae that feed on water-borne particles is a small, flattened, ovate or heart-shaped, thin-walled sac (fig. 8 C, *Phy*) opening directly from the wide mouth (fig. 7 B, *Mth*) and tilted upward and posteriorly in the head. From its posterior ventral surface is continued the thick-walled oesophagus (fig. 8 C, *Oe*). The ventral wall has an outer layer of semicircular muscles (E, *cmcl*) the dorsal wall is crossed by four wide muscle bands (C, *tmcl*) ; the extrinsic musculature includes dorsal and ventral dilator muscles from the head wall. The lateral margins of the pharynx are strengthened by two narrow, concentric, riblike thickenings on each side, convergent to the narrowed posterior end. Internally each of these ribs bears a long brush of fine hairs (D), suggestive of the brushes in the mouth of a baleen whale, and in fact they serve the same purpose, namely, that of filtering the food matter from the ingested water. A pharyngeal filter apparatus very similar to that of the mosquito larva is shown by Anthon (1943a) to be present in the larvae of several other nematocerous families. The pharynx of the predaceous culicid larva of *Toxorhynchites,* however, is a simple funnnel-shaped enlargement of the anterior end of the oesophagus, and has no filter brushes. In any case, the larval pharynx is not to be identified with the sucking pharynx of the adult mosquito, which lies in the posterior part of the head (fig. 24 A, *PhP*), and the larva has no cibarial pump.

Larval feeding.—The process of feeding by nonpredaceous larvae is not a mere matter of having food particles washed into the mouth by streams of water from the vibrating labral brushes. It involves cooperative action on the part of the labrum, the epipharyngeal apparatus, the mandibles, the maxillae, the labiohypopharynx, and the pharynx. The whole feeding process has been minutely described by Schremmer (1949) for the *Anopheles* larva, in which it is more readily

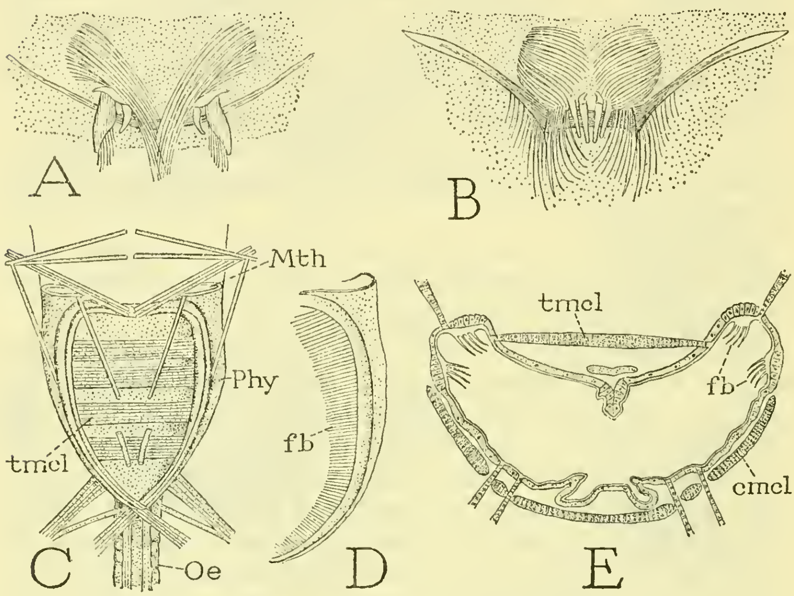

FIG. 8.—The larval epipharyngeal apparatus and the pharynx.

A, *Aedes aegypti,* epipharyngeal apparatus. B, *Culex* sp., same. C, *Anopheles maculipennis,* pharynx and its muscles, dorsal (from Schremmer, 1949). D, Same, filter-bearing rib of pharynx. E, Same, cross section of pharynx (from Imms, 1907).

cmcl, circular muscle; *fb,* filter brush; *Mth,* mouth; *Oe,* oesophagus; *Phy,* pharynx; *tmcl,* transverse muscles.

observed than in other species because the head is held with its underside turned upward against the surface of the water. Briefly, Schremmer's account is as follows.

The movements of the lateral brushes of the labrum create currents in the water that converge to the front of the head and are directed medially by the middle brush. With the backward stroke of the lateral brushes the mandibles and the maxillae are closed upon them, and as the brushes again go forward particles that may be adhering to them are scraped off by the combs of the mandibles. Accompanying the opening of the mandibles, the epipharyngeal apparatus is protruded by action of its muscles and its bristles remove the food particles from the mandible combs. These freed particles and others that may be adhering to the epipharyngeal surface are then collected by the long basal brushes of the mandibles (fig. 5 D) and, with the closure of the mandibles, are pushed into the mouth of the pharynx. Though the mandibles and the maxillae close at the same time, the maxillae open first and the mandibles following remove whatever particles may be adhering to the maxillae, which lodge on the hypopharynx and with the next stroke of the maxillae are thrust into the pharynx. Large particles collected on the hypopharynx are broken up by the toothed lobes of the mandibles, which strike on the hypopharynx like hammers on an anvil.

The pharynx, by muscular expansion of its walls, functions as a sucking organ for drawing in a stream of water accompanying the mechanically ingested food particles. A contraction then follows in which the dorsal wall is deeply infolded by the action of the dorsal transverse muscles (fig. 8 E), reducing the pharyngeal lumen to two lateral channels containing the filter brushes (*fb*). At the same time the water is driven toward the mouth and the food particles are filtered out by the brushes. The water is then discharged through the open angles of the mouth, goes above the mandibles and escapes past the sides of the head. Schremmer made further experiments on a *Culex* larva by impregnating the water in a dish with carmine particles. After feeding by the larva, the carmine was found massed in the brushes along the sides of the pharynx. When the pharyngeal brushes have worked as filters for some time and have become well loaded, the pharynx makes a strong contraction which suddenly removes the carmine particles from the brushes and lodges them in small clumps at the mouth of the oesophagus, into which they are finally taken. The mosquito larva swallows no appreciable amount of water, its water balance being maintained by the anal lobes.

The extreme specialization of the mouth parts and the pharynx in the filter-feeding mosquito larvae gives a striking example of how independent of the adult structure an insect larva may become in its adaptation to a new way of feeding. In various mosquito genera, however, the larvae of some or all species are predaceous on other small aquatic animals, particularly on other mosquito larvae. Notable in this group are members of the subgenus *Lutzia* among the Culicini, and of the genus *Toxorhynchites*. In these forms the mandibles are strongly developed jaws (fig. 5 B,C), the toothed lobes of which come together or overlap for grasping and biting. Yet these larvae have labral brushes and some of the other special features of particle-feeding larvae, so it is difficult to say whether they represent a partway stage in the evolution of filter feeding, or have been secondarily adapted for feeding on whole live prey. In some species the larvae are particle feeders in the first instar and become predaceous in their later instars. It would appear, therefore, as said by Bates (1949), "that the predacious habit has developed independently in the larvae of a number of mosquito groups, involving distinct adaptations both of structure and behavior."

THE THORAX

The larval thorax has a simple oval form, in which the intersegmental lines are but faintly marked as grooves of the cuticle, and there is no external trace of appendages. In the fourth instar the thorax becomes conspicuously enlarged (fig. 9 A). Beneath the cuticle on the ventral side are now plainly visible the extroverted wings and legs of the future pupa, and on the dorsal side the pupal respiratory trumpets. On removal of the cuticle (C) the legs are seen to be long, fully segmented appendages (E) closely folded in loops against the sides of the thorax. The forewings (W_2) are large pads corrugated in their basal parts (D) to allow expansion; the smaller hindwings (W_3) are more slender and tapering free folds of the metanotum. It has been shown by Imms (1908) that the rudiments of the wings, legs, and respiratory trumpets are formed in a young larval instar of *Anopheles* as integumental folds in pockets of the epidermis (B). Apparently they are extruded beneath the cuticle at the beginning of the fourth instar. This early eversion of the wings and legs occurs also in other nematocerous larvae, such as *Dixa, Corethra,* and *Chironomus,* shown by Miall and Hammond (1900) in *Chironomus.*

On each anterior lateral angle of the thoracic dorsum of *Anopheles* larvae there is usually to be seen a pair of minute, tapering, transparent lobes arising from a common base (fig. 9 A, *no*). These structures are known as the "notched organs." They are retractile and hence are not visible on all specimens, or only their tips may project. Between the lobes of each pair is a funnel-shaped depression that ends in a strand, which is said by Chang and Richart (1951) to be attached to the neighboring dorsal tracheal trunk. These writers contend, therefore, that the organs are the "prepupal respiratory trumpets." However, when the cuticle of a fourth-instar larva is removed, the lobes and the funnel come off with it, showing that the organs are larval structures. Furthermore, the trumpets of the "prepupa" (i.e., the pharate pupa) are present beneath the larval cuticle. They appear to arise from the pupa just beneath the larval organs, but they project forward or mesally until the pupal ecdysis, when they stand out from the thorax.

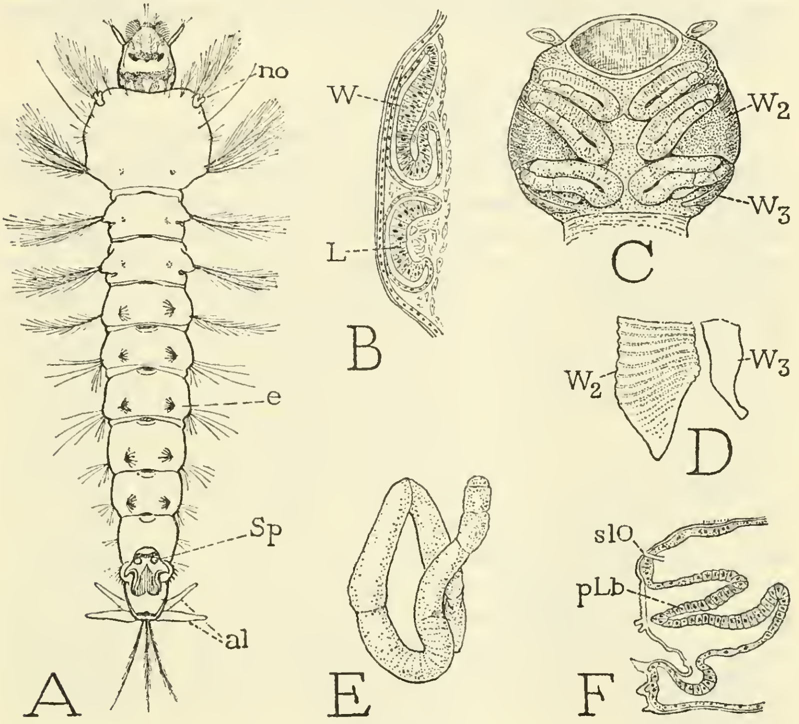

FIG. 9.—The larva, and developing pupal appendages.

A, *Anopheles punctipennis,* fourth instar larva, dorsal. B, *Anopheles maculipennis,* section of wing and leg buds in early larval instar (from Imms, 1908). C, *Aedes aegypti,* thorax of mature larva with cuticle removed, exposing extroverted legs and wings. D, Same, pupal wings of larva. E, Same, third left pupal leg of larva. F, *Anopheles maculipennis,* pupal labium developing inside larval labium (from Imms, 1908).

al, anal lobes; *e,* dorsal brush of larva; *L,* leg bud; *pLb,* pupal labium; *slO,* salivary orifice; *Sp,* spiracle; *W,* wing bud; W_2, W_3, pupal wings of larva.

The nature of the "notched organs" of the *Anopheles* larva is not clear. Their position on the dorsum of the thorax suggests that they might be remnants of anterior spiracles such as are present on larva of many other flies, including some Nematocera. Since these spiracles of successive instars are not formed in the usual manner within the preceding spiracle, but as independent branches from a persisting spiracular atrium, it is perhaps possible that the pupal trumpets are in this manner related to the "notched organs" of the larva. Chang and Richart contend that the latter serve to keep the anterior part of the *Anopheles* larva afloat while feeding at the surface, but experiments have shown that the organs can be cut off without any apparent effect on the suspension of the larva (Jones, unpublished observations).

THE ABDOMEN

The larval abdomen (fig. 10 G) appears to have only nine segments, and it is usually represented as nine-segmented, with the respiratory apparatus on the eighth segment and the terminal segment enumerated as the ninth. However, there is reason for believing that a true ninth segment is combined with the eighth. Christophers (1922) contended that though "much of the apparent eighth segment is actually this structure, the greater part of the spiracular apparatus must be assigned to the tergite of a hitherto unrecognized ninth abdominal segment." Convincing evidence of this interpretation is the fact that the rudiments of the male genitalia are formed beneath the larval cuticle at the base of the terminal segment, and that in the adult male the genital claspers are carried on the *posterior* margin of a small but distinct ninth segment (fig. 27 B). Though this segment is not evident as a distinct annulus in the larva, it must be represented by some part of the apparent eighth segment immediately anterior to the genital rudiments. In the pupa, as will be shown (fig. 16 D,E) a small ninth-segment ring (*IX*) lies behind the eighth segment and carries the tail fins and the small anal lobe. The anal segment of the larva (fig. 10 B) must therefore be the tenth, as it is in the pupa and the adult.

The fully segmented abdomen of the mosquito embryo is shown by Telford (1957) in *Aedes* and by Menees (1958a) in *Anopheles* to have 10 segments. Telford says the tenth segment, or telson, disappears with the ingrowth of the proctodaeum, but since a tenth segment is present in the adult, the "telson" must be an eleventh segment. In some larvae, as seen in *Mansonia* (fig. 11 A) a small lobe (*XI*) protrudes from the end of the tenth segment, which would appear to be the evaginated anus-bearing telson. Even in the embryo, then, the ninth segment is not differentiated from the eighth. It appears as a distinct ring first in the pupa and as a definite segment in the adult.

The first seven segments of the larval abdomen have no distinctive features, except that in Anophelini (fig. 9 A) the last five or six of them bear on the back pairs of small palmate brushes (*e*) that suspend the larva from the surface of the water in its usual horizontal feeding position. The respiratory apparatus on the dorsum of the ninth segmental region contains a pair of large open spiracles, which are either

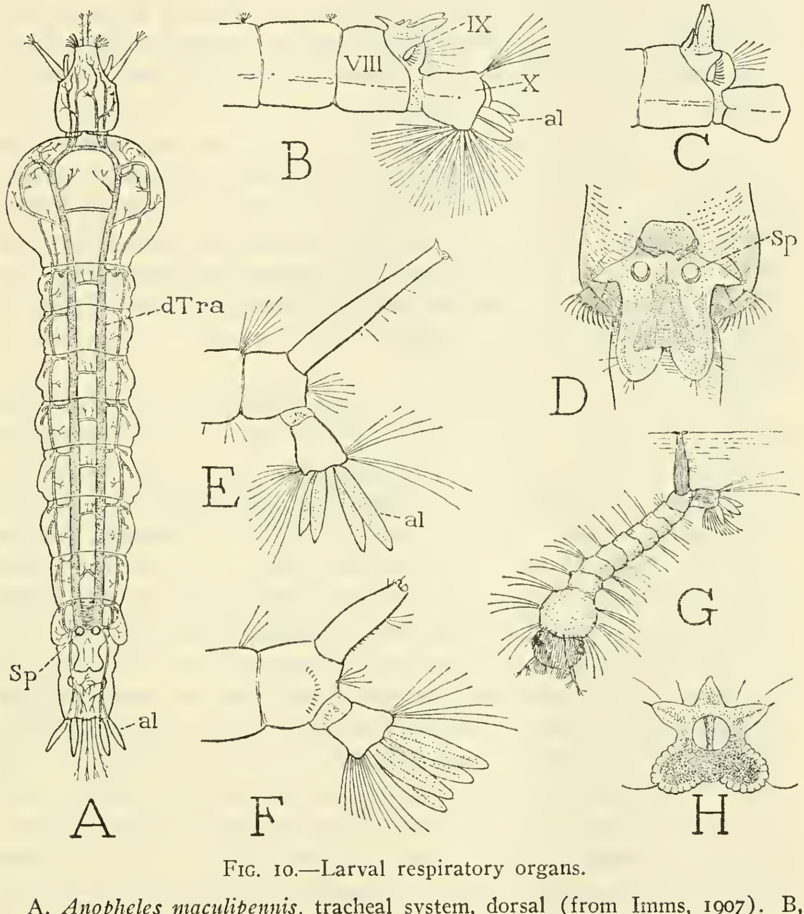

FIG. 10.—Larval respiratory organs.

A, *Anopheles maculipennis,* tracheal system, dorsal (from Imms, 1907). B, *Anopheles quadrimaculatus,* end of abdomen, spiracular apparatus open. C, Same, spiracular apparatus closed. D, Same, details of spiracular apparatus. E, *Culex pipiens,* end of abdomen. F, *Aedes aegypti,* same. G, *Culex quinquefasciatus,* larva in feeding position. H, *Culex pipiens,* end of respiratory siphon.
al, anal lobes; *dTra,* dorsal tracheal trunk; *Sp,* spiracle; *VIII-X,* abdominal segments.

flush with the surface (fig. 10 A, *Sp*) or carried out on the end of a respiratory tube (E,F,G). The tenth segment contains the functional anus at its end, and bears four lanceolate, thin-walled apical appendages, or *anal lobes* (A,B,E, *al*). Flat dorsal and ventral brushes of long, spreading hairs are usually present on the end of the tenth segment, and perhaps serve as a rudder during swimming. Though mosquito larvae are commonly known as "wrigglers" or "wigglers" they swim by lashing movements of the abdomen, which drive them forward, backward, or sideways. The active larvae of *Culex* zigzag through the water like tumbling acrobats. *Anopheles,* however, is a true wriggler; it swims either on the surface or under the water by quick lateral movements of the abdomen and propels itself backward.

The dorsal spiracles of the abdomen are the only breathing apertures of the mosquito larva. The lateral spiracles are closed except at the ecdyses, when they are temporarily opened to allow the tracheal linings to be pulled out. Since the dorsal spiracles open into the dorsal trunks of the tracheal system and the lateral spiracles into the lateral trunks (fig. 10 A), the dorsal spiracles cannot be supposed to be a pair of lateral spiracles that have moved up onto the back. It may be conceded that spiracles can change their position, but they cannot change their tracheal connections.

The spiracles of anopheline larvae lie in the floor of a shallow, basinlike peritremal structure elevated on the back, the margins of which are variously produced into lobes (fig. 10 B). In *Anopheles maculipennis* (D) there are two large, thin posterior lobes, a pair of small tapering lateral lobes, and a single anterior lobe supported on a transverse basal bar. The spiracles (*Sp*) lie anteriorly; behind them is a median V-shaped sclerotization on the floor of the basin, and on each posterior lobe is a weak submarginal sclerotization. As the *Anopheles* larva feeds stretched out against the surface film of the water the peritremal basin projects just above the water with the spiracles freely exposed to the air. When the larva submerges, the whole apparatus folds up and the lobes clamp tight together (C). Imms (1908) describes three sets of paired muscles that effect the closing of the lobes, which retain a bubble of air between them. When the muscles relax the lobes open. Curving around the end of the ninth segment beneath the ends of the posterior lobes is a narrow semicircular bar that supports on each side a small plate bearing a comb of strong recurved bristles (D), or in some species is armed with spines or teeth.

In the larvae of Culicinae and Toxorhynchitinae the spiracles are carried out on the end of a tube, or siphon, varying in length and thickness in different genera (fig. 10 E,F). The spiracles are at the end of the tube and are surrounded by lobes similar to those in *Anopheles,* but necessarily much smaller (H). When the larva is at the surface it hangs from the end of the siphon with the spiracles exposed to the air (G). Two strands of slender muscle fibers traverse the tube and converge to attachments on a strong apodeme from the terminal apparatus.

An extensive comparative study of the peritremal structure has been made by Montschadsky (1930) from a taxonomic standpoint. His illustrations are not realistic since they appear to have been drawn from flattened specimens, and the sclerotic parts are overemphasized by an unnaturally dark tone, but they show the great specific variation in the pattern of the peritremal lobes.

Glands associated with the spiracular apertures have been described by Keilin, Tate, and Vincent (1935). The secretion is oily and serves to give a hydrofuge quality to the peritremal surface, which prevents wetting and the entrance of water into the spiracles.

Though the respiratory siphon is primarily constructed for breathing air at the surface of the water, in species of *Mansonia* and a species of *Ficalbia* it is modified for insertion into the roots of aquatic plants. The siphon tapers distally and the apex is armed with spines, teeth, and hooks, which, operated by the inner muscles of the tube, enable the larva to insert the tip of the organ into the plant. In *Mansonia indubitans* (fig. 11 A) the siphon is large, conical in shape, and narrowed at the distal end. The apex is not sharp, but is armed with a pair of strongly toothed movable lobes (B), which can be retracted and brought together, or protracted with the teeth turned outward. The siphon in this case is a cutting and not a piercing instrument. It contains only one tracheal trunk, formed by the union of the dorsal body trunks in the eighth abdominal segment, and there is a single median, ventral spiracle between the bases of the toothed lobes. These larvae live entirely submerged and obtain their air from the air channels of the plant, to which they remain attached.

According to Iyengar (1935a, 1935b) species of *Mansonia* in India attach themselves only to the water plant *Pistia stratiotes*. To insert the siphon the larva moves backward with the siphon held horizontally and thrusts the tip against the root. It then wriggles actively backward, while it operates the apical armature with muscles attached on a rodlike apodeme, until the end of the siphon penetrates the root deep enough to enter an air chamber, when apical hooks anchor the larva to the root. The adult female lays her eggs only on submerged leaves of the *Pistia* plant, thrusting her abdomen into the water to do so, and where *Pistia* is not present she will lay no eggs.

While most other mosquito larvae spend most of their time at the surface of the water, any of them can stay below without apparent discomfort, and some do so indefinitely. It was formerly supposed that the four thin-walled tracheated lobes borne on the end of the tenth abdominal segment were gills serving for underwater respiration. Wigglesworth (1933), however, has produced evidence that

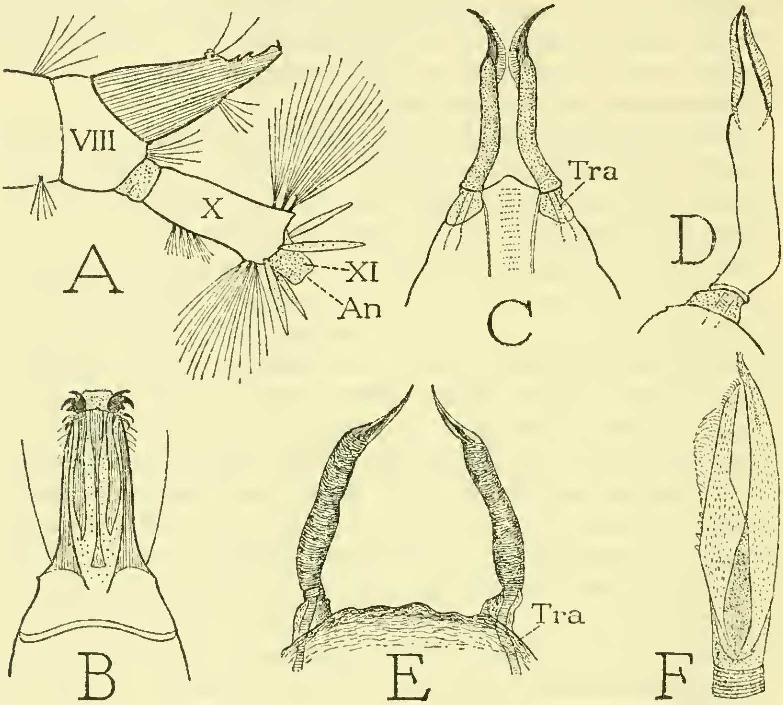

FIG. 11.—Respiratory tubes of larvae and pupae that get their air from the roots of aquatic plants.

A, *Mansonia indubitans,* terminal segments of larva. B, Same, apical part of siphon, ventral. C, *Mansonia* sp., thoracic respiratory horns of pupa, dorsal. D, Same, right horn, mesal. E, *Mansonia richiardii,* pupal respiratory horns, dorsal (from Wesenberg-Lund, 1920-21). F, *Ficalbia hybrida,* terminal part of pupal respiratory horn (from Bonne-Wepster, 1932).
An, anus; *Tra,* trachea.

these lobes are water-absorbing organs rather than gills. By immersing larvae in a water culture of the flagellate protozoon *Polytoma,* which is highly sensitive to the amount of oxygen in the water, he found that the flagellates first assemble at the posterior end of the larva and then spread all over the body surface. Soon, however, they move away in a mass, indicating that oxygen is being consumed by the general integument of the larva as well as by the anal lobes. The submerged mosquito larva, therefore, breathes through its skin, and some other aquatic larvae are known to do the same.

From experimental ligaturing of the body of the larva in different places, Wigglesworth furthermore showed that the larva absorbs water from the posterior end of the body, presumably through the thin, permeable anal lobes. During feeding, the larva does not swallow the water taken into the pharynx with its food, this water, as already noted, being discharged from the mouth. The anal lobes thus serve to maintain the physiological balance of water in the larval body.

INTERNAL ANATOMY

Inasmuch as the principal specializations of the mosquito larva have to do with feeding and breathing, there is little in the internal organization that is essentially different from that of other insects.

The tracheal system.—The tracheal system of most insects includes a pair of lateral tracheal trunks running lengthwise through the body, with which the lateral spiracles are connected. Many insects, however, have also a pair of dorsal longitudinal trunks. In dipterous larvae, including the mosquito larva, that breathe through dorsal spiracles, the dorsal trunks are particularly large (fig. 10 A, *dTra*), and the lateral trunks connected with the closed lateral spiracles are much reduced. The dorsal spiracles of the ninth abdominal segment are evidently secondary respiratory apertures to allow the larva to breathe at the surface of the water, since it is hardly to be supposed that a primitive lateral spiracle could migrate dorsally and change its tracheal connections. In general the last pair of lateral spiracles is on the eighth segment. In the larvae of higher Diptera there is also a pair of secondary anterior dorsal spiracles on the thorax.

The fine end branches of the insect tracheal system in general go to the cells of the body tissues, which are thus directly oxygenated. In the larva of *Anopheles*, Imms (1907) describes a series of small tubes from the longitudinal trunks in the eighth abdominal segment that break up into fine branches going to the posterior end of the heart. Imms suggested that these branches may oxygenate the blood in the heart, but Jones (1954) says they end on the heart wall.

At each larval ecdysis the cuticular intima of the tracheal tubes is shed with the outer cuticle. In the mosquito larva, according to Wigglesworth (1949), the intima of the main tracheal trunks breaks between the segments, and the pieces attached to the shed cuticle are drawn out through the lateral and the posterior dorsal spiracles of the new instar. The lateral spiracles are then closed again, since they are not functional in the larva for respiration. In the same manner, at the ecdysis of the pupa the tracheal trunks in *Culex* are said by Hurst (1890) to break up into segmental pieces, which are pulled out through the temporarily opened spiracles. The soft inner tissue of the respiratory siphon is withdrawn into the body where it is finally absorbed. The siphon itself is shed with the larval cuticle, and its two tracheal trunks break off at the base.

The tracheal system of the young larva on hatching is filled with a liquid. According to Frankenberg's (1937) observation on *Culex,* air enters the tracheae only when the end of the respiratory siphon comes above the water surface. One of the dorsal longitudinal trunks fills first, and then the other. The air is drawn into the tracheae as the embryonic liquid diffuses through the tracheal walls.

The dorsal blood vessel.—The dorsal blood vessel of the mosquito, particularly in *Anopheles quadrimaculatus,* has been elaborately described by Jones (1954). Structurally it differs in no essential respect from the vessel of other insects, except for a dilatation, or sinus, of the aorta in the thorax. The larval organ is a simple muscular tube extending along the midline of the back from the eighth abdominal segment into the head. The part in the abdomen, known specifically as the *heart,* is perforated along the sides by eight pairs of segmental openings, or ostia. The part in the thorax, called the *aorta,* is imperforate. In the head the aorta goes beneath the brain, where it is open ventrally allowing the blood to be freely discharged into the head cavity, whence it flows backward through the body to reenter the heart through the ostia. The larval heart, Jones says, always beats forward at an average of 85.2 pulsations a minute, but it has no nerve connections. Along the sides of the heart are attached the usual fan-shaped segmental groups of muscle fibers, the so-called *alary muscles,* that support the heart on the body wall.

The alimentary canal.—In the mosquito larva the alimentary canal (fig. 12) is a relatively simple tube. It consists of the usual three parts of the arthropod digestive tract, an ectodermal stomodaeum, an endodermal mesenteron, and an ectodermal proctodaeum. The stomodaeum begins in the head with the *pharynx* (*Phy*), which is followed by a narrow *oesophagus* (*Oe*) that goes through the neck into the thorax, where it enters the first part of the mesenteron, known as the *cardia* (*Car*). (This term, borrowed from vertebrate anatomy, has no literal significance in the insect.) Within the cardia the oesophageal walls are reflected to form the usual entrance funnel of the stomodaeum into the mesenteron. The cardia is followed by a long, straight tube, the stomach, or *ventriculus* (*Vent*), that extends back into the seventh abdominal segment. The anterior end of the ventriculus bears a circle of eight large pouchlike diverticula, the *gastric caeca* (*GCa*). The dark mass of food particles in the ventriculus is contained in a thin tubular *peritrophic membrane* (*PMb*), shown by Wigglesworth (1930) to be secreted by the cell walls of the cardia surrounding the stomodaeal funnel. The proctodaeum, or intestine, is differentiated into a short anterior part (*AInt*), and a longer posterior part, or *rectum* (*Rect*). The anterior intestine begins as an expansion against the end of the ventriculus, and then narrows to a tube that makes an S-shaped bend to the saclike anterior enlargement

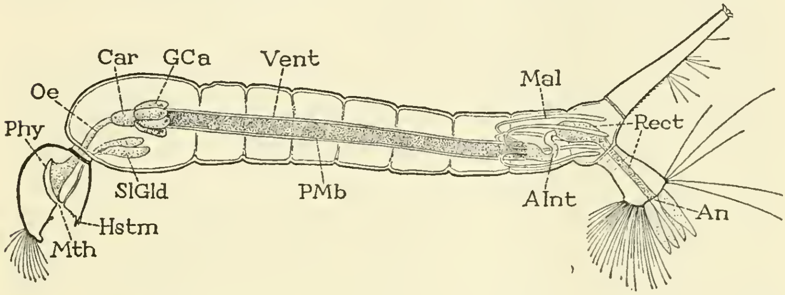

FIG. 12.—Lengthwise section of a *Culex* larva, showing the alimentary canal.

AInt, anterior intestine; *An*, anus; *Car*, cardia (anterior part of ventriculus); *GCa*, gastric caeca; *Hstm*, hypostomium; *Mal*, Malpighian tubules; *Mth*, mouth; *Oe*, oesophagus; *Phy*, larval pharynx; *PMb*, peritrophic membrane; *Rect*, rectum; *SlGld*, salivary glands; *Vent*, ventriculus (stomach).

of the rectum, which finally proceeds as a narrow tube to the anus (*An*).

For a detailed study of the general structure, histology, and movements of the larval alimentary canal of *Anopheles* the reader is referred to a forthcoming paper by Jones (in press).

The Malpighian tubules.—The excretory Malpighian tubules of the larva (fig. 12, *Mal*) are five in number. They arise from the anterior end of the proctodaeum, first going forward into the sixth abdominal segment, and then turning posteriorly to end in the subterminal segment around the rectal sac.

The salivary glands.—The larva has a pair of small salivary glands of various shapes lying ventrally in the thorax (fig. 12, *SlGld*). The ducts unite in a common outlet duct that enters the head and opens on the labiohypopharyngeal surface just below the mouth (fig. 15 A, *SlO*). The glands usually consist each of two parts of different shape separated by a constriction. The histology of the glands in *Anopheles* larvae has been described by Jensen and Jones (1957). In *Anopheles albimanus* the globular anterior part of each gland consists of 12 to 15 large cells; the pear-shaped posterior part contains 50 to 60 much smaller cells. The glands of opposite sides are connected by a strand of nephrocytes. In other genera the relative size and shape of the two gland parts differ in various ways.

The nervous system.—The central nervous system of the larva includes a brain and suboesophageal ganglion in the head, and a ventral chain of segmental ganglia in the abdomen united by paired connectives. The last ganglion is that of the eighth abdominal segment.

The reproductive organs.—Rudiments of the reproductive organs are present in the young larva in a very elementary state; they slowly develop during the larval life.

Food reserves.—The insect larva has no idea of the meaning of its life or of what is to become of it. Its hereditary factors automatically determine its destiny by converting it into a pupa and finally into an adult. Yet, physiologically, the larva is loaded with responsibilities. Not only must it maintain its own existence, but at the same time it must provide for the future nutritional needs of the pupa and for its transformation to the adult. In the mosquito pupa there is a minimal breakdown of larval tissues to furnish food for the developing adult organs. The active mosquito pupa, moreover, is not a "resting stage," and, since it cannot eat, it is dependent upon the larva for everything except the air it breathes. An important function of the larva, therefore, is the storage of food reserves in its body to maintain the pupa and to insure the development of the adult. Only when the winged adult finally emerges from the pupal skin can the mosquito again take food and become once more an independent, self-sustaining insect.

The elaboration and storage of food reserves in the body of the fourth-instar mosquito larva is the subject of a special study by Wigglesworth (1942). The stored materials include principally protein, fat, and glycogen, which are shown by experiments to be rapidly consumed when the larva is subjected to starvation, and replenished on subsequent feeding. Normally, it is to be supposed, the stored products are passed on intact to the pupa, but Wigglesworth does not go into this phase of the subject, or follow the utilization of the reserves by the pupa. The matter, however, is well-enough known in other insects.

II. THE PUPA

The active pupa is familiar to all students of mosquitoes *after* its ecdysis from the larva. The fact, however, that it is already fully formed shows that it became a pupa while still within the larval cuticle. It will therefore be of interest to follow the transformation processes that convert the larva into a pupa.

THE PUPAL DEVELOPMENT

As before noted, the primary buds of the pupal wings, legs, and respiratory trumpets are formed at an early larval period in pockets of the epidermis beneath the cuticle, as are also those of the antennae and the labium, and rudiments of the compound eyes are present in the first instar.

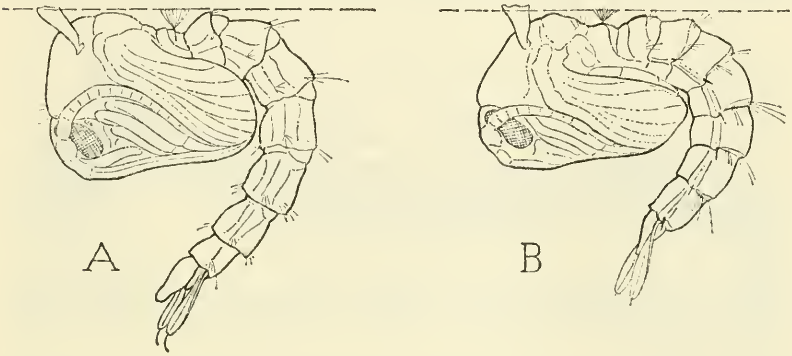

FIG. 13.—Pupae in natural floating position against the surface of the water. A, *Aedes atropalpus*. B, *Anopheles punctipennis*.

The development of the compound eyes of the mosquito has been described by Zavřel (1907), by Constantineanu (1930), and by Satô (1951a, 1953a, 1953b). The eye rudiments are first evident in the first larval instar as thickenings of the epidermis just in front of the larval eyes. With development of the eye pigment, the compound eyes become visible externally in the second instar or the early part of the third instar. From then on they increase in size as the ommatidia are slowly differentiated in the epidermis. During the larval stage the ommatidia are covered by the unmodified cuticle, but in the pupa the cuticle over each ommatidium becomes convex and the corneal facets are thus defined. After emergence of the adult the lenses become biconvex, and the ommatidia are completed in from 3 to 12 hours, but the lenses may continue to thicken during the first 24 hours of adult life.

The early development of the wings and legs in the mosquito larva is nothing unusual. The leg buds are always formed in the embryo, and all immature insects have legs, whether external or internal. Likewise the young of all winged insects have wing rudiments developing either externally or internally. The unusual thing about the mosquito and related Diptera is that the legs, wings, and pupal respiratory trumpets are fully extruded beneath the cuticle of the thorax at the third larval moult instead of at the moult to the pupa (fig. 9 C). The wings are still in the form of pads (W_2, W_3), but the legs (E) are already fully segmented appendages.

At a somewhat later period of the fourth instar, the larval cuticle is separated from the abdomen except at the posterior end (fig. 14), and beneath the cuticle on the back of the first segment are now seen the two small suspensory brushes of hairs characteristic of the pupal abdomen. The thorax and the abdomen inside the moulted larval

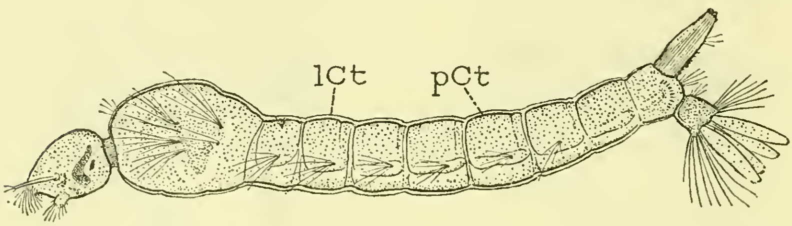

FIG. 14.—Fourth-instar larva of *Aedes aegypti* with larval cuticle (*lCt*) moulted over the thorax and most of the abdomen. The inner cuticle (*pCt*) is that of the pupa.

cuticle, therefore, pertain to the future pupa. The head cuticle of the larva has not yet been moulted, so that the larva in the fourth instar still feeds with its own mouth parts. It breathes with its posterior respiratory apparatus, and uses for locomotion the muscles now in the pupal abdomen.

The condition found in the mosquito is simpler than that described by Hinton (1958b) in *Simulium*. Here the fully formed pupa still within the larval skin is active for several days before ecdysis. Its activity is due to the fact that many of the former larval muscles, including those of the head, remain attached by tonofibrillae to the moulted cuticle of the larva. The pupa of *Simulium* is thus able to use the larval organs, and it not only continues to feed, but spins its own cocoon. In the mosquito there is no evidence of muscles retaining their attachment on the moulted larval cuticle; the insect feeds with the larval mouth parts until the latter are cast off at the final pupal moult.

The larval musculature of the thorax and abdomen is said by Thompson (1905) in *Anopheles* to go over into the pupa and the adult with little alteration. The rudiments of the future wing muscles, however, are present in the thorax during the last larval instar. Hulst (1906), on the other hand, reports that in the larva of *Culex* there takes place an extensive histolysis and histogenesis of the body musculature, beginning when the larva is two-thirds grown. Some imaginal muscles thus appear first in the larva, particularly those of the wings and legs, prior to the advent of the pupal stage. Destruction of the larval muscles of the abdomen, however, Hulst says, is not complete even in a late stage of the pupa. In the Simuliidae, according to Hinton (1959), "the indirect flight muscles and the tergal depressor of the trochanter develop quite independently of the larval muscles in all post-embryonic stages."

Histological changes in the alimentary canal beginning in the larva have been described by Samtleben (1929), by Berger (1938) for *Culex,* and by Richins (1945) for *Aedes.* The replacement of functional cells from regenerative cells in the ventriculus during larval life is generally in other insects not a metamorphic process but the usual procedure of replacing worn-out digestive cells by new cells. At the fourth ecdysis to the pupa, however, Berger (1938) says, rapid changes take place. The alimentary canal of the pupa, well illustrated by Hurst (1890), differs from that of the larva, but is still not that of the adult. The short pupal stomach is said by Richins to be formed from only the posterior part of the larval stomach. According to Samtleben no specific pupal epithelium is formed for the pupal stomach.

Considering the precocious development of so many of the imaginal organs, the fourth instar of the mosquito larva presents the anomalous condition of being part larval and part pupal. In other words, the pupal development begins within the larva long before its completion at the pupal ecdysis. It ends with the formation of the pupal head, mouth parts, and tail fins.

In most young insects the endocrinologists find that the larval structure is maintained by the inhibitory action of the corpus allatum hormone on the adult development until the end of the larval life. The early origin of pupal organs in the mosquito larva and the continuance of their development through the larval period shows, however, that the *juvenile,* or *status quo,* hormone does not necessarily function as a complete inhibitor of adult development. In the mosquito it appears to be selective in its action, allowing the growth of pupal parts that do not interfere with the normal activities of the larva, while it maintains to the end of the larval period such parts as the head, feeding organs, and respiratory apparatus that are essential to the life of the larva.

The corpora allata of the mosquito larva are described by Bodenstein (1945) as a "corpus allatum complex" composed of two small cellular bodies of elongate form, tapering posteriorly, attached laterally on the aorta just behind or within the neck. Anteriorly they adhere closely to a transverse trachea and are connected with each other by a loose chain of cells. Each body is entered by a slender nerve from the brain. Since the bodies contain different kinds of cells it is possible that they include elements of the usually separate corpora cardiaca. In higher Diptera the aorta is surrounded by a cellular ring, which is thought to include the corpora allata and corpora cardiaca, but according to Bodenstein the nature of the cells in the mosquito larva is not certain. The larval complex goes over into the adult in reduced form as two small, rounded bodies lying on the sides of the aorta.

If the fourth-instar larval mosquito behaves as other larvae have been shown to do when experimentally given an extra dose of juvenile hormone, it should go over into a fifth larval instar. In this case the larva issuing from the fourth-instar cuticle would have external legs and wings! We can only wait the results of some endocrinologist who may make the experiment.

When at last the cuticle of the larval head is moulted, taking with it the larval antennae and mouth parts, the corresponding pupal organs are rapidly developed within the still-unshed larval cuticle. The reconstruction of the mouth parts involves an extreme change from the specialized organs of the larva to the equally but differently specialized organs of the adult. The development of the pupal mouth parts has been described by Thompson (1905) for *Culex,* and by Imms (1908) for *Anopheles.*

The pupal labrum begins its growth as a fold of the epidermis at the anterior end of the dorsal wall of the head that first extends posteriorly beneath the cuticle (fig. 15 B, *pLm*). The fold elongates (C, *Lm*) and finally turns forward and downward over the other mouth parts. The buds of the new mandibles and maxillae are formed directly from the epidermis retracted into the bases of the larval organs. An early stage of their development still within the larval cuticle is seen at C of the figure taken from Thompson. The labium and the hypopharynx of the larva, as already shown, are greatly reduced and united in an area between the mouth and the hypostomium, the two components being separated only by the opening of the salivary duct. In *Aedes* the labiohypopharyngeal complex as shown by

Salem (1931) forms a distinct lobe below the mouth (fig. 15 A, *Hphy, Lb*), as it does also in a tipulid larva (fig. 7 A). The rudiment of the pupal labium within the larval labium (fig. 15 A, *pLb*) is said by Imms (1908) to be a pair of hollow lobes confluent at their bases. There is no separate rudiment of the adult hypopharynx. It is shown by Thompson (1905) that the hypopharynx is still united with the pupal labium (fig. 15 B) when the larval cuticle (*lCt*) is moulted. Later, as will be described, the hypopharynx of the adult female is separated from the labium. In their final stage of development the pupal mouth parts have become greatly lengthened and are closely pressed together in a long curved proboscis (D).

Rudiments of the pupal tail fins are formed beneath the cuticle of the fourth larval instar behind the respiratory apparatus, and the primary buds of the male external genital organs appear beneath the cuticle of the same instar behind the sternal region of the ninth abdominal segment.

THE MATURE PUPA

The pupa at ecdysis (fig. 16 A) is fully formed in all its outer parts and thereafter does not change externally. It is clearly a preliminary adult with the appendages in a halfway state of completion. The pupa can hardly represent a former active stage in the life of the mosquito, since its mouth parts are unfitted for any kind of feeding. The pupal thorax has already assumed the approximate size and shape of the adult thorax. In Simuliidae, Hinton (1959) says, the definitive thoracic structure is developed during the pharate stage of the pupa.

General external structure.—The head and thorax of the mosquito pupa are combined in a large cephalothorax, from which projects the slender abdomen (fig. 16 A). When at rest the pupa floats at the surface of the water (fig. 13), but it does not hang from its respiratory trumpets (as it often does in pictures). The back of the thorax and of the two anterior abdominal segments comes against the water, while the rest of the abdomen hangs downward as ballast. The open ends of the respiratory trumpets project just above the surface of the water, and two small brushes of spreading hairs on the back of the first abdominal segment help keep the pupa suspended. The floating position of the pupa is necessary for the future emergence of the adult, and is maintained by bubbles of air enmeshed in the folds of the legs and beneath the wings.

The source of the air that maintains the buoyancy of the pupa, according to Hurst (1890), appears to be a pair of large open spiracles

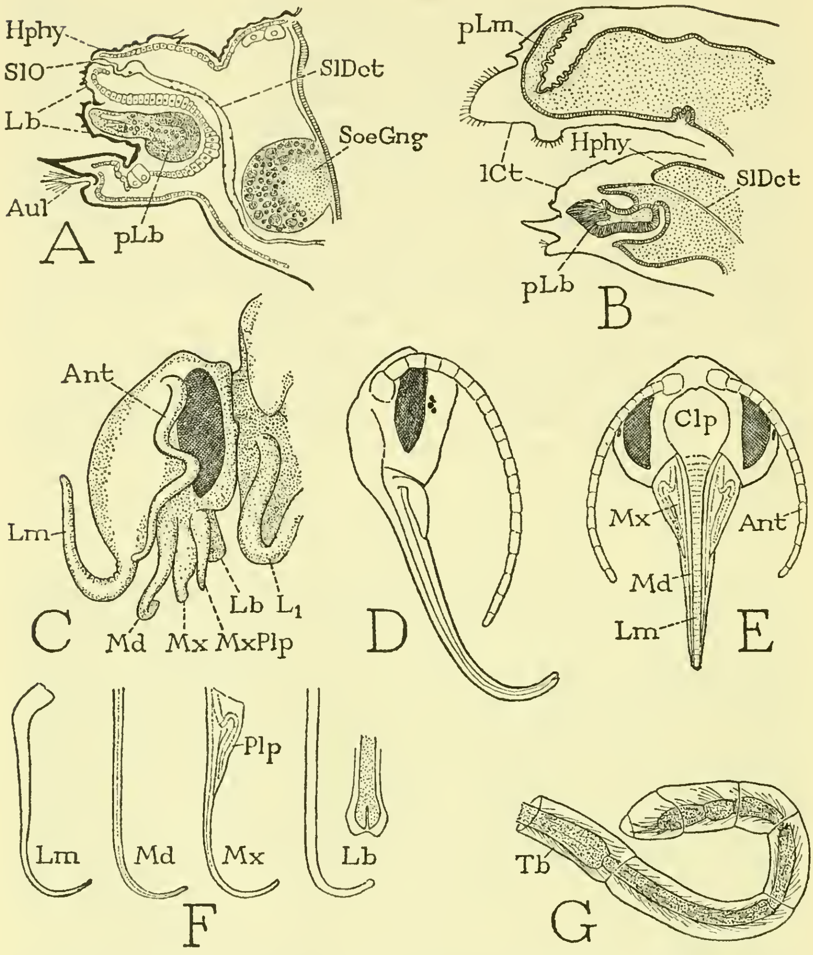

FIG. 15.—Development of pupal mouth parts and an adult leg.

A, Vertical median section through labiohypopharyngeal lobe of larva of *Aedes,* with contained rudiment of pupal labium (from Salem, 1931). B, Section of anterior part of head of *Culex* larva, with pupal labrum and labium forming inside the unshed larval cuticle (from Thompson, 1905). C, Head of *Culex* pupa removed from larval cuticle, with pupal mouth parts in early stage of development (from Thompson, 1905). D, Pupal head of *Aedes aegypti,* lateral. E, Same, anterior. F, Fully developed pupal mouth parts of *Aedes aegypti.* G, Distal part of a pupal leg with adult leg formed within it.

Ant, antenna; *Aul,* aulaeum; *Clp,* clypeus; *Hphy,* hypopharynx; L_1, first leg; *Lb,* labium; *lCt,* larval cuticle; *Lm,* labrum; *Md,* mandible; *Mx,* maxilla; *MxPlp,* maxillary palpus; *pLb,* pupal labium; *pLm,* pupal labrum; *Plp,* palpus; *SlDct,* salivary duct; *SlO,* salivary orifice; *SoeGng,* suboesophageal ganglion; *Tb,* tibia.

on the sides of the first abdominal segment of the pupa covered by the metathoracic wing pads. The tracheal system of the pupa, however, is so weakly developed that it would hardly seem capable of supplying the amount of air carried by the living pupa. Manzelli

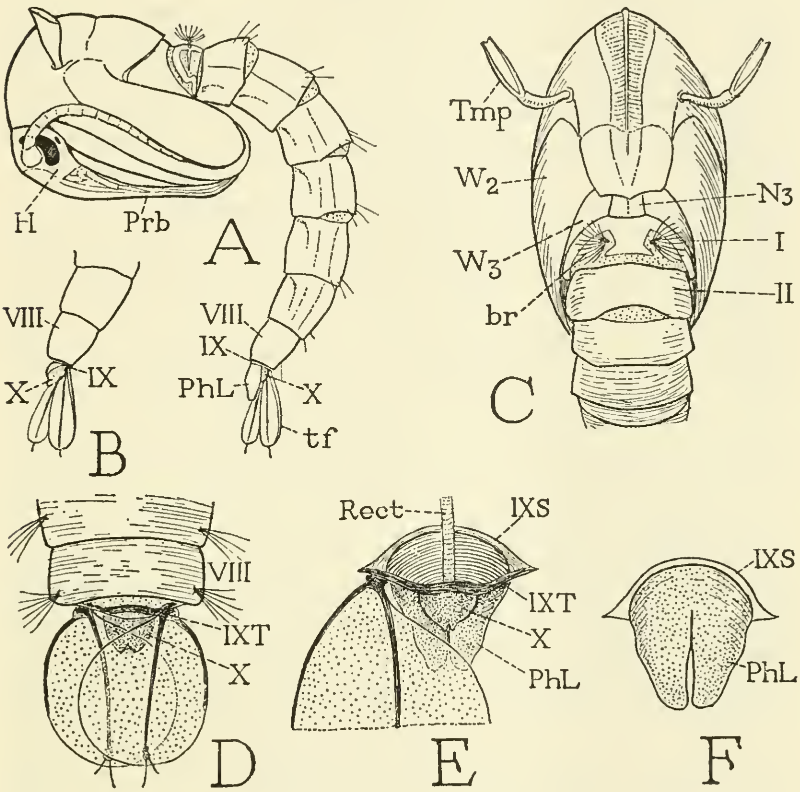

FIG. 16.—The pupa.

A, *Aedes aegypti,* male pupa, lateral. B, Same, terminal part of female abdomen. C, *Culex* sp., thorax and base of abdomen, dorsal. D, Same, end of female abdomen, dorsal. E, Same, apical structures of male abdomen. F, Same, phallic organ of male pupa, ventral.

br, suspensory brush of first abdominal tergum; *H,* head; N_3, metanotum; *PhL,* phallus; *Prb,* proboscis; *Rect,* rectum; *S,* sternum; *T,* tergum; *tf,* tail fin; *Tmp,* respiratory trumpet; W_2, mesothoracic wing; W_3, metathoracic wing; *I-X,* abdominal segments.

(1941) described and figured the pupa as "enclosed in a sac-like structure," which he says "has long been seen by all mosquito workers and is usually known to them as the pupal shell." This is a curious statement, since no such structure exists. Furthermore, the "shell" is said to enclose a large air cavity, but on pressing a pupa in alcohol the air issues as free bubbles from beneath the legs and wings.

The pupa has two features that are peculiarly its own. First are the trumpet-shaped respiratory tubes projecting from the back of the thorax (fig. 16 C, *Tmp*), and second, a pair of thin, oval fan-shaped tail fins, or paddles, borne on the end of the abdomen (A, *tf*). Because it is necessary for the pupa to float with the back of its thorax against the surface of the water, with the abdomen hanging down, it had to discard the posterior spiracles of the larva and have its breathing apertures forward. The trumpets are connected with the anterior ends of the dorsal longitudinal tracheal trunks, and their open ends project just above the surface of the water.

It is a curious fact that in species of *Mansonia* and *Ficalbia*, the larva of which gets its respiratory air from the roots of aquatic plants, the pupa does the same thing by means of its thoracic trumpets. The trumpets in these species are drawn out into a pair of long horns directed forward from the thorax. In *Ficalbia hybrida* each horn ends in a pair of tapering blades (fig. 11 F), but in species of *Mansonia* each terminates with a strong, curved spine. The spines of *Mansonia richiardii* (E) are convergent and are said to be applied close against each other as inserted into the plant. In the species shown at C of the figure the spines are divergent, and, as in other species, each is bordered anteriorly and posteriorly (D) by a very thin, transparent, faintly striated flange. A trachea (C,E, *Tra*) is attached to the base of the organ, but does not penetrate the latter. The cylindrical basal stalk contains a wide lumen, which narrows abruptly where it enters the spine and opens by a minute aperture at the tip. Wesenberg-Lund (1920-21), however, says of *M. richiardii* that "the trachea runs through the whole tube," and Grossbeck (1908) figures a tube of *Culex perturbans* with a trachea going through it to the tip of the spine. It seems very unlikely, however, that the thoracic respiratory tubes in any case contain tracheae. They are merely elongated trumpets, and a typical trumpet is an open funnel with the trachea opening into its base (fig. 17 C, *Tra*).

As the pupa of *Mansonia* emerges from the larval skin, according to Galliard (1934) as quoted by Marshall (1938), it brings the tips of its horns together and searches for a neighboring root. Then it violently works its way out of the anchored larval skin and at the same time inserts its horns. When the adult is ready to emerge, the pupa breaks away from the plant and comes to the surface where it floats by reason of two tracheal air sacs in the thorax. The winged mosquito thus escapes into the air in the usual manner.

It is truly remarkable that the same kind of structural adaptation for the same purpose has occurred twice in the life of the same individual, affecting two different organs. Furthermore, with the acquisition of a new structure designed for a new use, the insect must be twice endowed with a new instinct for using the modified organs. It is enough to make us wonder if we really understand the nature of biological adaptation.

Though pupae that breathe free air ordinarily float at the surface of the water, they can escape danger by darting around on the surface or submerging quite as actively as the larvae by snapping movements of the flexible and well-musculated abdomen. The large tail fins are organs for increasing the motor efficiency of the abdomen. Functionally they are comparable to the tail fan of a crayfish. The pupa when swimming progressively on or below the surface kicks backward with its abdomen and propels itself forward, but the crayfish does just the opposite. When the pupa swims downward in the water, however, it goes tail first, and thus maintains its floating position. If it remains inactive it passively rises to the surface, otherwise it swims up by abdominal movements.

The head and mouth parts.—The head of the pupa (fig. 16 A, *H*) is closely attached to the lower anterior angle of the thorax, with its true dorsal surface directed anteriorly. It retains nothing of the structure of the larval head. The long, many-jointed antennae curve upward and backward beneath the lower edges of the wings. The large, black compound eyes (fig. 15 D, E) are conspicuous beneath the cuticle, and between them the clypeal region (E, *Clp*) makes a prominent bulge on the face. Posteriorly the head is produced into a long, tapering proboscis that lies beneath the thorax with its end upcurved behind the lower legs (fig. 16 A, *Prb*). The component elements of the proboscis are closely adherent (fig. 15 E), but are easily separated (F). Along the lower side is the relatively thick labrum (E, *Lm*) which is continuous from the clypeus. Flanking the labrum are the very delicate slender mandibles (*Md*), and bordering the mandibles are the maxillae (*Mx*). The wide base of each maxilla bears a free, tapering palpus (F. *Plp*). On the posterior (upper) side of the proboscis is the soft, slender, tubular labium ending in a bifid tip (F. *Lb*). There is no free hypopharynx in the young pupa.

As we have seen, the hypopharynx is not separated from the labium in the larva, and the two parts go over still united into the pupa, with the salivary duct enclosed between them. In most adult insects the hypopharynx is an independent suboral lobe, and the salivary duct opens behind its base in front of the labium (fig. 23, *SlO*). The female of the mosquito and other adult Diptera possesses a free hypopharyngeal stylet, but it is traversed by the salivary duct. According to Thompson (1905) the hypopharynx of the female mosquito is differentiated by cellular growth from the median line of the anterior (lower) surface of the labium during the pupal stage. Since the hypopharynx, when it becomes a free stylet, contains the salivary duct, it would seem that in its separation from the labium it must take a part of the labium with it. In the male the hypopharynx is not separated from the labium, and the salivary channel remains in the labium. Dimmock (1881) says that in the male of *Culex* "the hypopharynx is, throughout its whole length, joined to the labium," and Hurst (1890) observes that it is "inseparable from the labium."

The fact that the hypopharynx of Diptera contains the salivary duct has given rise to the idea that this stylet is a new formation not homologous with the hypopharynx of other insects (see Demerec, 1950, pp. 375, 376). Yet the stylet in Diptera has all the usual relations of the hypopharynx to surrounding parts, and its base forms the floor of the preoral cibarial pump (fig. 24 E), just as in the cockroach (fig. 23) and other generalized insects.

The cuticle of the pupal mouth parts represents the organs as they are developed in the pupa. Inside the cuticular sheaths a renewed growth of the epidermis produces the final adult form of the stylets, just as the adult legs are formed within the cuticle of the pupal legs (figs. 15 G, 17 A). The segmented maxillary palpus of the adult, for example, is clearly seen inside the simple palpal sheath of the pupa (fig. 15 F, *Plp*), and within the end of the pupal labium (*Lb*) are visible the labellar lobes of the adult.

The thorax.—The large thorax of the pupa is indistinctly segmented, but it bears the legs and wings, and carries on its back the respiratory trumpets (fig. 16 A). The legs and the wings of the pupa have been taken over directly from the larva. The legs have increased in length and their joints are more distinct (fig. 17 A), but they are closely folded in loops against the sides of the thorax as in the larva. The mesothoracic wings are much larger and more winglike in shape; the hind wings are still triangular lobes of the metanotum. Within the cuticle of the pupal appendages are plainly seen the developing appendages of the adult. The venation of the forewing is already laid out (D). Within the hindwing may be seen the club-shaped halter (E, *Hlt*), which, whatever may be its evolutionary history, is not formed in ontogeny by a gradual modification of the wing.

The abdomen.—The abdomen of the pupa (fig. 16 A) resembles that of the larva except for the lack of the respiratory apparatus, the presence of the tail fins (*tf*), and the reduction of the tenth segment (*X*) to a small anus-bearing lobe. The dorsum of the first segment has a special pattern of sclerotization (figs. 16 C, 17 F) and bears the two brushes of spreading hairs that keep the base of the abdomen suspended at the surface of the water. It is suggested by Hurst (1890) that these brushes, besides serving as suspensoria, probably also are

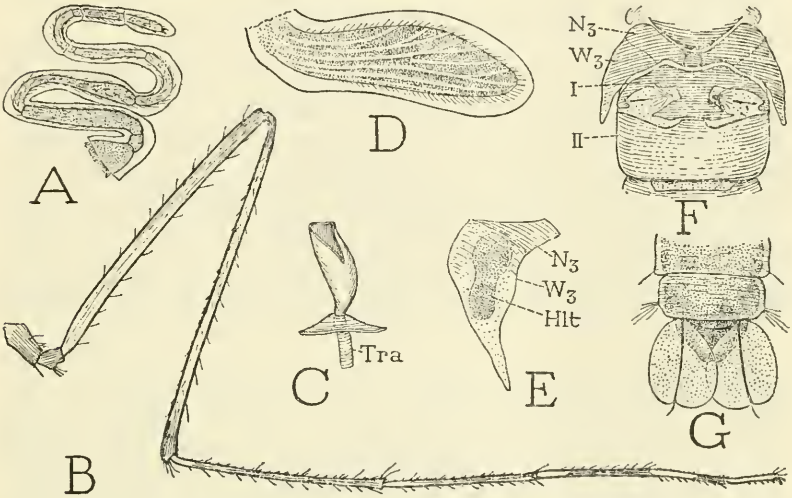

FIG. 17.—Pupal characters and an adult leg of *Aedes aegypti*.

A, Left third leg of pupa with adult leg formed inside the cuticle. B, Same leg of adult on emergence, same magnification. C, Right respiratory trumpet, mesal. D, Left mesothoracic wing with adult wing inside the cuticle. E, Left metathoracic wing with halter forming inside it. F, Metanotum and first two abdominal segments. G, End of abdomen with tail fins.

Hlt, halter; N_3, metanotum; *Tra*, trachea; W_3, metathoracic wing; *I*, *II*, first and second abdominal segments.

sensory organs responding to vibrations in the water. The pupa becomes immediately active on any disturbance of the water, even to a tap on the containing vessel.

The pupal tail fins, as usually drawn in illustration, appear to be attached to the end of the eighth abdominal segment (fig. 17 G). If they are pulled away from the eighth segment, however, they are seen to be carried by a transverse dorsal bar entirely separated from the tergum of the eighth segment (fig. 16 D,E, *IXT*), which, in fact, is the tergum of the ninth segment. On it is supported also the small tenth segment (*X*). In the male pupa (E) the ninth segment is a complete narrow annulus (*IXT, IXS*) as in the adult male (fig. 27 B), and below the small tenth segment projects a pair of large lobes (fig. 16 E, *PhL*) on a common base arising from the sternal arc of the ninth segment (F). These lobes are the genital appendages of the male as far as they are developed in the pupa. Male and female pupae, therefore, can be distinguished by the presence (A) or absence (B) of the genital lobes (*PhL*), though in the male the lobes might be mistaken for the tenth segment, since the latter is mostly concealed above them (A, *X*).

THE PUPAL METAMORPHOSIS

The pupal life of most mosquitoes is very short, two or three days or less, though with some species it is much longer. During this time the contour of the adult is modeled by new growth of the epidermis beneath the pupal cuticle, while the mouth parts, wings, halteres, and legs take on the adult structure within their pupal sheaths. At the same time reconstruction of internal organs takes place inside the body. The degree of reconstruction necessary to change the larval organs into those of the adult, however, is much less in the mosquito than in many other insects, especially in the higher Diptera.

The mosquito pupa breaks with the tradition that a pupa is a "resting stage" in the life of the insect. When an ordinary pupa is broken open it is seen to be full of a creamy mass of soft material resulting from the disintegration of the larval tissues. The inside of a mosquito pupa is as clean as that of the larva or the adult, and its organs appear to be intact. Whatever reorganization is going on takes place mostly inside the alimentary canal and the refuse is not thrown into the body cavity.

The abdominal muscles are so well preserved that the pupa is an extremely active stage of the mosquito, and the thoracic muscles are so well developed that the pupa might be expected to fly if its wings were more mature. As already noted, Hulst (1906) has described the process of muscle histolysis and histogenesis as beginning in the larva, but he is not explicit as to what larval muscles are destroyed or when the imaginal musculature is completed. In *Culex,* according to Hurst (1890), the muscles of the pupa are those of the imago; the principal muscles are present in the young pupa, but they increase greatly in size. A casual examination of the abdominal musculature in the larva, pupa, and adult shows little difference between the stages, except for the greater size of imaginal muscles. However, we need a more detailed comparative study of the muscle pattern and more information on the replacement of individual muscles.

The larval head musculature appears to be largely replaced by an imaginal musculature. According to Thompson (1905) there is an extensive histolysis of the larval head muscles, accompanied by a regeneration of muscles appropriate to the adult, which takes place in the eighth to tenth hour of pupal life.

The pupal tracheal system is weakly developed and is difficult to see in dissections. According to Hurst (1890) tracheae go from the base of each thoracic trumpet to various parts of the head and body, and a transverse trunk connects the two trumpets. A pair of longitudinal trunks runs back to the rear end of the body, giving off branches to the internal organs and to the site of each spiracle. Only the spiracles of the first abdominal segment remain open.

In his study of the heart of *Anopheles quadrimaculatus,* Jones (1954) reports that no evidence was found that the heart is "destroyed, reconstructed, or otherwise drastically modified during metamorphosis." In young pupae, according to Jones, the heart beats in a forward direction as in the larva, but later it may cease beating for prolonged periods of time. Circulation of the blood, therefore, appears to be unessential for the regenerative changes taking place in the pupa.

The alimentary canal of a young pupa, as described and illustrated by Hurst (1890) in *Culex,* might be supposed to be a functional organ if the pupa could feed. It more resembles the digestive tract of the larva than that of the adult, but since the adult feeds on a very different kind of food from that of the larva, the alimentary canal undergoes a complete reconstruction in the pupa, details of which have been described by Hurst (1890), Thompson (1905), Samtleben (1929), and Richins (1938). The oesophagus is least affected insofar as its epithelium goes over intact from larva to adult, but the larval pharynx is lost, and an enlargement in the back of the head forms the postcerebral sucking pump of the adult. In the thorax the dorsal and ventral diverticula of the adult grow out from the oesophageal wall. The larval gastric caeca are absorbed and not replaced in the adult. The larval epithelium of the stomach, according to Richins, degenerates completely and is cast off into the stomach lumen, as a new epithelium is formed by permanent regenerative cells. Transformation in the proctodaeum is brought about partly by histolysis and histogenesis of the epithelium and partly by regrowth. The five Malpighian tubules of the larva go over into the adult without change. In the rectal sac of the pupa are formed six invaginations of the wall that become the rectal papillae of the adult. The salivary glands of the larva degenerate and each is replaced by three slender tubules generated from cells in the neck of the larval gland.

The central nervous system undergoes little change in the pupa other than growth and union of some of the ganglia. The first abdominal ganglion of the larva is drawn into the thorax, where it fuses with the metathoracic ganglion, and later the four ganglia now in the thorax condense into a single mass. The last abdominal ganglion of the larva unites with the ganglion of the seventh segment. In the adult mosquito, therefore, there are only six separate ganglia in the abdomen (fig. 30 C). In the head, as described by Woolley (1943) for *Aedes,* the brain and the optic lobes grow rapidly by peripheral formation of new cells. The circumoesophageal connectives shorten and the suboesophageal ganglion unites with the brain around the oesophagus.

Though the visible changes that take place in the nervous system are slight, there must be a considerable reorganization of the internal structure. The behavior and instincts of the adult mosquito are entirely different from those of the larva. Since the activities of the insect resulting from sensory stimuli are determined by established neuromuscular pathways and synapses in the central nervous system, the system that serves the larva must be entirely reorganized into one appropriate for the activities of the adult. Of this, however, we know little or nothing in any insect.

III. THE ADULT

The adult mosquito fully formed within the pupa has now only to cast off its pupal mold to gain its freedom in the garb of a mature winged insect. But this is not easily done since the confined mosquito has no instruments for cutting or breaking the pupal cuticle. Moreover, the wings, legs, antennae, and mouth parts are enclosed in tight-fitting sheaths, from which they must be slowly extracted. However, much as we might wish that the mosquito should remain a prisoner in the pupal skin, nature has made provision for its liberation.

As noted by several observers, the first evidence that the adult is about to emerge is the appearance of a film of air beneath the pupal cuticle on the back of the thorax. A slight retraction of the adult apparently breaks the connections of the pupal trumpets with the tracheal system and thus allows air to escape beneath the cuticle. Usually a short piece of trachea remains attached to the base of each trumpet. According to Marshall and Staley (1932) rhythmical movements now begin in the sucking pump of the adult which draw the air forward, forming a bubble at the base of the proboscis. This air is then pumped into the stomach as a long narrow bubble that extends back to the fourth abdominal segment. Pressure by the distended abdomen now pushes the thorax forward until it ruptures the pupal cuticle in a median slit along the back from the neck to the end of the mesothorax. Outside air then enters the cleft and is rapidly swallowed, going back in the stomach as far as the sixth abdominal segment and greatly distending the abdomen. Knab (1909), in describing the role of air in the ecdysis of insects, says of the mosquito that on emergence from the pupa it is distended with air far beyond its natural size, the integument being stretched to its utmost. According to the writer's observations on emerging mosquitoes the degree of distention is highly variable, even with individuals of the same species.

Pupae of *Aedes aegypti,* before the adult ecdysis, are observed to have the abdomen extended straight back from the thorax, and during the emergence it is held, or floats, in this position with the tail fins against the water surface (fig. 18 A). When the pupal cuticle splits on the back of the thorax, the thorax of the adult bulges out and pushes apart the lips of the cleft. This produces a transverse split over the back of the pupal head, so that the pupal skin can now be widely opened anteriorly (B) to allow the egress of the adult. At the same time the cuticle on top of the pupal head between the eyes breaks out and folds forward as a free flap beyond the antennal bases (A,B). Behind the antennae the anterior tentorial arms project internally as a pair of slender tapering rods (B).

Inasmuch as the legs of the adult, as well as the wings and mouth parts, are enclosed in tight-fitting pupal sheaths, the mosquito cannot use its appendages for freeing itself. Yet, when the head and thorax are free, the abdomen follows and the entire adult slowly rises vertically from the pupal skin as if pushed out from below. The legs and wings are at first closely pressed against the body, but as the legs are freed they at once become active, and appear to be reaching for the surface of the water. The mosquito seems to know instinctively that now and henceforth it must support itself on its legs. It will be noted that the legs of the emerged adult are greatly longer than their pupal sheaths; the hindleg of an *Aedes* (fig. 17 B), for example, may lengthen to two and a half times the length of the corresponding folded leg of the pupa (A). When the end of the abdomen and the wings are finally out of the pupal thorax and the legs are all free, the new insect confidently steps out onto the surface of the water and calmly walks away from the discarded pupal skin. It may come to rest on some nearby floating object (as a bit of cardboard in the aquarium), but usually in a very short time it is able to fly, and immediately is gone. Sometimes, however, mosquitoes in culture appear to have much difficulty in finally extracting their legs; often they fall over on the surface of the water, and some perish in this position with their tarsi still held in the pupal sheaths. It is probable that in such cases the larvae were not properly nourished.

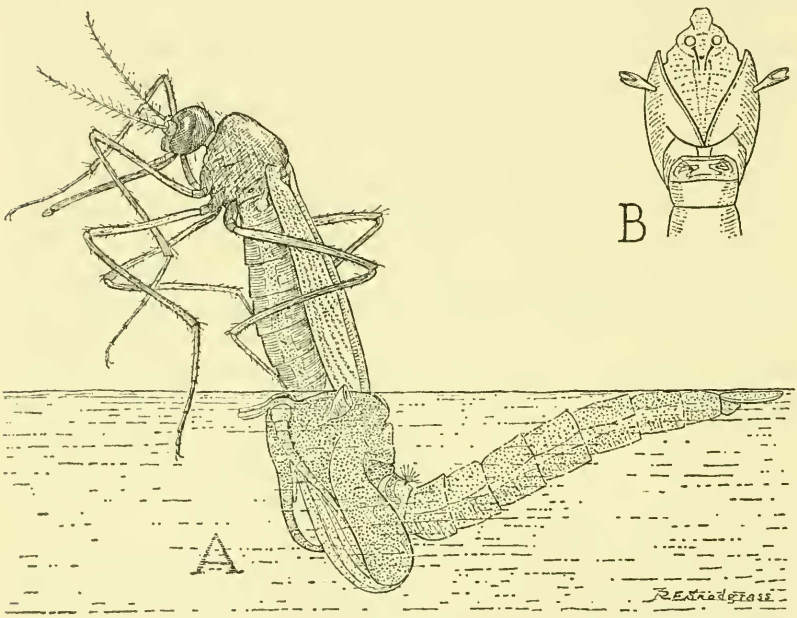

FIG. 18.—An adult female of *Aedes aegypti* emerging from the submerged pupal cuticle; and the open thorax of the discarded pupal cuticle of *Anopheles quadrimaculatus*.

A remarkable thing about the mosquito is that, after its whole previous life spent in the water, on emergence from the pupa it is at once at home in the air. Without a flutter of the wings or any practice trial, it makes a perfect takeoff, flight, and distant landing. During the pupal stage, therefore, the mosquito has not only been equipped with a complete mechanical apparatus of flight, but in its nervous system a mechanism of control has been fully elaborated. Compare this with the difficulty the young human has in learning even to walk, but of course his ancestors did not always walk upright on two legs.

The newly emerged mosquito (fig. 19) is really an elegant insect as it stands high on its long slender legs, the abdomen held straight back beneath the neatly folded wings, and the long proboscis extended from the head. The sexes of most species are readily distinguished at once by the antennae, those of the female having usually circles of short hairs, those of the male being large spreading plumes.

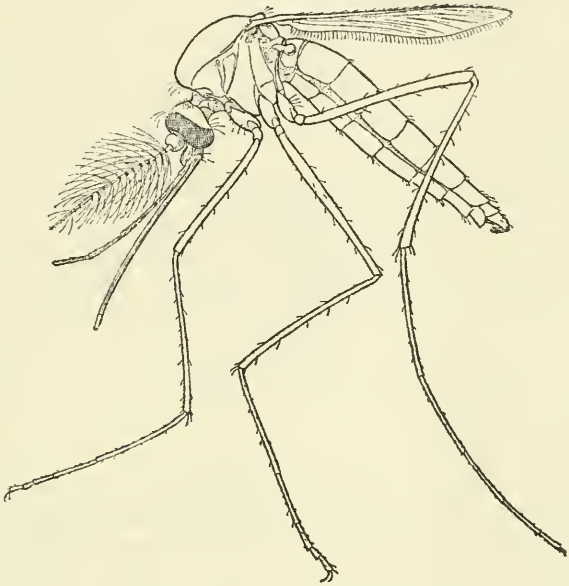

FIG. 19.—*Aedes aegypti*, adult male.

THE HEAD

The head of an adult mosquito has little likeness to that of the larva. It is an oval capsule (fig. 20 D) with the facial region carrying the antennae directed forward, and the long proboscis extended from its lower end. The sides are largely occupied by the great compound eyes, which almost meet dorsally and ventrally (A,B, *E*). The large bases of the antennae arise so close together on the face that the frons is reduced to a narrow verticle bar between them (A, *Fr*), but its lower end forks into diverging arms that support the clypeus (*Clp*). A median coronal sulcus (*cs*) on the vertex extends downward on the face through the frons. The strongly convex clypeus (A,C, *Clp*) forms a prominent lobe just above the base of the proboscis. The undersurface of the head (B) resembles that of the larva in that it is completely closed from the occipital foramen to the base of the proboscis. The head is attached to the thorax by a slender membranous neck and is supported by a pair of lateral cervical sclerites (D,E). The head of the male is similar to that of the female, but is a little smaller. The internal head skeleton consists of a pair of simple tentorial arms extending from anterior pits above the lateral angles of the clypeus (A, *at*) to posterior pits (B, *pt*) on the ventral margin of the occipital foramen.

From the front of the face arise the long antennae (fig. 20 D,E). The hairy flagellum of each organ is borne on a large globose base (A, *Pdc*), which is the pedicel, or so-called torus, but when the pedicel is removed (right) it is seen to be itself supported on a narrow ring (*Scp*) that represents the usually much longer scape of other insects. The slender shaft of the flagellum is divided into 14 sections (erroneously called "segments"), 13 of which carry each a whorl of hairs. In general the sexes are readily distinguished by the number and length of the flagellar hairs, which in the male (fig. 22 A) give the antennae a plumose appearance in contrast to the short-haired female antennae (D,E). The two types, however, intergrade, females of some species having bushy antennae, and some males short-haired antennae. In the female the hairs arise from clear areas near the bases of the flagellar units (B); in the male (C) they are borne on prominent, darkly sclerotized, subapical expansions of the units. Tulloch and Shapiro (1951) have shown from electron microscope studies that the flagellar hairs are armed with rows of minute teeth; in *Culex quinquefasciatus* they estimate there are at least 16 rows along each hair. These writers, however, are in error where they say the hairs "arise at the junctions of the flagellar segments."

The large globose pedicel of the antenna in each sex contains a highly developed sclopophorous sense organ, present also, though usually much smaller, in the antennal pedicel of most insects. The organ was first described in *Culex* as an auditory organ by Johnston (1855), who did not at all understand the nature of the structure in the pedicel, but it has since been known as *Johnston's organ.* Subsequently Child (1894) made good histological studies of the organ in various insects, including the mosquito, and his illustrations are now famliar in most entomological texts. A more recent comparative study of the organ in *Culex, Aedes,* and *Anopheles* is given by Risler (1955). The component sensory elements in the pedicel are attached to a plate or prongs on the base of the flagellum, and thus evidently register movements of the flagellum.

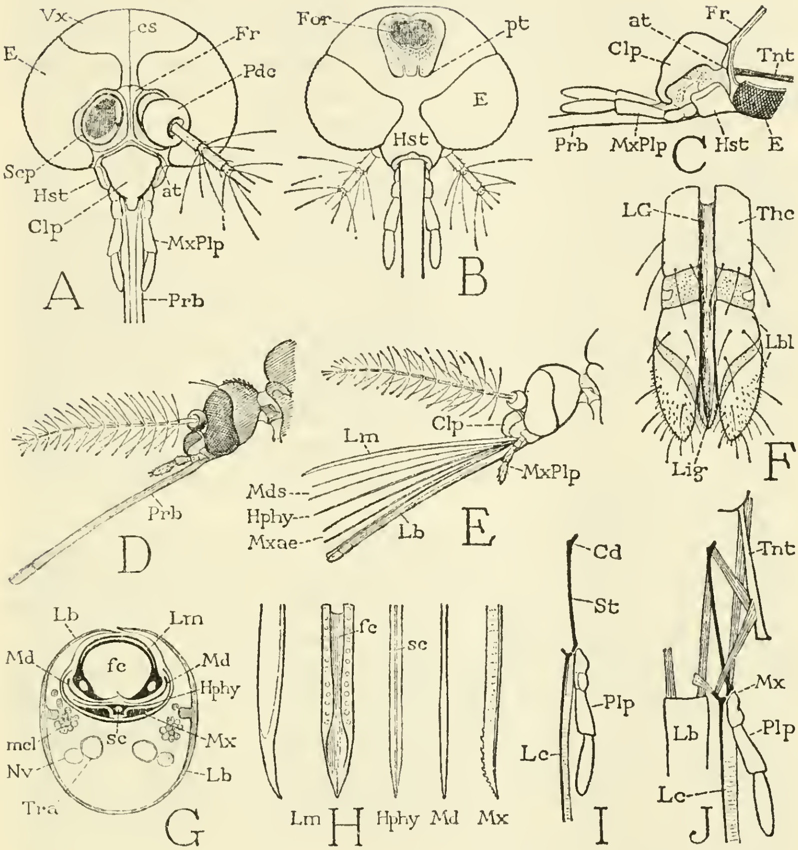

FIG. 29.—Head and mouth parts of an adult female mosquito, *Aedes aegypti* except G.

A, Head and base of proboscis, anterior. B, Same, posterior. C, Clypeus and base of proboscis, lateral. D, Head, lateral. E, Same, with mouth parts separated. F, End of labium, dorsal. G, Cross section of proboscis of *Anopheles* (from Vogel, 1921). H, Distal ends of mouth part stylets. I, Basal parts of maxilla. J, Proximal parts of right maxilla and labium, posterior.

at, anterior tentorial pit; *Cd*, cardo; *Clp*, clypeus; *cs*, median cranial sulcus; *E*, compound eye; *fc*, food canal; *For*, occipital foramen; *Fr*, frons; *Hphy*, hypopharynx; *Hst*, hypostome; *Lb*, labium; *Lbl*, labellum; *Lc*, lacinia; *LG*, labial gutter; *Lig*, ligula; *Lm*, labrum; *mcl*, muscle; *Md*,*Mds*, mandible, mandibles; *Mx*,*Mxae*, maxilla, maxillae; *MxPlp*, maxillary palpus; *Nv*, nerve; *Pdc*, antennal pedicel; *Plp*, palpus; *Prb*, proboscis; *pt*, posterior tentorail pit; *sc*, salivary canal; *Scp*, antennal scape; *St*, stipes; *Thc*, theca; *Tnt*, anterior tentorial arm; *Tra*, trachea; *Vx*, vertex.

While it is probable that the organ of Johnston in the antenna of most insects registers the movements of the flagellum, the elaborate experimental work of Roth (1948) leaves no doubt that the highly developed organ in the male mosquito is responsive to the effect of sound waves on the flagellum. This, of course, does not imply that the mosquito has an auditory "sense"; mechanical reaction to stimuli is all that we can attribute to the insects. Male mosquitoes are attracted to the females in flight by the tone produced by their wings. Roth showed that males with intact antennae, when subjected to the sound of a tuning fork at 480 vibrations a second held behind a suspended piece of cloth, fly to the source of the sound where they exhibit typical mating activities though no females are present. Even after complete removal of the flagellar hairs, males still respond to more intense sounds apparently by vibrations of the shaft alone, but on complete removal of the flagella they give no reaction. Roth's tests were made particularly on *Aedes,* but males of other genera were found to react similarly. Females of *Aedes aegypti* gave no evidence of being attracted to sounds, "though they may give shock-reaction to certain intensities."

Further experimental work of Roth (1951) on females of *Aedes* seems to show that the antennae function as directional distance thermoreceptors and probably also as chemoreceptors. Females deprived of their antennae are unable to locate a host from a distance. The antennae and the palpi are said to be the chief organs responding to stimuli that induce probing by the proboscis. The receptor organs of the antennae, however, are not described, but along the shaft of the female antennae (fig. 22 B) are numerous hairs, and on the male antenna (C) a ring of very short hairs encircles the distal end of each flagellar section. The antennae of insects in general are known to be the principal seat of chemoreception.

The compound eyes of the mosquito are so large that they almost encircle the head. Satô (1950, 1953a, 1953b) reports that by actual count there are from 440 to 462 facets in the eye of a male *Culex pipiens,* and 503 to 566 in the female; and that in *Aedes japonicus* the male eye contains 440 to 462 facets, the female eye 504 to 527. The surface area of the eye in each genus is larger in the female than in the male. The internal structure of the compound eye in *Culex* is described by Constantineanu (1930) and by Satô (1950).

An extensive experimental study of the visual responses of flying mosquitoes made by Kennedy (1939) on unfed females of *Aedes aegypti* shows that the mosquitoes react negatively to light, and are attracted to dark objects. Experimentally they orient toward black stripes on a white background, and continue to do so when the stripes are rotated about them. When confronted by two black stripes, they face one or the other and not the intervening space. In a wind tunnel freely flying mosquitoes move against the current.

THE ORGANS OF FEEDING

The feeding organs of the adult mosquito include the *proboscis* and two sucking pumps. One of the latter is a preoral *cibarial pump* beneath the clypeus, the other is a *pharyngeal pump,* being a part of the alimentary canal behind the brain in the back of the head. In describing the feeding organs of the adult it will be better to take the female first, because in most mosquitoes she is the biting and bloodsucking member of the species and has the mouth parts fully developed. In the nectar-feeding male some of the parts are much reduced or absent.

The proboscis.—The slender, rodlike proboscis in the female mosquito is usually composed of all the mouth parts possessed by insects that feed on solid food, namely, a *labrum,* a pair of *mandibles,* a *hypopharynx,* a pair of *maxillae,* and a *labium,* but the parts are all structurally modified in adaptation to the mosquito's way of feeding. The relation of the parts in the undisturbed proboscis is best seen in a cross section (fig. 20 G). In the deeply channeled upper side of the labium (*Lb*) are enclosed the labrum (*Lm*), the mandibles (*Md*), the hypopharynx (*Hphy*), and the maxillae (*Mx*). The labrum itself is practically an inverted tube, since its margins are curved downward and may overlap. The enclosed labral canal (*fc*) is the food conduit. The hypopharynx contains the salivary canal (*sc*). By careful manipulation with a dissecting needle all these parts can be separated as shown at E.

The labrum (fig. 20 H, *Lm*) is the thickest and the strongest of the stylets. It is movable by muscles from the clypeus attached on its base (fig. 24 D), but the muscles simply elevate and depress the labrum, which is firmly hinged on the clypeus. The term "labrum-epipharynx" often applied to the labrum is quite unnecessary, since in its general form the labrum is a flat lobe of the head and therefore has an upper and lower surface. In the mosquito the decurvature of the lateral parts converts the labrum into a tube through which the ingested liquid food is drawn up by the sucking apparatus at its base. At the sharp-pointed distal end (fig. 20 H, *Lm*) the walls of the channel diverge to make an opening like that of a hypodermic needle.

The mandibles are the slenderest of the stylets, but they vary somewhat in thickness and shape in different species. In *Aedes* here illustrated (fig. 20 H, *Md*) each is slightly enlarged toward the tapering distal end. The base of each mandible is movably connected with the lower part of the cranial wall by a small suspensory sclerite, and a slender muscle from the tentorium is inserted on the mandibular base. The mandibles are thus retractile for a short distance, and, when retracted, their withdrawn tips give free entrance to liquid into the open end of the labral food canal. Protraction results from the elasticity of the suspensory mechanism on relaxation of the muscles.

The single, median hypopharynx, present as an independent stylet only in the female, is a simple, flattened rod (fig. 20 H, *Hphy*) traversed by the salivary outlet canal (*sc*), which opens on its acute tip. The hypopharynx is not individually movable; its anterior wall is continued basally into the floor of the cibarial pump.

The maxillae are less reduced than the other mouth parts, and are well equipped with muscles. The principal part of each maxilla (fig. 20 I) is a long, flattened, sharp-pointed blade (*Lc*) armed with recurved teeth near the end of its outer margin (H, *Mx*). From the base of the blade projects a usually short four-segmented palpus (I, *Plp*). The maxillary blade has been regarded as the galea by some writers (Robinson, 1939; Snodgrass, 1944), but it is more reasonably interpreted by Schiemenz (1957) as the lacinia, which is usually the operative part of a generalized maxilla. From its base a long, strongly sclerotized, apodemelike rod extends backward in the head and gives attachment to muscles (J). This rod is evidently the stipes, or more probably stipes (*St*) and cardo (*Cd*) combined, sunk into the head, since in some related flies, such as *Phlebotomus* (fig. 22 G), it is superficial on the back of the head and articulates on the cranial margin.

The maxillary musculature of *Aedes* (fig. 20 J) includes a long retractor arising on the head wall close to the posterior end of the tentorial arm (*Tnt*) inserted on the distal end of the stipes, and two protractors attached proximally on the stipito-cardinal rod. One of these muscles arises on the tentorium, the other, very curiously, on the base of the labium. A lateral muscle from the tentorium and a short mesal muscle both attached on the base of the lacinia are regarded by Schiemenz (1957) in *Theobaldia* [*Culiseta*] as an abductor and adductor respectively of the maxilla. A short muscle from the stipes is inserted on the base of the palpus, and each palpal segment contains a small muscle inserted on the segment distal to it.

The long, gutterlike labium of the mosquito is the so-called prementum of a generalized labium, the usual basal part of the labium being absent, though a small postmental sclerite may be present in other Nematocera (fig. 22 G, *Pmt*). The prementum in Diptera is known as the *theca* because it ensheaths the other mouth parts. Apically it bears two small movable lobes, the *labella* (fig. 20 F, *Lbl*), and ends between them in a slender median projection, or *ligula* (*Lig*). The labella appear to be two-segmented, and evidently represent the labial palpi because each is provided with an abductor and an adductor muscle from the prementum. The only muscles attached on the base of the labium are the two already noted that arise on the maxillary stipites (J) and probably act as protractors of the maxilla, since the labium is firmly fixed to the head.

The styliform mouth parts within the labial theca adhere to one another in a compact fascicle. They are usually said to be held together by an oil liquid, but Bhatia and Wattal (1957) have described rings issuing from the margins of the labrum that surround the hypopharynx, mandibles, and maxillae and bind these stylets to the labrum. However, no other investigator has reported the presence of any such structures, and the writer has failed to see them in *Aedes, Culex,* or *Anopheles.* The incurved lower edges of the labrum enclose only the food canal.

When the female mosquito is about to take a meal of blood, she places the tip of the proboscis against the skin of the victim (fig. 21 A), closely holding the end of the stylet fascicle between the labial labella. The movable maxillary stylets are the active piercing organs. Acting alternately, first one is protracted and holds its position in the flesh by means of its recurved teeth, then the other is forced in beyond the first and takes a deeper hold. The labrum, mandibles, and hypopharynx penetrate along with the maxillae. The retractor muscles of the maxillae, instead of pulling the stylets out of the wound, where they are held by the maxillary teeth, bring the head down closer to the feeding surface. The labrum, still holding the stylet fascicle between the labella, is thus forced to bend backward (B) and the bend becomes greater the deeper the stylets penetrate (C). When finally the stylets pierce and enter a small blood vessel, or let out a pool of blood, the mandibles are drawn back from the end of the labrum to allow the blood to enter the food canal in response to the suction of the cibarial pump. Saliva discharged from the hypopharynx in some species serves to prevent coagulation of the blood. A more detailed account of the feeding act and of accompanying movements by the maxillary palpi is given by Robinson (1939). After feeding, the maxillary stylets are retracted, the female braces herself against the skin of the victim with her legs, and forcibly pulls out the fascicle of stylets, which again is ensheathed in the straightened labium.

In discussing the feeding of mosquitoes, we must not overlook the fact that not all females are bloodsuckers. A prominent exception to the rule are species of *Toxorhynchites,* in which both sexes feed on

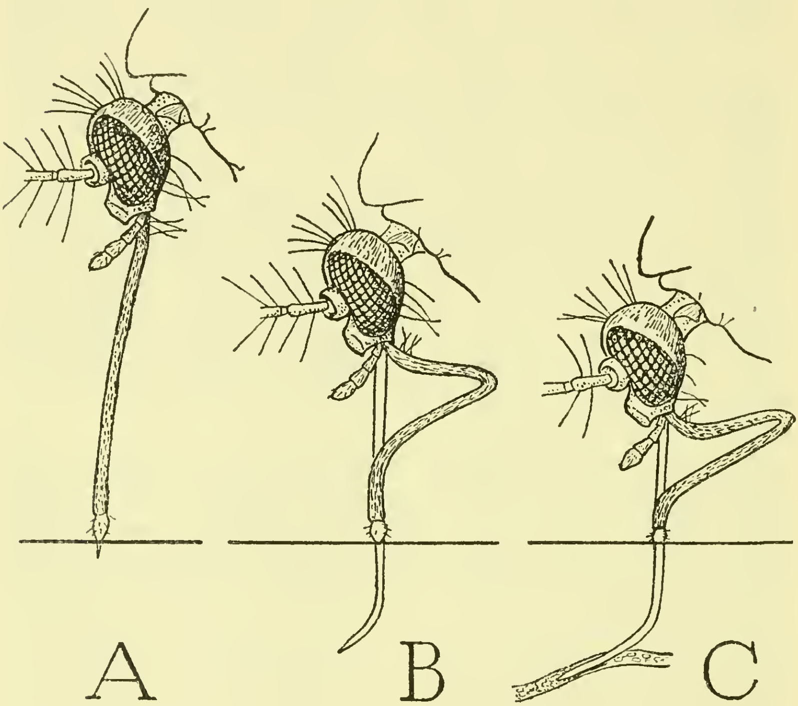

Fig. 21.—Successive stages in the penetration of the stylets of a female mosquito feeding on blood. (B, C, from Gordon and Lumsden, 1939, with neck plate added.)

nectar or other plant juices. In this genus (fig. 22 D) the proboscis is very long, tapering, and strongly decurved. The maxillary palpi projecting from the base of the proboscis are long and four-segmented. The laciniae by contrast are weak and taper into filaments reaching only a little beyond the end of the first palpal segment; evidently they play no part in feeding. A slender labrum extends to the tip of the proboscis, but mandibles appear to be absent.

Then there are species of *Malaya* (=*Harpagomyia*) that get their food from ants. In these the proboscis is curved forward at its lower end (fig. 22 E) ; the distal part is thickened and armed with long hairs. The elongate labella terminate with a pair of small transparent lobes. The species of *Malaya* are minute mosquitoes, much smaller than ordinary ants. As described by Jacobson (1911) they sit on branches

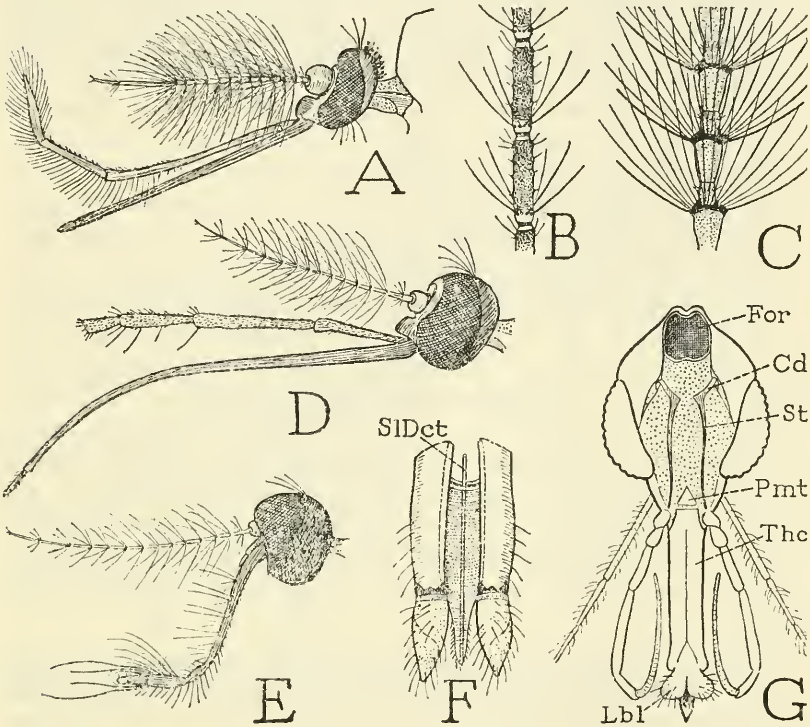

FIG. 22.—Various types of antennae, palpi, proboscides, and labia of adult mosquitoes.

A, *Culex* sp., head of male. B, Same, part of female antenna. C, Same, part of male antenna. D, *Toxorhynchites rutilus,* head and proboscis of female. E, *Malaya jacobsoni,* head and proboscis of female. F, *Culex,* distal end of male labium, showing salivary duct. G, *Phlebotomus verrucarum* (Ceratopogonidae), head and proboscis, posterior.

Cd, cardo; *For,* occipital foramen; *Lbl,* labellum; *Pmt,* postmentum; *SlDct,* salivary duct; *St,* stipes; *Thc,* theca (prementum).

inhabited by ants, and when an ant runs between the legs of one of them the mosquito thrusts the end of its proboscis between the open mandibles of the ant, which accommodatingly gives up its dinner to the mosquito. The proboscis of the adult *Malaya* lacks mandibles and maxillae. According to de Meijere (1911) these members are present in the pupa, but the imaginal parts formed inside of them are short and disappear.

The mouth parts of the male mosquito are much simplified by the great reduction of the mandibular and maxillary stylets and the entire absence of a hypopharyngeal stylet. The male proboscis, therefore, consists principally of only the labrum and the labium, but the maxillary palpi are usually highly developed and may be much longer than the proboscis (fig. 22 A). Mandibular stylets when present are seldom longer than half the length of the proboscis and are usually much shorter. Marshall and Staley (1935) report that they are present in all genera examined except "*Aedes* and *Ochlerotatus*." These writers found maxillary stylets to be present in representatives of all genera examined, but the length is highly variable, even in species of the same genus. The labium is a deep trough, as in the female, and ends with a tapering median ligular lobe between the labella (fig. 22 F). It will be recalled that the hypopharynx of the male mosquito is not separated from the labium, as in the female. The hypopharynx thus retains in the adult male the larval condition of union with the labium. The male "labium" is, therefore, really a labiohypopharynx. The hypopharyngeal component in *Anopheles* is identified by Vizzi (1953) as a sclerotic plate on the floor of the labial gutter. In sectional figures he shows the salivary canal in an apparent median thickening of the plate. In *Culex* (fig. 22 F) the salivary duct (*SlDct*) is a thread-like tube that traverses internally the floor of the labial gutter and opens on the tip of the ligula, but it appears to be free in the labial lumen.

The cibarial pump.—The structure here termed the cibarial pump lies just beneath the clypeus at the base of the proboscis, and is the organ that sucks the liquid food up through the canal of the labrum. The same pump is present in all Diptera and is the sucking apparatus of other liquid-feeding insects, such as the Hemiptera. It has long been erroneously called the "pharynx," and even some recent writers continue to call it such on the pretext of not wishing to confuse students. It is possible, however, that some students might prefer to know the facts. The organ in question is entirely outside the mouth, as no true pharynx could be, but admittedly it is difficult to understand its anatomical status in the mosquito. We must therefore turn to some other more generalized insect for light on the nature of the preoral sucking organ, and for this purpose the cockroach will be particularly illuminating.

In a vertical lengthwise section of the head of a cockroach (fig.

23) the mouth (*Mth*) is seen to lie beneath the upper end of the clypeal region (*Clp*) of the cranial wall. Below the mouth projects the large tonguelike lobe commonly termed the hypopharynx (*Hphy*), which has a long base sloping up to the mouth. On this basal part of the hypopharynx is a depression that forms the floor of a pocketlike space (*Cb*) in front of the mouth beneath the inner wall of the clypeus. The masticated food passed back from the mandibles is stored in this pocket before it is swallowed. The pocket, therefore, is named the

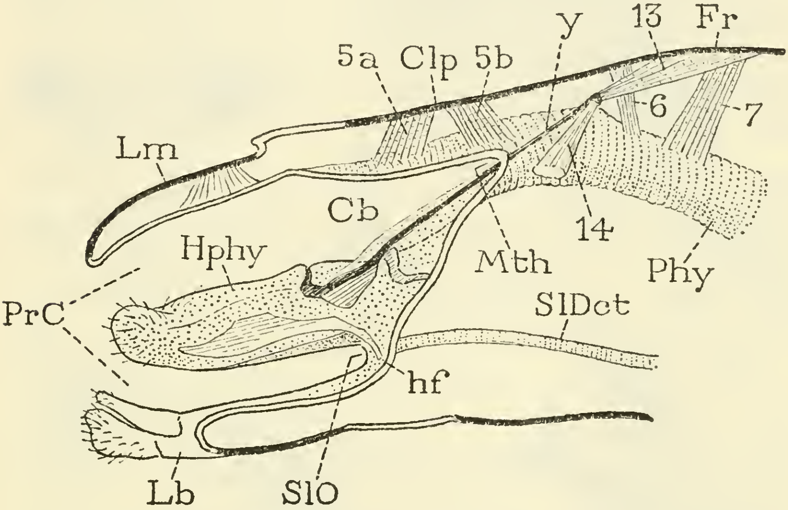

Fig. 23.—Vertical section through the left side of the head of a cockroach, exposing the preoral cavity.

Cb, cibarium; *Clp*, clypeus; *Fr*, frons; *hf*, hypopharyngeal fulcrum; *Hphy*, hypopharynx; *Lb*, labium; *Lm*, labrum; *Mth*, mouth; *Phy*, pharynx; *PrC*, preoral cavity; *SlDct*, salivary duct; *SlO*, salivary orifice; *y*, oral suspensory arm of hypopharynx.

5a,5b, dilator muscles of cibarium; *6,7*, frontal muscles of stomodaeum; *13*, adductor of hypopharynx; *14*, abductor of hypopharynx.

cibarium (food container). On its dorsal wall are attached strong muscles (*5a, 5b*) from the clypeus. The hypopharynx can be pressed against the inner clypeal wall by muscles (*13*) attached to arms (*y*) from its base. The cibarium then becomes a closed chamber that can be dilated by the clypeal muscles, and probably serves as a sucking organ when the cockroach drinks liquids. In insects that habitually feed on liquid food, the cibarium becomes elaborated to form a permanent sucking pump.

When we turn now to the mosquito, a section of the head (fig. 24 A) will show beneath the bulging clypeus (*Clp*) a small elongate capsule (*CbP*), which is the primary sucking pump. The basinlike lower wall is strongly sclerotized and, in the female, is directly con-

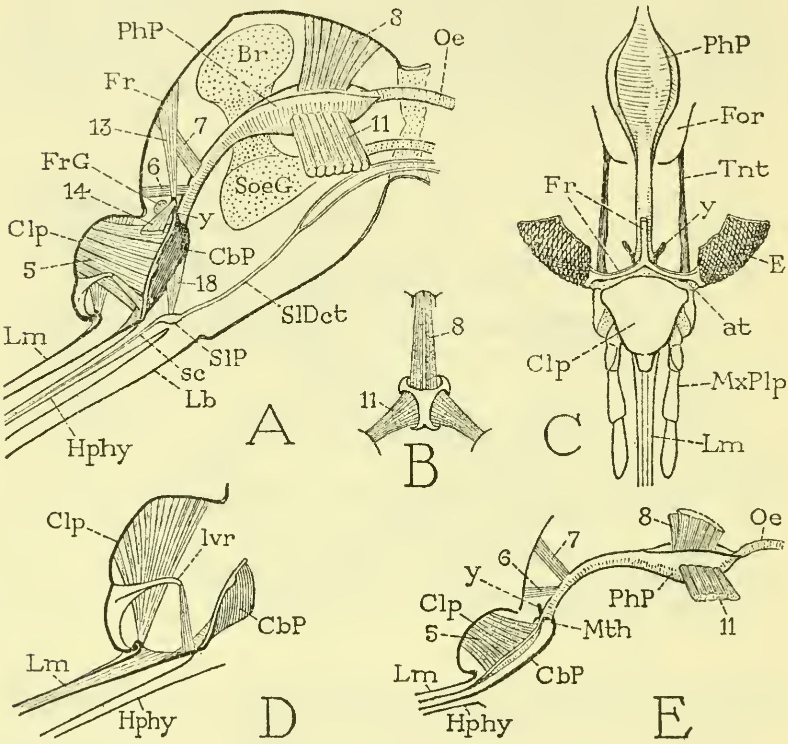

FIG. 24.—The sucking apparatus of an adult mosquito.

A, Diagrammatic section of female head. B, *Culex* sp., section of pharyngeal pump (from Thompson, 1905). C, *Aedes aegypti*, pharyngeal pump exposed by removal of anterior head wall. D, Same, muscles of labrum. E, Same, cibarial and pharyngeal pumps, left, cibarial pump opened to show lumen and dilator muscles.

at, anterior tentorial pit; *Br*, brain; *CbP*, cibarial pump; *For*, occipital foramen; *FrG*, frontal ganglion; *lvr*, labral lever; *MxPlp*, maxillary palpus; *Oe*, oesophagus; *PhP*, pharyngeal pump; *sc*, salivary canal; *SlP*, salivary pump; *SoeG*, suboesophageal ganglion; *Tnt*, tentorial arm; *y*, oral arm of cibarial pump. Other lettering as on figure 23.

tinuous with the supper surface of the hypopharynx (*Hphy*). The dorsal wall (E) is the so-called epipharyngeal surface from the labrum (*Lm*) to the mouth (*Mth*), and is thin and flexible. On it is attached a great mass of dilator muscles (5) from the clypeus. The inner end of the organ opens through the mouth (*Mth*) into the narrow first part of the alimentary canal, and at each side of the mouth projects a small process (*y*) on which are attached two antagonistic muscles (A, *13, 14*), as in the cockroach. All these features so closely duplicate those of the cibarium in the cockroach as to leave no doubt that the preoral sucking pump of the mosquito is the cibarium. In the mosquito, however, the organ has been made into a much more efficient sucking apparatus than that of the cockroach by the union of the edges of its lower hypopharyngeal wall with the epipharyngeal wall, thereby converting the lumen into a closed cavity. The clypeal muscles on contraction lift the flexible dorsal wall and expand the lumen, drawing in the liquid food from the canal of the labrum. On relaxation of the muscles the dorsal wall snaps back by its own elasticity and drives the liquid from the pump back through the mouth.

On the epipharyngeal wall of the cibarial pump are small spines and papillae of various kinds, some of which are sense organs. A comparative study of these structures and an armature of ventral teeth at the mouth entrance has been made by Sinton and Covell (1927), and Chwatt and Major (1945) in the anophelines, and by Barraud and Covell (1928) in anopheline and culicine species. The epipharyngeal sense organs are described by Day (1954).

The pharyngeal pump.—From the mouth at the inner end of the cibarial pump the stomodaeal section of the alimentary canal begins as a narrow tube (fig. 24 A,E) that curves upward and backward in the head, going between the brain (A, *Br*) and the suboesophageal ganglion (*SoeG*). Behind the brain it expands into a large, bulblike structure, which is the pharyngeal pump (*PhP*). The walls of the organ when relaxed are deeply concave above and on each side, as seen in cross section at B. Into the concavity of the dorsal wall is inserted a pair of large muscles (A,B,E, *8*) from the dorsal wall of the head behind the brain, and into each lateral concavity a large flat muscle (*11*) from the side of the cranium. Contraction of the muscles dilates the lumen of the pump; on their relaxation the walls spring together again by their own elasticity. From the rear end of the pump, the narrow oesophagus (*Oe*) proceeds through the neck into the thorax. A cibarial and a pharyngeal pump like those of the mosquito are common to bloodsucking nematocerous flies. Presumably the two pumps work in alternate phases to keep the ingested blood flowing freely back into the stomach. In the nectar-feeding male mosquito the sucking apparatus is less strongly developed than in the female.

THE THORAX

The thorax of a winged insect may truly be said to be the most remarkable anatomical mechanism developed anywhere in the animal kingdom. It is remarkable both for its efficiency as a flight mechanism and for its structural simplicity. In insects with two pairs of wings the two wing-bearing segments have essentially the same structure, and are equipped with duplicating sets of muscles. In the Diptera, however, in which the flight function has been taken over entirely by the first pair of wings, the mesothoracic wing muscles have to do the work of the muscles of both winged segments in four-winged insects. Consequently, the mesothorax of the flies has been greatly enlarged and the metathorax much reduced. The knobbed stalks known as *halteres* borne on the metathorax are undoubtedly reduced wings, since, as seen in the mosquito pupa (fig. 17 E), they are developed in flat wing lobes of the metanotum. They are still important accessories of flight, being vibratory organs for maintaining the equilibrium of the flying insect, but their musculature is very simple, and the usual wing musculature of the segment has been eliminated.

In the adult mosquito (fig. 25) the mesothorax appears as a great wedge inserted between the narrow prothorax and metathorax. It alone retains the structure typical of a thoracic segment. Two principal plates, an anterior *notum* (AN_2) and a posterior *postnotum* (PN_2), cover almost the entire dorsum of the thorax. The strongly convex postnotum, furthermore, is deeply infolded posteriorly beneath the narrow metanotum (N_3) and extends into the first abdominal segment as a bilobed *phragma* (fig. 27 D, *Ph*). A narrow paranotal fold (*pnf*) borders the edge of the notum between the first spiracle and the wing. The pleural area tapers downward and becomes continuous with the sternum (S_2) between the first and second legs. A typical *pleural sulcus* (PlS_2) extends from the base of the middle leg to the wing fulcrum at the base of the wing (*W*). The area before the groove is episternal, that behind it epimeral. The episternal area includes a major episternal plate (Eps_2) continuous below with the sternum, and a smaller preepisternum (eps_2). The epimeron (Epm_2) is a simple quadrate plate. Below it is a small triangular plate (S_3), which in the mosquito appears to be a postcoxal lobe of the sternum; but a plate in the same position in higher flies is the detached meron of the coxa. In some species the episternum is divided into an upper and a lower part (fig. 27 A).

The prothorax is so reduced and modified that it is difficult to interpret its parts. The notum (fig. 25 N_1) includes a narrow plate across the back beneath the overhanging front end of the mesonotum, and apparently a larger posterior plate on each side. This posterior plate, however, tapers narrowly down to the coxa so that its lower part must be epimeral. The episternum then is represented by a short plate (Eps_1) between the first notal plate and the coxa. A plate in the side of the neck (*CvPl*) that supports the head is unquestionably a cervical sclerite.

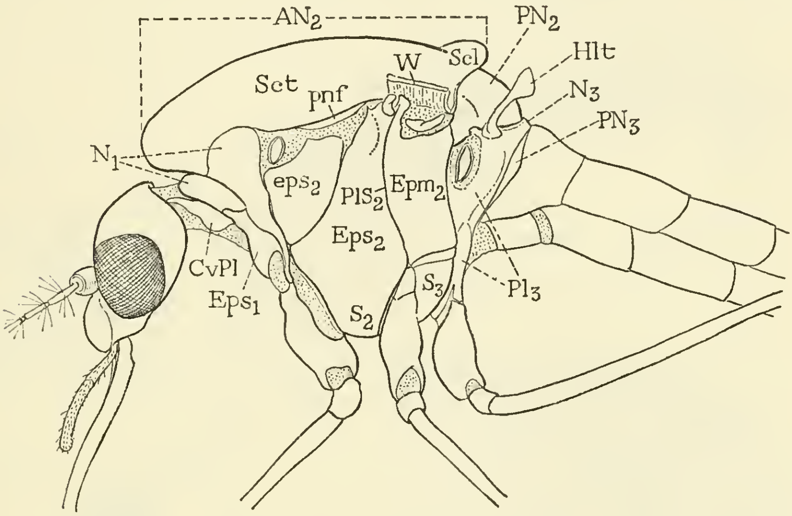

FIG. 25.—Thorax of *Psorophora*, with head and base of abdomen (from the author's illustration in Howard, Dyar, and Knab, 1912).

AN, wing-bearing notal plate; *CvPl*, cervical plate; *Epm*, epimeron; *Eps*, episternum; *eps*, preepisternum; *Hlt*, halter; *N*, notum; *Pl*, pleuron; *PlS*, pleural sulcus; *PN*, postnotum; *pnf*, paranotal fold; *S*, sternum; *Scl*, scutellum; *Sct*, scutum; *W*, wing.
Subnumbers *1,2,3* designate parts of prothorax, mesothorax, and metathorax.

The metathorax is even more simplified than the prothorax. The notum (fig. 25, N_3) is much narrowed across the back, but it expands on the sides where it carries the halteres (*Hlt*). From the notum the pleural region continues downward on the side, tapering to the hind coxa. Close to its posterior margin is a faint line that perhaps represents the pleural sulcus. A narrow strip (PN_3) between the metanotum and the first abdominal segment, more plainly seen in *Aedes* (fig. 27 C,D, PN_3), is clearly the metapostnotum, since it gives attachment to the first abdominal muscles (G).

The wings of the mosquito have a simple pattern of venation, shown at A of figure 26, in which the veins are named according to the Comstock-Needham system. Mosquito taxonomists, however, usually designate the veins behind the subcosta by numbers. In this scheme R_1 is vein *1*, R_2 and R_3 are branches of vein *2*, R_{4+5} is vein *3*, *M* and its two branches are vein *4*, *Cu* and its two branches are vein *5*, and *A* is vein *6*. The veins are densely clothed on both sides of the wing with long, slender, fusiform, or scalelike setae (omitted in the figure).

While the simple venation of the mosquito wing is of a fairly generalized pattern, the basal wing structure has little resemblance

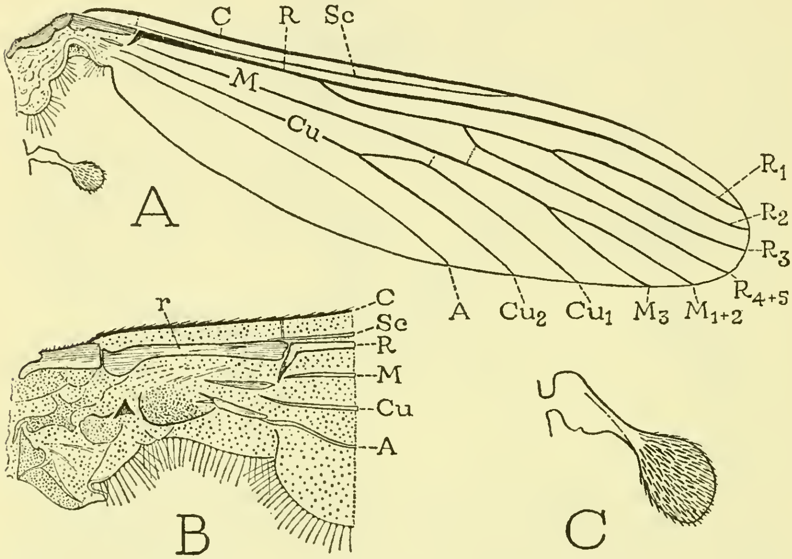

FIG. 26.—The wing and halter.

A, *Culex*, left wing and halter, wing partly flexed on basal lobe, scales removed to show venation. B, *Anopheles*, base of wing, flattened. C, *Culex*, halter enlarged, posterior.

A, anal vein; *C*, costa; *Cu*, cubitus; *M*, media; *R*, radius; *Sc*, subcosta.

to that of most other insects, and would appear to be specialized by elimination of the usual axillary sclerites. When the wing is flexed (fig. 26 A) a fold near the base sets off a triangular basal lobe by which the wing is attached to the thorax. During flexion the wing turns posteriorly over the basal lobe, which is then covered from above by the fully flexed wing, and gives the wing the appearance of being supported on a lobe of the thorax. The principal sclerotization of the wing base is a long, anterior jointed bar (B, *r*) that supports the radial vein, and bends at the joint when the wing is flexed (A).

Otherwise the membrane of the whole basal area is occupied by irregular thickenings or weak sclerotizations that are hardly sclerites and seem to have no mechanical significance. They are better developed in *Anopheles* (B) than in *Culex* (A). The same structure in modified form is present also in some related Nematocera, but not in Tipulidae.

The wing mechanism of extension and flexion is not understood, but all the direct muscles of flight appear to be attached on the basal lobe. The indirect flight muscles are as fully developed as in any other fly. They include great masses of dorsal longitudinal fibers and lateral vertical fibers that almost completely fill the thorax. The weight of the flight muscles of *Aedes* has been calculated by Hocking (1953) as from 16.5 to 18.7 percent of the total body weight, which, however, is small as compared with *Tabanus* in which the flight muscles are 23 to 35 percent of the body weight.

The rate of the wing vibration in flight, measured in wing beats per second, is given by Sotavalta (1947) for females as 165 to 196 for *Culex pipiens,* 165 to 247 for *Anopheles maculipennis,* 241 to 311 for *Aedes cantans* and *Aedes punctor.* With males the rate is consistently higher, from 330 to 587 beats per second by *Anopheles* and *Aedes.* Hocking (1953) has measured the flying speed of five species of *Aedes.* In ordinary cruising flight they go from 75 to 110 centimeters per second, but for short distances they can make 220 to 252 centimeters in a second.

The legs of the mosquito have no unusual features, except for their length and relative slenderness. Each leg (fig. 17 B) has the usual six segments of an insect leg, a coxa, trochanter, femur, tibia, tarsus, and pretarsus. The long tarsus is subdivided into five tarsomeres. The pretarsus has two decurved claws but no arolium. In some species, as in *Culex,* the foot is provided with a pair of small padlike pulvilli; in others there is only a heel-like hairy swelling at the bases of the claws. Most mosquitoes, however, whether they have foot pads or not, are able to cling to smooth vertical surfaces, such as window panes or the walls of a glass jar.

THE ABDOMEN

The abdomen of the adult mosquito (fig. 27 A) is broadly joined to the thorax and tapers posteriorly. The tergal and sternal plates are separated on the sides by membranous areas containing the spiracles, which are present on segments I to VII. In each sex the abdomen has 10 segments, as in the pupa, but in the females of some species the eighth segment is ordinarily retracted into the seventh, and in the male the ninth segment is concealed within the eighth.

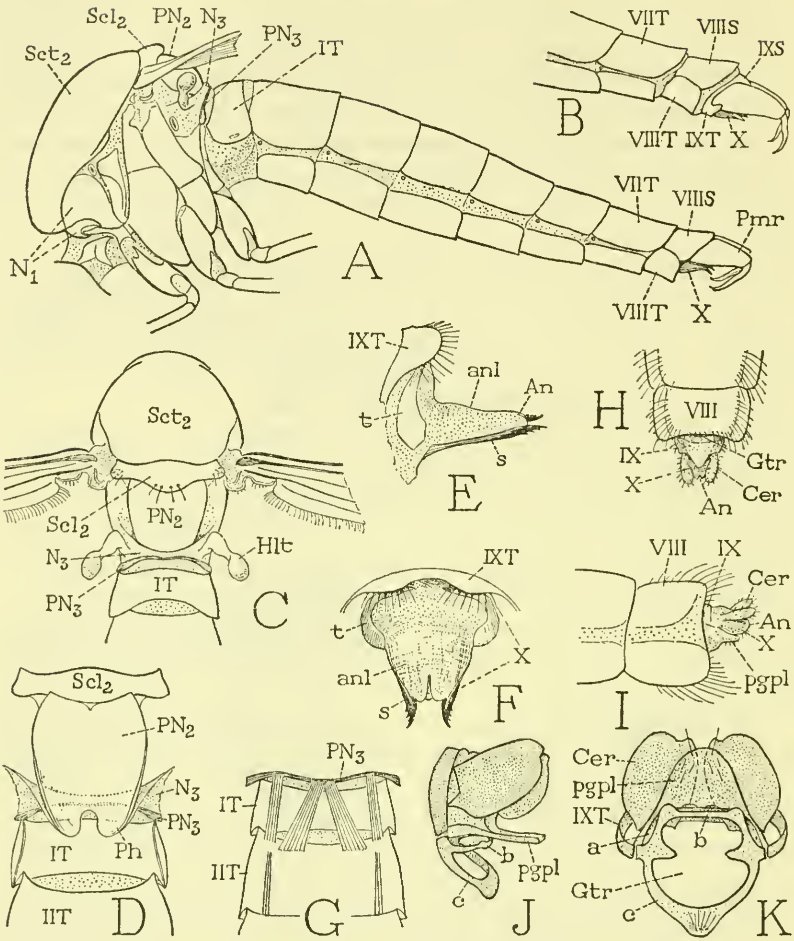

FIG. 27.—Details of the adult thorax and abdomen.

A, *Aedes aegypti*, male thorax and abdomen. B, Same, end of abdomen extended. C, Same, thorax and base of abdomen, dorsal. D, Same, postnotum of metathorax extended as a phragma into base of abdomen, ventral. E, Same, tenth abdominal segment of male, lateral. F, Same, undersurface (dorsal). G, Same, showing dorsal muscles of first abdominal segment. H, *Culex*, end of female abdomen, ventral. I, Same, lateral. J, Composite diagram of female terminalia, lateral (from Gerry 1932). K, Same, ventral, with ventral arc of sigma (*c*) turned forward (from Gerry 1932).

a, cowl; *An*, anus; *b*, dorsal arc of sigma (ninth sternum?); *c*, ventral arc of sigma; *Cer*, cercus; *Gtr*, gonotreme (opening of genital chamber); *Hlt*, halter; *N*, notum; *pgpl*, postgenital plate; *Ph*, phragma; *Pmr*, paramere; *PN*, postnotum; *s*, lateroventral prong of tenth segment; *S*, sternum; *Scl*, scutellum; *Sct*, scutum; *t*, tergum of tenth segment; *T*, tergum.

Subnumbers *1-3*, thoracic segments; *I-X*, abdominal segments.

The male mosquito is readily distinguished from the female by the presence of a pair of large, two-segmented genital claspers, or *parameres,* projecting from the end of the abdomen (fig. 27 A, *Pmr*). Though the ninth segment is ordinarily concealed by retraction into the eighth, on pulling out the end of the abdomen (B), it is seen to be a small sclerotic ring (*IX*) carrying the parameres. The anus-bearing tenth segment, or proctiger (*X*), is mostly hidden between the bases of the parameres, and is *apparently* ventral in position. In fact, the whole terminal part of the male abdomen beyond the seventh segment, except in newly emerged individuals, is turned upside down, so that the tergal plates are ventral and the sternal plates dorsal. The inversion takes place slowly during the first 24 to 48 hours after emergence from the pupa.

The tenth abdominal segment of the male is a flattened anal lobe with an expanded base projecting from above the inverted tergum of the ninth segment (fig. 27 E,F). In its base are two dorsolateral sclerites (*t*) that may be regarded as tergites. On the ventral (upper) surface are two marginal bars (*s*), the ends of which project as a pair of free, toothed prongs. These bars have commonly been regarded as sternites, but Christophers (1923) says they are the cerci united with the anal lobe.

The external genital organs of the male insect, because of their generic and specific variations, are important diagnostic features for taxonomists. In the mosquito they include primarily the paired lateral claspers and a median intromittent organ, carried by the ninth abdominal segment. Various names are given to these parts by different specialists, but the organs have essentially the same origin in all insects, and there is no need for special terms in the several orders, and certainly there is no excuse for specialists in one order to use different names for the same parts in different species. For simplicity the claspers are here termed the *parameres,* and the intromittent organ the *aedeagus.* Various secondarily developed accessory parts, of course, must have more specific names.

In the insects in general the male genitalia take their origin from a pair of *primary phallic lobes* that develop in a late instar of the nymph or larva on the posterior part of the ninth abdominal segment at the sides of the future gonopore. Later, each lobe divides into two parts, a mesal *mesomere* and a lateral *paramere.* Eventually the mesomeres unite around the gonopore to form the aedeagus, and the parameres become the claspers.

The development of the genital organs in the male mosquito has been shown by Christophers (1922) to proceed in the usual manner.

Early in the fourth instar of the larva paired thickenings of the epidermis appear behind the region of the ninth sternum. These "genital plaques" soon take on the form of budlike outgrowths, which are the primary phallic lobes (fig. 28 A, *PhL*). With further development the lobes elongate and unite at their bases, forming the genital ap-

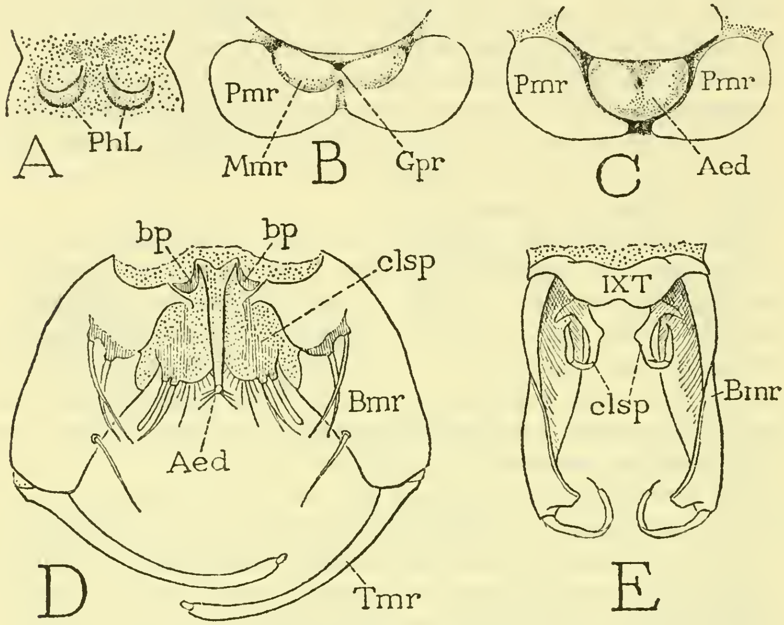

FIG. 28.—External genital organs of the adult male, and their development. (A,B,C, from Christophers, 1922.)

A, The primary phallic lobes that appear in a late instar larva behind the sternal region of the ninth abdominal segment. B, Later stage of same, each primary lobe divided into a mesomere and a paramere. C, Still later stage, mesomeres united around the gonopore to form the aedeagus. D, Adult genital apparatus of *Anopheles quadrimaculatus*, lower surface (dorsal). E, Parameres and claspettes of *Aedes pullatus*.

Aed, aedeagus; *Bmr*, basimere; *bp*, basal plate; *clsp*, claspette; *Gpr*, gonopore; *IXT*, ninth abdominal tergum; *Mmr*, mesomere; *PhL*, primary phallic lobes; *Pmr*, paramere; *Tmr*, telomere.

pendages as they appear in the pupa (fig. 16 F). At this stage the lobes are termed "proandropodites" by Christophers (1922), but this term literally translated would mean "primitive male parts of legs" (as "coxopodite" means the "coxal part of a leg"). Since there is no real evidence that the male genital organs of insects represent primitive legs, the genital organs of the pupa are simply the developed phallic lobes. Within them are formed the definitive genitalia of the adult. From the base of each lobe inside the pupal cuticle, as described by Christophers, is cut off a small median lobe (fig. 28 B, *Mmr*), and the lateral part becomes the rudiment of the clasper (*Pmr*). Finally, the two median lobes unite around the gonopore to form the aedeagus (C, *Aed*), while the lateral parameral lobes elongate to become the two-segmented claspers of the adult (D,E).

In the mature condition the genitalia take on a great variety of forms and are complicated by the development of accessory parts. All this is a great boon to taxonomists, but it often creates difficulty for the morphologist. *Anopheles quadrimaculatus* (fig. 28 D) gives a good example of one type of structure. Each paramere is divided into a large *basimere* (*Bmr*) and a long slender *telomere* (*Tmr*). The telomere is movable on the basimere by strong antagonistic muscles arising in the latter. The slender aedeagus (*Aed*) lies between the bases of the parameres and is connected with the basimeres by a pair of small *basal plates* (*bp*). The basimeres are equipped with long spines, and proximally each bears a membranous median lobe (*clsp*) united with the one from the opposite side. Each lobe is armed with strong spines and is known as a *claspette*, or *claspette lobe*. In other genera the claspettes are more commonly independent appendages of the parameres, as seen in *Aedes* (E). The claspettes, according to Christophers (1922), are cut out from the parameres by secondary incisions of the latter.

For illustrations of generic and specific variations in the male genital structure the student must consult taxonomic papers, but the nomenclature will be confusing. In the current terminology of mosquito specialists, the aedeagus is called the "mesosome" or "phallosome," the basal plates (*bp*) that connect it with the claspers are the "parameres," and the claspers are the "side pieces." In this scheme the term "paramere" is entirely misapplied, since it was first given to the claspers, and moreover, "side piece" is a direct English translation of "paramere." The segments of the claspers are known also as the "basistyles" and "dististyles," but as shown by their development the claspers have no relation whatever to legs or abdominal styli. The terminology given on figure 28 is recommended for its simplicity and because it can be applied, on the basis of development, to the male genitalia in all the principal orders of insects (see Snodgrass, 1957).

The terminal parts of the female abdomen are much simpler than those of the male, but their homologies are more difficult to understand. Beyond the eighth segment projects a small lobe (fig. 27 I) representing the combined ninth and tenth segments. The dorsum of the ninth segment is a transverse basal arc (*IX*) usually containing a small tergal sclerite. Beyond it is the tenth segment (*X*) bearing a pair of lateral cerci (*Cer*) and the terminal anus (*An*). Ventrally is a lobe known as the *postgenital plate* (*pgpl*) because the gonotreme (H, *Gtr*), or opening of the genital atrium, is situated at its base above the sternum of the eighth segment (*VIII*). The nature of the postgenital plate is doubtful; it looks as if it should be the projecting sternum of the ninth segment. On its base there is generally a transverse fold known as the *cowl* (K, *a*) because it is sometimes reflected to form a hoodlike pocket. Surrounding the gonotreme above the end of the eighth sternum is a sclerotized ring (*b, c*) named the *sigma* by Christophers (1923). In figure K the ventral arc of the sigma (*c*) is turned forward; normally it is directed posteriorly (J, *c*). The sigma thus, as described by Christophers, resembles the lips of a half-opened clasp purse, in which it is represented by the metal framework of the purse. Some writers, however, without adducing specific evidence, regard the dorsal arc of the sigma as the ninth sternum. According to Christophers the whole structure is formed as a sclerotization in the intersegmental membrane of the gonotreme.

All parts of the female terminalia are subject to much variation, as shown in comparative studies by Macfie and Ingram (1922), Christophers (1923), Davis (1926), Gerry (1932), Gjullin (1937), Roth (1946), Rees and Onishi (1951), and Hara (1957). The student, however, will be somewhat confused by the different ways the parts are represented and named. The drawings J and K on figure 27, taken from Gerry, are composite diagrams showing all the parts that have been described, but they probably do not present the exact structure in any one species.

The gonotreme surrounded by the sigma above the eighth abdominal sternum leads into a small infolded pouch, the *genital chamber,* or *atrium.* In its anterior wall is the female gonopore, which is the opening of the median oviduct. Behind the gonopore the globular spermathecae (one, two, or three in number) open through the dorsal wall of the atrium, and into a posterior pouch of the dorsal wall, the *caecus,* opens the single accessory gland, called the "mucus gland," but the nature of its secretion is not known (fig. 30 B).

INTERNAL ANATOMY

A thorough study of the internal anatomy of the mosquito has not been made, but the parts of principal interest will be the alimentary canal and the reproductive organs. The muscular and tracheal systems have no features peculiar to the mosquito, and even the unusual characters of the reproductive organs are common to other Diptera. The simple nervous system is that of the larva with an elaboration of the brain and the optic lobes in the head, a transposition of the first abdominal ganglion to the thorax, and the union of the eighth abdominal ganglion with the ganglion of the seventh segment. In the abdomen of the adult, therefore, the first ganglion is in the second segment (fig. 30 C, *GngII*), and the last is a composite ganglion (*Gng VII+VIII*) in the seventh segment. The tracheal system has lost the large dorsal trunks of the larva, and the lateral trunks along the spiracles have been enlarged.

The circulatory organs.—In the adult mosquito, as described by Jones (1954) in *Anopheles,* the dorsal blood vessel has in general the same structure as that of the larva. The part in the abdomen, however, is more distinctly "chambered" because of segmental swellings before the ostia. An aortic sinus is said by Jones (1952) to be present in the adult as in the larva and pupa of *Anopheles, Culex,* and *Aedes.* The sinus is a dilatation of the aorta in the dorsal part of the thorax, with the corpora allata-cardiaca attached to it laterally. Anteriorly the sinus is continued into the cephalic aorta. The adult heart, according to Jones, beats predominantly forward, but periodically reverses the direction of the beat. The heart has no innervation from any source and therefore its pulsations are myogenic, that is, engendered by the muscles themselves of the heart wall. Lateral alary muscles support the heart, but they do not vibrate, and when cut the heart keeps on beating.

A vibratile muscular membrane across the cavity of the mesothoracic scutellum appears to be an accessory pulsatile organ, as in some other insects. A frontal bulblike organ between the bases of the antennae has been described by Day (1955) as a sense organ, and by Clements (1956) as a pulsating organ for driving blood into the antennae. If it is a sense organ, it is a newly discovered one as Day claims; if it is a pulsating organ it is not unique since a pulsatile organ in the same place is present in various other insects.

The alimentary canal.—The alimentary canal of the adult mosquito (fig. 29 A) in its general form is quite different from that of the larva. From the pharyngeal pump in the head (*PhP*) a short, narrow oesophagus (*Oe*) extends into the front of the thorax, where it joins a wider tube, which is the beginning of the stomach, or *ventriculus* (*Vent*). Shortly before its junction with the stomach the oesophagus gives off three pouches, known as the *oesophageal diverticula,* two of which are dorsal and one ventral. In *Aedes aegypti* the dorsal diverticula (A, *ddv*) are small, flat, elongate sacs with slender necks diverging forward and laterally from the oesophagus (C). The single ventral diverticulum (*A, vdv*) has a long, slender neck which expands into a large sac in the anterior half of the abdomen. This ventral diverticulum corresponds with the usual "crop" of other Diptera.

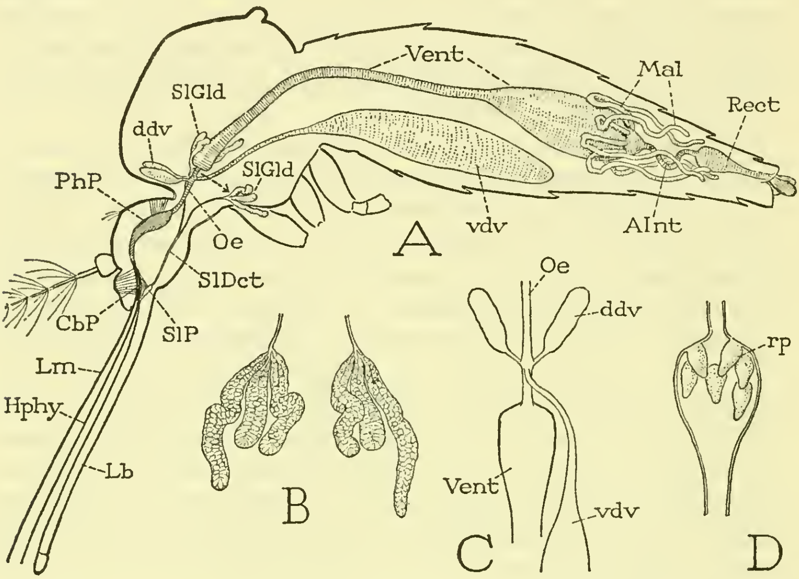

FIG. 29.—Alimentary canal and salivary glands of the adult female of *Aedes aegypti.*

A, Sectional view of body showing alimentary canal and salivary system (glands on left displaced). B, The salivary glands. C, The oesophageal diverticula, ventral. D, Rectal sac and papillae.

AInt, anterior intestine; *CbP,* cibarial pump; *ddv,* dorsal diverticulum; *Hphy,* hypopharynx; *Lb,* labium; *Lm,* labrum; *Mal,* Malpighian tubules; *Oe,* oesophagus; *PhP,* pharyngeal pump; *Rect,* rectum; *rp,* rectal papillae; *SlDct,* salivary duct; *SlGld,* salivary glands; *SlP,* salivary pump; *vdv,* ventral diverticulum; *Vent,* ventriculus.

The ventriculus (fig. 29 A, *Vent*), which is the functional stomach of the insect, for most of its length in the female mosquito is a narrow tube that extends upward through the thorax and then turns backward into the abdomen where it ends in a saclike enlargement that joins the intestine. The first part of the latter, or *anterior intestine* (*AInt*), is a short, slender tube thrown into a small loop. Its anterior end, the pyloric region, joins the ventriculus by a funnel-shaped expansion. At the other end the anterior intestine is continued into the *posterior intestine,* or *rectum* (*Rect*), which is much enlarged anteriorly and tapers back to the anus. The inner wall of the pyloric funnel is armed in some species with numerous small spines directed posteriorly. These pyloric spines have been described and well illustrated by Trembley (1951) in species of *Anopheles, Aedes,* and *Culex.* In the anterior end of the rectum are six small, soft, conical rectal papillae (D, *rp*) projecting inward from the rectal wall. Five Malpighian tubules (A, *Mal*) arise from the pyloric region of the intestine as in the larva.

The oesophageal diverticula are said to be empty on emergence of the mosquito from the pupa. Within an hour after ecdysis, however, according to Marshall and Staley (1932), the air that was pumped into the stomach begins to pass forward into the diverticula, and in 12 to 22 hours the stomach is empty.

The function of the oesophageal diverticula in relation to food intake has been studied by a number of investigators, but, though using the same experimental methods of feeding, the latter have not all come to the same conclusions. The subject has recently been well reviewed by Trembley (1952) and by Megahed (1958), and good bibliographies are given by both these writers. In general it is found that ingested blood goes directly to the stomach, while fruit juices and sugar solutions go first into the diverticula, to be later delivered to the stomach. According to Trembley, blood in small amounts may occasionally go to the diverticula, and sugar solutions sometimes go direct to the stomach. The work of Megahed on *Culicoides* gives essentially the same results, the stomach being ordinarily the receptacle for blood, the diverticula for concentrated sugar solutions, but water and dilute sugar solutions go direct to the stomach. Most observations seem to apply to the female insect. Day (1954), however, in experiments on male mosquitoes, found that the sexes react similarly: "blood went to the mid-gut and sugar to the diverticulum in the male in spite of the fact that males do not ingest blood under natural conditions."

The "switching mechanism" that determines whether the ingested food goes into the stomach or the diverticula, Day (1954) has proposed, is governed by the different kinds of sense organs in the wall of the cibarial pump (buccal cavity). If receptors of one type are stimulated by sugar it may be supposed that they cause a relaxation of sphincter muscles of the diverticula; if others are sensitive to blood components, they may effect a relaxation of the cardiac sphincter of the stomach. In the neck of the ventral diverticulum, Day notes the presence of a group of spines, which would appear to assist in keeping blood corpuscles out of the diverticulum when the circular muscles in the neck of the diverticulum are contracted.

The salivary glands.—The salivary glands of the mosquito consist each of three lobes (fig. 29 B), of which the middle lobe is shorter than the other two. The glands lie at the sides of the anterior end of the ventriculus (A, *SlGld;* the left gland is displaced in the figure). The two ducts extend into the back of the head, where they unite in a single outlet tube (fig. 24 A, *SlDct*), which ends at the base of the hypopharynx in a small syringelike swelling that acts as a salivary ejection pump (*SlP*). On the elastic dorsal wall of the pump is inserted a dilator muscle (*18*) from the floor of the cibarial pump. The salivary pump discharges through the salivary canal (*sc*) of the hypopharynx in the female; in the male the duct traverses the labium (fig. 22 F). The salivary secretion in species of *Anopheles,* according to Metcalf (1945), contains both an anticoagulin and an agglutinin, but in other pest species neither appears to be present.

The salivary glands are of particular interest in connection with the transmission of disease by mosquitoes. They offer the only avenue of escape for disease organisms from the body cavity of the mosquito into the blood of an alternate host. The sporozoites of malaria, for example, that penetrate into the salivary glands are carried in the saliva of the biting mosquito directly into the vertebrate host, which is necessary for the completion of the complex life history of the malaria parasite, *Plasmodium.* This suggests the question of how it became obligatory for some parasites to divide their developmental history between two different animals, but the known facts give no answer. Mosquitoes do not bite each other, and there is no way by which the malaria parasite can be normally transferred from one vertebrate to another.

The reproductive system.—The organs of reproduction in the Diptera include the parts common to all insects, but their structure in two respects is exceptional. Each testis appears to correspond with a single testicular tube in other insects; the egg tubes of each ovary are extremely small, and all are enclosed in a cellular sheath.

The male organs of the mosquito include a pair of *testes* (fig. 30 E, *Tes*), a pair of testicular ducts, or *vasa deferentia* (*Vd*), which enlarge posteriorly to form a pair of *seminal vesicles* (*SV*) that in some species are united (D). The vesicles end in a very short common *ductus ejaculatorius* (*Dej*), which receives a pair of large *accessory* glands (*AcGld*) and then opens directly into the base of the aedeagus (*Aed*). In the normal condition the reproductive organs lie beneath the alimentary canal, but, with the inversion of the terminal segments of the abdomen, the relation is reversed (fig. 30 A)—the ejaculatory

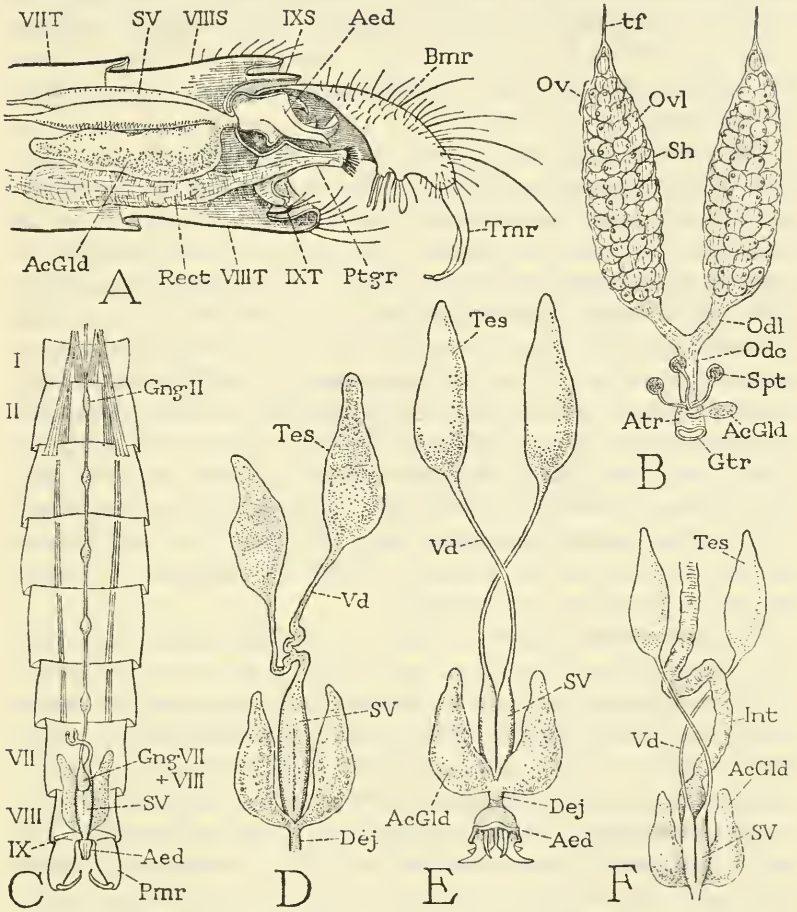

FIG. 30.—Reproductive organs and the abdominal nerve cord of the adult mosquito.

A, *Culex quinquefasciatus*, end of male abdomen, left side removed, exposing the inverted reproductive organs and rectum. B, Diagram of female reproductive organs, dorsal (adapted from Christophers, 1901). C, *Aedes aegypti*, male, ventral nerve cord of abdomen and genital outlets, dorsal. D, Same, male reproductive organs, ventral. E, *Culex quinquefasciatus*, male reproductive organs after inversion, lower side (dorsal). F, Same, with part of intestine, upper side (ventral).

AcGld, accessory gland; *Aed*, aedeagus; *Atr*, atrium, genital chamber; *Bmr*, basimere; *Dej*, ductus ejaculatorius; *Gng*, ganglion; *Gtr*, gonotreme; *Int*, intestine; *Odc*, oviductus communis; *Odl*, oviductus lateralis; *Ov*, ovary; *Ovl*, ovariole; *Pmr*, paramere; *Ptgr*, proctiger; *Rect*, rectum; *S*, sternum; *Sh*, sheath of ovary; *Spt*, spermatheca; *SV*, seminal vesicle; *T*, tergum; *Tes*, testis; *tf*, terminal filament of ovary; *Tmr*, telomere; *Vd*, vas deferens.

duct, the seminal vesicles, and the accessory glands now lie above the intestine. Since the testes are not affected by the inversion, the long *vasa deferentia* as in *Culex* (E) cross each other, but when the ducts are united as in *Aedes* (D) a simple twist takes place at the junction of the ducts.

The testis of most insects consists of a number of individual tubes in which the spermatozoa are formed as are the eggs in the ovarian tubes, and, except in the apterygotes, the tubes of each testis are enclosed in an investing sheath. The testes of the mosquito are elongate, pear-shaped bodies (fig. 30 D,E,F, *Tes*) continuous with the ducts. Each testis, however, appears in its entirety to be a single testicular tube. The same is true of the testes in other Diptera. In the narrowed upper end of each organ is a mass of undifferentiated cells; the rest of the lumen is filled with spermatocytes and spermatozoa in various stages of development. The mature spermatozoa are extremely long and threadlike; when liberated from the testis they exhibit active undulatory movements. The spermatozoa are stored in the seminal vesicles preliminary to mating, and the accessory glands probably have a prostate function, giving the spermatozoa a liquid medium in which they are discharged.

The reproductive organs of the female mosquito, represented diagrammatically at B of figure 30, include the parts characteristic of the female organs of insects in general. These are a pair of *ovaries* (*Ov*), the lateral *oviducts* (*Odl*) from the ovaries, and a median *common oviduct* (*Odc*) with which the lateral ducts are joined. The common duct opens by the primary genital aperture, or *gonopore,* into a small pocket above the end of the eighth abdominal sternum. This pocket, the *genital chamber,* or *atrium,* being a secondary inflection of the body wall between the eighth and ninth abdominal segments, is therefore not a part of the primary genital passage. The external opening of the atrium may be designated the *gonotreme* (*Gtr*). Into the dorsal wall of the atrium just behind the gonopore open the ducts of the spermathecae (*Spt*), which are usually three in number, though in *Anopheles* there is only a single spermatheca. Behind the spermathecal openings arises an *accessory gland* (*AcGld*), the function of which is not known in the mosquito. In other insects accessory glands usually secrete a cement for attaching the eggs to a support, or a material to form an egg covering.

The atrium serves as a copulatory pouch at the time of mating, and the spermatozoa from the male are stored in the spermathecae. Then when the eggs leave the oviduct they are received in the atrium and are here fertilized by sperm discharged from the spermathecae. Finally the eggs are passed out through the gonotreme at the time of laying.

The ovaries of the mosquito differ in several respects from the usual structure of these organs in other insects. A typical insect ovary consists of a group of slender tubes known as *ovarioles* opening into the end of a lateral oviduct. The ovarioles taper upward and end in filaments that unite in a common strand attached to tissues in the neighborhood of the heart. A mature ovariole contains a series of ripening egg cells of successively larger size, with the mature egg in its lower end. Each egg is accompanied by a number of nutritive cells, or so-called *nurse cells,* which are absorbed by the egg as it matures. Each egg and its nurse cells are contained in a compartment of the ovariole known as a *follicle.* The follicles appear as swellings along the ovariole, increasing in size with the growth of the egg. The egg cell and the nurse cells are formed by division of the undifferentiated cells in a chamber, the *germarium,* in the upper end of the follicle. The eggs do not pass down the ovarioles; each ovariole grows from the germarium as an egg leaves the lowermost follicle and the latter disintegrates.

In the mosquito ovary (fig. 30 B) the ovarioles (*Ovl*) are very short and are arranged in rows along an axial cavity of the ovary. As in other Diptera, each ovary is invested in a thin membranous sheath (*Sh*) in which there are fine muscle fibers, and the sheath itself ends in a terminal filament (*tf*) attached to tissues along the sides of the heart. The muscle fibers of the ovarian sheath in *Anopheles* are said by Nicholson (1921) to be striated, but Jones (1958) finds that those of *Aedes* do not show a distinct striation in live, unstained whole mounts at 1,000 magnification under phase optics.

Each ovariole consists of a large egg-containing follicle with a small projection on its free end representing the germarium and one or two minute undeveloped follicles. The structure of the egg follicle of *Culex* has been described by Nath (1924), and an account of the development of the ovary and the development and nutrition of the eggs in the ovary of *Anopheles* is given by Nicholson (1921), by Christophers, Sinton, and Covell (1928), and by Mer (1936). The developmental processes described in the mosquito differ little from those in insects generally.

Many female mosquitoes need a meal of blood for the production of eggs. The eggs of *Anopheles* and *Aedes* are fully developed in two to three days after the female has fed. It is said by Roy (1936) that in

Aedes there is "a definite quantitative relationship between the weight of the blood meal and the number of eggs produced." As noted by Christophers, Sinton, and Covell (1928), the eggs in the lower follicles of all the ovarioles mature at the same time, so that as many eggs are ready for laying as there are ovarioles. When these eggs are deposited the eggs in the next follicles above mature, and so the production of fresh lots of eggs "seems to have no limit other than the life of the mosquito."

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VOLUME 139, NUMBER 9

Roebling Fund

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By
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A LONG-RANGE FORECAST OF UNITED STATES PRECIPITATION

By C. G. Abbot

Research Associate, Smithsonian Institution

FOREWORD

A hidden family of harmonic regular periods exists in weather. The periodic members of this family persist with unchanged lengths for scores of years. By determining their average forms and amplitudes for intervals of a thousand months, successful forecasts may be made for years to come; or backcasts may be made for former years and compared to former events. Agreement of such backcasts with the records warrants confidence in future forecasts.

These claims seem preposterous to most meteorologists. Therefore, before proceeding to explain the method and to give forecasts to 1967 for 32 cities of the United States, illustrative forecasts for the years 1950 to 1958 will now be shown and compared to the records of that interval graphically.

Figures 1, 2, and 3 show forecasts (dotted) and the observed march of precipitation, 1950-1958. These curves represent 3-month running means, and are expressed in percentages of normal precipitation. Figure 1 represents precipitation at Madison, Wis., and figure 2 at Nashville, Tenn. The curve at the top of figure 2 will be described later. Figure 3 shows forecast and observation for Sacramento, Calif.

I have computed for several cities coefficients of correlation between my forecasts and the observed precipitation for the years 1950 through 1958. They are as follows: Washington, D. C., 52.3 percent; Cincinnati, Ohio, 57.3 percent; Nashville, Tenn., 59.0 percent; Independence, Kans., 52.0 percent; Madison, Wis., 56.6 percent; Sacramento, Calif., 69.0 percent.

These coefficients indicate that my forecasts are over halfway toward perfect long-range prediction of weather. There still remain undisclosed variables that produce the discrepancy of about 40 percent between my coefficients and perfect correlation.

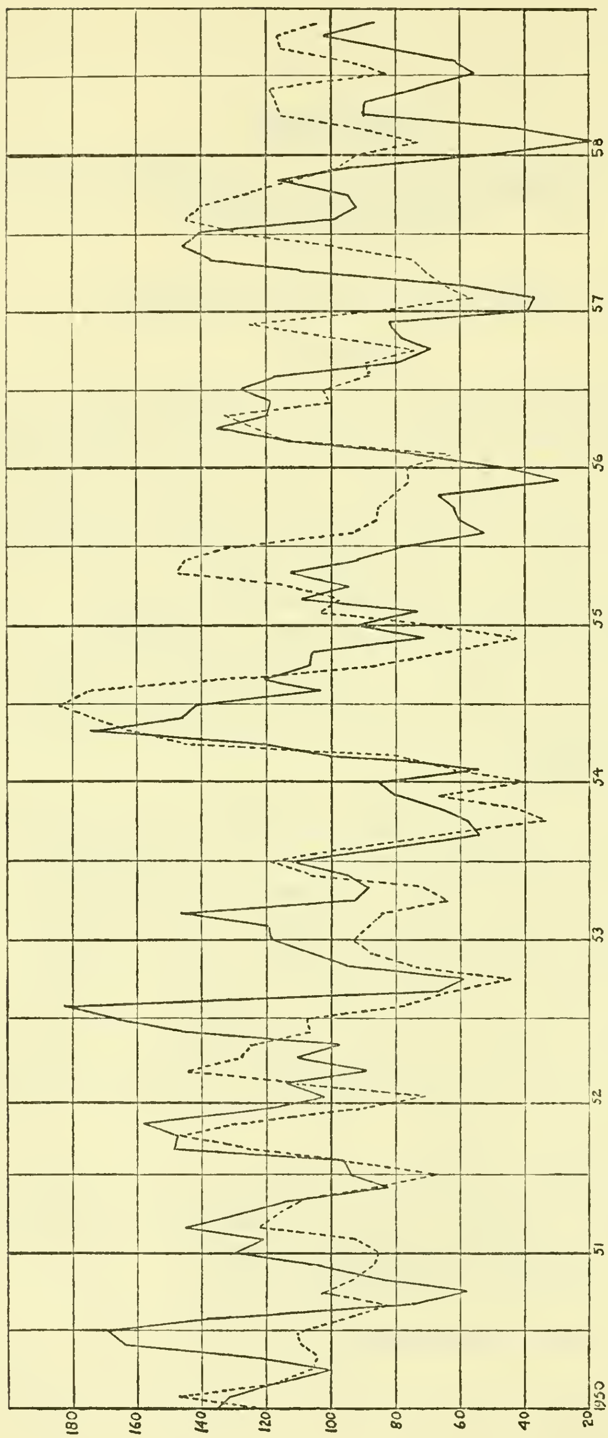

FIG. 1.—Madison, Wis. Forecast and event of monthly departures from normal precipitation, 1950-1958. Normal, heavy horizontal line; forecast, dotted line; event, full curve. All from 3-month running means.

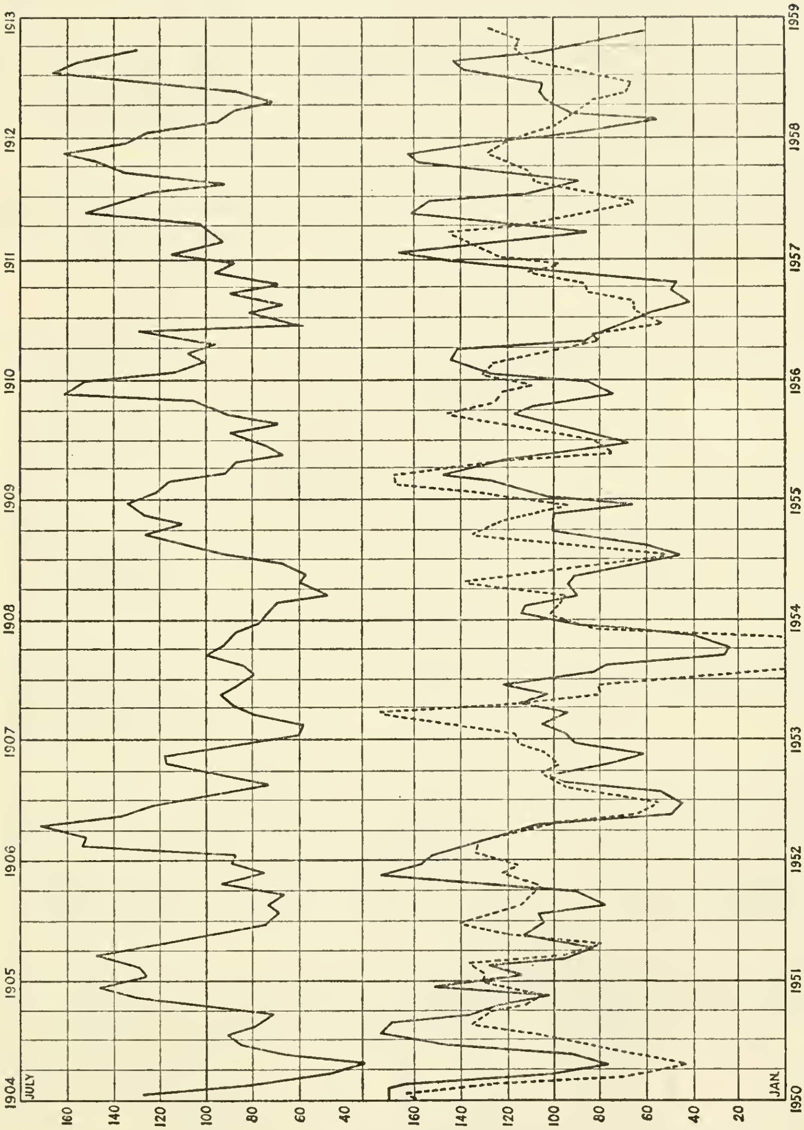

FIG. 2.—Nashville, Tenn. Forecast and event of monthly departures from normal precipitation, 1950-1958. Normal, heavy horizontal line; forecast, dotted line; event, full curve. All from 3-month running means.

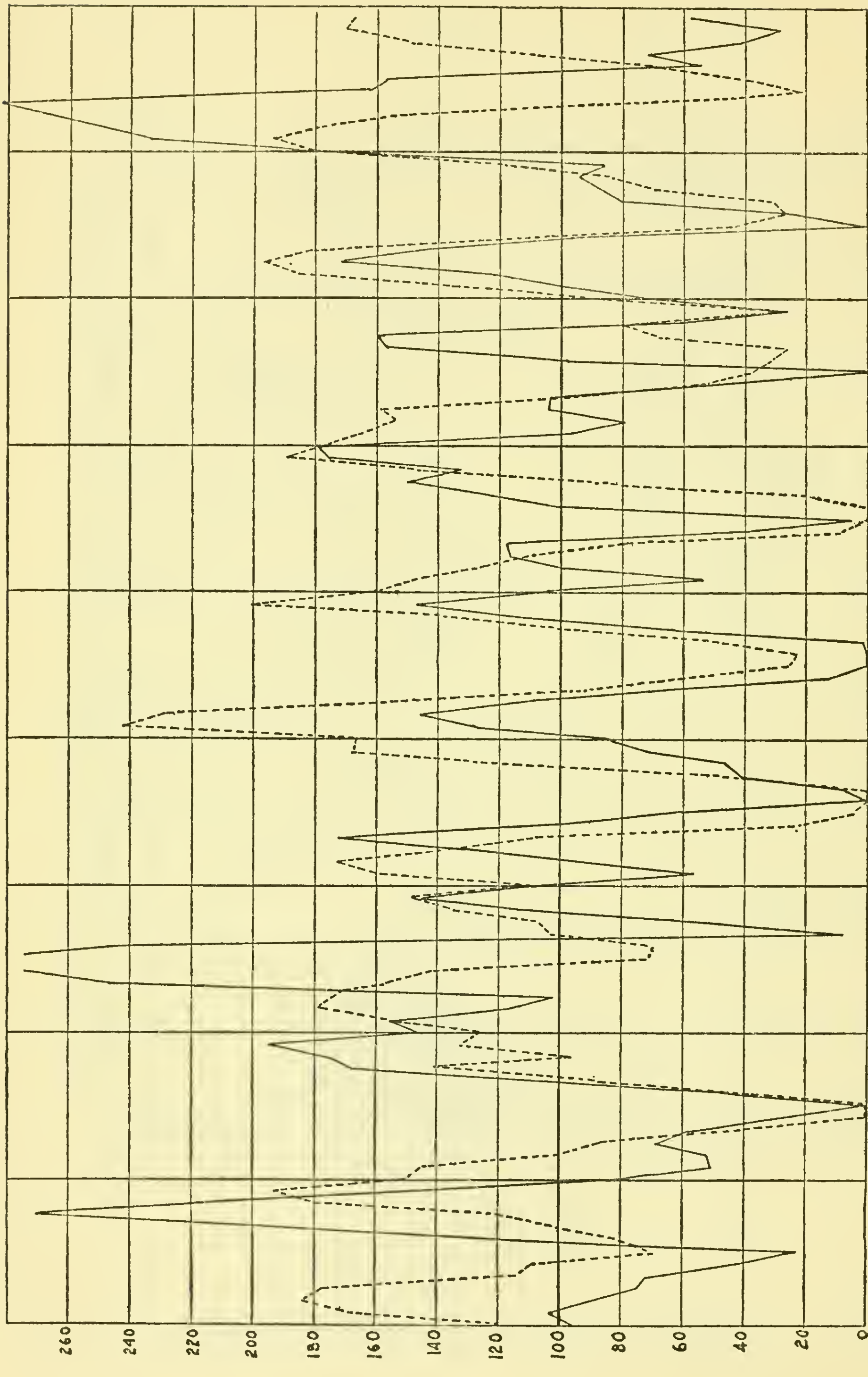

FIG. 3.—Sacramento, Calif. Forecast and event of monthly departures from normal precipitation, 1950-1958. Normal, heavy horizontal line;

FORECASTS OF PRECIPITATION FOR 32 CITIES, 1950-1967

This project was sponsored by the Association for Applied Solar Energy of Phoenix, Ariz., and the Smithsonian Institution of Washington, D. C. Funds for the costs of electronic computations were supplied to the Association by the Valley National Bank and the Arizona Public Service Company. About 7,000 tables of precipitation were electronically computed by Jonathan Wexler, a student at the Arizona State College at Tempe. He ingeniously programmed the machine for this special purpose. Monthly records of precipitation at 32 stations from about the year 1870 were taken from publications generously furnished by the United States Weather Bureau.

TABLE 1.—*List of stations*

1. Abilene, Tex.	17. Nashville, Tenn.
2. Albany, N. Y.	18. Natural Bridge, Ariz.
3. Albany, Oreg.	19. Omaha, Nebr.
4. Augusta, Ga.	20. Peoria, Ill.
5. Bismarck, N. Dak.	21. Port Gibson, Miss.
6. Charleston, S. C.	22. Rochester, N. Y.
7. Cincinnati, Ohio	23. Sacramento, Calif.
8. Denver, Colo.	24. Salisbury, N. C.
9. Detroit, Mich.	25. Salt Lake City, Utah
10. Eastport, Me.	26. San Bernardino, Calif.
11. El Paso, Tex.	27. Santa Fe, N. Mex.
12. Helena, Mont.	28. Spokane, Wash.
13. Independence, Kans.	29. St. Louis, Mo.
14. Little Rock, Ark.	30. St. Paul, Minn.
15. Madison, Wis.	31. Thomasville, Ga.
16. Montgomery, Ala.	32. Washington, D. C.

Secretary Leonard Carmichael of the Smithsonian Institution assigned Mrs. Lena Hill and Mrs. Isobel Windom to assist me in preparing forecasts. He approved grants from funds given for the study of solar radiation and weather by the late John A. Roebling. I am greatly indebted to Miss M. A. Neill for careful preparation of my manuscript.

I selected 32 cities distributed with approximate uniformity over the United States. The cities chosen are listed in table 1.

THE METHOD

As I suppose no one hitherto has ventured to predict values of precipitation, at definite places, for as much as 8 years in advance, I now indicate briefly how it is done. I quote apposite passages from my former papers,[1] with slight changes dictated by later experience.

Periods in sun and weather.—The sun's radiation which we see and feel, like that of many other stars, is variable. Solar output of radiation seldom exceeds 2 percent in its variation. However, its variation comprises as many as 60 regular periodic pulses, ranging from 1 month or less to 273 months or more. All are exact submultiples (or aliquot parts) of 273 months, as 91, 39, 7 months, and many more. They range in amplitude from 1/50 to 1/4 percent. All go on simultaneously, like overtones of a musical note.

As many as 30 of these exact periods have been found in monthly weather records which have been kept from 1870 and earlier. They occur in records both of precipitation and temperature. Far from being confined to fractions of 1 percent, as in solar radiation, in precipitation they individually range from 5 to 35 percent of the normal average. In temperature they range from 1° to 3° F., and these limits refer to 3-month smoothed records. Owing to the large number of these weather periods, some in plus, some in minus phases at any one time, their combined influence is not usually startlingly great.

Normals.—Long records of weather ordinarily state "normal" monthly values found by taking the monthly averages of all the years tabulated. I have found considerable differences in normals if computed separately for years of high and low sunspot frequencies, respectively. I therefore compute separate monthly normals for years above and below an average of 20 Wolf numbers in sunspot frequency. From these normals I tabulate the departures in temperature, and the percentages of normal precipitation.

The monthly values have too wide jumps to be most useful. I smooth the record by 3-month consecutive means. Thus for February I use (January + February + March) × 1/3, and similarly for other months.

Lags.—Supposing, contrary to meteorologists' opinion, that the variation of the sun is the real cause of the variation of the weather, since it has identically the same periods, I point out that well-known variations of insolation suffer variable lags in their weather influence, depending on place and time.

Lags of solar effects, as they differ with locality, indicate that the state of the atmosphere is an important factor. The atmospheric

[1] a, Journal of Solar Energy, Sci. and Eng., vol. 1, No. 1, January 1957; b, ibid., vol. 2, No. 1, January 1958; c, Smithsonian Misc. Coll., vol. 122, No. 4, August 1953; d, ibid., vol. 128, No. 3, April 1955; e, ibid., vol. 128, No. 4, June 1955; f, ibid., vol. 134, No. 1, September 1956; g, ibid., vol. 138, No. 3, February 1959.

condition varies not only with locality but with time of the year, prevalence of sunspots, and march of population. To partially meet these difficulties, I tabulate separately for three periods of the year: January-April; May-August; September-December; also with Wolf sunspot numbers above and below 20; also with lapse of time before and after the midpoint of the record. These divisions of the available monthly data lead to computing 220 tables at each station before undertaking a forecast.

Forecasts by periods.—My forecasts are made by adding the effects of 27 regular periodic cycles in precipitation. These cycles, like the harmonics of musical sounds, proceed simultaneously, and are integrally related to a fundamental cycle. This fundamental is 273 months. The harmonics employed are as follows:

TABLE 2.—*Periods used for forecasting*

Fraction	Months	Fraction	Months	Fraction	Months
1/3	91	1/12	22-3/4	1/27	10-1/9
1/4	68-1/4	1/14	19-1/2	1/28	9-3/4
1/5	54-3/5	1/15	18-1/5	1/30	9-1/10
1/6	45-1/2	1/18	15-1/6	1/33	8-3/11
1/7	39	1/20	13-13/20	1/36	7-7/12
1/8	34-1/8	1/21	13	1/39	7
1/9	30-1/3	1/22	12-9/22	1/45	6-1/15
1/10	27-3/10	1/24	11-3/8	1/54	5-1/18
1/11	24-9/11	1/26	10-1/2	1/63	4-1/3

The harmonic family referred to was discovered in the variation of the measures of the solar constant of radiation. Figure 4 shows 26 of over 60 periods discovered in solar variation.[2] Identical cycles were later found in precipitation and temperature by study of long-continued weather records. While the *periods* of the harmonics are invariable, both in the sun and weather, and their *phases* are invariable in solar radiation, their phases shift in weather, depending on atmospheric influences, as will be described below. On account of these phase changes, depending on several variables discovered in my studies of precipitation begun with Peoria, Ill., about 10 years ago, the harmonic family in weather is obscured and hidden, and is as yet unrecognized by most meteorologists. Nevertheless it is verified by an enormous mass of evidence, as will appear below.

No observations required.—Many meteorologists and others suppose that my method of long-range weather forecasting depends on solar observations, but this is not so. The harmonic family referred

[2] See in reference, footnote 1, e, above, figure 3 and table 3.

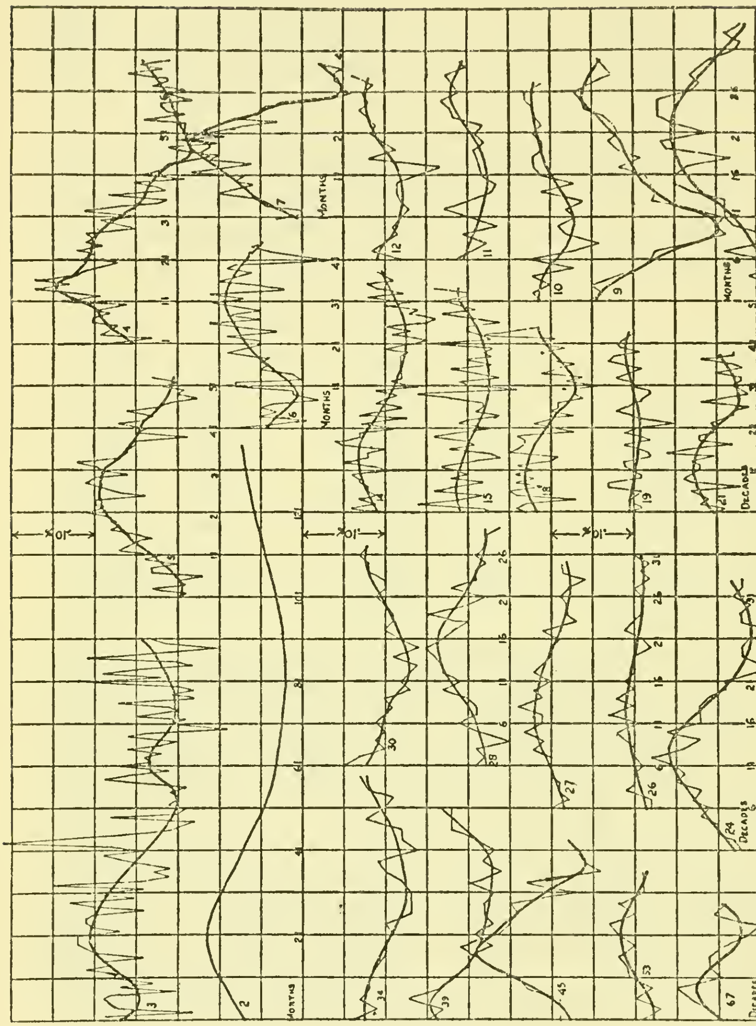

FIG. 4.—Twenty-six periods in solar variation, ranging from 273/67 to 273/2 months in length, all cleared of subordinate interfering integrally related periods. All from Smithsonian solar-constant observations of 1920-1952.

to was indeed discovered by the study of over 30 years of daily "solar-constant" observations of the Smithsonian Astrophysical Observatory. But now that the harmonic family has been found in weather, no observations of any kind are required. It is only necessary to employ a long record of monthly mean values of precipitation, or temperature, to make long-range predictions. These are approximately verified if no *unusual* alterations of atmospheric conditions make the averages from long records inapplicable.

Sports.—As my forecasts depend on the assumption that the *average* conditions of the periods over a thousand months will be projected into the future, it is important not to include wild "sport" values of precipitation in the thousand-month basis. Hence I have diminished sporadic very high values to about two times normal, and have raised sporadic drought values of less than 40 percent of normal to exceed that limiting low value. These limits refer to 3-month smoothed records. For most of my 32 stations these changes are very rare. But in two or three of the desert stations possibly one value in ten was changed to avoid spoiling the representative character of the basis. The considerable measure of success of my forecasts is the main defense of the method used to produce them. If the degree of success is found to be valuable, no doubt those who in future will use the method will greatly improve it by modifications dictated by reason and experience.

Backcasts.—Since my forecasts are made by adding the average effects of 27 harmonic periods over an interval of about 1,000 months, the 12 months of record for any one year can produce only about 1 percent of influence on the forecast for that year, even if those 12 months are among the thousand months employed as a basis. Therefore all forecasts or backcasts are equally sound, whether they relate to time before, within, or after the thousand months of record.[3]

The preceding paragraph is important. The forecasts for 32 cities all extend from 1950 to 1967. The degree of similarity between the forecasts and what happened up to 1958 is the index of their probable agreement from 1959 to 1967.

The 273-month period.—Daily solar-constant observations proceeded from 1920 to 1952 at Montezuma, Chile. This interval is not long enough to determine the master period accurately. But the 10-1/9-month period in *weather* is a strong one and has long been followed in Washington precipitation. I determined its amplitude for several periods differing slightly from 10-1/9 months. For this pur-

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[3] See discussion of backcasts at a later page.

pose I used about 790 monthly mean values of Washington precipitation, all observed when Wolf sunspot numbers exceeded 20. These values were smoothed by 3-month consecutive means, which of course reduces the ranges of percentage departures from normal to about two-thirds of their actual monthly values. Table 3 and figure 5 show the results.

Figure 5 clearly shows that a value of the master period between 273 and 275 months is definitely indicated.

I have preferred 273 months rather than 275 months because it is an integral multiple of the strong periods 7, 13, 39, and 91 months. It cannot be much more than 1/3 percent from the true master period.

TABLE 3.—*Percentage amplitudes of proposed periods*

Period *Months*											Ranges *Percent*
271.2/27	105.7	103.4	102.5	100.7	100.9	96.3	97.3	97.9	98.0	97.7	9.4
273.0/27	95.7	95.8	93.4	96.1	99.3	102.0	103.7	108.0	104.8	101.1	14.6
275.0/27	109.8	102.4	103.3	99.3	95.4	92.9	96.2	97.6	98.8	104.5	16.9
277.0/27	94.6	104.4	106.2	101.3	105.8	105.5	94.6	97.5	96.9	93.3	12.9

The subordinate periods.—Of the 27 periods used in forecasting, 12 exceed 15-1/6 months in length. Owing to arrangements used to treat changes of phase, which will be described, 42 tabulations for each city are made of these 12 periodicities. Almost without exception the curves representing these 42 tables betray overriding harmonics of the period in question, from two to eight in number. These overriders must be evaluated and eliminated before the period in question stands free.

I show in table 4 and figure 6 the treatment of one only of the four tables representing the 39-month period in precipitation at Helena, Mont. Eight tabulations of successive runs of this period over the interval of years 1891 to 1917 give the mean values and average deviations from the mean in percentages of normal precipitation. Then five harmonics of 39 months are successively removed, yielding the smooth-curve deviations from 100 percent given in column *S*, and its deviations from what remains after the five removals of harmonics. In the final column of table 4, and the final smooth curve of figure 6, we see the real periodicity of 39 months. The average deviation from curve *a* is 29.6 percent, and that from curve *b* is 2.1 percent. The reduction of 93 percent in deviation is due to removing exact harmonics of 39 months.

Overriding periods.—As another example I quote from footnote 1, g, cited above, showing figure 4 of that reference (here figure 7).

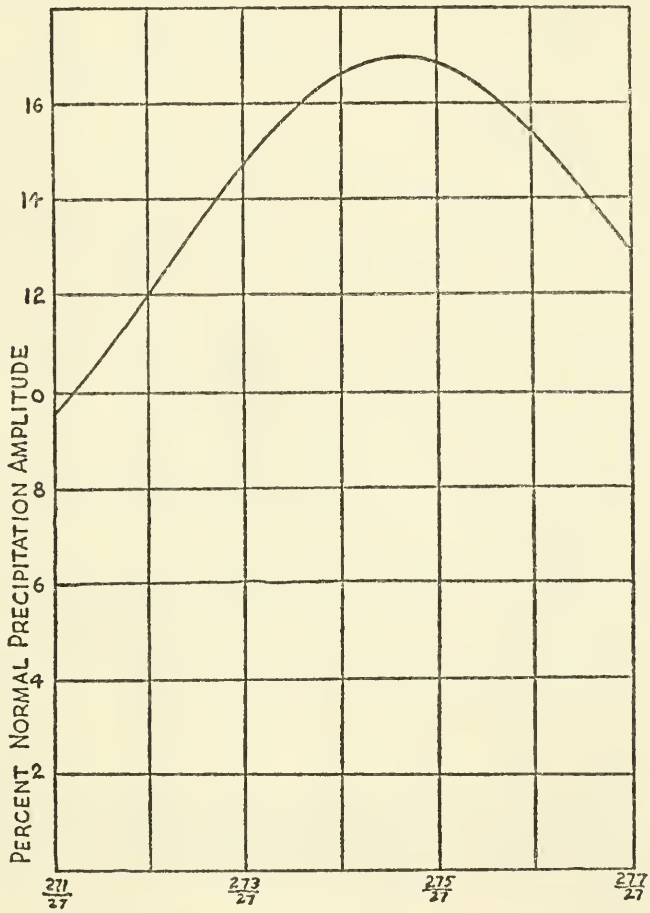

FIG. 5.—Demonstration of 273-month master period in weather.

From the mean of 16 repetitions of the periodicity of 45-1/2 months in Natural Bridge precipitation, the true 45-1/2-month period is cleared of four overriding harmonics.[4] The reader will note what similarity to true sine curves is attained in both the above examples,

[4] Refer also to the clearing of overriders from the period of 68-1/4 months at St. Louis. Note 1, g, figure 3.

when overriding harmonics are computed and removed. From the examples given (out of about 10,000 cases available in my files) the following 10 exact harmonics of 273 months are exposed as follows:

1/4, 1/7, 1/8, 1/12, 1/14, 1/21, 1/28, 1/35, 1/49, 1/56.

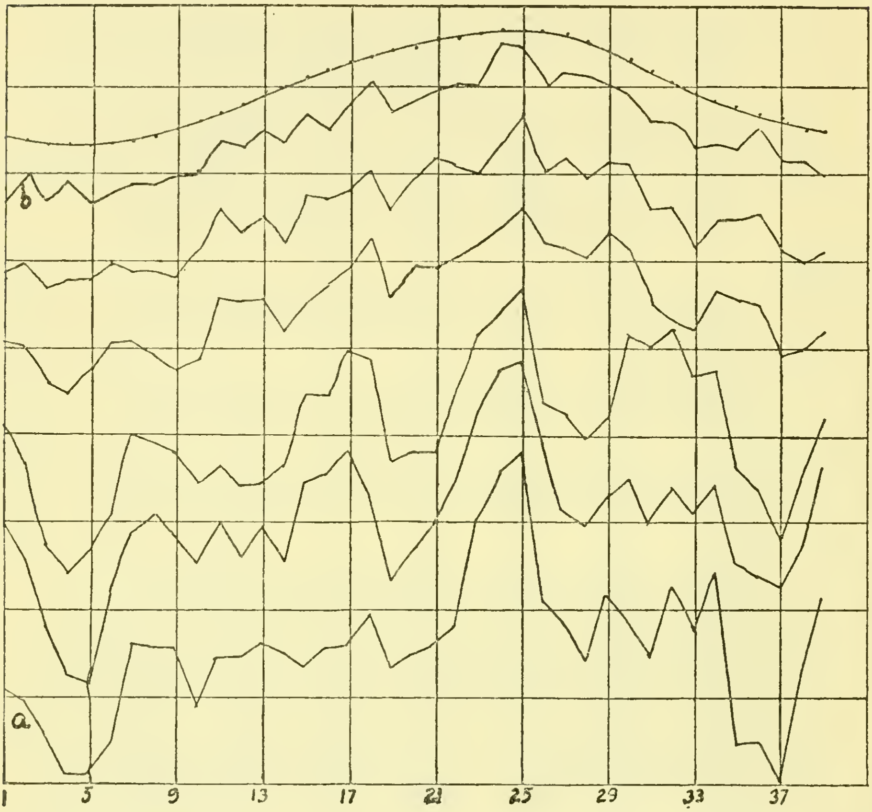

Fig. 6.—Helena, Mont. Thirty-nine-month period in precipitation as cleared of overriding subordinate integrally related periods. Original tabulation, *a;* cleared curve, *b,* with smoothed curve above. Note approximate sine form. Range, 27 percent of normal precipitation.

While most removals of harmonic riders are done to clear periods exceeding 15-1/6 months, many curves representing periods between 9-1/10 and 15-1/6 months required removal of harmonics of 1/2 or 1/3 of their length. An algebraic theorem affords a check on mistakes of computation when clearing half periods.

Let a periodic curve be represented by equally spaced ordinates a, b, c . . . k, l, m, and proceeding further, n, o, p . . . x, y, z.

The mean form of the supposed overriding period of one-half length is:

$$\frac{a+n}{2},\quad \frac{b+o}{2},\quad \frac{c+p}{2},\quad \ldots\quad \frac{k+x}{2},\quad \frac{l+y}{2},\quad \frac{m+z}{2}.$$

When this half-length curve is written twice, and subtracted, we have:

$$\frac{a-n}{2},\quad \frac{b-o}{2},\quad \frac{c-p}{2},\quad \ldots\quad \frac{k-x}{2},\quad \frac{l-y}{2},\quad \frac{m-z}{2},$$

and following that:

$$\frac{n-a}{2},\quad \frac{o-b}{2},\quad \frac{p-c}{2},\quad \ldots\quad \frac{x-k}{2},\quad \frac{y-l}{2},\quad \frac{z-m}{2}.$$

So the last half of the long curve, when cleared of the period of one-half of its length, is exactly like the first half, but with reversed signs.

Grouping of periods.—All weather influences caused by changes in solar rays are subject to lags. For instance, June and noonday are times of highest solar altitudes, but the warmest months and hours occur later. The lag is longer the longer the period of the solar radiation change. These lags are due to atmospheric conditions, and vary from locality to locality, from month to month, from times of great sunspot activity to quiet solar times, and as population and forestation change. Hence, though the family of periods integrally related to 273 months proceeds with perfect regularity in measures of the solar constant, in weather the same family of periods is affected by changes of phase, depending on the locality, the population, the sunspot frequency, and the time of the year. The *periods* are the same in weather that they are in solar radiation, but owing to complex atmospheric influences on the lags the *weather phases* are so altered from time to time that these periods are unrecognizable without a segregation of the data, governed by consideration of these modifying influences.

It is not possible to anticipate and allow for these phase changes precisely. I content myself as follows:

(*a*) The year divided: January to April; May to August; September to December.

(*b*) Solar activity divided: Wolf numbers > 20; Wolf numbers < 20.

(*c*) Secular time divided: first half of tabulated records; second half thereof.

All these divisions of data hold for periods up to 15-1/6 months, or 15 groupings for these periods. The segregation according to the Wolf numbers holds from 18-1/5 months up to 39 months, but not the segregation for times of the year.

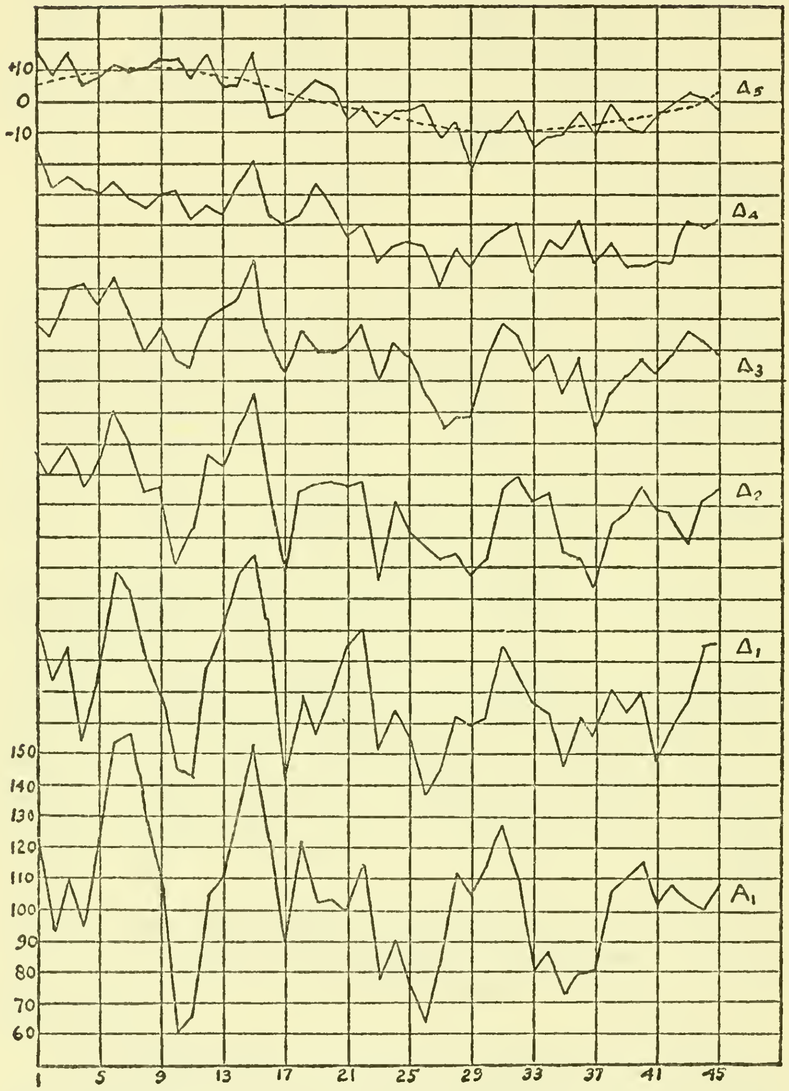

FIG. 7.—Natural Bridge, Ariz. Forty-five-and-one-half-month period in precipitation cleared of overriding subordinate integrally related periods. Range reduced ninefold by clearing.

TABLE 4.—*From three-month running means of precipitation, Helena, Mont.*
39-month period = *p*

Elimination of subordinate periods. Interval 1891-1917
Mean percentages of the normal. Original mean and departures after removing subordinate periods

Original mean of 8 determinations *a*	Average deviations. Percent of normal ppt	Removed periods *p*/2	*p*/3	*p*/5	*p*/7	*p*/8	Smooth = *S*	*p*/8 − *S* Δ	Final mean cleared
102	30	0	+2	−9	−13	−17	−12	−5	88
99	40	−8	−8	−10	−11	−11	−13	+2	87
92	29	−24	−26	−18	−17	−17	−14	−3	86
82	35	−35	−32	−20	−15	−12	−14	+2	86
82	29	−37	−27	−15	−15	−17	−14	−3	86
89	32	−16	−9	−9	−11	−15	−13	−2	87
112	34	−2	0	−9	−13	−13	−13	0	87
111	31	+2	−2	−12	−13	−13	−12	−1	88
111	29	−6	−4	−15	−14	−11	−10	−1	90
98	38	−9	−11	−13	−8	−10	−8	−2	92
109	23	0	−7	+1	+1	−3	−6	+3	94
109	30	−8	−12	0	−4	−4	−4	0	96
112	40	−1	−11	+1	0	0	−1	+1	99
110	40	−9	−7	−7	−6	−3	0	−3	100
107	18	+9	+9	0	+5	+3	+2	+1	102
111	19	+11	+9	+4	+4	0	+4	+4	104
112	34	+16	+19	+8	+6	+6	+6	0	106
119	26	+7	+17	+15	+11	+11	+7	+3	107
97	34	−13	−6	+2	+1	+4	+9	−5	109
100	23	−6	−4	+8	+9	+7	+9	−2	109
102	27	0	−4	+8	+13	+9	+11	−2	111
116	20	+9	+11	+11	+11	+11	+11	0	111
146	16	+25	+13	+14	+10	+10	+12	−2	112
152	20	+35	+28	+18	+17	+20	+13	+7	113
156	33	+37	+33	+22	+23	+19	+13	+6	113
122	34	+17	+7	+5	+10	+10	+13	−3	113
117	21	+3	+5	+13	+13	+13	+12	+1	112
108	16	−1	−1	+11	+9	+12	+11	+1	111
123	27	+6	+4	+16	+12	+10	+9	+1	109
117	21	+10	+13	+13	+12	+8	+8	0	108
109	28	0	+10	+1	+2	+2	+4	−2	104
125	37	+8	+15	−3	+2	+2	+2	0	102
115	26	+2	+4	−7	−7	−4	−1	−3	99
128	32	+9	+5	+3	−1	−3	−3	0	97
89	32	−9	−7	+1	0	−4	−4	0	96
90	33	−10	−12	0	+1	+1	−6	+7	94
81	30	−15	−24	−12	−7	−7	−7	0	93
106	50	−6	−10	−10	−10	−7	−9	+2	91
123	30	+13	+3	−6	−8	−10	−10	0	90

Mean *da* 29.6 percent. Mean Δ 2.1 percent.
Average deviation before clearance 29.6 percent. After clearance 2.1 percent.

NOTE.—Thus the removal of overriding harmonics reduces the average deviation by 93 percent. Of about 10,000 such removals of overriding harmonic periods, probably 4,000 gave fully as satisfactory end results as the 39-month curve at Helena did for the years 1891 to 1917.

Hence for these longer periods there are about four divisions to a period. The secular time segregation holds beyond 39 months, two divisions each for four periods.

The grouping just indicated leads to computing many tables for each station:

Up to 15-1/6 months,	$15 \times 12 = 180$	tables
Thence to 39 months,	$8 \times 4 = 32$	tables
Thence to 91 months,	$4 \times 2 = 8$	tables
Total	220	tables

Shifts of phases.—The numerous groups used for the shortest 15 periods leads to tabulations with so few columns that the mean values of individual periods are of little weight. To remedy this defect, I assume that the forms and amplitudes of periods up to 15-1/6 months in length, and in the same grouping as regards Wolf numbers, will be similar, though in different phase relations. I therefore make superposed graphs of the six tables of one period for each of the two stated conditions of sunspot activity. From inspection checked numerically I am then able to shift the individual curves of the graphs to the same phase relations. Then I take a mean for all six tables and use that generalized mean in forecasting. But when using it in forecasting, I must shift back the generalized mean to the proper phase, as will appear by an example later. Figure 8 gives an example of these shiftings in phase.

NOMENCLATURE, SYMBOLS, AND TIME

As stated above, 27 periods, all aliquot parts of 273 months, are to be used in the forecasts. But, as just stated, these are used in several groups, depending on the length of the periods. Lags, depending on atmospheric conditions, dictated tabulations of 12 independent groupings for the periods of shortest length, that is a_1, b_1, c_1, a_2, b_2, c_2, as tabulated for the period of 9-1/10 months of SS>20 in tables 5 and 6. Besides these, there are six tables a'_1, b'_1, c'_1, a'_2, b'_2, c'_2, for SS<20. However, for periods above 15-1/6 months this extended grouping brings too few columns into the tables to be capable of yielding satisfactory mean values. Hence for periods 273/15 to 273/7, the distinction between months of the year is dropped, thus reducing the number of groupings from 12 to 4 for these 8 periods. For the remaining 4 periods, 45-1/2 to 91 months, the distinction SS>20 or SS<20 is also dropped, reducing their groupings to 2. So there are three different arrangements of assembly, as just explained (12×15)

$= 180 + (8 \times 4) = 32 + (4 \times 2) = 8$, making 220 separate tabulations in all.

In tables of periods 1/18 to 1/63 of 273 months, there are many cases when the number of columns for a_1, b_1, c_1, a_2, b_2, c_2, and a'_1, b'_1,

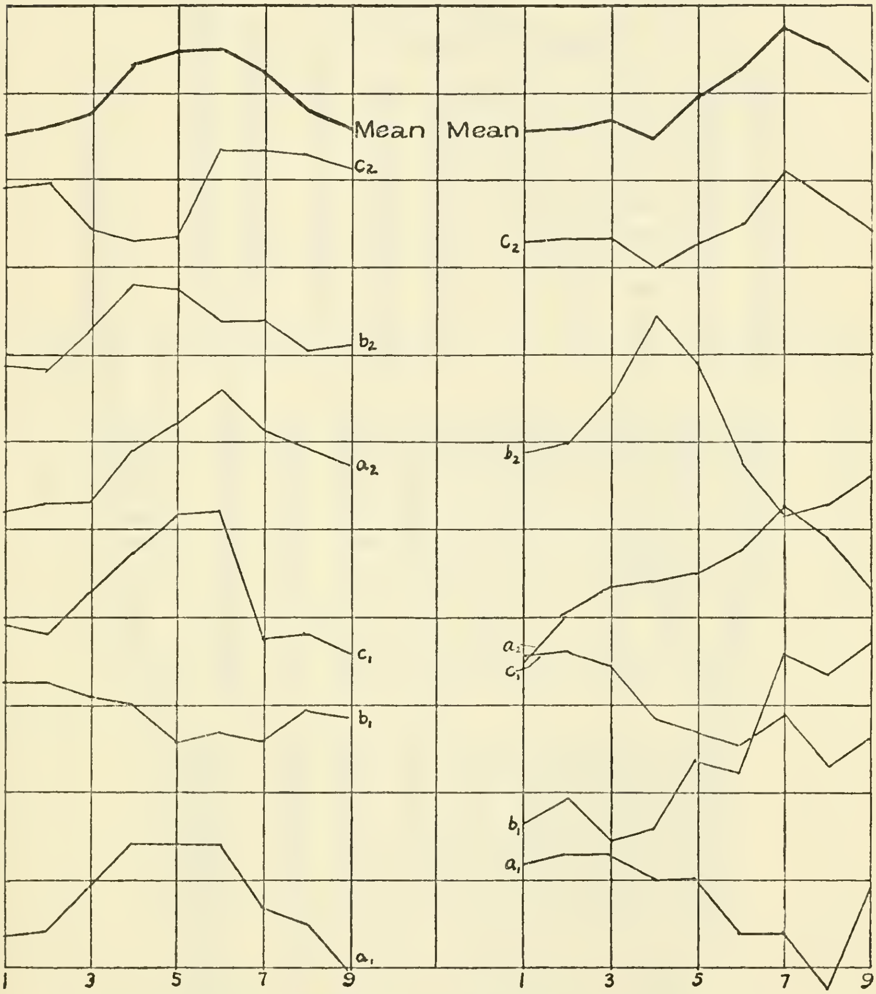

FIG. 8.—Sixfold grouping of periods to form generalized means.

c'_1, a'_2, b'_2, c'_2 are too few to give a trustworthy mean. Accordingly, as I stated above, I have made the assumption that in form and amplitude groups of SS>20 will be fairly similar, though of different phases, and in form and amplitude groups for SS<20 will also be fairly similar, though differing in phases. Making this assumption, I combine into one table $a_1b_1c_1a_2b_2c_2$, merely changing the phases to give best accord, and similarly I combine $a'_1b'_1c'_1a'_2b'_2c'_2$ into a single

TABLE 5.—*Grouping of six tables when SS > 20. Period of 9-1/10 months. Eastport, Me.*

First half of the records, 1891 to 1920

1893 Apr.	1894 Jan.	1896 Apr.	1897 Jan.	1906 Feb.	1909 Mar.	1915 Mar.	1916 Jan.	1918 Apr.	1919 Jan.	Means a_1
64	92	55	62	130	158	79	84	70	72	87
71	47	56	92	164	127	91	66	85	80	88
79	54	98	104	180	87	127	79	96	78	98
103	62	98	179	156	81	129	69	95	109	108
103	89	106	173	116	80	120	96	108	93	108
91	78	123	166	64	133	92	123	108	101	108
51	72	144	108	55	120	66	127	107	86	94
89	47	119	88	70	134	54	109	77	114	90
88	59	80	61	81	78	78	79	70	116	79
						75				

1892 June	1895 July	1898 July	1904 Aug.	1905 May	1907 Aug.	1908 June	1917 July	1920 July	Means b_1
86	115	72	160	81	132	70	167	64	105
114	120	67	162	103	131	76	94	79	105
85	94	134	103	90	128	82	115	88	102
86	94	164	66	102	126	103	77	85	100
59	98	159	77	75	114	77	89	79	92
65	94	117	93	94	128	108	72	75	94
69	65	94	82	83	126	130	100	84	92
75	70	109	53	109	119	168	96	86	98
71	72	86	57	95	112	178	94	103	97
75					78				

1891 Sept.	1894 Oct.	1897 Oct.	1903 Nov.	1906 Nov.	1916 Oct.	1919 Oct.	Means c_1
128	67	80	96	123	77	118	98
100	72	85	94	131	88	104	96
99	71	129	104	148	95	87	105
105	68	146	130	135	106	119	115
104	80	151	142	143	101	140	123
117	83	147	128	116	104	172	124
81	79	105	86	99	95	119	95
89	63	112	70	96	150	92	96
90	73	73	115	101	134	55	92

table. I give samples of this simplification here in tables 5 and 6 for SS>20. Figure 9 shows the matter graphically.

The final combinations of two sets of six tables each, with phases shifted to harmonize, is given in figure 9 and table 7, both from Eastport data.

TABLE 6.—*Grouping of six tables when SS > 20. Period of 9-1/10 months. Eastport, Me.*

Second half of the records, 1925 to 1956

1925 Feb.	1928 Feb.	1937 Mar.	1940 Apr.	1941 Jan.	1947 Feb.	1950 Feb.	1956 Mar.	Means a_2
77	76	44	76	48	127	116	106	84
68	72	66	71	50	116	116	129	86
64	82	89	63	50	136	87	119	86
69	96	77	75	68	166	117	113	98
83	109	63	126	54	198	107	89	104
91	129	74	117	91	134	162	95	112
93	129	95	128	93	88	114	88	103
124	119	102	83	101	50	102	93	97
122	87	67	84	105	69	111	101	95

1926 Aug.	1927 May	1929 Aug.	1930 May	1936 June	1939 July	1945 July	1946 May	1948 Aug.	1949 May	1951 Aug.	1952 May	1955 June	Means b_2
63	95	92	55	97	87	100	134	94	90	159	130	60	97
136	135	93	95	91	78	66	83	64	71	135	121	80	96
145	185	87	107	77	73	110	68	104	54	139	131	89	105
150	189	74	100	101	84	157	80	130	104	159	99	87	116
92	180	76	55	92	103	170	82	138	111	200	105	87	115
90	178	104	41	112	65	130	75	127	153	184	81	65	108
85	167	103	51	104	61	127	112	127	111	145	95	113	108
70	119	101	65	91	56	119	119	116	138	107	110	102	101
70	91	69	76	52	79	166	145	108	113	96	136	126	102
			84			154							

1925 Nov.	1928 Nov.	1934 Dec.	1935 Sept.	1937 Dec.	1938 Oct.	1941 Oct.	1947 Nov.	1950 Nov.	Means c_2
116	72	125	71	56	110	79	74	181	98
91	76	111	89	56	73	84	120	194	99
99	84	102	66	59	65	61	98	165	89
112	93	63	85	70	74	59	101	114	86
96	93	54	60	76	92	87	88	139	87
82	112	62	102	104	125	81	141	150	107
81	95	68	103	131	109	86	146	144	107
73	80	81	119	131	93	70	176	132	106
71	63	89	117	146	94	81	121	149	103
				112					

The meaning of the symbols on figure 9 is as follows:

ok, no shift.
↑ , shift backward.
↓ , shift forward.
Subscripts, number of months shifted.

TABLE 7.—*Phase adjustment. The 6-1/15-month period*

Division = Time before and after 1900.
Category = Records when Wolf sunspot numbers ≧ 20.
Phase shifts indicated: ok, ↑N, ↓N, drawn dotted below.
Basis of forecast, over 1,000 monthly records smoothed by 3-month running means. Forecasts employ 27 periods all exact submultiples of 273 months.
Phases shift with changing atmospheric conditions, but periods remain, and are of the exact lengths found i solar variation. It requires 220 tables electronically computed to make a forecast for one station.

CATEGORY 2 ASSEMBLY

a_1↑1	$b_1$ok	c_1↑3	$a_2$ok	$b_2$ok	$c_2$ok	Mean	Δ
105	95	108	100	96	95	100	+1
102	95	106	93	97	88	97	−2
100	94	95	92	93	80	92	−7
106	92	104	97	94	88	97	−1
105	103	98	106	100	91	101	+2
103	114	108	105	101	99	105	+6
						6⌋593	
						99	

CATEGORY 1 ASSEMBLY

a_1↑3	b_1↓1	$c_1$ok	$a_2$ok	b_2↑2	$c_2$ok	Mean	Δ
120	95	100	105	96	117	107	+
108	86	100	91	94	110	98	
110	86	100	90	92	100	95	−
92	97	102	87	84	88	91	−
105	91	104	91	90	93	93	−
110	98	103	102	94	97	101	+
						6⌋586	
						98	

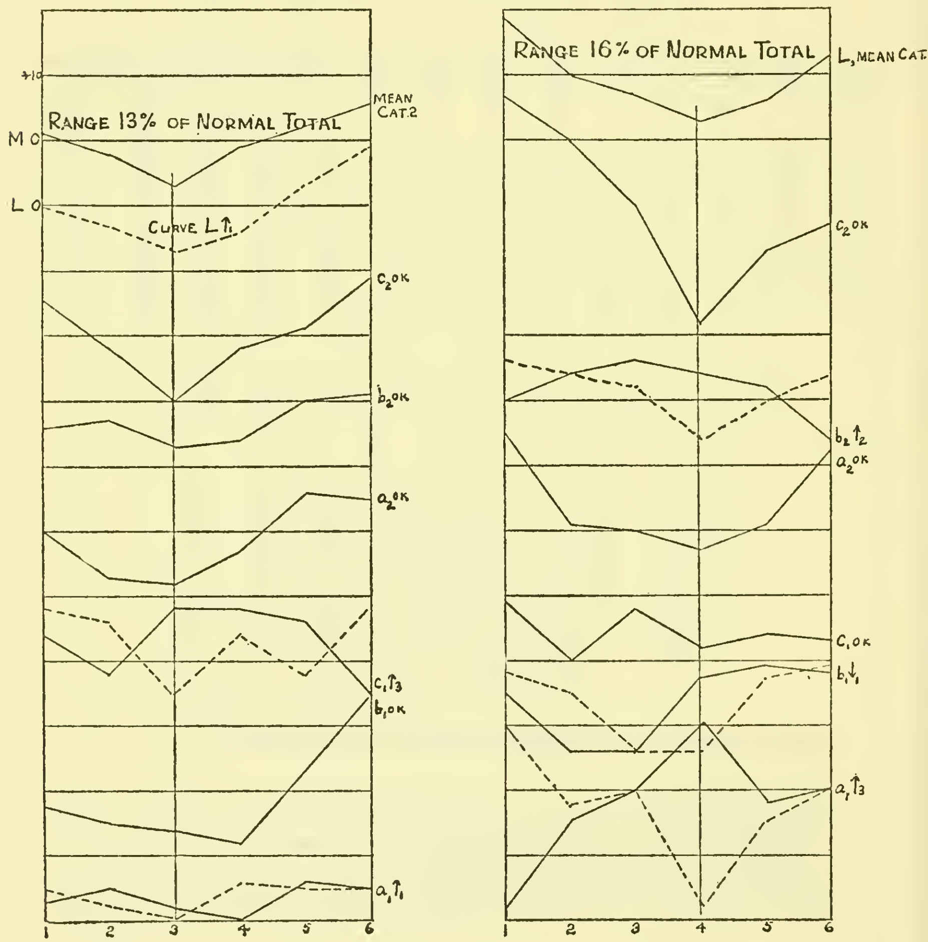

FIG. 9.—Phase shifts in sixfold grouping of periods.

Times.—The growth of population, destruction of forests, multiplying of oil engines, automobiles, and airplanes alter the properties of the atmosphere and thereby shift phases of periods. Hence, as stated above, I divide the thousand months of records into first and second halves and compute the phases and amplitudes within the two parts separately.

TABLE 7a.—*The sixfold groupings.* The 9-1/10-month period. Eastport, Me.*

Values in percentages of normal precipitation

A. WOLF SUNSPOT NUMBERS BELOW 20

$a_1\uparrow 4$	b_1 ok	$c_1\uparrow 4$	a_2 ok	$b_2\downarrow 3$	c_2 ok	Σ	Σ ÷ 6	Δ
101	83	94	90	63	106	537	89	—9
88	88	91	101	66	107	547	90	—8
88	79	98	107	73	107	552	92	—6
75	82	81	108	78	100	509	88	—10
97	97	93	110	80	106	583	97	—1
104	95	111	115	91	110	626	104	6
106	111	112	105	109	122	685	114	16
106	107	109	118	98	116	654	109	11
101	114	97	107	76	109	604	101	2
						Mean	98	

B. WOLF SUNSPOT NUMBERS EXCEED 20

a_1 ok	$b_1\downarrow 3$	$c_1\downarrow 1$	a_2 ok	b_2 ok	$c_2\uparrow 2$	Σ	Σ ÷ 6	Δ
87	92	92	84	97	89	541	90	—10
88	98	98	86	96	86	552	92	—8
98	97	96	86	105	87	569	95	—5
108	105	105	98	116	107	639	106	6
108	105	115	104	115	107	654	109	9
108	102	123	112	108	106	659	110	10
94	100	124	103	108	100	629	105	5
90	92	95	97	101	98	573	96	—4
79	94	96	95	102	99	565	94	—6
						Mean	100	

* The shifting of phases is indicated by arrows as in figure 9 and table 7. The accompanying subscripts indicate the number of months shifted up or down.

Not only so, but considerable differences of amplitude between the two halves are sometimes found. As forecasts are for present and future time, weights, as 2/1, 3/1, or 4/1, are given to favor the second half when considerable differences in amplitude of periods between the two halves appear. It matters not whether the later amplitudes are the less or the greater, the larger weight is ascribed to amplitudes of the second half. If a backcast were to be made to long ago, the weights would of course be reversed.

At some chosen date all periods must be in the same phase and preferably in zero phase. I chose 1957-0 as this zero date. To insure that any particular period will be in zero phase with 1957-0 it is necessary to compute ahead from the start at about the year 1870. This may be done as follows. Take the period 8-3/11 months for example.

From 1870 to 1957, 87 years, there are 1,044 months. About 126 periods of 8-3/11 months would cover this interval. But a date must be chosen which is an exact integral multiple of 8-3/11. The nearest is that which gives 121 periods in the interim. Multiplying, we find that 121 periods require 1,001 months, or 83 years 5 months. Subtracting these figures from 1957-0 we find 1873-7. Thus a suitable starting point is August 1873. But it was assumed that the record begins about 1870-0. If so, 43 months would be lost. One therefore counts backward from 1873-7 five periods, and therefore begins with March 1870.

Table 8.—*Repeated 8-3/11 months and round numbers*

1	8.2737	8	7	57.9089	8
2	16.5454	9	8	66.1816	8
3	24.8181	8	9	74.4543	8
4	33.0908	8	10	82.7270	9
5	41.3635	8	11	90.9997	8
6	49.6362	9			

We now come to considering periods ending in fractions of a month. We may make tables of accumulation for them. Again using the period 8-3/11 months, table 8 results.

For most of the periods of inexact months, tables to 91 months suffice. But for such as 12-9/22, 13-13/20, 24-9/11 and 27-3/10 the tables must be carried on to 273 months.

RESULTS OF FORECASTS

Having treated of most of the features of the method, the remainder of this paper will disclose the results of these forecasts of precipitation. As I have stated, I discovered discrepancies sometimes as great as 10 percent between the published monthly normals and new normals obtained by separating years when Wolf sunspot numbers are respectively above and below 20. As my new normals may be of value to other investigators of periodicity I first give in table 9 the two sets of normals for the 32 cities I have investigated.

The cities are in alphabetical order. The months in the first column apply for all cities. Precipitation is given in inches. Columns A and B give monthly normals for times when Wolf sunspot numbers are respectively *less* and *more* than 20.

Departures; observation minus forecast 1950-1958.—There are 20 cities showing (1950-1958) departures in *level* of 4 percent or more from the values given in table 9. This is to be expected. One could not suppose the mean precipitation, 1950-1958, would be identical with the average precipitation, 1870-1958. Table 9a gives all the cities where such differences of 4 percent or more occurred.

When I come to give tables and maps of forecasts, 1959-1967, I shall not use table 9a to correct the maps, but shall quote the results as they are determined from table 9. Persons interested may apply the values of Δ, table 9a, as corrections in *level* to the *forecasts,* using them in reverse of the signs given in table 9a.

Sunspot effect on normals.—Lest readers think the differences between mean precipitation values attending high and low sunspot frequency are merely due to the sparsity of evidence, considering the irregularity of precipitation, I call attention to the numbers of months entering into the mean values of table 9. For nearly all of the stations approximately a thousand months participated. That indicates about 600 for high sunspot frequency, about 400 for the low. Dividing by 12, there were about 50 values per monthly mean for sunspots exceeding 20 Wolf sunspot numbers, and about 33 per month for the low sunspot frequencies.

Referring to table 9, the yearly sums show seven cities where sunspot frequency makes no more than 1 percent difference in the totals. For seven other cities low sunspot activity brings more precipitation, with an average difference of 5 percent. For the remaining 18 cities precipitation averages 5-1/2 percent higher at high sunspot frequency. While the discovery and elimination of these differences by computing new normals was of importance in my forecasting, seasonal differences made the elimination of the sunspot effect imperative. Thus at Salisbury, N. C., precipitation averages 17 percent *higher* with *low* Wolf numbers, January-April; 9 percent *lower,* May-August; and 11 percent *higher,* September-December, for Wolf numbers below 20 than for those above 20.

Credibility of forecasts.—It is difficult to compress within the limits of a paper, aimed to be available at moderate price to all who desire

TABLE 9.—*Normal monthly precipitation after 1870 through 1957 in inches*

A = Wolf number < 20; B = Wolf number > 20.

	Abilene, Tex. A	B	Albany, N.Y. A	B	Albany, Oreg. A	B	Augusta, Ga. A	B	Bismarck, N.D. A	B	Charleston, S.C. A	B	Cincinnati, O. A	B	Denver, Colo. A	B
January	0.7	0.9	2.4	2.4	6.8	6.3	3.4	3.7	0.4	0.5	2.7	3.2	3.1	3.6	0.3	0.5
February	1.1	0.8	2.5	2.2	4.4	5.6	4.0	4.1	0.4	0.5	3.1	3.4	2.6	3.0	0.5	0.5
March	1.1	1.1	2.5	3.3	4.1	4.2	4.4	4.4	0.9	0.9	3.1	3.3	4.2	3.7	1.1	1.0
April	2.7	2.2	2.6	2.8	2.7	2.6	3.3	3.4	1.3	1.6	2.8	2.5	2.9	3.0	1.8	2.1
May	4.1	3.9	3.2	3.0	2.3	2.1	2.8	3.3	2.4	2.1	3.9	3.1	3.2	3.7	2.1	2.4
June	2.0	2.9	3.5	3.6	1.5	1.2	4.3	4.2	3.8	3.1	4.7	4.8	3.7	3.9	1.2	1.5
July	1.7	1.9	3.8	3.3	0.3	0.4	4.8	5.1	2.3	2.3	6.3	6.5	3.5	3.4	1.6	1.7
August	1.5	2.0	3.7	3.5	0.5	0.4	4.4	4.9	1.7	1.9	5.5	6.1	3.7	2.9	1.4	1.4
September	2.1	2.4	3.3	3.4	1.7	1.7	3.1	3.4	1.4	1.2	5.2	4.5	2.6	2.6	0.7	1.0
October	2.5	2.4	2.9	3.0	3.5	3.2	2.8	2.1	1.0	0.8	3.8	3.2	2.2	2.5	0.8	1.0
November	1.5	1.0	2.7	2.9	5.9	6.2	2.4	2.6	0.5	0.6	2.4	2.4	2.7	3.1	0.5	0.6
December	1.4	1.0	2.4	2.5	6.6	7.1	3.6	3.4	0.4	0.5	2.8	3.1	3.0	2.8	0.7	0.5
Year	22.4	22.5	35.5	35.9	40.3	41.0	43.3	44.6	16.5	16.0	46.3	46.1	37.4	38.2	12.7	14.2
	Detroit, Mich.		Eastport, Maine		El Paso, Tex.		Helena, Mont.		Independence, Kans.		Little Rock, Ark.		Madison, Wis.		Montgomery, Ala.	
January	1.9	2.2	3.9	3.5	0.33	0.48	0.6	0.8	1.2	1.6	4.4	4.8	1.0	1.8	4.5	4.8
February	2.1	2.1	3.3	3.1	0.38	0.35	0.5	0.6	1.8	1.5	3.7	4.0	1.4	1.3	5.3	5.1
March	2.8	2.3	4.3	2.9	0.23	0.28	0.8	0.7	2.4	2.4	5.1	4.5	2.1	2.0	6.1	6.2
April	2.4	2.8	2.9	2.7	0.23	0.21	1.0	0.9	4.0	3.8	5.0	4.9	2.3	2.7	4.7	4.6
May	3.4	3.4	2.8	2.6	0.30	0.27	2.1	1.8	5.2	4.4	4.5	4.9	3.6	3.4	3.6	3.6
June	2.9	3.5	3.2	2.7	0.68	0.44	2.0	2.4	4.6	5.4	2.9	3.9	3.5	4.2	3.7	4.1
July	3.2	3.1	2.9	2.7	1.61	1.70	0.8	1.2	3.8	3.7	3.7	3.1	4.0	3.5	4.3	5.0
August	2.6	2.8	3.3	2.8	1.40	1.58	0.8	0.7	3.0	2.9	3.3	3.2	3.2	3.2	4.0	3.8
September	2.8	2.6	3.0	2.9	1.06	1.09	0.9	1.2	4.1	3.9	3.5	2.7	3.6	3.4	3.3	3.0
October	2.4	2.5	3.7	3.0	0.59	0.76	0.8	0.7	2.8	3.0	2.1	3.1	2.2	2.3	2.5	2.0
November	2.2	2.4	3.2	3.6	0.46	0.37	0.6	0.7	2.0	2.0	3.7	4.2	1.9	1.8	3.0	3.1
December	2.3	2.2	3.6	3.4	0.41	0.47	0.5	0.7	2.0	1.4	4.2	3.8	1.5	1.5	5.1	4.7
Year	31.0	31.9	40.1	35.9	7.58	8.00	11.4	12.4	36.9	36.0	46.1	47.1	30.3	31.1	50.1	50.0

	Nashville, Tenn.		Natural Bridge, Ariz.		Omaha, Nebr.		Peoria, Ill.		Port Gibson, Miss.		Rochester, N.Y.		Sacramento, Calif.		Salisbury, N.C.	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
January	4.6	5.0	2.2	2.6	0.7	0.8	2.1	1.5	5.5	5.3	2.7	2.6	3.3	3.7	3.8	3.7
February	4.3	4.1	2.8	2.8	0.8	0.9	1.4	1.8	5.0	5.2	2.6	2.5	2.7	3.0	4.1	3.8
March	5.5	5.0	2.2	2.5	1.6	1.1	2.7	3.0	6.2	5.5	3.2	2.8	2.2	2.5	5.5	4.0
April	4.4	3.9	1.1	1.6	2.1	2.7	3.2	3.1	6.1	4.8	2.7	2.5	1.2	1.2	4.1	3.3
May	3.7	3.7	0.5	0.6	3.2	3.5	4.2	3.6	3.9	4.7	2.5	2.8	0.5	0.6	3.6	4.1
June	3.6	3.3	0.3	0.4	4.5	4.3	3.5	3.7	4.5	4.3	2.7	2.8	0.2	0.1	4.1	4.1
July	4.0	3.9	2.5	2.8	3.2	3.6	3.5	3.8	4.7	4.7	2.5	3.1	0.0	0.0	4.7	5.8
August	3.9	3.0	2.7	3.7	3.3	3.0	3.1	2.3	3.4	4.0	2.8	2.7	0.0	0.0	5.1	5.0
September	3.4	3.0	1.6	2.4	3.0	2.8	3.5	4.1	2.8	2.5	2.6	2.4	0.1	0.2	3.9	3.1
October	2.1	2.6	1.5	1.6	1.7	2.3	2.4	2.6	2.0	2.6	2.4	2.7	0.7	0.8	3.0	2.9
November	3.0	3.7	1.8	1.8	1.0	1.2	2.4	2.7	3.4	4.1	2.6	2.5	1.8	1.6	2.2	2.9
December	4.4	3.6	2.6	2.6	1.0	0.8	1.9	1.8	7.1	4.8	2.7	2.4	2.9	3.5	4.4	3.5
Year	46.9	44.8	21.8	25.4	26.1	27.0	33.9	34.0	54.6	52.5	32.0	31.8	15.6	17.2	48.5	46.2

	Salt Lake, Utah		San Bernardino, Calif.		Santa Fe, N.Mex.		Spokane, Wash.		St. Louis, Mo.		St. Paul, Minn.		Thomasville, Ga.		Washington, D.C.	
January	1.2	1.4	3.2	3.2	0.4	0.7	2.0	2.0	1.9	2.5	0.9	1.0	3.8	4.0	3.3	3.3
February	1.3	1.4	3.2	3.3	0.7	0.7	1.3	1.8	2.5	2.5	0.8	1.0	4.4	4.1	2.9	2.9
March	1.9	1.9	2.4	2.7	0.8	0.8	1.2	1.3	3.3	3.5	1.2	1.6	4.4	4.6	4.1	3.4
April	1.9	1.9	1.3	1.3	0.8	1.0	1.0	1.1	3.5	3.9	2.2	2.2	3.3	3.8	3.4	3.4
May	1.6	1.8	0.4	0.6	1.0	1.3	1.2	1.4	4.2	4.3	3.1	3.5	3.4	3.6	3.7	3.8
June	0.8	0.8	0.1	0.1	1.2	0.9	1.2	1.4	4.1	4.2	4.0	4.3	5.8	4.8	4.0	3.8
July	0.5	0.5	0.0	0.0	2.4	2.1	0.6	0.6	3.3	3.3	3.1	3.2	6.8	6.8	4.3	4.4
August	0.7	0.8	0.1	0.1	2.0	2.1	0.7	0.5	3.3	3.4	3.1	3.3	5.3	6.2	4.4	4.2
September	0.6	0.9	0.1	0.1	1.4	1.6	0.8	0.9	3.5	3.1	3.3	3.1	4.7	4.8	4.1	3.2
October	1.5	1.4	0.6	0.6	1.0	1.0	1.4	1.3	2.5	2.9	2.0	2.1	2.8	2.3	3.4	2.9
November	1.2	1.4	1.4	0.9	0.7	0.5	1.9	2.0	2.5	2.9	1.3	1.5	2.1	2.6	2.6	2.6
December	1.4	1.3	2.4	2.5	0.7	0.7	2.1	2.2	2.4	2.4	0.9	1.0	4.0	3.9	3.2	3.0
Year	14.6	15.5	15.2	15.4	13.1	13.4	15.4	16.5	37.0	38.9	25.9	27.8	50.8	51.5	43.4	40.9

it, the results and comments representing this project. Even with 32 stations, the United States is so vast in area and so varied in contrasting conditions that with the fullest use of my results no adequate country-wide coverage of the expected precipitation to 1967 can be made. As stated above, confidence in the forecasts must depend largely on the fidelity with which the first half of the forecast, 1950-1958, inclusive, fits the observed record.

Table 10 presents in parallel columns for all 32 stations the monthly percentage departures of forecasts and observed records, 1950-1958, from the normals given in table 9.

That readers may see from a graphical standpoint to what degree the forecasts represent the events, I present figure 10. It gives the march of forecasts and events from 1950 to 1958 for Cincinnati, one of the best, and Denver, a less favorable station.

TABLE 9a.—*Percentage departures (O-F) 1950-1958, from table 9*

City	Abilene	Augusta	Bismarck	Charleston	Cincinnati
% Δ	—12	—17	—6	—11	+4
City	Detroit	Eastport	Helena	Independence	Little Rock
% Δ	—4	+23	—11	—17	+4
City	Natural Bridge	Peoria	Sacramento	Salisbury	Salt Lake
% Δ	—7	—6	—4	—5	—7
City	San Bernardino	Santa Fe	St. Louis	St. Paul	Thomasville
% Δ	+10	—17	—8	—11	—9

Figure 10 shows for a more favorable and a less favorable station a graphic view of data taken from table 10.

A glance at figure 10 shows for both cities an obvious similarity of the features of the forecasts and of the events for the majority of months covered. There are, to be sure, differences in *amplitude* of features observed and forecasted. In many cases the forecast, built on average conditions of about 1,000 previous months, hits the features found in the observed record from 1950 to 1958 on the exact months. But in the better station, as well as in the worse, there occur relative displacements of features common to both forecast and event. These displacements are rarely as great as 5 months for any station, but may extend through durations sometimes as great as several years before returning to agreement.

Displacements of features.—Several years ago I published the account of a forecast for 104 years of St. Louis precipitation, including a comparison with the observed records. I quote from my discussion *

* Text continued on page 44.

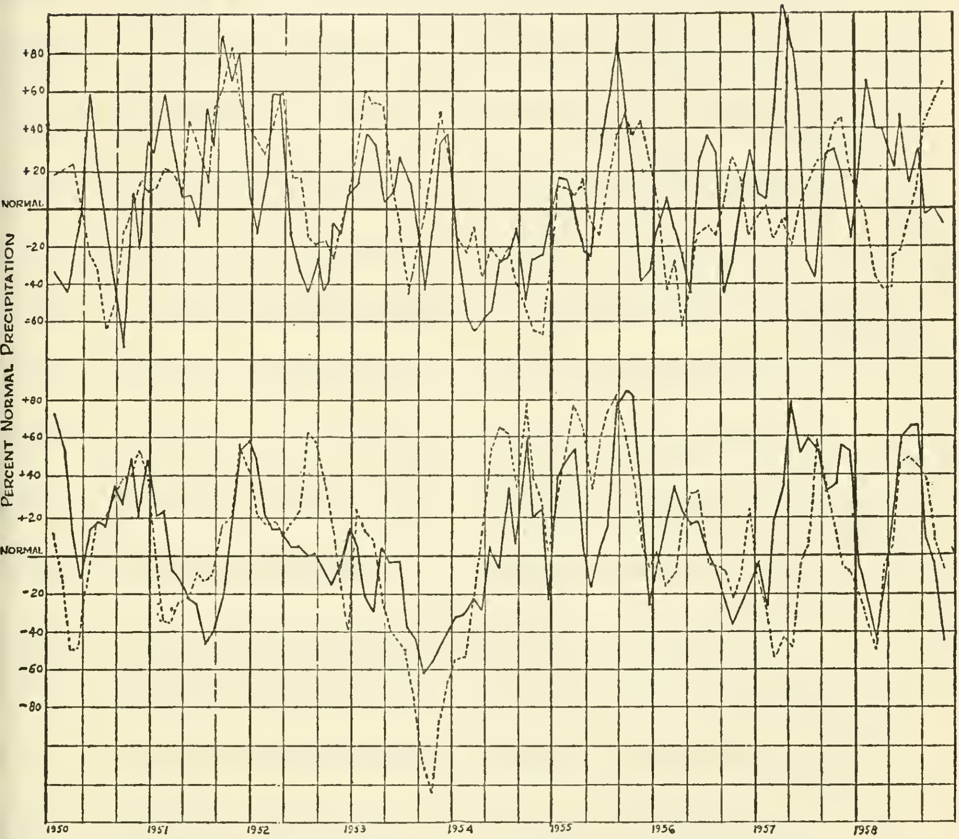

FIG. 10.—Comparison of forecasts and events, 1950-1958. Upper curves, Denver, Colo.; lower curves, Cincinnati, Ohio. Forecasts, dotted lines; events, full curves.

TABLE 10.—*Forecast and observation*, 1950-1958

A

	Abilene, Tex.			Albany, N. Y.			Albany, Oreg.			Augusta, Ga.			Bismarck, N. Dak.			Charleston, S. C.			Cincinnati, Ohio			Denver, Colo.		
	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
1950																								
Jan.	91	90	—1	117	127	+10	108	132	+24	65	45	—20	113	139	+26	100	49	—51	111	172	+61	119	67	—52
Feb.	77	55	—22	135	133	—2	86	152	+66	40	37	—3	124	215	+91	88	50	—38	88	152	+64	120	57	—63
Mar.	109	58	—51	154	103	—51	71	102	+31	20	53	+33	133	185	+52	85	65	—20	50	110	+60	123	71	—52
Apr.	109	89	—20	127	78	—49	42	81	+39	32	100	+68	127	178	+51	104	66	—38	51	88	+37	81	97	+16
May	77	101	+24	138	72	—66	69	54	—15	56	74	+18	118	86	—32	120	104	—16	82	113	+31	77	159	+82
June	74	149	+75	122	80	—42	114	75	—39	84	142	+58	84	66	—18	124	90	—34	115	118	+3	68	122	+54
July	64	203	+139	108	116	+8	117	110	—7	103	96	—7	72	53	—19	119	108	—11	120	115	—5	37	90	+53
Aug.	102	225	+123	104	126	+22	146	124	—22	114	128	+14	90	85	—5	129	104	—25	128	135	+7	50	69	+19
Sept.	80	139	+59	100	115	+15	171	155	—16	124	88	—36	103	93	—10	139	109	—30	139	125	—14	85	26	—59
Oct.	38	41	+3	87	83	—4	153	149	—4	142	107	—35	74	87	+13	116	96	—20	140	149	+9	100	108	+8
Nov.	57	2	—55	111	108	—3	148	145	—3	151	103	—48	64	77	+13	101	85	—16	152	120	—32	116	77	—39
Dec.	105	3	—102	136	122	—14	131	116	—15	131	81	—50	91	91	0	89	67	—22	139	148	+9	108	133	+25
1951																								
Jan.	128	31	—97	132	133	+1	82	103	+21	101	70	—31	119	131	+12	76	79	+3	100	121	+21	112	129	+17
Feb.	130	55	—75	123	134	+11	82	117	+35	97	70	—27	106	103	—3	97	77	—20	66	123	+57	120	158	+38
Mar.	114	77	—37	123	132	+9	87	81	—6	98	78	—20	93	76	—17	88	56	—32	63	91	+28	118	130	+12
Apr.	144	86	—58	133	118	—15	51	77	+26	93	63	—30	84	40	—44	111	72	—39	75	86	+11	110	106	—4
May	172	97	—75	145	99	—46	14	37	+23	110	50	—60	88	54	—34	101	83	—18	79	77	—2	143	107	—36
June	169	99	—70	144	107	—37	45	37	—8	94	63	—31	85	100	+15	119	73	—46	90	73	—17	131	91	—40
July	100	65	—35	125	117	—8	76	13	—63	87	74	—13	81	168	+87	103	91	—12	87	53	—34	113	150	+37
Aug.	46	41	—5	109	133	+24	95	42	—53	90	87	—3	42	166	+124	92	78	—14	91	60	—31	149	132	—17
Sept.	0	34	+34	108	146	+38	109	108	—1	125	82	—43	96	126	+30	79	91	+12	117	76	—41	162	188	+26
Oct.	32	43	+11	103	153	+50	99	136	+37	157	99	—58	99	50	—49	74	95	+21	122	116	—6	184	166	—18
Nov.	64	35	—29	105	146	+41	110	144	+34	150	96	—54	159	87	—72	75	88	+13	156	154	—2	154	179	+25
Dec.	117	43	—74	94	124	+30	92	106	+14	123	87	—36	171	155	—16	97	85	—12	143	159	+16	142	106	—36
1952																								
Jan.	92	47	—45	95	107	+12	70	101	+31	107	88	—19	144	213	+69	140	100	—40	120	148	+28	134	87	—47
Feb.	56	75	+19	110	84	—26	73	89	+16	111	99	—12	137	174	+37	148	117	—31	117	120	+3	127	114	—13

May	57	33	—4	113	139	+26	93	110	+17	141	79	—62	71	39	—32	170	114	—56	117	105	—12	116	89	—27
June	68	34	—34	103	108	+5	84	92	+8	146	84	—62	76	64	—12	155	97	—58	124	105	—19	116	66	—50
July	22	13	—9	86	82	—4	84	97	+13	127	97	—30	79	70	—9	117	97	—20	162	101	—61	83	57	—26
Aug.	30	45	+15	69	72	+3	85	21	—63	121	103	—18	85	46	—39	92	88	—4	158	102	—56	80	72	—8
Sept.	56	33	—23	46	68	+22	121	29	—92	93	88	—5	98	25	—73	75	92	+17	138	93	—45	82	57	—25
Oct.	79	148	+69	46	82	+36	119	24	—25	113	55	—58	65	22	—43	57	97	+40	114	85	—29	73	92	+19
Nov.	135	143	+8	76	108	+32	125	49	—76	112	59	—53	49	19	—30	35	78	+43	86	96	+10	98	87	—11
Dec.	107	146	+39	126	140	+14	130	102	—28	102	75	—27	73	46	—27	46	70	+24	71	114	+43	109	109	0
1953																								
Jan.	124	47	—77	126	141	+15	151	131	—20	99	118	+19	93	69	—24	76	87	+11	123	104	—19	129	113	—16
Feb.	101	46	—55	108	137	+29	79	133	+54	158	106	—52	126	124	—2	101	81	—20	113	78	—35	160	137	—23
Mar.	99	66	—33	104	147	+43	58	97	+39	144	117	—27	168	159	—9	90	73	—17	109	70	—39	153	132	—21
Apr.	107	80	—27	110	213	+103	50	124	+74	125	105	—20	208	188	—20	87	93	+6	77	104	+27	152	102	—50
May	160	94	—66	81	174	+93	18	128	+110	122	124	+2	172	175	+3	100	87	—13	62	98	+36	108	108	0
June	119	149	+30	73	134	+61	36	103	+67	101	95	—6	128	123	—5	71	82	+11	55	99	+44	87	127	+40
July	124	135	+11	69	62	—7	58	121	+63	66	76	+10	84	82	—2	71	91	+20	50	62	+12	54	113	+59
Aug.	77	115	+38	86	72	—14	125	91	—34	64	92	+28	73	42	—31	80	90	+10	23	56	+33	77	81	+4
Sept.	82	86	+4	81	95	+14	147	128	—19	40	82	+42	91	62	—29	106	71	—35	0	38	+38	100	57	—43
Oct.	64	79	+15	86	85	—1	135	87	—48	81	69	—12	76	76	0	96	88	—8	0	43	+43	158	89	—69
Nov.	62	60	—2	97	94	—3	136	116	—20	98	84	—14	71	96	+25	107	80	—27	14	52	+38	149	132	—17
Dec.	36	52	+16	105	91	—14	156	132	—24	129	102	—27	73	104	+31	109	65	—44	34	60	+26	122	137	+15
1954																								
Jan.	33	47	+14	113	113	0	117	129	+12	95	113	+18	14	83	+69	99	75	—24	45	69	+24	84	79	—5
Feb.	26	47	+21	125	104	—21	101	118	+17	68	67	—1	64	84	+20	104	71	—33	47	70	+23	77	42	—35
Mar.	93	58	—35	129	104	—25	56	104	+48	61	74	+13	64	58	—6	102	56	—46	76	79	+3	90	34	—56
Apr.	155	92	—63	113	124	+11	0	80	+80	94	82	—12	72	74	+2	89	48	—41	105	71	—34	63	41	—22
May	162	91	—71	97	124	+27	65	125	+60	87	85	—2	93	75	—18	106	62	—44	153	106	—47	79	44	—35
June	144	39	—105	78	103	+25	136	162	+26	72	93	+21	103	118	+15	126	75	—51	166	93	—73	72	71	—1
July	125	20	—105	58	93	+38	179	212	+33	62	88	+26	164	144	—20	137	85	—52	163	135	—28	77	73	—4
Aug.	100	32	—68	50	86	+36	181	170	—11	18	69	+51	169	177	—92	114	93	—21	133	107	—26	60	90	+30
Sept.	96	58	—38	80	90	+10	141	133	—8	44	52	+8	160	133	—27	75	104	+29	180	160	—20	27	50	+23
Oct.	122	76	—46	97	87	—10	143	102	—41	57	59	+2	92	85	—7	52	114	+62	139	120	—19	34	73	+39
Nov.	167	78	—89	93	110	+13	109	104	—5	77	69	—8	96	25	—71	47	121	+74	127	124	—3	32	74	+42
Dec.	236	88	—148	101	101	0	91	78	—13	103	94	—9	103	44	—59	22	111	+89	102	77	—25	66	95	+29

(*continued*)

TABLE 10.—*continued*

A

	Abilene, Tex.			Albany, N. Y.			Albany, Oreg.			Augusta, Ga.		
	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
1955												
Jan.	249	71	−178	102	101	−1	88	62	−26	112	75	−37
Feb.	254	75	−179	94	92	−2	120	73	−47	170	72	−98
Mar.	202	60	−136	104	112	+8	116	119	+3	189	92	−97
Apr.	282	92	−180	96	80	−16	92	125	+33	253	118	−135
May	160	128	−32	107	65	−42	105	117	+12	85	123	+38
June	114	130	+16	104	43	−61	123	128	+5	118	87	−31
July	83	105	+22	82	74	−8	121	107	−14	135	62	−73
Aug.	89	104	+15	65	89	+24	137	113	−24	135	58	−77
Sept.	126	95	−31	95	183	+88	136	113	−23	110	59	−51
Oct.	116	75	−41	79	175	+96	152	150	−2	65	87	+22
Nov.	76	23	−53	78	153	+75	152	168	+16	58	74	+16
Dec.	75	35	−40	105	82	−23	158	156	−2	67	61	−6
1956												
Jan.	141	89	−52	120	86	−34	136	149	+13	61	65	+4
Feb.	168	98	−70	97	138	+41	118	137	+19	84	100	+16
Mar.	128	107	−21	103	141	+38	117	91	−26	85	119	+34
Apr.	94	47	−47	131	130	−1	82	94	+12	81	78	−3
May	72	38	−34	142	83	−59	46	79	+33	76	63	−13
June	79	18	−61	171	74	−97	31	68	+37	79	44	−35
July	88	26	−62	118	67	−51	63	58	−5	79	52	−27
Aug.	73	25	−48	84	97	+13	74	42	−32	108	76	−32
Sept.	61	36	−25	81	86	+5	108	105	−3	136	86	−50
Oct.	47	42	−5	96	90	−6	105	87	−18	149	78	−71
Nov.	88	74	−14	116	91	−25	114	94	−20	139	54	−85
Dec.	64	69	+5	97	93	−4	172	45	−127	134	51	−83

	Bismarck, N. Dak.			Charleston, S. C.			Cincinnati, Ohio			Denver, Colo.		
	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
1955												
Jan.	94	77	−17	49	85	+36	131	139	+8	111	117	+6
Feb.	116	82	−34	73	94	+21	158	149	−9	110	116	+6
Mar.	100	95	−5	86	89	+3	178	154	−24	107	101	−6
Apr.	89	106	+17	121	68	−53	166	109	−57	117	78	−39
May	71	146	+75	117	71	−46	132	84	−48	96	73	−23
June	123	124	+1	126	79	−47	160	106	−54	85	123	+38
July	109	92	−17	119	97	−22	174	118	−56	112	147	+35
Aug.	114	107	−7	106	83	−23	183	177	−6	136	185	+49
Sept.	114	94	−20	105	79	−26	165	185	+20	148	148	0
Oct.	144	144	0	83	92	+9	134	182	+48	138	120	−18
Nov.	110	102	−8	86	94	+8	104	114	+10	145	61	−84
Dec.	136	158	+22	79	66	−13	95	74	−21	127	67	−60
1956												
Jan.	102	101	−1	83	74	−9	102	92	−10	105	85	−20
Feb.	106	125	+19	98	88	−10	86	120	+34	57	106	+49
Mar.	57	61	+4	104	73	−31	93	133	+40	71	89	+18
Apr.	98	109	+11	106	81	−25	119	122	+3	38	74	+36
May	74	88	+14	108	86	−22	130	118	−12	61	54	−13
June	94	126	+32	101	84	−17	131	120	−11	87	124	+37
July	110	119	+9	114	87	−27	96	101	+5	90	135	+45
Aug.	96	109	+13	109	89	−20	95	94	−1	85	126	+41
Sept.	79	79	0	118	73	−45	91	76	−15	103	53	−50
Oct.	93	109	+16	103	64	−39	78	63	−15	124	75	−49
Nov.	123	110	−13	110	59	−51	91	74	−17	114	114	0
Dec.	102	129	+27	94	54	−40	124	84	−40	86	128	+42

1957																								
Jan.	93	114	+21	101	80	−21	145	66	−79	124	57	−67	98	62	−36	52	62	+10	87	98	+11	95	108	+13
Feb.	95	98	+3	113	47	−66	118	106	−12	107	62	−45	131	55	−76	41	69	+28	71	72	+1	100	105	+5
Mar.	104	177	+73	130	58	−72	91	115	+24	88	60	−28	119	60	−59	72	98	+26	47	117	+70	84	148	+60
Apr.	119	229	+110	123	97	−26	84	144	+60	90	105	+15	81	88	+7	102	115	+13	58	135	+77	94	204	+110
May	111	240	+129	112	104	−8	45	114	+69	82	100	+18	88	106	+18	125	118	−7	52	179	+127	81	191	+110
June	116	151	+35	124	99	−25	45	127	+82	116	93	−23	78	94	+16	139	114	−25	97	151	+54	103	150	+47
July	65	46	−19	97	60	−37	102	97	−5	86	52	−34	68	79	+11	107	142	+35	109	159	+50	113	72	−41
Aug.	79	60	−19	104	54	−50	133	82	−51	79	99	+20	83	72	−11	122	132	+10	158	152	−6	124	62	−62
Sept.	64	109	+45	111	61	−50	165	83	−82	91	129	+38	110	115	+5	123	126	+3	136	131	−5	125	126	+1
Oct.	92	185	+93	106	71	−35	158	69	−89	113	192	+79	146	111	−35	94	142	+48	117	135	+18	141	128	−13
Nov.	118	162	+44	94	109	+15	117	98	−19	100	149	+49	130	115	−15	71	110	+39	94	156	+62	144	119	−25
Dec.	152	155	+3	120	136	+16	98	104	+6	93	142	+59	164	78	−86	78	126	+48	92	152	+60	118	82	−36
1958																								
Jan.	139	142	+3	106	152	+46	91	133	+42	80	93	+13	121	128	+7	125	107	−18	79	96	+17	102	119	+17
Feb.	163	165	+2	132	122	−10	95	107	+12	105	95	−10	100	116	+16	121	121	0	60	43	−17	98	164	+66
Mar.	160	166	+6	95	103	+8	80	107	+27	92	113	+21	98	103	+5	115	164	+49	50	58	+8	63	139	+76
Apr.	148	124	−24	106	85	−21	79	88	+9	90	92	+2	110	44	−66	134	154	+20	95	91	−4	58	139	+81
May	84	107	+23	134	80	−54	99	116	+17	89	86	−3	131	70	−61	142	144	+2	113	122	+9	58	121	+63
June	66	109	+43	143	87	−56	117	73	−44	93	89	−4	132	79	−53	134	66	−68	146	158	+12	78	145	+67
July	92	114	+22	81	76	−5	119	58	−61	150	93	−57	142	76	−66	118	79	−39	149	162	+13	98	112	+14
Aug.	77	149	+72	83	84	+1	98	33	−65	152	88	−64	118	50	−68	116	83	−33	146	166	+20	109	129	+20
Sept.	85	146	+61	76	80	+4	97	57	−40	157	37	−120	99	45	−54	92	98	+6	136	109	−27	145	96	−49
Oct.	70	135	+65	73	104	+31	88	95	+7	132	26	−106	114	132	+18	89	80	−9	107	96	−11	154	100	−54
Nov.	102	83	−19	64	85	+21	95	91	−4	90	38	−52	100	152	+42	86	60	−26	93	54	−39	163	92	−71
Dec.	123	34	−89	75	81	+6	90	122	+32	72	36	−36	126	141	+15	64	72	+8	83	107	+24	146	139	−7

(continued)

TABLE 10.—*continued*

B

	Detroit, Mich.			Eastport, Maine			El Paso, Tex.			Helena, Mont.			Independence, Kans.			Little Rock, Ark.			Madison, Wis.			Montgomery, Ala.		
	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
1950																								
Jan.	131	193	+62	73	113	+40	76	106	+30	71	73	+2	65	81	+16	177	187	+10	120	135	+15	70	67	−3
Feb.	134	177	+43	81	116	+35	61	45	−16	88	92	+4	57	58	+1	181	182	+1	146	131	−15	59	65	+6
Mar.	130	171	+41	123	116	−7	75	25	−50	100	91	−9	76	75	−1	123	132	+9	118	116	−2	37	79	+42
Apr.	117	125	+8	133	87	−46	111	12	−99	106	107	+1	103	92	−11	119	113	−6	106	100	−6	38	86	+50
May	111	108	−3	154	117	−37	105	21	−84	102	100	−2	123	108	−15	112	94	−18	104	121	+17	52	84	+32
June	119	91	−28	137	107	−30	93	91	−2	123	74	−49	146	157	+11	108	95	−13	109	164	+55	64	102	+38
July	149	80	−69	148	162	+14	73	82	+9	139	111	−28	145	164	+19	91	116	+25	110	169	+59	111	87	−24
Aug.	155	89	−66	122	114	−8	114	114	0	127	109	−18	158	154	−4	122	183	+61	96	136	+40	159	166	+7
Sept.	143	95	−48	104	102	−2	99	85	−14	152	110	−42	97	77	−20	135	177	+42	82	74	−8	177	133	−44
Oct.	124	134	+10	114	111	−3	54	81	+27	157	125	−32	72	31	−41	141	130	−11	103	57	−46	196	124	−72
Nov.	107	142	+35	135	181	+46	52	41	−11	159	127	−32	72	9	−63	127	58	−69	93	84	−9	165	56	−109
Dec.	104	122	+18	109	194	+85	98	23	−75	134	124	−10	62	29	−33	125	74	−51	87	103	+16	161	67	−94
1951																								
Jan.	92	114	+22	68	165	+97	102	84	−18	63	61	−2	76	80	+4	108	77	−31	85	130	+45	143	68	−75
Feb.	102	114	+12	69	114	+45	133	154	+21	66	69	+3	73	99	+26	87	78	−9	92	120	+28	125	59	−66
Mar.	92	119	+27	76	139	+63	157	201	+44	59	109	+50	66	93	+27	79	75	−4	122	145	+23	98	63	−35
Apr.	79	102	+23	93	150	+57	165	140	−25	87	114	+27	87	71	−16	68	52	−16	116	128	+12	82	65	−17
May	62	95	+33	95	144	+49	178	70	−108	121	98	−23	123	112	−11	69	79	+10	109	113	+4	32	70	+38
June	49	107	+58	123	132	+9	165	49	−116	110	89	−21	146	118	−28	93	133	+40	88	82	−6	57	57	0
July	78	110	+32	107	149	+42	96	64	−32	148	143	−5	115	121	+6	93	130	+37	67	94	+27	63	65	+2
Aug.	89	106	+17	111	159	+48	102	65	−37	152	144	−8	140	108	−32	97	139	+42	93	96	+3	109	124	+15
Sept.	96	129	+33	116	135	+19	30	35	+5	174	133	−41	143	123	−20	107	99	−8	125	148	+23	176	129	−47
Oct.	86	141	+55	131	139	+8	27	31	+4	173	76	−97	150	144	−6	109	124	+15	145	147	+2	206	134	−72
Nov.	78	168	+90	144	159	+15	78	77	−1	104	106	+2	161	134	−27	142	121	−21	129	158	+29	187	77	−100
Dec.	64	149	+85	144	200	+56	93	60	−33	151	75	−76	137	94	−43	135	104	−31	93	119	+26	153	75	−78
1952																								
Jan.	71	125	+54	95	184	+89	150	142	−8	123	92	−31	108	65	−43	129	112	−17	70	102	+32	130	75	−55
Feb.	82	119	+37	73	145	+72	211	203	−8	114	97	−17	102	69	−33	113	108	−5	108	114	+6	96	76	−20
Mar.	86	113	+27	63	107	+44	204	370	+166	82	104	+22	62	93	+31	93	111	+18	144	88	−56	58	84	+26

May	163	80	−83	81	130	+49	212	312	+100	29	72	+43	49	44	−5	21	60	+39	124	97	−27	91	93	+2
June	167	72	−95	104	121	+17	173	180	+7	71	75	+4	61	39	−22	30	62	+32	106	146	+40	96	75	−21
July	147	70	−77	102	131	+29	130	146	+16	108	65	−43	68	45	−23	50	56	+6	107	164	+57	121	58	−63
Aug.	154	90	−64	101	99	−2	60	61	+1	109	52	−57	48	41	−7	81	88	+7	77	132	+55	122	71	−51
Sept.	143	76	−67	116	105	−11	31	25	−6	124	52	−72	82	21	−61	79	64	−15	64	67	+3	162	77	−85
Oct.	119	90	−29	105	81	−24	3	23	+20	133	75	−58	104	44	−60	93	92	−1	44	59	+15	128	52	−76
Nov.	130	89	−41	126	95	−31	3	31	+28	112	84	−28	121	63	−58	123	107	−16	74	95	+21	119	81	−38
Dec.	112	98	−14	83	110	+27	36	31	−5	71	90	+19	132	70	−102	111	143	+32	87	106	+19	130	91	−39
1953																								
Jan.	92	71	−21	43	136	+93	79	40	−39	61	104	+43	101	58	−43	93	118	+25	93	118	+25	112	125	+13
Feb.	92	77	−15	40	159	+119	107	47	−60	130	100	−30	124	80	−44	153	134	−19	88	118	+30	153	86	−67
Mar.	101	94	−7	35	163	+128	168	149	−19	112	104	−8	104	109	+5	163	141	−22	84	146	+60	166	125	−41
Apr.	93	111	+18	51	131	+80	165	165	0	91	80	−11	88	99	+11	146	157	+11	64	92	+28	145	109	−36
May	92	111	+19	79	101	+22	198	174	−24	109	100	−9	76	91	+15	89	95	+6	71	88	+17	164	124	−40
June	122	93	−29	122	117	−5	187	92	−95	96	79	−17	83	74	−9	42	58	+16	106	95	−11	124	93	−31
July	117	83	−34	165	133	−32	150	57	−93	74	61	−13	109	65	−44	0	40	+40	119	112	−7	144	78	−66
Aug.	119	69	−50	180	144	−36	110	30	−80	70	44	−26	108	68	−40	0	49	+49	95	54	−41	138	121	−17
Sept.	113	50	−63	119	120	+1	97	47	−50	48	44	−4	156	93	−63	0	55	+55	65	57	−8	115	93	−22
Oct.	95	43	−52	77	116	+39	2	37	+35	12	29	+17	107	111	+4	0	43	+43	33	37	+4	105	106	+1
Nov.	85	41	−44	53	121	+68	20	69	+49	46	43	−3	116	94	−22	1	55	+54	41	66	+15	84	99	+15
Dec.	72	62	−10	54	120	+66	19	42	+23	66	107	+41	63	59	−4	105	97	−8	66	80	+14	65	98	+33
1954																								
Jan.	54	106	+52	63	136	+73	35	42	+7	64	102	+38	78	46	−32	147	116	−31	39	85	+46	87	91	+4
Feb.	13	133	+120	39	119	+80	26	23	−3	92	96	+4	17	39	+22	119	107	−12	61	54	−7	47	52	+5
Mar.	0	140	+140	96	138	+42	49	40	−9	75	50	−25	23	69	+46	107	76	−31	78	101	+23	40	61	+21
Apr.	0	97	+97	162	148	−14	141	158	+17	71	62	−9	71	92	+21	118	91	−27	145	120	−25	52	54	+2
May	21	85	+64	222	189	−33	161	156	−5	55	78	+23	84	94	+10	117	84	−33	162	174	+12	61	42	−19
June	48	69	+21	215	172	−43	144	147	+3	79	104	+25	76	70	−6	113	68	−45	173	145	−28	48	54	+6
July	115	82	−33	181	144	−37	189	86	−103	142	144	+2	104	55	−49	54	22	−32	183	141	−42	12	54	+42
Aug.	131	76	−55	149	118	−31	147	105	−42	148	131	−17	140	61	−79	26	32	+6	175	103	−72	0	45	+45
Sept.	134	140	+6	102	136	+34	99	103	+4	137	120	−17	189	119	−70	11	80	+69	125	120	−5	16	39	+23
Oct.	117	134	+17	98	142	+44	47	47	0	89	89	0	166	99	−61	66	89	+23	85	106	+21	71	46	−25
Nov.	95	131	+36	91	154	+63	55	19	−36	86	73	−13	141	110	−31	105	105	0	62	105	+43	66	68	+2
Dec.	73	76	+3	38	113	+75	94	61	−33	58	46	−12	83	75	−8	115	57	−58	42	71	+29	73	81	+8

(*continued*)

TABLE 10.—*continued*

B

	Detroit, Mich.			Eastport, Maine			El Paso, Tex.			Helena, Mont.			Independence, Kans.			Little Rock, Ark.			Madison, Wis.			Montgomery, Ala.		
1955	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
Jan.	60	95	+35	45	115	+70	62	66	+4	61	32	−29	89	97	+8	158	82	−76	69	91	+22	94	80	−14
Feb.	74	96	+22	35	99	+64	117	90	−27	102	78	−24	37	86	+49	147	81	−66	103	73	−30	108	66	−42
Mar.	122	93	−29	59	119	+60	134	30	−104	106	111	+5	70	53	−17	214	94	−120	97	109	+12	123	77	−46
Apr.	135	64	−71	72	90	+18	131	58	−73	112	116	+4	102	95	−7	199	125	−74	113	94	−19	168	123	−45
May	94	57	−37	99	75	−24	91	46	−45	105	92	−13	123	113	−10	87	126	+39	147	112	−35	99	151	+52
June	103	41	−62	76	60	−16	110	118	+8	96	121	+25	108	113	+5	74	124	+50	145	91	−54	112	137	+25
July	115	74	−41	89	80	−9	116	101	−15	114	113	−1	112	61	−51	97	68	−29	131	77	−54	135	88	−47
Aug.	118	80	−38	103	89	−14	92	92	0	116	90	−26	139	54	−85	101	95	−6	93	53	−40	127	57	−70
Sept.	114	129	+15	110	87	−23	118	52	−66	156	27	−129	160	130	−30	144	85	−59	86	60	−26	121	45	−76
Oct.	129	117	−12	99	87	−12	93	56	−37	152	78	−74	150	113	−37	138	87	−51	85	62	−23	118	46	−72
Nov.	122	115	−7	66	65	−1	105	45	−60	147	127	−20	111	97	−14	136	44	−92	80	67	−13	117	48	−69
Dec.	108	71	−37	90	113	+23	91	38	−53	132	146	+14	122	27	−95	112	71	−41	76	29	−47	76	41	−35
1956																								
Jan.	76	73	−3	95	102	+7	109	111	+2	92	89	−3	34	44	+10	140	127	−13	76	46	−30	74	55	−19
Feb.	56	103	+57	99	126	+27	122	111	−11	56	53	−3	52	36	−16	141	139	−2	63	74	+11	83	93	+10
Mar.	82	132	+50	92	106	+14	146	95	−51	24	49	+25	58	46	−12	124	131	+7	113	110	−3	94	95	+1
Apr.	95	156	+61	99	129	+30	117	108	−9	45	67	+22	78	49	−29	95	82	−13	123	135	+12	52	74	+22
May	80	120	+40	112	119	+7	122	98	−24	71	73	+2	88	63	−25	98	97	−1	132	119	−13	57	57	0
June	87	88	+1	127	113	−14	122	112	−10	66	76	+10	77	67	−10	63	123	+60	100	118	+18	39	103	+64
July	112	106	−6	97	89	−8	115	125	+10	98	118	+20	79	55	−24	59	124	+65	102	128	+26	109	121	+12
Aug.	146	99	−47	94	95	+1	79	48	−31	136	98	−38	63	45	−18	67	85	+18	88	116	+28	163	169	+6
Sept.	147	94	−53	79	88	+9	58	26	−32	157	119	−38	95	35	−60	72	59	−13	89	78	−11	200	207	+7
Oct.	142	62	−80	83	93	+10	81	14	−67	133	59	−74	104	65	−39	76	77	+1	74	69	−5	208	188	−20
Nov.	113	88	−25	93	101	+8	75	45	−30	127	77	−50	136	90	−36	82	96	+14	102	78	−24	198	173	−25
Dec.	96	109	+13	133	91	−42	57	62	+5	155	71	−84	151	84	−67	129	105	−24	125	81	−44	171	95	−76

1957																								
Jan.	109	91	−18	118	92	−26	45	106	+61	135	82	−53	113	89	−24	130	108	−22	84	39	−45	167	99	−68
Feb.	90	79	−11	70	74	+4	74	100	+26	121	113	−8	94	88	−6	122	123	+1	56	36	−20	146	65	−81
Mar.	87	103	+16	44	88	+44	94	97	+3	98	96	−2	62	116	+54	95	160	+65	65	59	−6	99	100	+1
Apr.	75	104	+29	57	85	+28	87	66	−21	81	138	+57	64	150	+86	88	195	+107	70	106	+36	59	162	+103
May	90	114	+24	77	84	+7	126	29	−97	85	115	+30	105	175	+70	79	186	+107	74	137	+63	44	178	+134
June	80	125	+45	82	81	−1	133	66	−67	70	112	+42	128	163	+35	61	138	+77	99	145	+46	17	141	+124
July	113	119	+6	115	110	−5	100	140	+40	70	108	+39	163	99	−64	53	103	+50	128	140	+12	49	82	+33
Aug.	132	126	−6	127	102	−25	84	142	+60	90	130	+40	178	71	−107	82	99	+17	144	98	−46	89	147	+58
Sept.	136	126	−10	134	85	−49	93	192	+99	109	169	+60	171	83	−88	106	128	+22	141	92	−49	94	140	+46
Oct.	117	149	+32	153	79	−74	59	171	+112	127	143	+16	139	111	−28	144	159	+15	125	94	−31	140	182	+42
Nov.	96	180	+84	130	117	−13	38	170	+132	126	107	−19	133	102	−31	161	168	+7	112	116	−4	139	101	−38
Dec.	91	127	+36	105	189	+84	35	119	+84	132	54	−78	109	79	−30	163	139	−24	97	94	−3	169	104	−65
1958																								
Jan.	90	91	+1	74	169	+95	77	160	+83	73	78	+5	98	52	−46	161	80	−81	94	43	−57	121	73	−48
Feb.	111	29	−82	69	137	+68	106	426	+320	69	114	+45	75	94	+19	135	78	−57	72	18	−54	118	107	−11
Mar.	103	37	−66	64	103	+39	120	375	+255	90	137	+47	101	107	+6	130	103	−27	89	42	−47	79	117	+38
Apr.	109	38	−71	84	129	+45	104	273	+169	87	106	+19	87	123	+36	132	141	+9	115	89	−26	75	121	+46
May	90	60	−30	91	138	+47	113	133	+20	130	117	−13	94	87	−7	111	171	+60	117	89	−28	88	90	+2
June	91	72	−19	98	149	+51	179	159	−20	124	117	−7	94	147	+53	119	153	+34	119	71	−48	98	112	+14
July	98	88	−10	115	124	+9	126	178	+52	122	119	−3	132	120	−12	74	138	+64	82	55	−27	138	86	−52
Aug.	89	110	+21	126	123	−3	97	243	+146	149	72	−77	179	189	+10	65	167	+102	93	61	−32	132	112	−20
Sept.	105	92	−13	122	109	−13	127	303	+176	131	48	−83	133	59	−74	77	132	+55	115	82	−33	160	72	−88
Oct.	114	109	−5	134	122	−12	107	296	+189	119	58	−61	93	59	−34	89	136	+47	116	102	−14	170	91	−79
Nov.	105	68	−37	126	111	−15	96	104	+8	107	97	−10	67	30	−37	106	57	−49	104	86	−18	138	56	−82
Dec.	88	88	0	121	117	−4	120	32	−88	95	106	+11	21	39	+18	96	59	−37	72	75	+3	113	69	−44

(*continued*)

TABLE 10.—*continued*

C

	Nasbville, Tenn.			Natural Bridge, Ariz.			Omaha, Nebr.			Peoria, Ill.			Port Gibson, Miss.			Rochester, N. Y.			Sacramento, Calif.			Salisbury, N. C.		
	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
1950																								
Jan.	165	189	+24	159	107	—52	109	97	—12	148	228	+80	135	125	—10	124	142	+18	120	95	—25	68	52	—16
Feb.	135	161	+26	139	76	—63	97	107	+10	159	137	—22	163	135	—28	112	166	+54	168	103	—65	79	66	—13
Mar.	63	102	+39	94	48	—46	88	90	+2	109	147	+38	117	120	+3	94	144	+50	184	91	—93	56	61	+5
Apr.	41	75	+34	67	28	—39	95	86	—9	64	109	+45	109	134	+25	74	109	+35	177	75	—102	73	102	+29
May	56	91	+35	53	23	—30	104	81	—25	60	135	+75	97	132	+35	68	105	+37	114	71	—43	60	98	+38
June	85	144	+59	40	80	+40	95	122	+27	69	97	+28	106	172	+66	91	117	+26	109	43	—66	75	115	+40
July	108	180	+72	100	84	—16	106	141	+35	73	104	+31	128	142	+14	119	113	—6	69	23	—46	98	71	—27
Aug.	134	179	+45	135	79	—56	72	133	+61	107	90	—17	152	157	+5	111	90	—21	80	104	+24	103	76	—27
Sept.	129	134	+5	110	21	—89	74	115	+41	124	60	—64	125	109	—16	130	98	—32	101	181	+80	115	74	—41
Oct.	113	121	+8	8	23	+15	54	62	+8	117	70	—47	116	94	—22	155	145	—10	119	271	+152	117	86	—31
Nov.	104	102	—2	0	12	+12	50	64	+14	152	53	—99	120	79	—41	176	148	—28	177	212	+35	103	76	—27
Dec.	130	150	+20	24	56	+32	55	47	—8	163	70	—93	152	87	—65	141	139	—2	190	157	—33	96	62	—34
1951																								
Jan.	128	114	—14	0	61	+61	107	108	+1	154	104	—50	167	108	—59	108	106	—2	155	85	—70	107	57	—50
Feb.	135	128	—7	15	84	+69	157	194	+37	139	128	—11	173	129	—44	98	133	+35	144	51	—93	128	67	—61
Mar.	97	98	+1	47	119	+72	166	241	+75	142	139	+3	131	117	—14	94	144	+50	100	52	—48	133	100	—33
Apr.	79	82	+3	84	157	+73	175	234	+59	161	98	—63	85	81	—4	94	129	+35	86	69	—17	110	87	—23
May	120	113	—7	154	134	—20	130	179	+49	150	87	—63	69	104	+35	78	122	+44	41	58	+17	97	95	—2
June	140	104	—36	110	61	—39	144	143	—1	118	107	—11	65	122	+57	63	117	+54	0	35	+35	71	74	+3
July	128	107	—21	124	94	—30	114	153	+39	79	123	+44	60	122	+62	86	105	+19	0	0	0	71	75	+4
Aug.	115	75	—40	125	99	—26	122	147	+25	81	114	+33	61	120	+59	92	83	—9	15	42	+27	84	58	—26
Sept.	111	99	—12	116	132	+16	114	124	+10	98	102	+4	55	76	+21	116	62	—54	74	99	+25	92	32	—60
Oct.	105	127	+22	57	100	+43	75	61	—14	132	99	—33	88	93	+5	125	104	—21	141	167	+26	131	68	—63
Nov.	121	178	+57	102	163	+61	106	68	—38	135	95	—40	117	81	—36	141	117	—24	96	174	+78	168	101	—67
Dec.	113	155	+42	106	163	+57	130	82	—48	122	78	—44	105	96	—9	118	126	+8	132	195	+63	172	130	—42
1952																								
Jan.	132	150	+18	134	118	—16	160	93	—67	81	73	—8	56	103	+47	70	109	+39	126	146	+20	159	123	—36
Feb.	131	133	+2	128	126	—2	141	123	—18	106	103	—3	83	68	—15	64	98	+34	153	156	+3	167	160	—7

May	62	49	−13	74	83	+9	[illegible]	112	+23	78	111	+33	[illegible]	67	−15	[illegible]	83	−12	157	246	+89	115	66	−49
June	55	43	−12	34	40	+6	74	103	+29	95	99	+4	57	57	0	105	78	−27	141	445	+304	111	58	−53
July	73	63	−10	125	63	−62	69	138	+69	88	120	+32	18	43	+25	105	55	−50	71	442	+371	130	92	−38
Aug.	97	97	0	190	99	−91	84	119	+35	94	91	−3	39	49	+10	123	86	−37	73	246	+173	114	90	−24
Sept.	104	103	−1	184	61	−123	88	93	+5	64	80	+16	68	35	−33	120	74	−46	103	8	−95	104	79	−25
Oct.	98	79	−19	138	133	−5	95	86	−9	51	71	+20	90	35	−55	102	89	−13	106	52	−54	111	59	−52
Nov.	102	61	−41	101	134	+33	115	109	−6	51	87	+36	105	75	−30	86	75	−11	133	114	−19	120	83	−37
Dec.	114	90	−24	134	146	+12	112	127	+15	68	96	+28	105	95	−10	66	89	+23	148	145	−3	92	101	+9
1953																								
Jan.	118	95	−23	77	62	−15	68	92	+24	58	68	+10	119	122	+3	57	80	+23	109	105	−4	93	121	+29
Feb.	150	106	−44	90	53	−37	131	87	−44	77	89	+12	89	108	+19	58	91	+33	158	56	−102	113	114	+1
Mar.	81	94	+13	110	65	−45	126	111	−15	99	98	−1	149	149	0	83	78	−5	172	98	−74	72	100	+28
Apr.	115	118	+3	132	61	−71	123	99	−24	115	104	−11	143	172	+29	105	109	+4	131	129	−2	31	60	+29
May	80	102	+22	158	39	−119	120	90	−30	145	81	−64	199	160	−39	117	95	−22	108	173	+65	16	67	+51
June	81	122	+41	131	48	−83	87	59	−28	141	107	−34	127	117	−10	127	98	−29	23	99	+76	35	74	+39
July	35	83	+48	33	69	+36	37	53	+16	133	105	−28	74	76	+2	132	92	−40	4	66	+62	55	90	+35
Aug.	0	75	+75	66	61	−5	10	30	+20	117	91	−26	16	65	+49	129	114	−15	0	0	0	92	95	+3
Sept.	0	26	+26	53	30	−23	0	35	+35	93	45	−48	51	59	+8	104	112	+8	0	8	+8	119	71	−48
Oct.	0	24	+24	50	13	−37	2	93	+91	55	33	−22	70	48	−22	78	99	+21	47	41	−6	116	55	−61
Nov.	23	40	+17	71	23	−48	42	130	+88	53	59	+6	60	61	+1	71	81	+10	119	47	−72	128	58	−70
Dec.	94	90	−4	129	73	−56	38	126	+88	55	70	+15	39	56	+17	46	80	+34	167	72	−95	163	121	−42
1954																								
Jan.	102	113	+11	78	80	+2	100	135	+35	67	112	+45	17	79	+62	78	76	−2	166	84	−82	172	128	−44
Feb.	97	113	+16	121	133	+12	121	108	−13	73	107	+34	44	84	+40	83	94	+11	242	127	−115	112	107	−5
Mar.	95	90	−5	144	80	−64	133	142	+9	91	146	+55	53	53	0	118	110	−8	228	146	−82	81	76	−5
Apr.	135	93	−42	106	158	+52	99	94	−5	109	121	+12	109	127	+18	91	98	+7	156	114	−42	78	87	+9
May	116	90	−26	86	146	+60	122	103	−19	132	140	+8	76	110	+34	84	80	−4	91	65	−20	47	92	+45
June	78	62	−16	83	197	+114	120	65	−55	118	114	−4	80	111	+31	68	65	−3	62	14	−48	48	94	+46
July	49	42	−7	67	144	+77	167	100	−67	98	188	+90	83	72	−11	96	88	−8	26	0	−26	42	88	+46
Aug.	95	61	−34	14	137	+123	180	91	−89	76	138	+62	181	124	−57	133	88	−45	23	0	−23	43	64	+21
Sept.	133	101	−32	70	104	+3¼	199	148	−51	91	146	+55	176	133	−43	173	131	−42	51	1	−50	118	106	−12
Oct.	124	100	−24	80	74	−6	157	80	−77	99	82	−17	131	118	−13	207	119	−88	99	62	−37	144	132	−12
Nov.	111	100	−11	156	28	−128	87	68	−19	99	108	+9	72	72	0	206	136	−70	138	118	−20	151	158	+7
Dec.	92	64	−28	140	66	−74	77	40	−37	99	125	+26	49	71	+22	135	87	−48	200	148	−52	104	104	0

(*continued*)

TABLE 10.—*continued*

C

	Nashville, Tenn.			Natural Bridge, Ariz.			Omaha, Nebr.			Peoria, Ill.			Port Gibson, Miss.			Rochester, N. Y.			Sacramento, Calif.			Salisbury, N. C.		
1955	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
Jan.	130	104	—26	16	82	+66	107	83	—24	93	135	+42	47	78	+31	98	77	—21	159	104	—55	67	85	—18
Feb.	168	121	—47	32	82	+50	126	96	—30	97	122	+25	63	69	+6	76	80	+4	147	53	—94	49	72	—23
Mar.	169	147	—22	123	49	—74	105	114	+9	94	104	+10	77	85	+8	115	105	—10	126	97	—29	44	88	—44
Apr.	128	121	—7	176	32	—144	124	82	—42	111	88	—23	132	101	+31	111	101	—10	110	117	+7	65	87	—22
May	74	87	+13	83	150	+67	130	100	—30	118	94	—24	107	97	—10	92	69	—23	78	117	+39	110	96	—14
June	81	67	—14	71	185	+114	73	83	+10	80	60	—20	109	119	+10	63	41	—22	9	41	+32	116	87	—29
July	99	85	—14	160	239	+79	99	86	—13	67	83	+17	118	99	—19	85	87	+2	0	5	+5	107	93	—14
Aug.	121	106	—15	196	119	—77	82	95	+13	58	82	+24	105	115	+10	119	97	—22	0	101	+101	106	87	—19
Sept.	145	118	—27	154	61	—93	106	64	—42	90	129	+39	128	76	—52	130	173	+43	19	125	+106	99	108	+9
Oct.	127	108	—19	58	37	—21	62	50	—12	76	87	+11	117	76	—41	138	135	—3	111	150	+39	106	99	—7
Nov.	122	72	—50	20	83	+63	48	16	—32	86	69	—17	84	76	—8	112	137	+25	147	131	—16	79	79	0
Dec.	108	83	—25	74	91	+17	62	38	—24	96	20	—76	109	61	—48	107	77	—30	189	175	—14	58	42	—16
1956																								
Jan.	129	126	—3	49	81	+32	117	49	—68	120	30	—90	132	87	—45	90	94	+4	177	178	+1	66	67	+1
Feb.	126	142	+16	42	35	—7	88	42	—46	121	31	—90	135	119	—16	93	110	+17	165	96	—69	76	92	+16
Mar.	109	140	+31	38	55	+17	104	28	—76	99	55	—44	145	124	—21	101	140	+39	154	78	—76	61	112	+51
Apr.	81	89	+8	78	35	—43	73	29	—44	80	76	—4	116	101	—15	117	142	+25	159	104	—55	52	99	+47
May	85	83	—2	69	55	—14	67	48	—19	76	77	+1	104	88	—16	122	112	—10	96	103	+7	64	84	+20
June	54	63	+9	94	46	—48	27	88	+61	71	93	+22	53	81	+28	94	87	—7	53	52	—1	73	102	+29
July	65	58	—7	86	60	—26	61	116	+55	51	100	+49	25	76	+51	102	111	+9	38	0	—38	68	76	+8
Aug.	67	40	—27	87	43	—44	99	118	+19	37	96	+59	35	52	+17	136	149	+13	31	101	+70	122	150	+28
Sept.	87	50	—37	87	44	—43	91	91	0	74	62	—12	80	92	+12	124	129	+5	26	158	+132	140	133	—7
Oct.	89	45	—44	84	27	—57	91	100	+9	89	45	—44	110	92	—18	95	81	—14	67	159	+92	146	148	+2
Nov.	112	102	—10	61	31	—30	79	85	+6	75	74	—1	137	125	—12	80	61	—19	79	60	—19	139	92	—47
Dec.	97	138	+41	90	67	—23	75	71	—4	52	92	+40	127	93	—34	93	83	—10	26	26	0	141	88	—53

1957																								
Jan.	125	165	+40	92	88	−4	107	27	−80	86	76	−10	146	97	−49	96	84	−12	92	71	−21	116	126	+10
Feb.	136	124	−12	90	95	+5	145	92	−53	99	75	−24	142	94	−48	60	75	+15	135	99	−36	123	125	+2
Mar.	144	85	−59	90	37	−57	168	106	−62	120	94	−26	127	120	−7	80	79	−1	186	122	−64	116	128	+12
Apr.	101	117	+16	67	72	+5	141	149	+8	154	146	−8	87	112	+25	89	94	+5	196	172	−24	119	97	−22
May	83	160	+77	93	128	+35	119	125	+6	163	138	−25	46	137	+91	117	115	−2	180	142	−38	110	125	+15
June	63	152	+89	126	159	+33	42	113	+71	167	106	−61	57	105	+48	98	101	+3	106	97	−9	126	115	−11
July	90	106	+16	118	143	+25	78	144	+66	133	66	−67	86	86	0	87	78	−9	44	0	−44	104	100	−4
Aug.	108	89	−19	114	81	−33	128	124	−4	132	47	−85	77	67	−10	80	69	−11	23	23	0	111	105	−6
Sept.	112	124	+12	99	111	+12	128	164	+36	130	90	−40	108	81	−27	84	57	−27	31	80	+49	88	104	+16
Oct.	122	154	+32	133	120	−13	49	144	+95	97	108	+11	102	160	+58	108	70	−38	69	87	+18	98	175	+77
Nov.	128	162	+34	113	134	+21	96	132	+36	79	158	+79	149	147	−2	82	63	−19	83	94	+11	88	138	+50
Dec.	122	129	+7	101	69	−32	91	123	+32	91	118	+27	187	146	−41	96	89	−7	118	85	−33	101	157	+56
1958																								
Jan.	100	84	−16	111	64	−47	119	95	−24	133	93	−40	184	79	−105	87	120	+33	182	180	−2	100	95	−5
Feb.	99	56	−43	111	102	−9	147	102	−45	130	36	−94	154	86	−68	81	150	+69	193	229	+36	77	96	+19
Mar.	89	93	+4	87	137	+50	136	107	−29	151	39	−112	90	97	+7	87	155	+68	178	301	+123	68	132	+64
Apr.	83	104	+21	121	137	+16	94	93	−1	115	55	−60	87	104	+17	86	121	+35	153	238	+85	73	134	+61
May	68	107	+39	153	155	+2	62	79	+17	107	89	−18	60	131	+71	76	118	+42	86	282	+96	99	156	+57
June	67	106	+39	133	121	−12	62	117	+55	101	144	+43	62	126	+64	80	120	+40	21	162	+141	88	108	+20
July	98	137	+39	74	92	+18	73	133	+60	102	154	+52	82	132	+50	106	129	+23	36	156	+120	96	105	+9
Aug.	110	142	+32	94	120	+26	89	172	+83	82	145	+63	88	131	+43	122	124	+2	69	54	−15	113	96	−17
Sept.	118	106	−12	123	133	+10	89	84	−5	103	79	−24	104	104	0	133	141	+8	108	72	−36	144	85	−59
Oct.	115	80	−35	135	135	0	106	80	−26	95	71	−24	110	107	−3	146	148	+2	148	42	−106	165	68	−97
Nov.	127	60	−67	131	32	−99	92	31	−61	83	49	−34	131	55	−76	154	108	−46	169	28	−141	151	87	−64
Dec.	124	68	−56	85	29	−56	69	51	−18	67	79	+12	108	70	−38	126	97	−29	167	58	−109	32	79	+47

(*continued*)

TABLE 10.—*continued*

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	Salt Lake, Utah			San Bernardino, Calif.			Santa Fe, N. Mex.			Spokane, Wash.			St. Louis, Mo.			St. Paul, Minn.			Thomasville, Ga.			Washington, D. C.		
	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
1950																								
Jan.	103	107	+4	88	81	−7	106	100	−6	107	127	+20	108	204	+96	125	93	−32	62	30	−32	85	67	−18
Feb.	66	90	+24	104	65	−39	149	63	−86	111	198	+87	132	184	+52	137	106	−31	95	71	−24	65	38	−27
Mar.	51	69	+18	89	61	−28	168	37	−131	120	145	+25	115	113	−2	120	104	−16	107	112	+5	54	89	+35
Apr.	73	80	+7	81	46	−35	153	12	−141	120	126	+6	117	98	−19	108	83	−25	128	131	+3	71	119	+48
May	69	69	0	37	50	+13	144	49	−95	142	106	−36	138	96	−42	143	93	−50	80	91	+11	79	100	+21
June	96	114	+18	58	28	−30	149	99	−50	147	127	−20	142	74	−78	138	77	−61	73	81	+8	93	113	+20
July	113	75	−38	99	17	−82	107	110	+3	123	137	+14	141	119	−22	116	67	−49	68	72	+4	43	104	+61
Aug.	145	130	−15	83	0	−83	104	98	−6	70	66	−4	124	117	−7	121	62	−59	83	66	−17	18	148	+130
Sept.	149	76	−73	118	2	−116	73	38	−35	84	112	+28	100	113	+13	106	68	−38	95	69	−26	36	155	+119
Oct.	139	123	−16	114	68	−46	101	29	−72	109	118	+9	84	73	−11	105	83	−22	89	58	−31	87	149	+62
Nov.	127	74	−53	76	68	−8	65	4	−61	131	148	+17	50	56	+6	103	81	−22	101	75	−26	79	115	+36
Dec.	114	100	−14	55	100	+45	54	12	−42	132	119	−13	99	76	−23	94	106	+12	100	48	−52	84	102	+18
1951																								
Jan.	83	68	−15	41	42	+1	70	24	−46	95	115	+20	102	119	+17	83	133	+50	143	54	−89	94	95	+1
Feb.	68	79	+11	39	49	+10	75	40	−35	71	126	+55	115	132	+17	94	137	+43	181	98	−83	80	85	+5
Mar.	55	84	+29	14	60	+46	71	49	−22	59	86	+27	106	120	+24	108	122	+14	180	110	−70	94	100	+6
Apr.	60	84	+24	13	119	+106	64	66	+2	54	72	+18	132	55	−77	124	139	+15	198	109	−89	93	98	+5
May	30	65	+35	31	112	+81	87	59	−28	26	56	+30	122	81	−41	122	138	+16	161	93	−68	58	148	+90
June	36	90	+54	20	100	+80	118	54	−64	33	67	+34	122	98	−24	109	112	+3	122	96	−26	45	127	+82
July	69	147	+78	47	48	+1	116	90	−26	66	78	+12	120	107	−13	116	134	+18	92	96	+4	94	115	+21
Aug.	107	143	+36	120	102	−18	49	86	+37	59	71	+12	128	96	−32	127	123	−4	65	76	+11	94	55	−39
Sept.	146	120	−26	121	107	−14	44	87	+43	81	129	+48	130	94	−36	109	127	+18	69	66	+3	87	55	−32
Oct.	145	84	−61	155	144	−11	48	32	−16	114	134	+20	123	109	−14	103	116	+13	120	129	+9	112	102	−10
Nov.	173	156	−17	158	164	+6	59	43	−16	161	180	+19	88	104	+16	105	126	+21	114	141	+27	96	135	+39
Dec.	151	163	+12	195	195	0	67	53	−14	159	138	−21	70	89	+19	92	112	+20	107	136	+29	111	163	+52
1952																								
Jan.	132	170	+38	157	148	−9	48	42	−6	108	181	+73	51	80	+29	84	138	+54	109	109	0	118	122	+4
Feb.	97	162	+65	121	138	+17	62	57	−5	62	94	+32	60	81	+21	84	114	+30	114	105	−9	136	114	−22
Mar.	71	141	+70	85	120	+35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

May	51	99	+48	77	50	−27	113	69	−44	85	89	+4	117	69	−48	83	115	+32	133	111	−22	122	146	+24
June	77	136	+59	81	64	−17	117	62	−55	92	83	−9	136	69	−67	99	101	+2	123	105	−18	127	101	−26
July	82	124	+42	92	64	−28	131	65	−66	76	79	+3	153	86	−67	142	98	−44	103	105	+2	142	110	−32
Aug.	90	78	−12	130	189	+59	104	76	−28	65	38	−27	138	70	−68	132	75	−57	90	119	+29	125	124	−1
Sept.	91	8	−83	130	124	−6	111	55	−56	76	38	−38	139	43	−96	115	75	−40	89	109	+20	77	104	+27
Oct.	101	26	−75	161	235	+74	100	40	−60	109	40	−69	104	46	−58	89	54	−35	71	62	−9	65	136	+71
Nov.	133	55	−78	127	155	+28	109	42	−67	140	64	−76	74	62	−12	89	40	−49	55	45	−10	80	135	+55
Dec.	140	120	−20	122	175	+53	93	58	−35	149	131	−18	79	83	+4	85	64	−21	78	59	−19	125	164	+39
1953																								
Jan.	134	104	−30	142	67	−75	59	59	0	160	143	−17	73	74	+1	80	104	+24	109	103	−6	108	100	−8
Feb.	88	91	+3	112	43	−69	72	73	+1	125	145	+20	107	89	−18	99	105	+6	99	95	−4	139	120	−19
Mar.	88	73	−15	110	80	−30	47	67	+20	119	124	+5	42	97	+55	79	109	+30	108	146	+38	110	125	−15
Apr.	90	85	−5	63	102	+39	76	72	−4	94	143	+49	66	101	+35	74	133	+29	177	94	−83	108	154	+46
May	47	92	+45	20	82	+62	118	48	−70	65	119	+54	53	77	+24	67	150	+83	181	133	−48	77	119	+42
June	57	99	+42	0	26	+26	138	110	−28	47	69	+22	28	52	+24	83	128	+45	143	86	−57	75	103	+28
July	43	119	+76	0	19	+19	127	99	−28	112	97	−15	34	33	−1	82	113	+31	119	136	+17	81	65	−16
Aug.	46	104	+58	0	19	+19	86	112	+26	136	92	−44	39	21	−18	72	102	+30	129	136	+7	97	80	−17
Sept.	18	56	+38	73	22	−51	104	58	−46	123	97	−26	100	52	−48	47	90	+43	107	117	+10	91	84	−7
Oct.	10	40	+30	99	25	−74	105	106	+1	100	62	−38	108	54	−54	3	85	+82	58	96	+38	139	89	−50
Nov.	14	56	+42	115	29	−86	76	121	+45	76	72	−4	127	55	−72	3	73	+70	71	120	+49	85	87	+2
Dec.	30	73	+43	178	99	−79	96	127	+31	170	135	−35	82	43	−39	42	78	+36	86	127	+41	108	189	+81
1954																								
Jan.	35	68	+33	202	106	−96	71	70	−1	144	127	−17	27	41	+14	73	110	+37	52	98	+46	108	76	−32
Feb.	50	72	+22	251	169	−82	55	96	+41	101	119	+18	16	45	+29	69	119	+50	11	45	+34	70	71	+1
Mar.	97	59	−38	224	103	−121	94	72	−22	23	70	+47	39	48	+9	87	97	+10	0	58	+58	42	71	+29
Apr.	135	51	−84	178	76	−102	186	126	−60	3	62	+59	82	62	−20	89	115	+26	54	75	+21	50	90	+40
May	187	103	−84	183	74	−109	220	101	−119	32	62	+30	106	73	−33	107	115	+8	53	68	+15	19	78	+59
June	225	154	−71	187	129	−58	264	149	−115	82	101	+19	106	67	−39	121	101	−20	87	58	−29	86	50	−36
July	242	225	−17	219	128	−91	220	146	−74	183	146	−37	106	84	−22	147	91	−56	64	48	−16	36	60	+24
Aug.	234	179	−55	139	63	−76	180	129	−51	148	185	+37	142	106	−36	171	87	−84	47	40	−7	23	48	+25
Sept.	171	129	−42	135	0	−135	82	105	+23	128	148	+20	186	134	−52	176	73	−103	38	33	−5	102	77	−25
Oct.	101	88	−13	175	73	−102	40	54	+14	127	108	−19	171	112	−59	138	71	−67	26	66	+40	119	73	−46
Nov.	54	73	+19	201	90	−111	51	48	−3	103	69	−34	129	99	−30	128	62	−66	44	90	+46	141	95	−46
Dec.	51	98	+47	221	137	−84	50	80	+30	81	71	−10	84	76	−8	101	79	−22	61	120	+59	93	56	−37

(*continued*)

TABLE 10.—*continued*

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	Salt Lake, Utah			San Bernardino, Calif.			Santa Fe, N. Mex.			Spokane, Wash.			St. Louis, Mo.			St. Paul, Minn.			Thomasville, Ga.			Washington, D. C.		
1955	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ	Fore-cast	Ob-served	Δ
Jan.	110	87	−23	127	82	−45	61	87	+26	130	77	−53	117	100	−17	99	75	−24	78	87	+9	59	75	+16
Feb.	131	74	−57	72	71	−1	100	77	−23	80	75	−5	123	91	−32	109	74	−35	141	62	−79	70	176	+106
Mar.	155	73	−82	43	43	0	109	59	−50	87	115	+28	137	91	−46	81	71	−10	165	72	−93	69	100	+31
Apr.	181	64	−117	0	111	+111	153	78	−85	61	101	+40	104	64	−40	77	68	−9	235	92	−143	42	82	+40
May	88	102	+14	94	127	+33	158	78	−80	100	100	0	117	63	−54	137	73	−60	131	104	−27	96	86	−10
June	75	117	+42	78	184	+106	146	70	−76	125	118	−7	149	93	−56	139	82	−57	106	107	+1	161	104	−57
July	89	110	+21	79	98	+19	132	79	−53	117	100	−17	158	99	−59	127	80	−47	100	76	−24	187	192	+5
Aug.	97	103	+6	80	78	−2	143	98	−45	140	127	−13	123	120	−3	109	96	−13	96	82	−14	154	165	+11
Sept.	113	74	−39	76	2	−74	95	77	−18	136	130	−6	104	112	+8	114	104	−10	86	68	−18	134	181	+47
Oct.	145	110	−35	86	66	−20	81	37	−44	160	184	+24	81	119	+38	105	83	−22	97	72	−25	77	91	+14
Nov.	166	102	−64	94	84	−10	47	64	+17	161	193	+32	75	77	+2	88	76	−12	109	61	−48	87	87	0
Dec.	183	138	−45	105	161	+56	28	98	+70	180	158	−22	54	38	−16	85	73	−12	120	69	−51	81	47	−34
1956																								
Jan.	146	111	−36	136	102	−34	80	108	+28	153	132	−21	48	58	+10	92	73	−19	146	109	−37	134	69	−65
Feb.	97	86	−11	133	82	−51	90	53	−37	92	107	+15	70	69	−1	102	65	−37	134	124	−10	130	100	−30
Mar.	64	55	−9	93	48	−49	79	12	−67	68	63	−5	125	86	−39	120	54	−66	150	107	−43	125	96	−29
Apr.	59	71	+12	88	75	−13	60	31	−29	41	50	+9	113	74	−39	97	75	−22	126	104	−22	89	82	−7
May	62	97	+35	116	75	−41	82	53	−29	32	49	+17	95	81	−14	83	104	+21	129	126	−3	100	76	−24
June	43	75	+32	126	257	+131	112	80	−32	55	77	+22	70	131	+61	100	115	+15	105	128	+23	123	97	−26
July	42	34	−8	115	225	+110	95	71	−24	127	161	+34	82	116	+34	90	115	+25	108	97	−11	109	92	−17
Aug.	76	11	−65	121	225	+104	95	50	−25	135	134	−1	85	109	+24	78	119	+41	116	116	0	78	99	+21
Sept.	91	51	−40	134	28	−106	92	30	−62	151	157	+6	76	40	−36	92	106	+14	98	126	+28	96	91	−5
Oct.	93	64	−29	95	28	−67	73	14	−59	150	64	−86	62	49	−13	100	76	−24	112	120	+8	106	108	+2
Nov.	109	100	−9	53	34	−19	114	28	−86	153	78	−75	82	92	+10	99	51	−48	86	62	−24	119	102	−17
Dec.	113	88	−25	51	73	+22	151	70	−81	156	46	−110	67	99	+32	106	63	−43	69	23	−46	85	92	+7

1957																								
Jan.	118	92	—26	84	91	+7	102	105	+3	144	69	—75	98	129	+31	106	61	—45	90	26	—64	99	94	—5
Feb.	155	90	—65	103	97	—6	67	158	+91	125	96	—29	92	99	+7	91	55	—36	97	56	—41	104	83	—21
Mar.	123	113	—10	84	58	—26	36	149	+113	107	98	—9	90	148	+58	71	69	—2	113	84	—29	121	88	—33
Apr.	90	157	+67	82	98	+16	36	148	+112	94	161	+67	100	154	+54	76	81	+5	107	121	+14	113	83	—30
May	62	183	+121	58	244	+186	53	92	+39	42	182	+140	108	241	+133	86	104	+18	101	131	+30	98	86	—12
June	69	146	+77	76	216	+140	117	88	+29	42	160	+118	125	205	+80	114	123	+9	96	118	+22	67	61	—6
July	78	153	+75	103	157	+54	128	105	+23	64	71	+7	128	162	+34	112	123	+11	68	91	+23	106	50	—56
Aug.	108	101	—7	117	0	—117	147	98	—48	93	30	—63	133	58	—85	135	118	—17	54	127	+73	95	62	—33
Sept.	98	100	+2	100	134	+34	153	167	+14	100	17	—83	134	64	—70	161	120	—41	51	135	+84	109	81	—28
Oct.	94	63	—31	97	162	+65	136	193	+57	99	99	0	128	86	—42	150	85	—65	51	184	+133	98	106	+8
Nov.	90	92	+2	100	220	+120	88	202	+114	103	101	—2	110	118	+8	121	54	—67	59	114	+55	118	137	+19
Dec.	147	94	—53	127	105	—22	94	134	+40	125	101	—24	105	115	+10	111	48	—63	54	119	+65	109	143	+34
1958																								
Jan.	128	115	—13	131	144	+13	53	96	+43	122	149	+27	122	77	—45	91	37	—54	83	75	—8	131	142	+11
Feb.	92	114	+22	154	164	+10	53	155	+102	110	140	+30	122	75	—47	87	35	—52	101	88	—13	106	151	+45
Mar.	46	144	+78	152	243	+91	53	166	+113	79	134	+55	96	71	—25	124	39	—85	140	122	—18	103	165	+62
Apr.	51	96	+45	97	206	+109	102	125	+23	63	91	+28	76	87	+11	118	44	—74	153	134	—19	63	146	+83
May	69	50	—19	72	128	+56	112	77	—35	86	110	+24	59	76	+17	103	59	—44	117	152	+35	86	96	+10
June	72	10	—62	85	30	—55	129	38	—91	94	125	+31	92	131	+39	108	73	—35	106	128	+22	125	108	—17
July	94	6	—88	92	178	+86	165	94	—71	101	117	+16	109	139	+30	111	63	—48	94	110	+16	144	142	—2
Aug.	116	5	—111	91	396	+305	173	118	—55	138	95	—43	112	153	+41	90	69	—21	106	85	—21	125	130	+5
Sept.	127	2	—125	89	404	+415	190	150	—40	124	47	—77	126	91	—35	101	74	—27	135	62	—73	115	96	—19
Oct.	139	28	—111	131	232	+101	171	128	—43	106	99	—7	104	106	+2	100	58	—42	147	60	—87	122	63	—59
Nov.	135	40	—95	143	13	—130	107	95	—12	121	126	+5	71	66	—5	92	42	—50	134	56	—78	141	64	—77
Dec.	135	52	—83	161	20	—141	63	70	+7	109	187	+78	65	68	+3	68	47	—21	98	49	—49	140	65	—75

of discrepancies from pages 2-3 of my paper cited in footnote 1, d, above:

8. Of 100 years of St. Louis precipitation forecasted, 70 seem fairly satisfactory and yield high correlation coefficients with the events. The failure of the other 30 is reasonably explained.

9. As shown by Dr. W. J. Humphreys in his "Physics of the Air," figure 227, great volcanic eruptions, which throw high columns of vapor and dust, profoundly modify weather. He cites the first four cases in the following list [here my table 11], and I add several more.

TABLE 11.—*Great atmospheric disturbing causes*

Approximate dates	Volcanic eruptions
1856	Cotopaxi and others.
1883-1890	Krakatoa and others.
1901-1904	Pele, Santa Maria, Colima, and others.
1912	Katmai.
1924 and 1928	Many great eruptions.
1930	Great eruptions.
1947	Niuafoo Island.

10. Of 30 unsatisfactory years, in 100 years of synthesis of St. Louis precipitation, these lie in groups as follows: 1854 first half; 1856 to 1860; 1887 to 1889; 1900; 1901; 1905 to 1907; 1912 last half; 1913 first half; 1915 to 1917; 1920; 1923 to 1926; 1930; 1940 to 1950. It will be seen that many of these unsatisfactory intervals fall either soon after tremendous volcanic eruptions occurred or there was tremendous use of explosives in war or explosions of atomic bombs. As has been pointed out, atmospheric changes alter the lags in the weather effects of all solar impulses, and of course unequal periods have unequal lags. These unusual atmospheric disturbances may very well have mixed up the timing of terrestrial responses to the 23 periods so as to cause the events to differ from the predictions.

At some future time it may be possible to connect theoretically the displacements found in my forecasts with causes producing atmospheric alterations of importance in weather. As yet I have been unable to name with certainty causes operative to produce these occasional displacements. For the practical inquiries of farmers, however, it is of importance to estimate the *magnitude* of forecasting *error* rather than the *cause* attending such discrepancies.

As a step toward that, I cite the case of Spokane, Wash., figure 11. A computation made in 1957 derived a "correlation coefficient" of 59 ± 5 percent over the interval March 1950 through October 1956 between forecast and event in Spokane precipitation. In simple language this means that my forecast represented the observed precipitation 59 percent perfectly for almost 7 years.

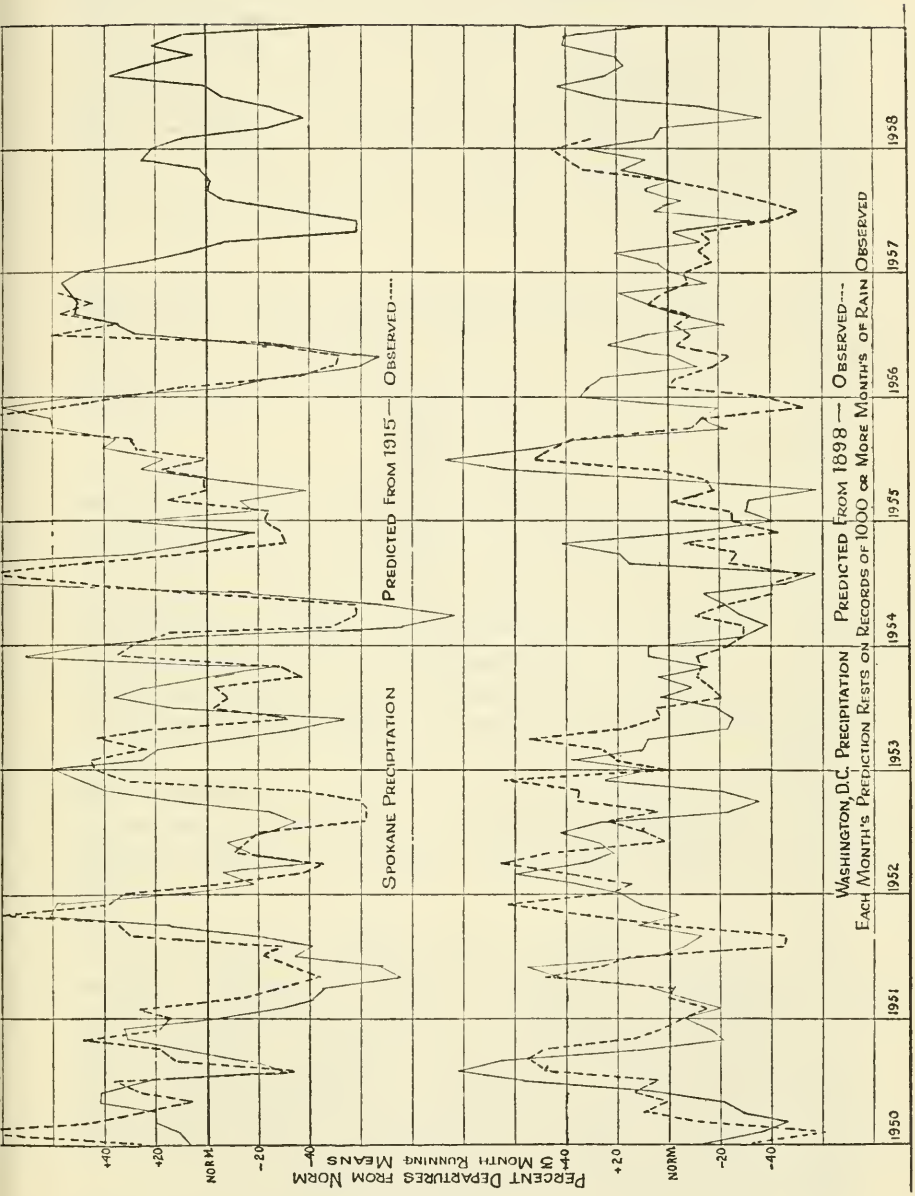


FIG. 11.—Comparison of forecasts and events, 1950-1958. Upper curves, Spokane, Wash.; lower curves, Washington, D. C. Forecasts, full curves; events, dotted curves.

When records through 1958 became available two considerable discrepancies between forecast and event were noted. In the months January and March 1950 heavy precipitation (over twice the normal even in 3-month running means) raised the February observed curve far above the predicted curve. Both curves, as has been said, are smoothed by using 3-month running means in all computations, hence the February effect. Not until April did the two curves come close together. Yet there was a difference of only 6 percent of normal precipitation between the averages of their heights, January-April, 1950.

Beginning October 1956, and extending through August 1957, there was a shift of 5 months, leaving the predicted curve in the rear, and exposing opposed high and low values of the prediction and event. When the two curves were averaged over this interval of 11 months, the predicted curve was 116 percent of the normal and the observed curve 96 percent of the normal.

To sum up: At Spokane, in the 9-year interval, my forecast gives for over 7 years a correlation with observations of 59 percent. Two intervals of marked discrepancy occurred. The first, of 4 months, culminating with February 1950, was obviously caused by extraordinary precipitation in two almost adjacent months. It produced a difference of only 6 percent between the averages over these 4 months. The second discrepancy, extending 11 months, was of unknown cause. It involved a 5-month shift of phases and produced 20 percent difference between forecast and event in average precipitation over those 11 months.

Having set forth those discrepancies I remark that this is in the infancy of my method of forecasting, before any help has come to me from theoretical meteorologists. It may be that some of them will discover the causes of occasional displacements of features between forecast and event. If so, it may reduce error of forecasts greatly. Then, too, my method assumes that the average behavior of periods in weather in a thousand months that are past will be followed in the months to come. It perforce neglects changed conditions which may arise from unpredictable storms, volcanoes, or even from man's interposition, as from forest destruction, invention of new powerful devices, wars and the like. Even a minor atmospheric change may alter the *time* of a feature in precipitation by a month. All these factors tend to lower the coefficient of correlation.

The 273-month period in weather features.—It will have occurred to some readers that if one were backcasting from April 1927 or from July 1904 he would employ the same tabular data that I have used in forecasting from January 1950. Hence one might infer that the precipitation following these earlier dates should parallel that following January 1950.

There is indeed a partial similarity, as I pointed out many years ago, between the march of weather at successive intervals of 273 months. But the correspondence is very imperfect. This appears in figure 2, where the precipitation at Nashville following July 1904 is compared to that following January 1950. However, I call attention to the close agreement of the two curves for the last three years of the comparison. I have computed for several cities, including Nashville, the coefficients of correlation of the observed precipitation following April 1927 and July 1904, and compared with the forecast made to follow January 1950. These coefficients have fallen between 18 and 22 percent, while, as stated in my foreword, the correlation following January 1950 ranges from 52 to 59 percent.

This difference is easily explained. Over 40 percent of perfect 100 percent correlation is unpredictable as yet. There are several causes. (a) There is occasional unusual precipitation, as occurred in January and March 1950 at Spokane. (b) There are displacements of features as yet unexplainable. (c) The graphs I have published show large discrepancies in *amplitude* between forecast and event of obviously identical features. (d) Unpredictable events occur to alter weather from the averages of 1,000 months.

In the march of precipitation from April 1927 and from July 1904, the vicissitudes of the *later* years up to January 1950 cannot have affected the observed precipitation of the earlier times as they have done that following 1950. As such vicissitudes account for 40 percent and more in coefficients of correlation, the tabulation suited to January 1950 can only roughly forecast what follows these earlier dates.

FORECASTS, 1959 TO 1967

Table 12 gives for 32 stations for the interval 1959-1967 the expected monthly mean percentages of the normal precipitation tabulated in table 9. The reader will recall that all forecasts are made from 3-month running means taken from published monthly mean values, and expressed in percentages of the normal values of table 9.

Expressing these forecasts in a more usable form, table 13 gives average percentages of the normal for the intervals January-April, May-August, September-December, of each year, 1959 to 1967, inclusive.

TABLE 12.—*Forecast precipitation*

Percentage departures from columns A and B, Table 9

Months	Abilene, Tex.		Albany, N. Y.		Albany, Oreg.		Augusta, Ga.		Bismarck, N. Dak.		Charleston, S. C.		Cincinnati, Ohio		Denver, Colo.	
	1959	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*
Jan.	+14	−41	−20	+ 3	−17	+42	−36	−15	+ 2	+22	−52	−24	−18	−26	+39	−29
Feb.	−22	+ 4	−31	−14	− 2	+41	−44	−27	−36	+26	−44	− 5	−35	−15	+81	+ 1
Mar.	− 7	+ 3	−31	+ 3	−25	+66	−36	−25	−32	+63	−29	+ 1	−48	−25	+68	+37
Apr.	−32	+47	−18	−12	−62	+64	−14	−25	−48	+68	−32	− 2	−66	−31	+58	+48
May	−15	+66	−11	−38	−71	−11	+31	+ 5	−65	+22	−27	−36	−14	−46	+53	+27
June	− 5	+59	+22	−44	−46	−57	+28	+15	−28	−33	+ 8	+22	+35	−54	−12	+10
July	+ 9	− 1	+ 5	−37	− 1	−10	+19	+ 2	+ 2	−66	+32	+41	+39	−23	− 5	+60
Aug.	−49	−57	− 9	−22	+ 9	−37	+12	−14	+47	−54	+33	+23	+37	−29	−32	+60
Sept.	−29	−97	+ 7	−16	+49	− 8	+38	−36	+22	−26	+14	− 5	+30	−42	+ 2	+28
Oct.	−23	−59	+ 6	+17	+49	−13	+28	−15	+47	+17	+25	− 4	− 1	+ 1	+25	0
Nov.	−20	−37	− 5	− 1	+36	+ 8	+33	−20	+20	+20	+ 1	0	−21	+ 7	+49	+ 3
Dec.	+ 2	+ 6	−15	− 5	+30	+24	− 6	−22	+18	+11	+ 9	+14	−32	+32	+37	+ 6
	1960	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*
Jan.	− 4	+42	+16	− 2	− 6	− 5	0	+40	− 1	+18	+11	+10	−60	+27	+42	+31
Feb.	−15	+89	+26	+ 3	−14	+12	−14	+48	+28	+41	+27	+31	−68	+71	+23	+43
Mar.	−36	+106	+24	+22	+ 6	−25	− 2	+72	− 3	+26	+41	+23	−46	+64	− 1	+56
Apr.	−20	+106	+19	+20	+27	−51	− 4	+91	+29	−26	+45	+30	−22	+79	−33	+47
May	0	+46	− 2	+ 3	+19	−21	+ 7	+40	− 2	−11	+38	−17	+21	+58	−23	+61
June	−16	+55	+15	− 6	+50	−15	−24	+28	+ 2	+ 7	+20	−15	+53	+54	−19	+29
July	− 2	+36	+ 7	− 1	+66	+21	−42	+ 7	−15	+21	+ 1	− 7	+73	+30	−35	+ 8
Aug.	+ 5	+ 2	+21	− 3	+58	+27	−42	−19	−27	+24	+15	+10	+64	+42	− 9	−50
Sept.	+56	−49	−20	+23	+50	+67	−26	−36	−10	− 6	− 7	− 9	+25	+23	− 4	−75
Oct.	+60	−42	− 9	+39	+35	+77	−29	−37	+14	+64	−45	+21	−20	−29	+15	−94
Nov.	+40	−19	+34	+20	+18	+111	−21	− 7	− 6	+46	−48	+52	−41	−12	+31	−54
Dec.	+16	+19	+32	+11	+19	+17	+ 1	+ 3	− 8	+13	−37	+66	−44	+14	+42	+14
	1961	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*
Jan.	+42	+30	+22	+24	+32	+43	+20	+52	−13	+ 2	−15	+67	−32	+74	+43	+46
Feb.	+47	+66	− 4	+15	+ 5	+ 2	+38	+70	+ 7	− 8	+19	+58	−23	+79	− 1	+39
Mar.	+86	+38	+ 6	+ 4	− 9	+17	+11	+80	+17	−15	+37	+37	0	+81	+ 5	+ 5

July	−50	−42	+15	− 3	−20	+10	+29	−17	−13	−18	+27	−52	+52	−15	+42	−29
Aug.	−33	−30	+19	−12	+20	+46	+10	−28	− 7	−11	− 3	−55	+42	−22	+27	−46
Sept.	−19	+45	+13	−18	− 1	+53	0	−62	− 5	−30	−12	−36	+52	−40	+23	−34
Oct.	−30	−40	+10	−32	− 9	+13	+13	−14	+10	−32	−17	+ 8	+18	−11	+ 9	+41
Nov.	+16	−21	−20	−40	− 7	+19	+24	+ 2	+ 8	−24	− 8	+ 3	−16	− 8	+11	+74
Dec.	+31	+19	−30	+ 3	+ 4	− 2	+ 7	+13	− 5	0	− 6	− 5	−21	−33	−34	+66
	1962	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*
Jan.	+33	+17	−31	− 5	+ 1	−46	−33	+ 9	−23	+ 4	−26	−10	−45	−63	−75	+26
Feb.	+25	+43	− 9	−26	0	−36	−64	−18	−19	+ 4	−17	− 7	−23	−56	−74	+15
Mar.	+ 5	+40	+28	− 3	− 1	−38	−47	+ 1	+ 8	+ 3	− 7	0	−11	−47	−79	−12
Apr.	−30	+14	+31	+21	+27	−20	−27	+ 8	−26	+10	+ 2	+18	+ 3	−11	−91	−18
May	−25	+24	+33	+10	+14	−26	−16	+14	−48	− 5	− 6	+35	+23	−12	−72	+ 7
June	−42	+15	−28	+28	+ 1	− 6	−46	− 3	−14	+17	−50	+44	+ 4	−22	−23	+13
July	−28	+11	−24	+24	+16	−27	−41	+15	+ 9	+27	−54	+63	−14	−26	−19	+32
Aug.	+15	−27	− 7	+ 9	+ 1	−19	−18	+22	+11	+30	−24	− 8	+ 3	+ 9	−34	+30
Sept.	+24	+ 4	+ 4	+12	+ 7	−24	−28	+25	+23	+35	+10	+18	− 5	+38	−33	+24
Oct.	−42	−13	− 1	+10	+32	0	−50	+ 3	+41	+18	− 5	+ 8	−27	+16	−25	+ 8
Nov.	−17	− 1	− 8	+ 7	+17	−24	−45	− 3	+16	+38	+18	0	−14	+ 4	− 1	+12
Dec.	+ 1	−11	−12	0	+19	−14	−51	− 1	−20	+14	0	− 9	+18	−31	0	+12
	1963		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*	
Jan.	+49		+ 4		− 1		− 8		−53		− 1		+37		− 2	
Feb.	+89		+ 9		−10		+21		−58		−35		+66		− 5	
Mar.	+31		0		+13		+17		−41		−33		+75		−25	
Apr.	+19		−17		+ 4		+18		+ 3		−51		+35		−13	
May	− 4		−15		−19		+30		+41		−43		+ 8		−12	
June	−15		− 5		+19		−19		+41		+ 3		+38		−30	
July	+ 1		+ 8		−29		−19		+12		−25		+27		−11	
Aug.	+21		−17		−48		−34		−10		−20		+18		−10	
Sept.	+10		+17		−38		−23		+ 5		−12		−17		+24	
Oct.	+ 4		−18		−22		− 4		+16		−20		+ 1		− 3	
Nov.	−40		−16		+14		+16		+22		− 8		−32		−10	
Dec.	−44		−16		+ 2		− 8		+25		−15		−27		−41	

(continued)

TABLE 12—*continued*

Months	Detroit, Mich.		Eastport, Maine		El Paso, Texas		Helena, Mont.		Independence, Kans.		Little Rock, Ark.		Madison, Wis.		Montgomery, Ala.	
	1959	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*
Jan.	−24	−49	−17	−20	+48	+ 3	−14	−41	−77	−40	− 1	− 5	−58	−12	−32	+12
Feb.	−13	−25	−20	− 7	+59	+ 9	−31	−52	−75	−24	+14	+ 5	−36	+ 7	−37	+57
Mar.	−17	− 6	− 7	− 8	+27	− 9	−62	−53	−56	− 3	−19	+46	−19	−16	−73	+37
Apr.	− 2	+34	− 9	+ 4	−13	−18	−61	−19	−16	+ 9	−24	+67	− 6	−30	−64	+16
May	− 8	+54	+10	+16	+25	−36	−16	+44	+12	+14	−17	+42	+18	−35	−24	− 2
June	−13	+53	+10	+25	+63	+24	+23	+47	+40	+ 8	−14	+26	+28	−14	+ 9	−16
July	−11	+ 7	+28	+13	+73	+79	+20	+ 7	+55	+14	+ 8	+16	+40	+ 8	+40	+ 2
Aug.	+17	+17	+40	+37	+53	+76	+63	+14	+42	+33	− 5	−56	+47	+ 5	+62	−24
Sept.	+24	−13	+16	+36	−15	+92	+88	+15	+70	+27	+ 4	−46	+35	− 2	+76	−30
Oct.	+17	−53	− 8	+33	−16	+75	+54	+ 2	+26	− 8	+29	−80	+45	+ 2	+24	−16
Nov.	+44	−68	−22	+10	+ 4	+39	+ 2	−14	+16	−41	+24	−48	+24	+ 7	+24	− 5
Dec.	+55	−58	−28	−25	+ 5	+47	−20	+ 9	− 9	−53	−18	−25	−14	+24	−11	− 6
	1960	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*
Jan.	+32	−23	−54	−69	+37	+50	−51	− 7	−28	−17	−16	+24	−47	+18	−30	+ 8
Feb.	− 2	−39	−33	−81	+41	+22	−62	− 7	−33	+10	− 5	+86	−35	+33	−14	+60
Mar.	−19	−43	−20	−63	+30	+37	−53	−27	−23	−16	+14	+69	−36	− 5	+ 6	+80
Apr.	−21	−39	−10	−38	+78	+96	−11	+23	+ 9	+29	+10	+64	−38	−11	+13	+69
May	− 7	−27	+14	−16	+104	+95	0	+50	+40	+34	+28	+48	−18	− 7	+24	+35
June	−10	+ 3	+33	− 8	+69	+94	− 4	+86	+39	+70	+26	− 7	− 4	−13	+ 5	+40
July	+ 6	+33	+20	− 4	−12	+106	+13	+76	+61	+37	+16	−43	+23	− 3	+ 4	+22
Aug.	+36	−15	− 4	+16	−51	+104	+41	+56	+39	+26	+ 5	−83	+ 8	+27	− 2	+12
Sept.	+54	+ 1	−13	+30	−11	+48	+69	+34	+44	+30	+47	−94	+16	+66	+ 6	− 9
Oct.	+48	+28	−34	+48	−23	−24	+60	+39	+46	+ 2	+32	−64	− 6	+31	−18	−23
Nov.	+28	+30	−64	+49	− 8	−149	+13	+42	+46	+11	+37	−30	−11	− 6	−16	− 5
Dec.	− 3	+31	−49	+ 9	−10	−111	+10	− 2	+ 3	+ 8	+19	+13	+ 2	−28	+ 8	− 1
	1961	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*
Jan.	−15	+17	− 9	−45	−25	−82	+37	+23	−14	+22	−30	+40	+ 6	−32	+52	+40
Feb.	−28	+ 5	+ 1	−32	+35	−45	+62	−19	−21	+25	−35	+86	+ 8	−42	+52	+34
Mar.	−34	−30	+20	−14	+43	−58	+54	− 4	− 5	+28	−15	+27	+ 3	−48	+36	+36
Apr.	−41	− 1	+16	−10	+28	−97	0	−37	+16	−14	− 3	+29	+21	−61	+ 5	− 4

July	+26	+82	+14	+102	−28	+10	+ 3	− 3	+15	−82	−28	−27	+20	+ 7	−43	+11
Aug.	+26	+99	− 8	+100	−24	+32	− 9	+ 1	+14	−11	− 6	−28	+13	+ 3	+26	+12
Sept.	+20	+112	+ 1	+66	−48	+85	− 9	−17	− 3	+ 1	+30	−63	+20	+11	+20	−18
Oct.	+27	+27	+12	+ 1	−22	−78	+ 9	+32	+ 5	+15	+42	+13	+25	+11	+40	+20
Nov.	+18	+30	+52	−36	−24	−41	+21	+52	−11	+ 2	+38	+31	+28	+15	+15	+38
Dec.	+29	+26	+12	−56	−13	−19	−10	+42	−21	+ 9	+15	+18	+ 7	+ 9	+13	+20
	1962	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*
Jan.	− 4	+ 3	+ 3	−51	−55	−29	−46	+22	−37	+14	− 8	−22	−19	+27	− 9	−10
Feb.	− 8	−13	−15	−37	−49	−13	−48	+17	−52	+ 7	− 7	+ 8	− 1	+39	− 8	+ 6
Mar.	−17	−13	− 7	−19	−39	+ 3	−13	+10	−63	− 1	−23	− 3	+ 3	+22	+ 2	−14
Apr.	−17	− 3	− 7	− 9	−40	+41	−15	+31	−49	+19	−27	−18	+ 2	+34	+ 3	−22
May	+ 8	− 8	− 5	−16	−49	+38	−35	+15	− 5	− 5	−46	−45	−47	+19	+ 4	−47
June	+ 7	− 5	+ 6	−30	+34	− 6	+30	+ 7	+26	0	−32	−50	+ 1	+23	−22	−25
July	+ 2	+16	+50	−47	+40	−29	+32	−20	−16	−18	− 8	−29	+20	+15	− 1	−21
Aug.	−12	+23	+ 6	−33	+26	−27	+11	+ 8	+ 7	+23	+ 1	−28	+44	+27	−22	+42
Sept.	−24	+12	+12	0	+19	−40	+45	+49	−41	+64	− 3	+17	+27	+10	−48	+71
Oct.	−12	− 8	+12	+ 7	−34	−21	+23	+47	−18	+21	− 7	+55	+ 9	− 3	−30	+53
Nov.	−15	−15	− 4	+15	−83	+ 6	−18	+72	−31	+23	+12	+41	−16	0	−21	+37
Dec.	−20	−19	−19	−16	−82	+ 1	−40	+57	− 5	+22	+76	+28	−30	+ 8	0	+32
	1963		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*	
Jan.	−46		−42		−55		+ 1		−55		+67		− 9		+ 3	
Feb.	−48		−58		−11		− 7		−41		+46		−40		+25	
Mar.	−68		−50		+29		+ 4		−55		+24		−35		+ 9	
Apr.	−34		−27		+12		−21		−13		− 3		−27		+ 5	
May	− 8		0		+34		+34		−18		−10		+13		−11	
June	+26		− 7		+ 1		+ 6		−24		−12		− 4		−23	
July	+45		+20		+16		+17		−36		−57		+34		+18	
Aug.	+58		+31		−40		+ 4		+27		−77		+39		+16	
Sept.	− 3		+29		−80		−24		+24		−43		− 2		− 6	
Oct.	−11		+ 7		−54		−51		+45		−45		+24		−47	
Nov.	−33		+ 4		−75		−58		+14		−23		+10		−65	
Dec.	−52		− 1		−63		−24		+18		−30		−12		− 3	

(*continued*)

TABLE 12—*continued*

Months	Nashville, Tenn.		Natural Bridge, Ariz.		Omaha, Nebr.		Peoria, Ill.		Port Gibson, Miss.		Rochester, N. Y.		Sacramento, Calif.		Salisbury, N. C.	
	1959	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*
Jan.	−4	+22	−45	+64	−7	+4	−23	+37	+1	+17	+9	−72	+51	+88	−13	−24
Feb.	−22	−25	−45	+88	+5	0	−46	+14	+22	−52	−20	−59	+28	+54	−22	−9
Mar.	−80	−49	+23	+97	+26	−9	−44	+6	−17	−77	−33	−28	−4	+40	−33	−21
Apr.	−42	−25	+46	+97	+15	+8	−31	+21	−12	−65	−47	−30	−25	+28	−21	−22
May	−35	−2	+47	+14	+21	−8	+29	+34	−24	−5	−42	−13	−49	−28	+24	−29
June	+4	+29	+10	−8	+34	+32	+30	+43	−49	+20	−56	−16	−70	−84	+23	−12
July	−6	+18	−27	+4	+27	+33	+20	+35	−53	−45	+8	−13	−124	−48	+31	0
Aug.	+20	−35	+36	+6	+19	+12	−21	+24	−42	−44	+59	−16	−97	−93	+70	−15
Sept.	+34	−22	+45	+52	+39	−19	−21	+1	−12	−14	+56	−9	−44	−108	+61	−34
Oct.	+63	−21	+53	+48	+26	+31	−4	−19	−6	+25	+19	−5	+22	+2	+53	−27
Nov.	+38	−4	+35	+15	+4	+55	+9	−12	−6	−35	+10	−7	+9	+59	+23	−4
Dec.	+4	−23	+16	−21	−41	+40	−4	+10	−6	−5	+13	+2	+53	+122	+4	+22
	1960	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*
Jan.	+24	+8	+3	+13	−23	+18	−39	+13	+17	−30	−8	−21	+46	+149	+11	+17
Feb.	+13	+9	−23	+71	+25	+28	−14	+4	+31	−2	−15	+18	+43	+116	+10	+50
Mar.	+6	+33	−59	+83	+26	+32	+16	0	+29	+9	−1	+19	+29	+62	+15	+61
Apr.	−24	+72	−16	+30	+7	0	−12	−1	−21	+16	+28	+31	+32	−1	+6	+48
May	−12	+27	−37	−32	+16	−18	+1	−18	−14	−40	+9	+18	+2	−1	+5	+28
June	−14	+18	+43	−77	−8	−4	−16	−14	−38	+21	+11	+21	−57	−43	−13	−3
July	0	+11	−1	−88	0	−32	−21	−21	−41	+54	+26	−6	−47	−51	−24	+8
Aug.	+2	+4	+29	−73	+17	−53	−33	−19	−95	+34	+65	+2	−24	−27	−20	−5
Sept.	+8	−6	+49	−72	+45	−63	+18	−27	−40	+3	+45	+1	+26	−8	−8	+3
Oct.	−1	−23	+62	−52	+37	−94	+62	+6	−15	−2	+24	+11	+63	+77	−14	−28
Nov.	−16	−38	+36	−10	+1	−62	+66	+3	−14	−37	−25	+17	+90	+121	−33	−22
Dec.	−22	0	−63	−5	0	+27	+37	−15	+5	+2	−38	+47	+99	+93	−36	−12
	1961	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*
Jan.	+23	+49	−88	+16	+17	+18	+57	−22	+14	+9	−28	+48	+114	+117	0	+22
Feb.	+39	+59	−62	−2	+12	+45	+68	−26	−3	+12	−27	+66	+114	+90	−15	+66
Mar.	+21	+14	−19	+14	+31	+7	+75	−18	+26	+30	−7	+51	+75	+39	−13	+62
Apr.	+22	−7	−42	+16	+38	−16	+40	−5	+25	−16	−7	+48	+42	+7	−9	+10
May	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

June	0	+23	+ 2	−65	−27	−32	− 3	+26	−27	−80	−10	+18	−53	−142	+ 4	−28
July	− 7	+14	+56	−62	−27	−28	−25	+24	−13	−78	−17	− 4	−73	−141	+27	−52
Aug.	−23	−39	+78	−28	0	+ 3	−18	+19	+49	−123	−10	−11	−76	−122	+26	−56
Sept.	+ 8	−81	+56	+12	+ 5	− 1	−40	+ 5	+47	−108	+41	−42	−70	−94	+48	−84
Oct.	+17	−18	+10	+18	+10	+32	−25	−72	+42	−13	+37	+18	−37	−24	+60	+29
Nov.	+26	−15	−46	+ 9	+ 7	+30	+ 8	+11	+18	−32	+18	+16	− 6	+26	+52	+23
Dec.	+30	− 7	−30	−14	−15	−27	+14	+71	+22	+14	− 6	− 8	+26	+78	−16	+35
	1962	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*
Jan.	−23	−20	−24	+ 2	−51	+ 3	+41	+52	+29	+15	+ 6	−10	+67	+75	−46	+58
Feb.	−18	−15	−14	+31	−21	+22	+ 5	+45	+26	−12	+10	−24	+74	+79	−63	+35
Mar.	− 1	−41	−66	−24	0	+36	− 6	+32	+10	−27	−16	−51	+ 3	+34	−36	+ 5
Apr.	−21	−37	−85	+ 4	− 2	+43	− 2	+50	−14	−47	−28	−55	−65	+17	−19	+30
May	−32	− 3	−36	− 2	+27	+ 5	+ 1	+43	−34	−33	−29	−48	−92	+ 3	−13	+35
June	−17	−30	−119	−28	− 4	−28	−19	+32	+17	−25	− 6	−58	− 8	−13	−50	+ 9
July	−50	−30	−88	+20	−34	−31	−26	+15	+ 3	−33	−12	−12	−35	−31	−21	−10
Aug.	−33	− 6	−84	− 7	−28	− 6	−42	+30	−15	+13	0	−10	−21	−14	−33	− 3
Sept.	−11	+ 5	−99	+16	−16	+10	−35	+38	+ 5	− 8	+11	+23	+ 2	−34	−43	+19
Oct.	+ 9	+54	−95	+11	+ 7	− 8	−29	+46	+19	+ 7	+ 5	+25	+52	−38	−28	+23
Nov.	+ 3	+63	−30	+43	+35	+28	− 2	+29	+23	−35	−10	+41	+43	−44	+ 5	+19
Dec.	+35	+71	− 2	+ 7	+58	+29	+17	− 6	+17	−20	− 5	+ 4	+66	−25	+22	+11
	1963		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*	
Jan.	+22		+15		−10		− 3		+27		−22		+51		+ 3	
Feb.	+22		+26		−65		− 7		+20		0		+76		−11	
Mar.	−12		+25		−89		−16		− 5		+21		+37		+ 6	
Apr.	−49		+19		−73		−35		− 3		+ 6		−31		+14	
May	−47		−55		−24		−27		+17		+ 2		−53		− 3	
June	0		−55		+36		−14		− 6		+40		−72		−38	
July	− 3		−20		+62		+ 3		+48		+50		−99		−19	
Aug.	+ 6		−51		+13		− 2		+51		+39		−128		+ 6	
Sept.	−31		+ 5		−33		+ 9		+66		0		−88		+27	
Oct.	−46		−52		−37		+23		+ 9		−14		−35		+23	
Nov.	−17		+ 7		−46		+49		+ 5		− 2		+56		+ 1	
Dec.	+10		+22		+19		+39		+ 2		−23		+92		−18	

(continued)

TABLE 12—*concluded*

Months	Salt Lake, Utah		Santa Fe, N. Mex.		San Bernardino, Calif.		Spokane, Wash.		St. Louis, Mo.		St. Paul, Minn.		Thomasville, Ga.		Washington, D. C.	
	1959	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*	*1959*	*1964*
Jan.	−1	−9	−50	−40	+41	+63	−51	+79	−18	−84	−37	−3	−21	−9	+12	−8
Feb.	−4	−27	−43	−24	−34	+48	−70	+92	+8	−48	−26	+18	−8	+15	−36	−22
Mar.	−39	+3	−25	−10	−36	+18	−51	+69	+37	−58	−23	+16	+15	−10	−44	−74
Apr.	−33	+11	−23	−27	−35	−18	−26	+76	+12	+1	−14	−10	+27	+3	−35	−81
May	−30	+38	−15	−10	−26	−23	−38	+32	+6	−1	+24	+3	+28	+48	−22	−65
June	+1	+49	+17	+19	+7	−33	+5	+12	+4	−12	+35	+29	+35	+64	−14	+17
July	+4	+34	+13	+47	+47	−55	−9	−6	+14	−43	+30	+42	+8	+87	−18	+37
Aug.	+58	+6	+25	+37	+52	−47	−9	+21	−7	−39	+37	+24	−31	+56	−3	+58
Sept.	+79	−16	+40	−7	+37	−64	+42	+48	−19	+15	−4	+35	−57	+12	+38	−3
Oct.	+82	−39	+33	−55	+13	−40	+83	+72	−10	+61	−55	+19	−43	+7	+55	−11
Nov.	+43	−11	+59	−99	+26	+14	+90	+64	0	+43	−31	−1	−14	−24	−21	+1
Dec.	+30	+2	+30	−33	+26	+46	+46	+62	−6	+14	−14	+10	+8	−19	+18	+43
	1960	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*	*1960*	*1965*
Jan.	+12	+65	−27	−53	−19	+98	+16	+60	+8	−25	−26	+32	+20	−15	+24	+6
Feb.	+31	+49	−40	−42	−75	+98	+35	+66	−14	−38	−22	+68	+48	+13	−15	+6
Mar.	−58	+6	−54	−28	−89	+57	+15	+16	+3	−24	+3	+57	+74	+30	−17	+34
Apr.	−39	−22	−44	+21	−87	+49	+28	−34	+10	+49	+2	+30	+66	+79	+2	+35
May	−13	−35	−27	+40	−73	+17	+47	−64	+14	+60	+2	0	+104	+91	+27	+58
June	+19	−44	−28	+111	−39	+7	+42	−53	+3	+29	+26	−17	+41	+73	+47	+31
July	+32	+7	−4	+73	−3	−37	+52	−30	+7	−39	+30	−19	+19	+39	+34	+22
Aug.	+49	+16	−26	+11	+41	−18	+45	−24	+4	−29	+26	−25	−12	−4	−5	+38
Sept.	+30	+53	−32	−24	+82	−23	−1	+17	+15	−20	+16	−46	−18	−22	−59	+9
Oct.	+15	+64	−34	−22	−91	+45	+5	+35	+8	−33	+11	−51	−50	−46	−44	−16
Nov.	+29	+51	−18	−39	+58	+82	+7	+64	+23	−23	+3	−34	−50	−73	+3	−18
Dec.	+14	+10	−36	−71	+35	+79	+3	+52	0	+1	−6	−17	−22	−58	+10	−12
	1961	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*	*1961*	*1966*
Jan.	+1	−11	−19	−110	+21	+16	+21	+45	−28	+31	−16	+18	+10	−33	+13	−7
Feb.	−46	−2	−32	−108	+44	−27	−26	+28	−3	+30	+4	+46	+39	−13	−8	−26
Mar.	−59	0	−5	−37	+33	−78	−80	−15	+21	+72	−5	+48	+51	+35	−32	−6
Apr.	−55	−19	+6	−20	−20	−96	−59	−15	+36	+13	+13	0	+48	+26	−63	−36
May	−30	−32	−7	+18	−31	−103	−17	−18	+46	−11	+33	−7	+1	+20	+37	−43

June	−14	−27	+44	+34	−18	−111	+ 6	−14	+37	−81	+51	+ 1	+ 5	+37	+ 6	−19
July	−30	−29	+34	− 2	− 6	−75	− 5	−20	+62	−62	+29	−41	−15	−29	−24	0
Aug.	−31	0	+42	+16	−11	−47	− 6	−22	+51	+ 3	+ 2	−63	−38	−24	−62	−17
Sept.	− 2	−12	+60	+16	+27	−23	+ 6	−69	+43	+62	−19	−73	−47	−53	−28	−13
Oct.	+31	+56	+57	− 6	+32	− 5	+16	+62	+36	+60	−21	− 3	−48	−58	− 6	−25
Nov.	+23	+47	+86	+ 4	+ 3	− 5	− 1	+19	0	+26	−47	−14	−30	−53	+27	−22
Dec.	− 3	+25	+ 8	− 1	−22	−19	+ 9	− 6	−12	− 5	+50	−30	−23	−16	+16	+19
	1962	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*	*1962*	*1967*
Jan.	−19	−15	−19	− 2	− 4	0	−29	+ 2	−41	−31	− 9	− 5	−12	+19	+52	+14
Feb.	−16	−25	−31	−28	−13	−12	−81	+ 8	−15	−20	−10	− 8	+11	+54	+48	−10
Mar.	−34	−39	−68	−25	−23	+ 5	−63	+ 2	−30	+ 2	+ 5	−11	+38	+61	+23	−32
Apr.	−73	−42	−57	− 4	−20	+22	−51	−37	0	+ 6	+15	−18	+63	+41	−39	−20
May	−56	−47	−26	+55	− 9	+19	−21	−28	−25	+ 9	+ 9	− 1	+56	+23	−30	− 8
June	+53	−31	+30	+17	−76	+ 7	0	− 9	−28	+10	−24	+12	+16	− 1	−27	+22
July	+50	−45	− 1	+37	−38	+36	+49	+15	−13	+29	−53	+23	−30	+ 3	−39	+54
Aug.	+78	−12	+38	+38	+ 2	+32	+46	+13	−17	+57	−27	+16	−21	+ 1	−48	+62
Sept.	+37	+ 5	+ 5	+54	+25	+14	+48	+17	−28	+45	−54	− 3	−44	+ 5	−22	+33
Oct.	+10	+ 6	0	+45	+27	+ 9	+26	−19	−21	+41	−41	+13	−23	−41	+12	+12
Nov.	+23	+43	+34	+28	+25	− 2	+19	+15	−45	+17	−12	−25	− 8	−54	+ 1	− 5
Dec.	+12	+17	+22	+22	+10	−15	−51	+15	−59	+ 3	+23	−39	−24	−63	−22	−14
	1963		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*		*1963*	
Jan.	−20		+27		− 2		−21		−81		+ 8		−23		+69	
Feb.	−25		+ 9		+19		+ 7		−86		+15		+12		−34	
Mar.	−28		+15		+19		−16		−61		+31		− 8		−29	
Apr.	+11		+26		+12		−32		−27		+ 4		−12		− 6	
May	+42		+39		+22		−52		−26		− 5		+ 5		−44	
June	+20		+ 9		0		−32		−20		− 2		+ 8		− 2	
July	−10		+32		+ 3		−32		+19		− 4		+13		+31	
Aug.	+10		−10		+28		−15		+51		− 6		−13		+53	
Sept.	−11		−18		− 7		− 2		+76		−27		+ 7		+53	
Oct.	−20		−51		−17		+30		+41		− 2		+11		+16	
Nov.	−44		−25		−37		+33		−10		−20		−20		− 6	
Dec.	−40		−55		− 8		+38		−36		−16		−30		+32	

At the end of text are 27 maps of the United States with the 32 cities as listed above, and each accompanied above the circle by a number identical with the appropriate number in the column headings in table 13. Below is the predicted departure from normal. Each group of three maps covers the three intervals per year of four months each named with table 13. Large areas of approximately equal departures from normal precipitation are clearly noticeable on the maps. These area similarities may aid farmers remote from the 32 cities to estimate the precipitation probable in their locations.

APPLICATIONS

Periods control long-range weather.—I have sought to present to meteorologists evidence of two important propositions. First, that there exists in weather a family of periods, all exact submultiples of 273 months. These periods are hidden from immediate recognition because their phases are shifted according to the state of the atmosphere. When, however, the long monthly records are grouped and reduced with reference to time of the year, sunspot activity, and march of population, the family of periods is clearly disclosed with constant length, and with approximate sine-curve forms.

Second, long-range precipitation is to nearly 60 percent governed by this family of periods. By evaluating the average forms and amplitudes of these periods from thousand-month records, precipitation and temperature may be forecasted for years in advance, with considerable approximation to the event.

Whether these forecasts will appear to interested parties as trustworthy guides to help in planning their future operations must depend on the agreement attained between forecasts and events, 1950-1958. I therefore prepared table 14 which gives for 32 cities the 4-month forecasts and observations, 1950-1958, and the differences in percentages of normal precipitation, Δ, in the sense observed minus forecasted. Their means are given disregarding signs.

Agricultural requirements.—For agricultural purposes a foreknowledge of *seasons* rather than of individual months is most desired. Hence I give in table 14 4-month mean values computed from table 10. But it is the *difference* between forecast and event which would be the controlling factor in estimating the value of the forecasts.[5] The average differences, Δ (observed minus scale-corrected forecasts) are

[5] As differences in *level* of *observed* precipitation, 1950-1958, from the averages of 1,000 months, are disclosed in table 9a, I refer to that table for possible corrections of level which might be applied to values for some stations in table 14.

entered at the bottom of the columns of Δ in table 14. These averages will be needful to the use of table 15 which is to follow.

Assuming that the degree of success attained in the forecasts from 1950 through 1958 will be attained from 1959 through 1967, I have prepared table 15 from which the probable sizes and numbers of discrepancies between forecasts and events in 4-month mean values over the entire interval of 9 years, 1959-1967, may be estimated. Selected from table 14, four groups of cities, 25 in all, are tabulated in table 15. The first group of 11 cities have average 4-month mean discrepancies, 1950-1958, of about 20 percent between forecasts and events.

The second group of six cities have mean 4-month discrepancies of about 26 percent, the third group of five cities, 30 percent, and the fourth group of three cities, 40 percent. All the percentages relate to normal precipitation given in table 9, with the scale corrections from table 9a used in table 14.

The six columns of table 15 give, respectively, the numbers of cases in table 14 when the discrepancies between forecast and event, 1950-1958, are (a) less than one-fourth, (b) one-fourth to one-half, (c) one-half to one times, (d) one to one and one-half, (e) one and one-half to two, and (f) over two times the average discrepancy of the group.

If the same degree of success is reached 1959-1967 as was reached 1950-1958, the interested person of a city in Group 1 would expect the numbers of discrepancies (O-F) among the 4-month means stated in the mean values at the bottom of the columns of table 15 to occur in the entire interval of 9 years with magnitudes in percent of the normals as stated at the top of the columns of the first group. If he were located at a city of Group 4, the percentages would be twice as large, because the numbers heading Group 4 are twice those heading Group 1. But the numbers of cases would be the same.

Stated numerically, a person residing where the mean departure of forecast from observation, given in table 14 for 4-month intervals from 1950 through 1958, was about 20 percent of normal precipitation, may expect the following numbers and magnitudes of departure from the forecast of 4-month means during the entire 9 years, 1959-1967, given in table 14.

Numbers of departures.....	4.6	4.5	6.1	6.0	2.8	3.0
Magnitudes in percent......	0-5	6-10	11-20	21-30	31-40	>40

If he resided where the mean departure given in table 14 was greater, the numbers of departures as just given would be unchanged, but †

† Text continued on page 67.

TABLE 13.—*Predicted departures from normal precipitation* 1959-1967

Four-month mean

		1 Abilene Tex.	2 Albany, N. Y.	3 Albany, Oreg.	4 Augusta, Ga.	5 Bismarck, N. Dak.	6 Charleston, S. C.	7 Cincinnati, Ohio	8 Denver, Colo.
1959	A	—15	—25	—26	—32	—28	—39	—42	+61
	B	—15	+2	—27	+22	—11	+25	+24	+1
	C	—17	—2	+41	+23	+27	+12	—6	+18
1960	A	—19	+21	+3	—5	+13	+31	—49	+8
	B	—3	+10	+48	—25	—10	+18	+53	—21
	C	+43	+9	+30	—19	—2	—34	—20	+21
1961	A	+52	+3	+8	+18	+2	+27	—5	+13
	B	—28	+19	—4	+12	—1	+30	+55	+18
	C	0	—7	—3	+11	+2	—11	+8	+2
1962	A	+8	+5	+7	—43	—15	—12	—19	—80
	B	—20	—4	+8	—30	—10	—33	+4	—37
	C	—8	—4	+19	—43	+15	+6	—7	—15
1963	A	+47	—1	+1	+12	—37	—30	+53	—11
	B	+1	—7	—19	—10	+21	—21	+23	—16
	C	—17	—16	—11	—5	+17	—14	—19	—7
1964	A	+3	—5	+53	—23	+45	—7	—24	+14
	B	+14	—35	—29	+2	—33	+12	—38	+39
	C	—47	—1	+3	—23	+5	+1	0	+9
1965	A	+26	+11	—17	+63	+15	+23	+60	+44
	B	+35	—2	+3	+14	+10	—42	+46	+12
	C	—23	+23	+83	—19	+29	—7	—1	—52
1966	A	+37	+12	+15	+66	—5	+39	+61	+16
	B	—40	+2	+11	—6	—23	—42	—22	—32
	C	+1	—22	+21	—15	—21	—7	—23	+37
1967	A	+28	—15	—35	0	+5	0	—44	+3
	B	+6	+18	—19	+12	+17	+33	—13	+20
	C	—5	+7	—15	+6	+26	+4	+7	+14

		9 Detroit, Mich.	10 Eastport, Maine	11 El Paso, Tex.	12 Helena, Mont.	13 Independence, Kans.	14 Little Rock, Ark.	15 Madison, Wis.	16 Montgomery, Ala.
1959	A	−14	−13	−30	−42	−56	−8	−30	−51
	B	−4	+22	+53	−22	+37	−7	+33	+22
	C	+35	−10	−5	+31	+26	+10	+22	+28
1960	A	−2	−29	+46	−44	−19	+1	−39	−6
	B	+6	+16	+27	+12	+45	+19	+2	+8
	C	+32	−40	−13	+38	+35	+34	0	−5
1961	A	−29	+7	+20	+38	−6	−21	+9	+38
	B	+14	+16	−12	−5	+20	−16	+26	−22
	C	+23	+19	−27	+3	−7	+31	+20	+22
1962	A	−11	−6	−46	−30	−50	−16	−4	−3
	B	+1	+14	+13	+9	+3	−21	+4	−10
	C	−18	0	−45	+2	−24	+19	−2	−25
1963	A	−49	−44	−6	−1	−41	+33	−28	+10
	B	+30	+11	+3	+15	−13	−39	+20	0
	C	−25	+10	−68	−39	+25	−35	+5	−30
1964	A	−11	−8	−4	−41	−14	+28	−13	+30
	B	+33	+23	+36	+28	+17	+7	−9	−10
	C	−48	+13	+63	+3	−19	−50	+8	−14
1965	A	−36	−63	+51	−4	+1	+61	+9	+54
	B	−1	−3	+100	+67	+42	−21	+1	+27
	C	+22	+34	−59	+28	+13	−44	+16	−9
1966	A	−2	−25	−70	−9	+15	+45	−46	+26
	B	+61	+68	−28	−7	−42	−8	−29	−3
	C	+49	−6	−13	+27	+7	0	+11	+15
1967	A	−6	−29	0	+20	+10	−9	+30	−10
	B	+6	−31	−6	+2	0	−38	+21	−13
	C	−7	+1	−13	+56	+32	+35	+4	+48

(continued)

TABLE 13.—*continued*

		17 Nashville, Tenn.	18 Natural Bridge, Ariz.	19 Omaha, Nebr.	20 Peoria, Ill.	21 Port Gibson, Miss.	22 Rochester, N. Y.	23 Sacramento, Calif.	24 Salisbury, N. C.
1959	A	−37	−5	+10	−36	−2	−23	+12	−22
	B	−4	+16	+25	+14	−42	−8	−85	+37
	C	+35	+37	+7	−5	−7	+24	+10	+35
1960	A	+5	−24	+9	−12	+14	+1	+38	+10
	B	−6	+8	+6	−17	−47	+28	−31	−13
	C	−8	+21	+21	+46	−16	+4	+69	−23
1961	A	+26	−53	+24	+60	+15	−17	+86	−9
	B	−10	+21	−4	−15	0	−4	−58	+14
	C	+20	−2	+1	−11	+32	+22	−22	+36
1962	A	−16	−47	−18	+9	+13	−7	+20	−41
	B	−33	−82	−10	−21	−7	−12	−39	−29
	C	+9	−56	+21	−12	+16	0	+41	−11
1963	A	−4	+21	−59	−15	+10	+1	+33	+3
	B	−11	−45	+22	−10	+27	+33	−88	−13
	C	+21	−4	−25	+30	+20	−10	+6	+8
1964	A	−19	+86	+1	+19	−44	−47	+52	−19
	B	+2	+4	+17	+34	−18	−14	−63	−14
	C	−17	+23	+27	−5	−7	−5	+19	−11
1965	A	+30	+49	+20	+4	−2	+12	+82	+44
	B	+15	−68	−27	−18	+17	+13	−30	+7
	C	−17	−35	−48	−8	−6	+19	+71	−15
1966	A	+29	+11	+13	−18	+9	+52	+63	+40
	B	−4	−42	−15	+25	−80	+6	−116	−38
	C	−30	+6	+8	+4	−35	−4	−3	+1
1967	A	−28	+3	+26	+45	−18	−35	+51	+32
	B	−17	−4	−15	+30	−19	−32	−14	+8
	C	+48	+19	+15	+27	−14	+23	−38	+18

		25 Salt Lake, Utah	26 San Bernardino, Calif.	27 Santa Fe, N. Mex.	28 Spokane, Wash.	29 St. Louis, Mo.	30 St. Paul, Minn.	31 Thomasville, Ga.	32 Washington, D. C.
1959	A	—19	—16	—35	—49	+10	—25	+3	—25
	B	+10	+20	+10	—13	+4	+31	+10	—14
	C	+58	+25	+40	+65	—9	—26	—26	+32
1960	A	—13	—67	—41	+23	+2	—11	+52	—1
	B	+22	—18	—21	+46	+7	+21	+38	+26
	C	+22	+66	—30	+3	+11	+6	—35	—23
1961	A	—40	+19	—12	—36	+6	—1	+37	—22
	B	—26	—16	+28	—5	+49	+29	—12	—11
	C	+12	+10	+53	+7	+17	—9	—37	+2
1962	A	—35	—15	—44	—56	—41	0	+25	+21
	B	+31	—30	+11	+18	—21	—24	+5	—36
	C	+20	+22	+15	+10	—38	—21	—25	—8
1963	A	—15	+12	+19	—15	—64	+14	—8	—54
	B	+15	+13	+17	—33	+6	—4	+3	+9
	C	—29	—17	—37	+25	+18	—16	—8	+24
1964	A	—5	+28	—25	+49	—47	+5	0	+46
	B	+32	—39	+23	+15	—24	+24	+64	+12
	C	—16	—11	—48	+61	+33	+16	—6	+7
1965	A	+24	+75	—25	+27	—10	+47	+27	+20
	B	—14	—8	+59	—43	+5	—15	+50	+37
	C	+44	+46	—24	+47	—39	—37	—40	—9
1966	A	—8	—46	—69	+11	+36	+18	+4	—19
	B	—22	—84	+16	—18	—38	—28	+1	—10
	C	+29	—13	+3	+2	+36	—30	—45	—20
1967	A	—30	+4	—15	—6	—11	—10	+44	—12
	B	—34	+23	+37	—2	+26	+12	+6	+32
	C	+18	+1	+37	+7	+26	—14	—38	+6

TABLE 14.—*Forecast and observation, 1950-1958* *

Four-month mean values

Year		Abilene, Tex. Ob-served	Fore-cast	O-F Δ	Albany, N. Y. Ob-served	Fore-cast	O-F Δ	Albany, Oreg. Ob-served	Fore-cast	O-F Δ	Augusta, Ga. Ob-served	Fore-cast	O-F Δ
1950	A	73	85	−12	110	133	−23	120	77	+47	64	22	+42
	B	169	67	+102	67	118	−51	94	111	−17	111	72	+35
	C	46	58	−12	107	108	−1	70	151	−81	95	120	−35
1951	A	62	117	−55	129	128	+1	97	76	+21	70	80	−10
	B	75	110	−35	114	131	−17	35	58	−23	68	78	−10
	C	38	41	−3	142	102	+40	126	102	+24	91	117	−26
1952	A	71	60	+11	104	102	+2	81	67	+14	99	90	+9
	B	36	32	+4	100	93	+7	83	87	−4	91	117	−26
	C	118	82	+36	99	74	+25	54	124	−70	69	88	−19
1953	A	60	96	−36	159	112	+47	124	85	+39	111	114	−3
	B	123	108	+15	110	77	+33	114	59	+55	97	95	+2
	C	69	49	+20	91	92	−1	119	143	−24	84	96	−12
1954	A	61	65	−4	111	120	−9	111	69	+42	84	63	+21
	B	45	121	−76	101	71	+30	170	140	+30	84	43	+41
	C	75	143	−68	97	96	+1	107	121	−14	68	53	+15
1955	A	74	135	−61	96	99	−3	98	104	−6	89	176	−87
	B	117	99	+18	68	90	−22	119	121	−2	77	101	−24
	C	57	86	−29	148	89	+59	150	149	+1	70	58	+12
1956	A	85	121	−36	124	113	+11	121	113	+8	90	61	+29
	B	27	66	−39	80	129	−49	65	54	+11	59	69	−10
	C	55	53	+2	90	98	−8	86	125	−39	67	122	−55
1957	A	154	91	+63	70	117	−47	111	109	+2	71	85	−14
	B	124	81	+43	79	109	−30	108	81	+27	86	74	+12
	C	153	94	+59	94	108	−14	91	134	−43	153	82	+71
1958	A	149	140	+9	115	110	+5	112	86	+26	98	75	+23
	B	120	68	+52	82	110	−28	73	108	−35	89	85	+4
	C	121	83	+38	87	72	+15	94	93	+1	34	96	−62
Mean				34.7			21.5			26.0			26.3

Year		Bismarck, N. Dak. Ob-served	Fore-cast	O-F Δ	Charleston, S. C. Ob-served	Fore-cast	O-F Δ	Cincinnati, Ohio Ob-served	Fore-cast	O-F Δ	Denver, Colo. Ob-served	Fore-cast	O-F Δ
1950	A	179	118	+61	57	83	−26	130	79	+51	73	113	−40
	B	72	85	−13	101	112	−11	120	115	+5	109	58	+51
	C	87	78	+9	87	100	−13	135	147	−12	86	102	−16
1951	A	87	94	−7	71	82	−11	105	80	+15	131	115	+16
	B	122	68	+54	81	93	−22	66	91	−25	120	134	−14
	C	104	125	−21	90	70	+20	126	139	−13	160	160	0
1952	A	125	107	+18	111	141	−30	124	121	+3	129	140	−11
	B	55	72	−17	99	123	−24	103	144	−41	71	99	−28
	C	28	54	−26	84	42	+42	97	106	−9	86	91	−5
1953	A	135	143	−8	83	78	+5	89	109	−20	121	148	−27
	B	105	108	−3	87	70	+17	79	52	+27	107	82	+25
	C	84	72	+12	76	95	−19	48	10	+38	104	132	−28
1954	A	75	48	+27	62	88	−22	72	73	−1	49	79	−25
	B	128	126	+2	79	110	−31	110	158	−48	69	72	−3
	C	41	107	−66	112	38	+74	120	141	−21	73	40	+33
1955	A	90	94	−4	84	71	+13	138	162	−24	103	111	−8
	B	117	98	+19	82	106	−24	121	166	−45	132	107	+25
	C	124	120	+4	83	77	+6	139	128	+11	99	139	−40
1956	A	99	85	+14	79	87	−8	117	104	+13	89	68	+21
	B	110	88	+22	86	91	−5	108	117	−9	110	82	+28
	C	107	95	+12	62	95	−33	74	100	−26	92	107	−15
1957	A	66	101	−35	86	56	+30	105	70	+35	141	93	+48
	B	88	73	+15	126	112	+14	160	108	+52	119	105	+14
	C	105	131	−26	126	81	+45	143	114	+29	114	132	−18
1958	A	98	101	−3	136	113	+23	72	75	−3	140	80	+60
	B	69	125	−56	93	114	−21	153	142	+11	127	86	+41
	C	106	104	+2	82	72	+10	91	109	−18	107	152	−45
Mean				20.6			22.2			18.7			26.6

		Detroit, Mich.			Eastport, Maine			El Paso, Tex.			Helena, Mont.			Independence, Kans.			Little Rock, Ark.			Madison, Wis.			Montgomery, Ala.		
		Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ
1950	A	166	114	+52	108	125	−17	47	81	−34	91	80	+11	76	58	+18	154	154	0	120	122	−2	74	51	+23
	B	92	129	−37	125	163	−33	77	96	−19	98	112	−14	146	126	+20	122	112	+10	147	104	+43	110	97	+13
	C	123	115	+8	147	138	+9	57	76	−19	121	139	−18	36	59	−23	110	136	−26	80	93	−13	95	175	−80
1951	A	112	87	+25	142	100	+42	145	139	+6	88	58	+30	86	59	+27	70	90	−20	131	104	+27	64	112	−48
	B	104	66	+38	146	132	+14	62	135	−73	118	122	−4	115	114	+1	120	92	+28	96	89	+7	79	65	+14
	C	147	77	+70	158	157	+1	51	57	−6	97	164	−67	124	131	−7	112	127	+15	143	123	+20	104	180	+76
1952	A	118	87	+31	133	98	+35	262	196	+66	101	85	+16	77	69	+8	108	104	+4	103	112	−9	87	83	+4
	B	78	154	−76	120	120	0	175	144	+31	66	68	−2	42	40	+2	66	50	+16	135	103	+32	74	106	−32
	C	88	122	−36	98	130	−32	28	18	+10	75	99	−24	49	93	−44	101	105	−4	87	67	+20	75	135	−60
1953	A	88	91	−3	147	135	+12	100	130	−30	97	88	+9	86	87	−1	137	143	−6	118	82	+36	111	144	−33
	B	89	108	−19	124	159	−35	88	161	−73	71	76	−5	74	77	−3	60	29	+31	87	98	−11	104	142	−38
	C	49	87	−38	119	99	+20	49	15	+34	56	32	+24	89	93	−4	62	6	+56	60	51	+9	99	92	+7
1954	A	119	8	+111	135	113	+22	66	137	−71	77	65	+12	61	30	+31	97	116	−19	90	81	+9	64	57	+7
	B	78	75	+3	156	215	−59	123	160	−37	114	90	+24	70	84	−14	51	82	−31	141	173	−32	49	30	+19
	C	120	101	+19	136	105	+31	70	74	−4	82	82	0	101	128	−27	83	78	+5	100	79	+21	58	57	+1
1955	A	87	94	−7	106	76	+30	61	111	−50	84	84	0	83	58	+25	95	183	−88	92	96	−4	86	123	−37
	B	63	104	−41	76	85	−9	89	102	−13	104	97	+7	85	103	−18	103	94	+9	83	129	−46	108	118	−10
	C	108	114	−6	88	86	+2	48	102	−54	94	136	−42	92	108	−16	72	136	−64	54	82	−28	45	108	−63
1956	A	116	78	+43	116	119	−3	106	123	−17	64	43	+21	44	39	+5	120	121	−1	91	94	−3	79	76	+3
	B	103	102	+1	104	130	−26	96	109	−13	91	82	+9	57	60	−3	108	76	+32	120	105	+15	112	92	+20
	C	88	120	−32	93	120	−27	37	68	−31	81	132	−51	68	104	−36	84	94	−10	76	98	+22	166	194	−28
1957	A	94	86	+8	85	95	−10	92	75	+17	107	98	+9	111	66	+45	146	113	+33	60	69	−9	106	118	−12
	B	121	100	+21	94	123	−29	94	111	−17	116	68	+48	127	126	+1	131	73	+58	130	111	+19	137	50	+87
	C	145	104	+41	118	153	−35	163	56	+107	118	112	+6	94	121	−27	148	147	+1	99	119	−20	132	135	−3
1958	A	49	99	−50	134	96	+38	208	102	+106	109	69	+40	94	73	+21	100	143	−43	48	93	−45	104	98	+6
	B	82	86	−4	133	130	+3	178	129	+49	106	121	−15	138	108	+30	157	96	+61	69	103	−34	100	114	−14
	C	90	99	−9	114	149	−35	209	112	+87	77	102	−25	47	62	−15	96	96	0	86	102	−16	72	145	−73
Mean				30.7			22.4			39.0			19.7			17.5			24.8			20.3			30.0

(continued)

TABLE 14.—*continued*

		Nashville, Tenn.			Natural Bridge, Ariz.			Omaha, Nebr.			Peoria, Ill.			Port Gibson, Miss.			Rochester, N. Y.			Sacramento, Calif.			Salisbury, N. C.		
		Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ	Observed	Forecast	O-F Δ
1950	A	132	101	+31	65	108	−43	95	97	−2	154	174	−20	129	131	−2	140	101	+39	91	158	−67	70	64	+6
	B	148	96	+52	66	75	−9	113	94	+25	106	71	+35	141	121	+20	106	97	+9	60	89	−29	90	79	+11
	C	127	119	+8	28	20	+8	72	58	+14	63	133	−70	92	128	−36	132	150	−18	205	143	+62	74	103	−29
1951	A	105	114	−9	105	26	+79	194	151	+43	117	143	−26	109	139	−30	128	94	+34	64	117	−53	78	114	−36
	B	100	126	−26	97	135	−38	155	127	+28	108	101	+7	117	64	+53	107	80	+27	34	10	+24	75	76	−1
	C	140	112	+28	189	102	+87	84	106	−22	93	116	−23	86	91	−5	102	125	−23	159	107	+52	83	136	−53
1952	A	127	120	+7	142	118	+24	122	136	−14	101	99	+2	84	81	+3	104	74	+30	130	154	−24	146	157	−11
	B	63	72	−9	71	111	−40	118	79	+39	105	83	+22	54	49	+5	76	107	−31	223	104	+119	76	114	−38
	C	83	104	−21	118	146	−28	104	102	+2	83	53	+30	60	92	−32	82	94	−12	80	118	−38	80	103	−23
1953	A	103	141	−38	60	109	−49	97	112	−15	90	80	+10	138	125	+13	89	76	+3	97	138	−41	99	73	+26
	B	95	46	+49	54	104	−50	58	64	−6	96	128	−32	104	104	0	100	126	−26	84	23	+61	81	46	+35
	C	45	5	+40	35	69	−64	96	20	+76	52	58	−6	66	55	+11	93	75	+18	42	70	−28	76	127	−51
1954	A	102	107	−5	111	119	−8	120	113	+7	121	79	+42	86	56	+30	94	93	+1	118	94	+24	99	107	−8
	B	64	85	−21	156	56	+100	90	147	−57	145	100	+45	104	113	−9	80	95	−15	20	47	−27	84	41	+43
	C	91	115	−24	69	104	−35	84	130	−46	115	91	+24	98	107	−9	118	180	−62	82	118	−36	125	125	0
1955	A	123	149	−26	61	79	−18	94	115	−21	112	93	+19	83	80	+3	91	100	−9	93	131	−38	83	52	+31
	B	86	94	−8	173	134	+39	91	96	−5	80	74	+6	107	110	−3	73	90	−17	66	7	+59	91	106	−15
	C	95	125	−30	69	70	−1	42	70	−28	76	81	−5	72	109	−37	130	122	+8	145	112	+33	82	82	0
1956	A	124	111	+13	51	45	+6	37	96	−59	48	99	−41	108	132	−24	121	117	+4	114	160	−46	92	60	+32
	B	61	68	−7	52	107	−55	92	64	+28	91	54	+37	74	54	+20	115	136	−21	64	51	+13	103	78	+25
	C	84	96	−12	42	76	−34	87	84	+3	68	67	+1	100	113	−13	88	98	−10	101	46	+55	115	137	−22
1957	A	123	126	−3	73	78	−5	93	140	−47	98	122	−24	106	125	−19	83	81	+2	116	148	−32	119	114	+5
	B	127	86	+41	128	120	+8	126	92	+34	89	155	−66	97	67	+30	91	96	−5	65	85	−20	111	109	+2
	C	142	121	+21	108	118	−10	141	116	+25	118	93	+25	134	136	−2	70	93	−23	86	71	+15	143	90	+53
1958	A	84	93	−9	110	114	−4	99	124	−25	56	126	−70	91	129	−38	136	85	+51	187	172	+15	114	76	+38
	B	123	86	+37	122	120	+2	125	72	+53	133	92	+41	130	73	+57	123	96	+27	163	49	+114	116	95	+21
	C	79	121	−42	82	125	−43	62	89	−27	70	81	−11	84	113	−29	124	140	−16	50	144	−94	80	144	−64
Mean				22.7			32.5			28.8			27.4			19.6			19.4			38.4			25.1

		Salt Lake, Utah			San Bernardino, Calif.			Santa Fe, N. Mex.			Spokane, Wash.			St. Louis, Mo.			St. Paul, Minn.			Thomasville, Ga.			Washington, D. C.		
		Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ	Ob-served	Fore-cast	O-F Δ
1950	A	86	66	+2	63	101	−38	53	127	−74	149	114	+35	150	110	+40	96	111	−15	86	89	−3	76	69	+7
	B	97	99	−2	24	79	−55	89	105	−16	109	120	−11	101	128	−27	75	118	−43	78	67	+11	116	131	−15
	C	93	126	−33	59	101	−42	21	56	−35	124	114	+10	80	75	+5	84	91	−7	62	87	−25	130	110	+20
1951	A	79	60	+19	67	37	+30	45	53	−8	100	70	+30	106	106	0	133	91	+42	91	166	−75	94	94	0
	B	111	53	+58	90	64	+25	72	76	−4	68	46	+22	95	115	−20	127	107	+20	90	101	−11	111	124	−13
	C	131	147	−16	152	147	+5	54	38	+16	145	129	+16	99	95	+4	120	91	+29	118	93	+25	114	101	+13
1952	A	145	87	+58	130	120	+10	63	64	−1	85	74	+11	84	66	+18	119	67	+52	116	121	−5	135	136	−1
	B	109	68	+41	92	105	−13	68	99	−31	72	79	−7	74	128	−54	97	103	−6	110	103	+7	120	129	−9
	C	52	109	−57	172	145	+27	49	86	−37	68	118	−50	58	91	−33	58	84	−26	69	64	+5	135	113	+22
1953	A	88	93	−5	73	117	−44	68	47	+21	139	124	+15	90	67	+23	113	72	+41	109	114	−5	125	121	+4
	B	104	41	+65	36	6	+30	92	100	−8	94	90	+4	46	37	+9	123	65	+58	123	134	+11	102	83	+19
	C	56	11	+45	44	126	−82	103	88	+15	91	117	−26	51	86	−35	81	13	+68	115	72	+43	87	106	−19
1954	A	62	72	−10	113	224	−111	91	84	+7	94	68	+26	49	33	+16	110	69	+41	69	19	+50	77	68	+9
	B	160	113	+47	98	28	+70	131	104	+27	123	145	−22	82	92	−10	98	125	−27	53	54	−1	61	56	+5
	C	120	87	+33	75	193	+118	72	39	+33	99	133	−34	105	151	−46	71	125	−54	77	33	+44	80	113	−33
1955	A	74	137	−63	77	70	+7	75	89	−14	92	90	+2	86	107	−21	72	87	−15	78	146	−68	83	60	+23
	B	108	80	+28	122	93	+29	81	128	−47	111	120	−9	94	124	−30	83	107	−24	92	99	−7	137	150	−13
	C	106	145	−39	78	100	−22	69	46	+23	166	159	+7	86	88	−2	84	91	−7	67	95	−28	103	95	+8
1956	A	81	85	−4	77	122	−45	51	60	−9	88	89	−1	72	66	+6	67	92	−25	111	130	−19	85	119	−34
	B	54	49	+5	195	129	+66	63	79	−16	105	87	+18	109	80	+29	113	77	+36	117	105	+12	91	102	−11
	C	76	94	−18	41	93	−52	35	90	−55	86	152	−66	70	68	+2	74	90	−16	83	82	+1	98	101	−3
1957	A	113	114	−1	86	98	−12	140	43	+97	106	117	−11	132	79	+53	66	75	−11	72	93	−21	87	109	−22
	B	146	72	+74	154	99	+55	96	94	+2	111	60	+51	166	107	+59	117	101	+16	117	71	+46	65	92	−27
	C	87	100	−13	155	116	+39	174	101	+73	97	107	−10	96	118	−22	77	125	−45	138	45	+83	117	108	+9
1958	A	117	72	+45	189	143	+46	135	48	+87	130	94	+36	78	92	−14	39	94	−55	105	110	−5	151	101	+50
	B	18	81	−63	183	95	+88	82	128	−46	112	105	+7	125	85	+40	66	92	−26	119	97	+22	119	122	−3
	C	31	127	−96	167	141	+26	111	116	−5	115	115	0	83	84	−1	58	79	−21	57	119	−62	72	130	−58
Mean				31.3			43.9			29.9			19.9			22.9			30.9			25.7			16.7

TABLE 15.—*Expected numbers of discrepancies of forecasts between assigned limits*

Numbers expected of 4-month intervals in 9 years, 1959-1967, when (O-F) has certain values

Group 1. Mean (O-F)=20 percent

	<5	6-10	10-20	20-30	30-40	>40
Bismarck	6	3	8	5	1	4
Charleston	4	0	10	8	1	4
Cincinnati	4	4	7	3	4	5
Independence	4	5	4	8	2	4
Madison	3	5	8	4	4	3
Nashville	2	7	2	8	5	3
Port Gibson	8	2	6	5	4	2
Rochester	5	5	5	7	3	2
Spokane	3	6	7	6	2	3
St. Louis	6	4	3	6	4	4
Washington	6	5	8	4	2	2

Group 2. Mean (O-F)=26 percent

	<6	7-13	14-26	27-40	41-52	>52
Albany, Oreg.	4	5	7	5	4	2
Augusta	1	7	9	6	1	3
Denver	3	2	10	7	3	2
Little Rock	5	6	4	6	1	5
Peoria	4	3	6	7	4	3
Salisbury	5	5	3	8	3	3

Group 3. Mean (O-F)=30 percent

	<7	8-15	16-31	32-46	47-62	>62
Detroit	5	5	4	8	2	3
Natural Bridge, Ariz.	6	4	4	9	2	2
Salt Lake	6	2	4	6	4	5
Santa Fe	5	5	7	4	2	4
St. Paul	3	5	8	6	4	1

Group 4. Mean (O-F)=40 percent

	<10	11-20	21-40	41-60	61-80	>80
El Paso	3	5	5	3	7	4
Sacramento	0	4	11	6	3	3
San Bernardino	3	2	9	7	2	4
Sums of 25	104	106	159	152	74	80
Means	4.2	4.2	6.4	6.1	3.0	3.2
Limits	<¼	¼-½	½-1	1-3/2	3/2-2	>2

their magnitudes would be greater in proportion as the mean departure of his place bears to 20 percent.

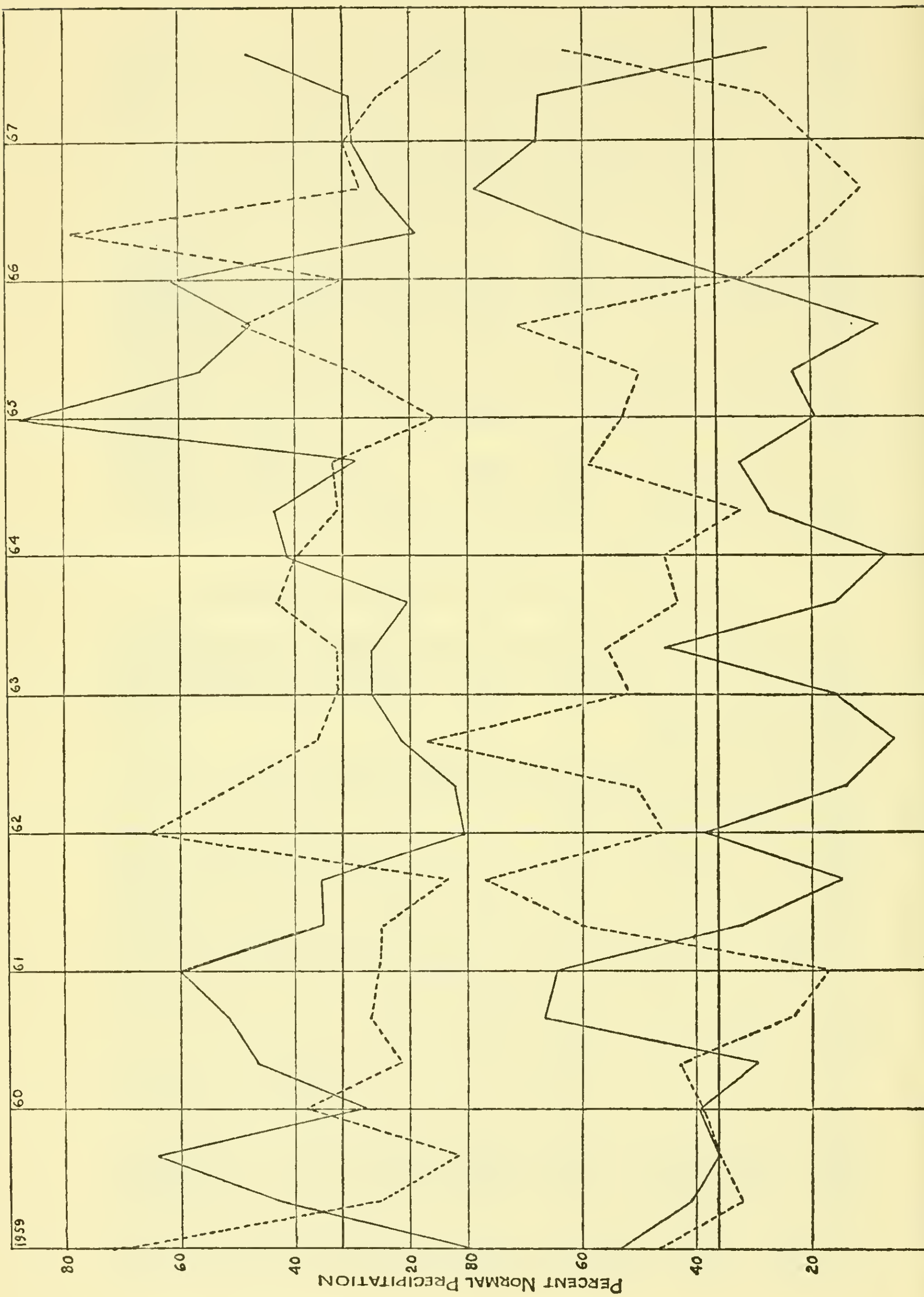
As actual cases, farmers living near Albany, Oreg., or Augusta, Ga., both by table 14 lying in the 26-percent class of table 15, may expect, according to table 15, during the 9 years 1959-1967, the numbers of 4-month averages found in table 14 to differ as follows from the 27 mean 4-month departures from normal precipitation they will actually experience: Four cases less than 7 percent; four cases between 7 and 13 percent; six cases between 14 and 26 percent; six cases between 26 and 39 percent; three cases between 39 and 52 percent; and four cases over 52 percent. Farmers living near one of the cities of the 20-percent class might expect this same division of the 27 cases for the 4-month mean departures from normal precipitation, but these departures would be smaller in percentages in the ratio $\frac{20}{26}$. It will be for their judgment to dictate whether it is worth while to procure from the Smithsonian Institution, and make use of this paper, "A Long-range Forecast of U. S. Precipitation."

COUNTRY-WIDE TRENDS IN PRECIPITATION

The maps of the United States presented below show large areas over which similar forecasts prevail. This should be helpful to interested persons who reside at a distance from the 32 cities for which forecasts were made.

I have been interested to search further to see if similar trends of precipitation sometimes prevail over the whole United States. Table 14 gives the actual departures of 3-month consecutive means of precipitation as averaged over three 4-month intervals per year, 1950-1958. A working table of these results was prepared, giving the 32 departures from normal of the cities employed in each line of a table of 27 lines, 3 lines per year for 9 years. Recording separately plus and minus departures, sums were taken for each line. These plus and minus departure-sums were plotted in figure 12, lower two curves. Plus sums are given in full lines, minus sums in dotted lines.

The plus and minus departure curves run generally in opposite directions, and in some 4-month intervals are widely separated. In such cases of wide separation the 4-month intervals were strongly heavy in precipitation if the high points are on full lines, and strongly drought-prevailing if dotted. With this explanation it is seen that the autumn of 1951 and winter of 1952 were wet periods generally for the whole United States, and similarly from the summer of 1957



Percent Normal Precipitation
80
60
40
20
80
60
40
20
1959
60
61
62
63
64
65
66
67
1950
51
52
53
54
55
56
57
58

through the summer of 1958. On the other hand from the summer of 1952 through the autumn of 1956 the country was generally dry.

This interpretation of generality over the country is justified by the fact that the high points of figure 12 depend on observations of identity of signs for more than 20 out of 32 cities, in 15 cases. Some peaks are supported by 28 cities out of 32.

When both curves are near the heavy horizontal line the precipitation of the country as a whole was nearly normal. That is, through 1950 and the first four months of 1951, and for portions of the years 1953, 1954, and 1957 precipitation generally averaged nearly normal. The curves of figure 12 show plainly that the entire country is subject to nearly simultaneous trends of precipitation, depending, as they do, on nearly universal agreement of observations of departures in 32 cities over an interval of 9 years.

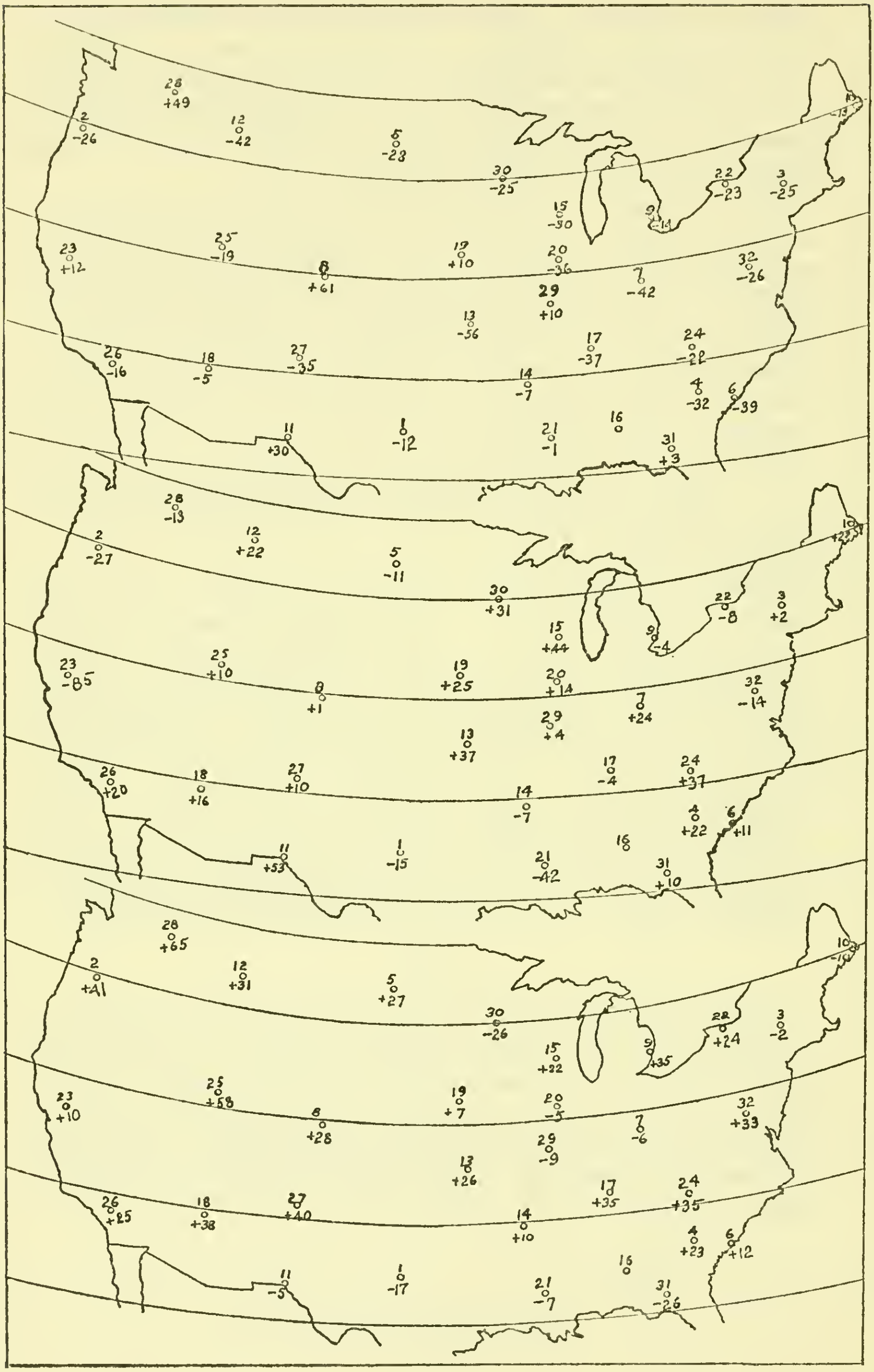
With this result established, turn to the two upper curves on figure 12. These are plotted similarly to those below, but are from table 13 which gives the 4-month mean departures from normal precipitation forecasted 1959-1967.

Reading these upper curves: After the dry winter of 1959 there should follow a short well-watered interval, and an interval of nearly normal precipitation before a rather well-watered period in 1960. Then, following normal precipitation in 1961, should come pretty dry conditions in the winter and early summer of 1962. A long period of normal rainfall follows from the autumn of 1962 through the summer and autumn of 1964. A very wet winter of 1965 follows, and fairly normal precipitation thereafter, except for the dry summer of 1966.

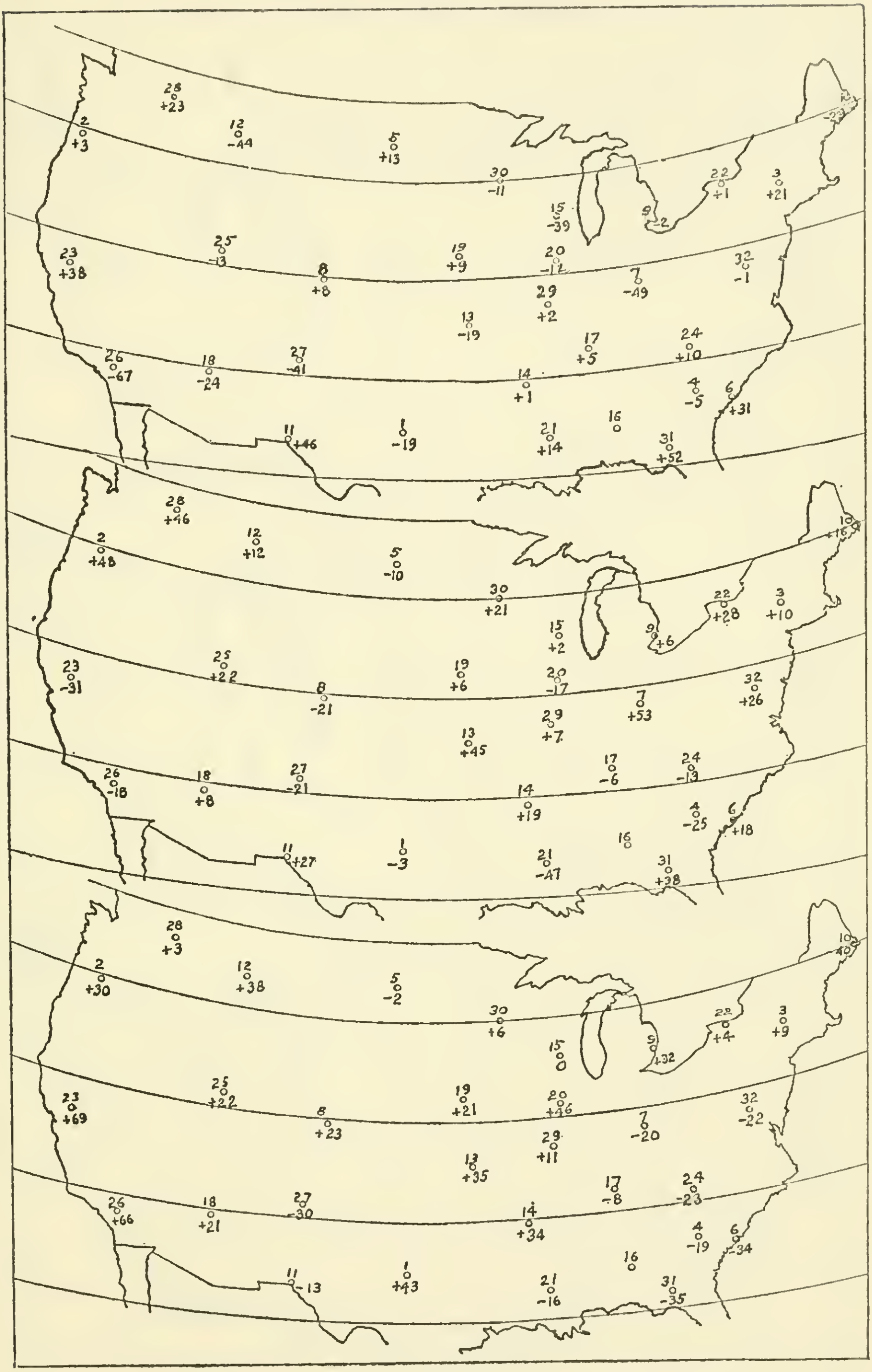
The last preceding paragraph concerns the country as a whole. For details of forecasts for individual stations, the predictions may be found in tables 12 and 13, and in the 27 maps of the United States.

MAPS

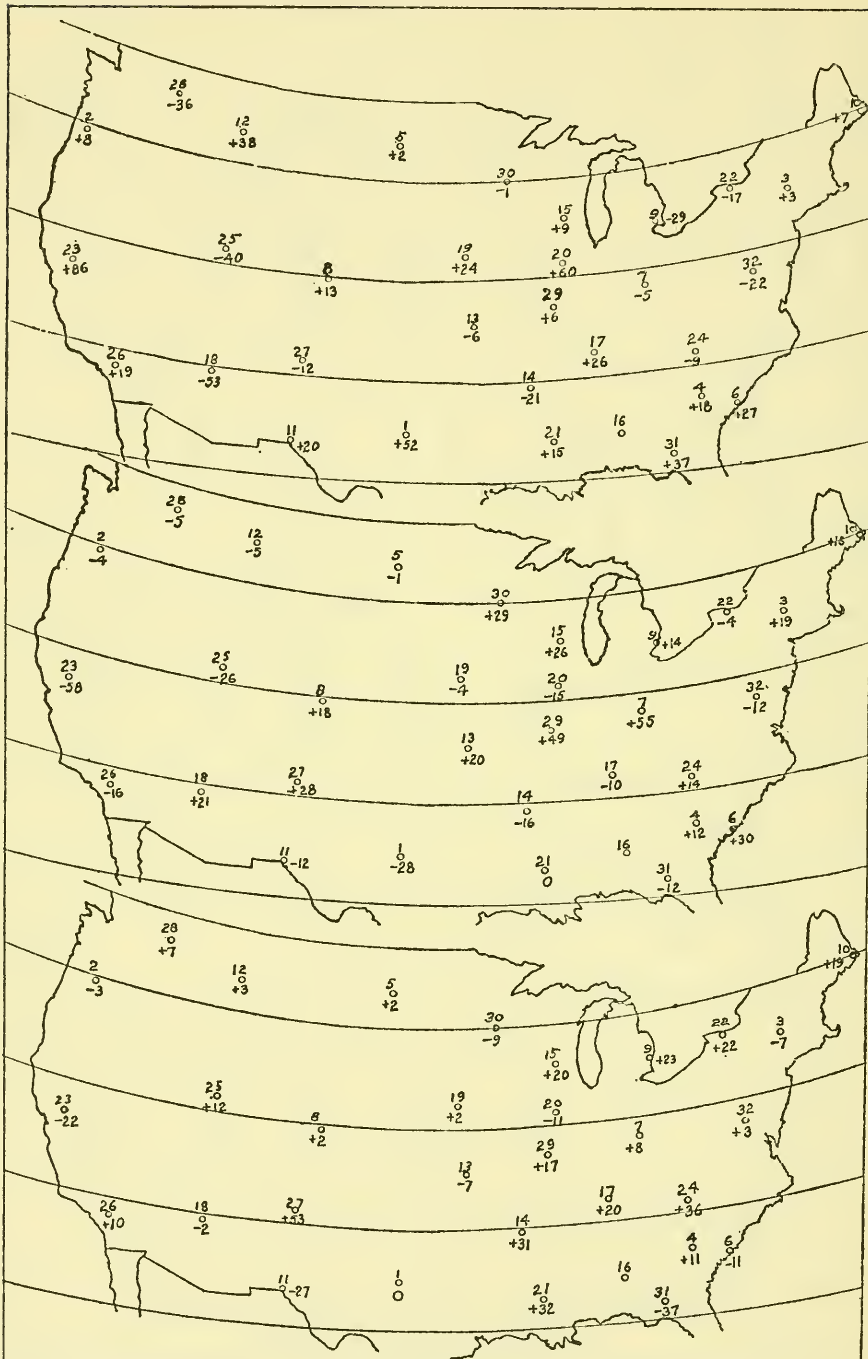
Twenty-seven maps of the United States follow, with circles showing location of 32 cities. Numbers above the circles refer to the cities given in table 13, which are numbered correspondingly. Numbers below the circles give percentage departures from normal precipitation as forecasted as means for 4-month intervals in table 13, 1959-1967, A, B, and C, for each year. Three maps form one chart. The nine charts are dated from 1959 to 1967.


28 +49
2 -26
12 -42
5 -23
30 -25
15 -30
22 -23
3 -25
9 -14
23 +12
25 -19
8 +61
19 +10
20 -36
7 -42
32 -26
29 +10
13 -56
17 -37
24 -22
26 -16
18 -5
27 -35
14 -7
4 -32
6 -39
11 +30
1 -12
21 -1
16
31 +3
28 -13
2 -27
12 +22
5 -11
30 +31
10
15 +44
22 -8
3 +2
9 -4
23 -85
25 +10
8 +1
19 +25
20 +14
7 +24
32 -14
29 +4
13 +37
26 +20
18 +16
27 +10
17 -4
24 +37
14 -7
4 +22
6 +11
11 +53
1 -15
21 -42
16
31 +10
28 +65
2 +41
12 +31
5 +27
30 -26
15 +22
9 +35
22 +24
3 -2
23 +10
25 +58
19 +7
20 -5
8 +28
7 -6
32 +33
29 -9
13 +26
17 +35
24 +35
26 +25
18 +38
27 +40
14 +10
4 +23
6 +12
11 -5
1 -17
21 -7
16
31 -26

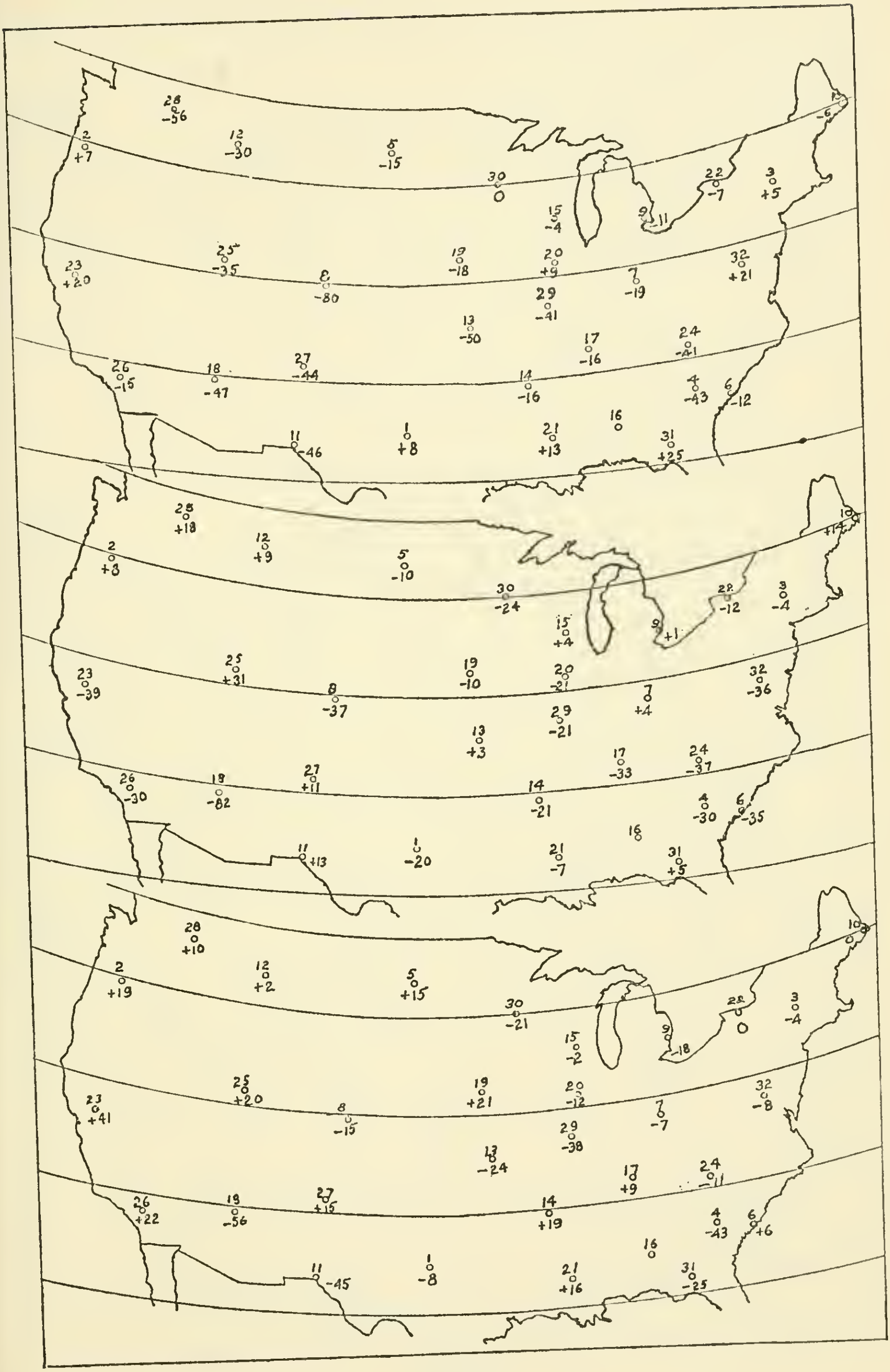
1959



1960



1961


28 -56
2 +7
12 -30
5 -15
30 0
15 -4
9 -11
22 -7
3 +5
-6
23 +20
25 -35
8 -80
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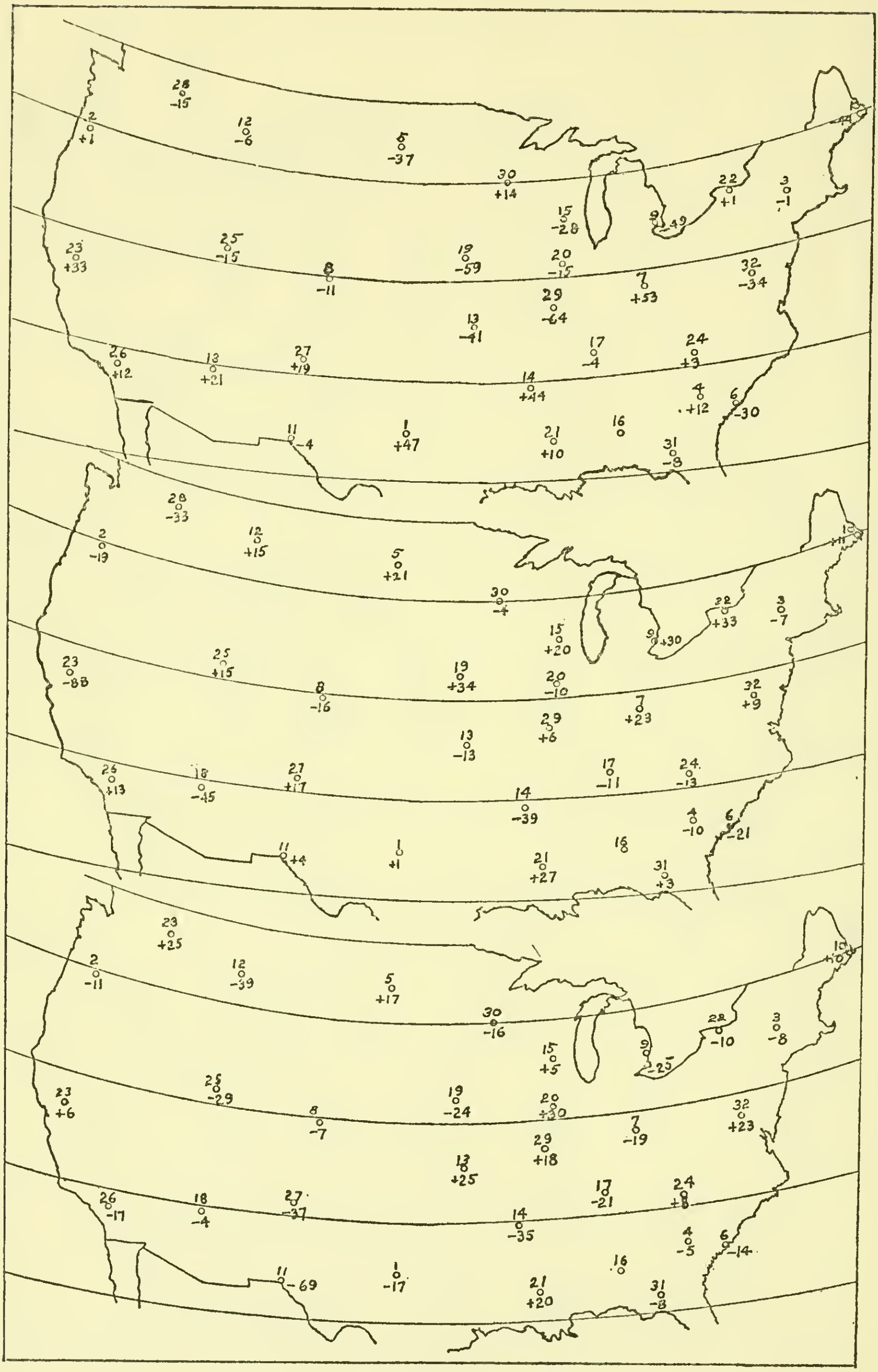
1962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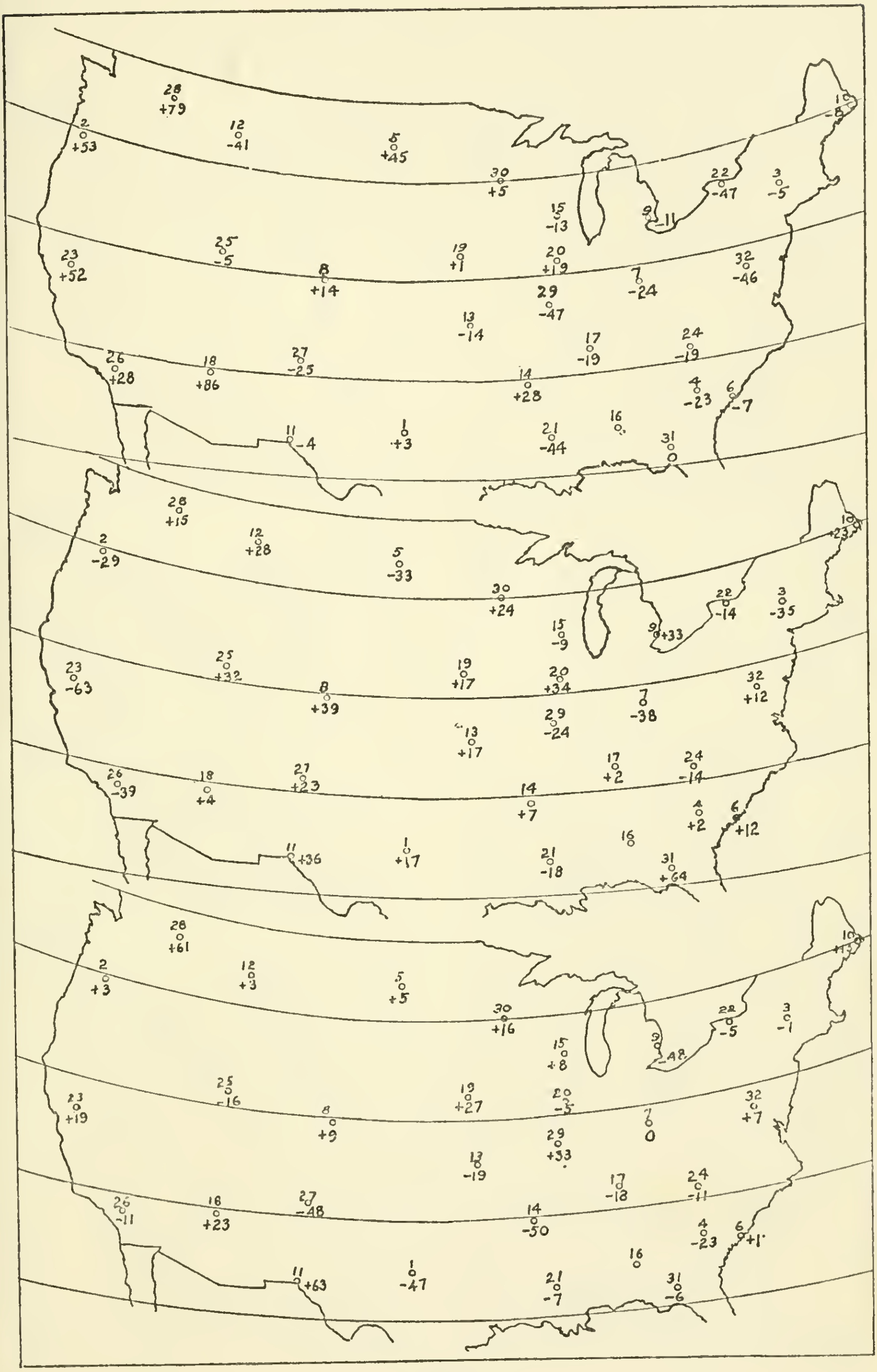
1963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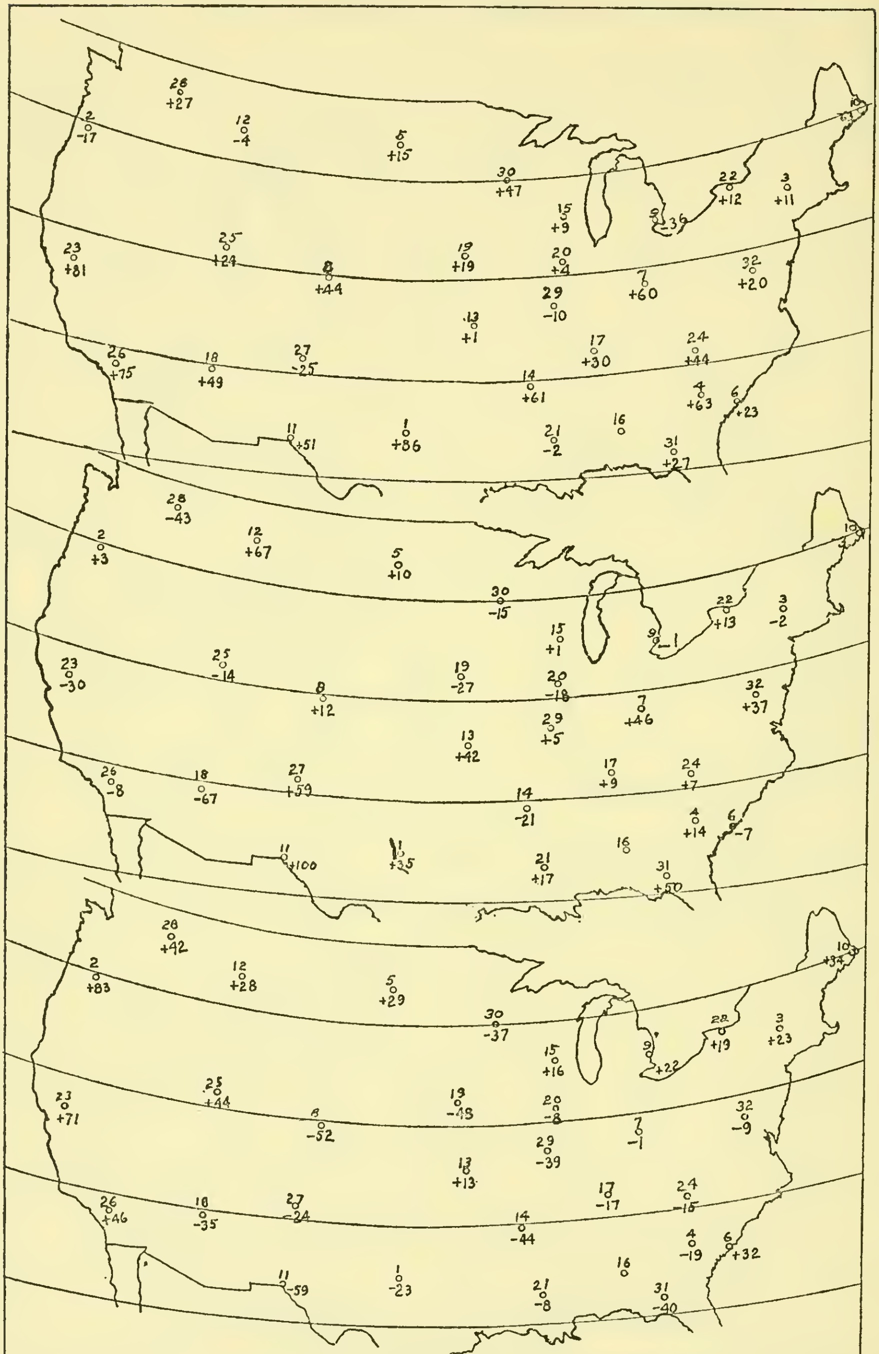
1964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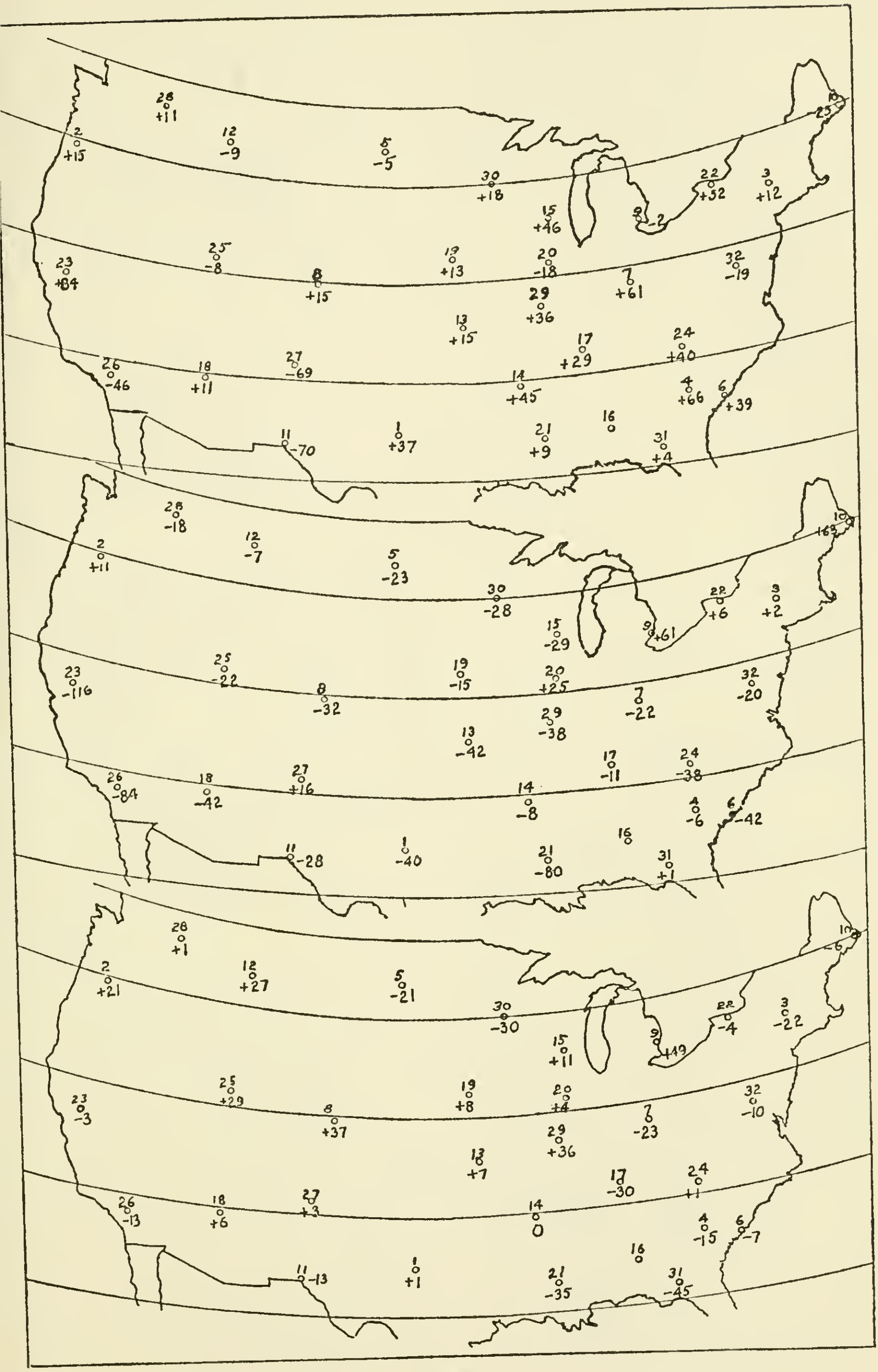
1965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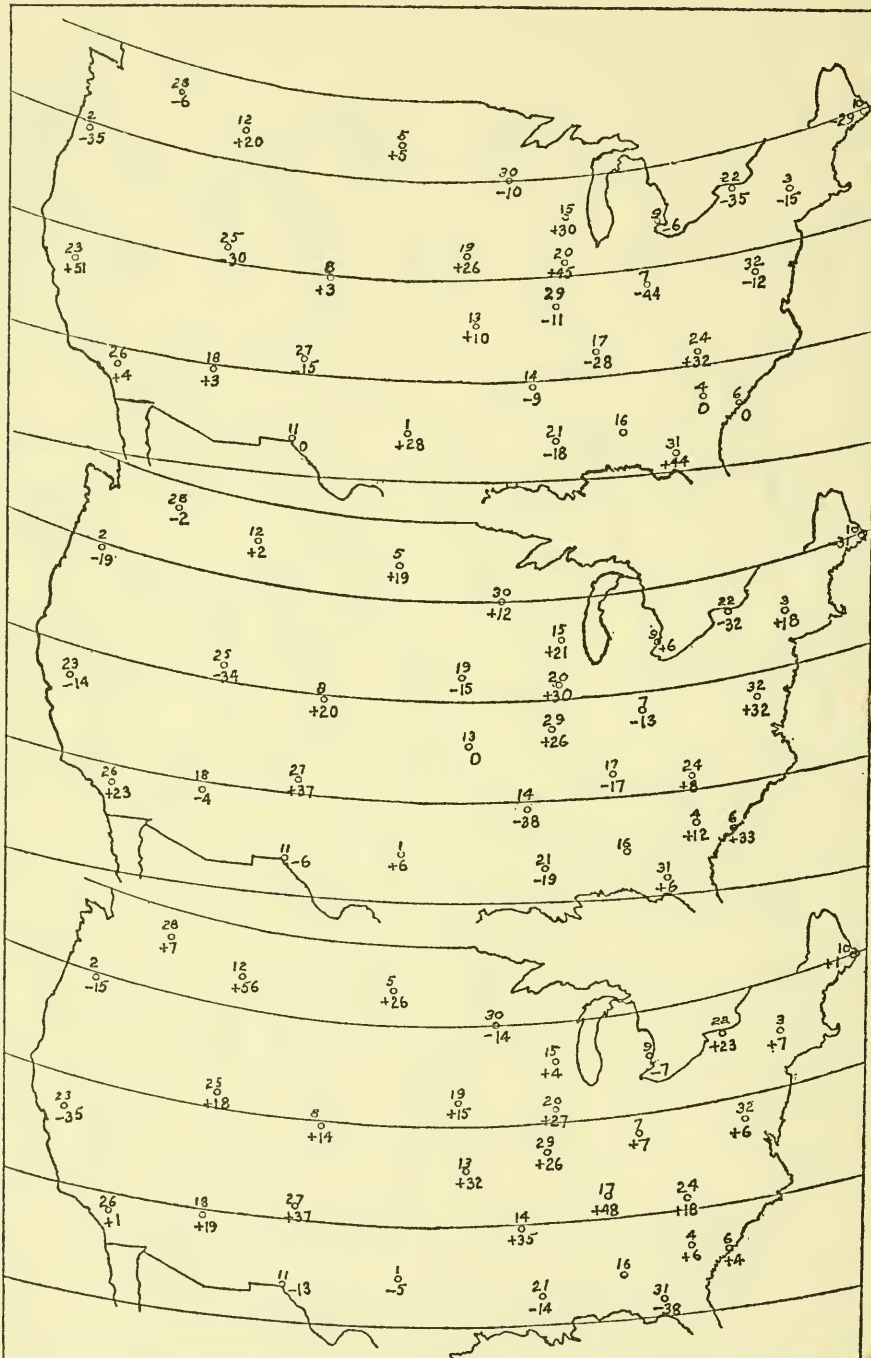
1966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4 +6
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1967

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 139, NUMBER 10

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(WITH 2 PLATES)

BY
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E. R. FENIMORE JOHNSON
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(PUBLICATION 4391)

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THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

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By JEROME WILLIAMS, E. R. FENIMORE JOHNSON AND ALBERT C. DYER[1]

(With 2 Plates)

INTRODUCTION

Marine biologists have long been interested in the transparency of natural waters as an important parameter in the determination of both the amount and type of plant life at various depths. Owing to this interest, many transparency surveys, in the oceans [4, 8, 16, 19, 22, 23],[2] in lakes [7, 33], and on pure water [27], have been made. In recent years, however, this interest in water clarity has spread to other fields, such as underwater photography (1, 9, 20, 24, 33) and television. In addition, there is a growing movement among workers in the field to utilize transparency as a "tag" for water masses in the study of such things as circulation patterns [23, 25].

During the years 1947-51 the yacht *Elsie Fenimore* made a rather extensive survey of water transparency conditions along the east coast of North America from Labrador to the Gulf of Mexico, including some stations around Newfoundland and the British West Indies. Even though the data herein presented are admittedly far from complete and a number of other studies have been made of the area [3, 5, 10, 11, 12, 13, 14, 15, 17, 18, 21, 28, 31] this study represents, from a geographical standpoint, the most extensive single piece of work done on the subject to date. For this reason, if for no other, it seems desirable to publish this information in the present form so that it may become available.

To make the data as universal as possible the unit chosen was the so-called Equivalent Secchi Disc Reading. Since it is obviously impossible to use the Secchi Disc [32] for measurement of water transparency if the water mass to be measured is at a great depth, this water mass is hypothetically brought to the surface for measurement. Thus the Equivalent Secchi Disc Reading may be said to be the dis-

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[1] Mr. Williams is associated with the Chesapeake Bay Institute; Mr. Johnson is a research associate in the Limnology Department, Academy of Natural Sciences of Philadelphia; and Mr. Dyer is connected with the Fenjohn Company.

[2] Numbers in brackets indicate references in the bibliography.

tance at which a Secchi Disc would just disappear if it were immersed in water and if that water were at the surface.

As an example, if an Equivalent Secchi Disc Reading were given as 10 feet for water at a depth of 100 feet, this would mean that if the water mass at a depth of 100 feet were brought to the surface a Secchi Disc would disappear from view at a distance of 10 feet in this transposed volume of water.

The Secchi Disc is admittedly a crude indicator of water transparency, since it was originally used by marine biologists to measure the so-called *extinction coefficient*. This is a measure of the amount of light reaching a horizontal surface at some depth. Unfortunately, the extinction coefficient is not only a measure of the water transparency but also a function of such things as sea state, cloud cover, altitude of sun, and other factors. Even so, however, the Secchi Disc reading is probably a reasonably good indicator of water clarity if it is taken with the sun fairly high in the sky and if it is viewed through a glass-bottom viewer or hydroscope [30].

In addition, the Secchi Disc reading is an easily understood unit, generating an intuitive feeling for the existing conditions, so that it has become fairly universal in its use as an indicator of water transparency.

Of course, the actual Secchi Disc reading gives an average value of the transparency of the surface layers, so that if a layer of markedly different water exists somewhere from top to bottom, it will not be seen. For this reason, other instruments which measure transparency of relatively small volumes of water were used in conjunction with the disc. These will be discussed in a later section.

The writers wish to express their appreciation to Dr. Ruth Patrick, Curator, and Miss Margaret Le Mesurier, Librarian, of the Department of Limnology, Academy of Natural Sciences of Philadelphia, for their indispensable aid in the preparation of this manuscript. Appreciation is also expressed to the Smithsonian Institution for material aid and advice in this project and publication of the paper, and to the Academy of Natural Sciences of Philadelphia for its contribution of personnel and materials in the carrying out of this program. We regret that space does not permit the listing of over 50 other persons and institutions to whom we are indebted for advice and assistance rendered.

INSTRUMENTS

The instruments utilized in the accumulation of the data presented herein can roughly be divided into two classes: (1) those that measure the medium in its natural environment and (2) laboratory-type instruments in which a water sample is removed from the medium and examined in the shipboard laboratory. The first type is usually considered the more reliable when dealing with natural waters, since the transparency properties seem to change rather markedly when a sample is taken out of its natural environment, and therefore this type is discussed first.

I. IN SITU INSTRUMENTS

A. Secchi Disc (pl. 1, fig. 4)

The Secchi Disc, owing to its ruggedness and ease of use, was the most often used of any of the devices to be listed. The disc used was $7\frac{1}{2}$ inches in diameter and was painted a flat white, having a reflectance coefficient of about 0.8. It was obtained from the Oceanographic Institution at Woods Hole, Mass. A specially designed hydroscope (pl. 1, fig. 3) was occasionally used in conjunction with the Secchi Disc to eliminate water-surface effects. Generally the Secchi Disc was observed by means of a glass-bottom bucket. Readings were made from the sunny side of the ship, except where otherwise noted in the data tables, and the recorded value is the distance from the bottom of the hydroscope to the disc, i.e., the distance traveled by the reflected light from the disc surface through the medium in which it is suspended.

B. Point Source Light

On a number of occasions the transparency of water was measured by observing the distance at which a point source of light can be seen. This method of measurement may be seen to be similar to that of the Secchi Disc.

Although a true point source of light is well-nigh physically impossible, the tungsten filament of a 1,000-watt diver's lamp approximated this well enough for the range of transparency encountered in the near coastal and inland waters. It unfortunately fails badly in the ultraclear sections of the open ocean, where it diminishes in size and eludes the observer before reaching extinction through absorption.

In turbid waters the point source shows up as an incandescent spot surrounded by scattered light having the appearance of luminescence in which the visual range is the point at which it disappears into the background of scattered light. In clearer water, on the other hand, the background of scattered light, if it can be seen at all, is seen only when the point source is close to the observer and disappears while the incandescent spot is still plainly visible. The energy from this spot is so reduced by attenuation that the structural shape of the filament can be clearly seen. The visual range is then taken to be the distance to that point at which the filament completely disappears.

Most of these observations were made horizontally with the lamp and the objective of the hydroscope both placed 5 feet below the water surface. For the sake of completeness, observations were made both during the day and at night. Plate 1, figure 1, shows the point source of light being observed through the hydroscope.

C. Illuminated Letter

This observation method involved the use of a low-powered lamp enclosed in a small housing with an opal glass window, in front of which was mounted a rotatable disc which had a series of cutout letters. The whole rig was mounted on a pole which could be extended approximately 5 feet below the surface and was observed by means of the hydroscope. The procedure adopted consisted of bringing the illuminated letter toward the hydroscope in a horizontal direction until the observer could make a positive identification of the nature of the letter.

D. Underwater Objects

To obtain some idea of the horizontal visibility available at various stations, black and white balls approximately 6 inches in diameter were lowered about 5 feet below the surface of the water and observed with the hydroscope. The horizontal distance at which the balls disappeared from view was recorded.

E. U.S. Navy Hydrophotometer Mk. II (pl. 1, fig. 2)

To obtain a measure of the variation in transparency with depth, standard U.S. Navy hydrophotometers were used quite extensively. They consisted of two principal parts; a control box and an underwater unit connected by an electrical cable. The underwater unit may be lowered to any desired depth and the transparency at that depth is indicated at the control box. It is very similar in its operation to a number of earlier instruments [6, 29, 33].

The underwater unit consists of two heads separated by a fixed distance of 0.5 meter, one head containing a photocell, P_1, and the other containing a collimated light source and another photocell, P_2 which is connected so that its output is in opposition to the output of cell P_1. In operation the light shines both on P_1 and P_2 and the combined output of the two cells is adjusted by means of light irises so that the meter in the control box reads 100 percent when the underwater unit is in air (air is assumed to be a nonattenuating medium). Then, as an attenuating medium such as water is placed between the light and photocell P_1, the meter will read some fraction of 100 percent. Actually, since there is a light loss of about 4 percent per glass-air interface owing to the different indices of refraction of glass and air which does not occur when the device is submerged because of the similarity of glass and water indices of refraction, the reading in air should be set to 92 percent instead of 100 percent [34].

There is a definite temperature effect on the device, but in view of the sources of error existent in the other methods of measurement and the length of time required for an internal temperature change to occur, it is felt that this temperature dependence is negligible. This temperature effect is reported in the National Bureau of Standards Text No. 43P-1/47.

F. Hydroscope

This instrument is essentially an underwater telescope having a 15° field of view with interchangeable heads for either vertical or horizontal viewing for Secchi Disc or other visibility range readings. Plate 1, figure 3, shows the device which is approximately 15 feet long and uses a lens system of unit magnification. The viewing head is equipped with a focusing eyepiece, a rubber face pad to exclude external light, and two positioning control handles.

In use, the hydroscope is supported in a ball-and-socket mount on a platform extending from the side of the ship, with the objective head of the instrument extending 5 feet below the water surface.

II. LABORATORY TYPE INSTRUMENTS

A. Peraquameter (*pl. 2, fig. 1*)

This device is very similar in principle to the illuminated letter described above, except that the letter to be identified is placed in a long tube (11 feet long) which is filled with the water of interest by means of a pump. The observer looks into this tube and is able to move the image of the letter, by means of a movable mirror, until positive identification is possible.

The peraquameter was used when visual range, using the illuminated letter, was found to be under 22 feet.

B. Scattering Meter (pl. 2, fig. 2)

To measure light scattering due to suspended particles in natural waters, Dyer developed a device which essentially consisted of a light source that sent a beam of light through the sample. At right angles to the beam, a photocell was placed, and the amount of scattering was then a function of the output of this photocell.

The sample cell used was first a 2½″ x 2½″ x 1″ rectangular glass container, but this was later changed to a 3″ x 3″ x 2″ plastic cell to handle a larger sample and at the same time defeat the problem of condensation on the outside of the cell due to cold-water samples.

The electrical circuit was so designed that the output current of the photronic tube affected the grid current of an amplifier tube, thus causing changes in the plate current of the amplifier for small changes in the output of the photocell. A microammeter with scale ranging from 0 to 100 was selected as an indicator of the degree of scattering and was connected in the plate circuit of the amplifier. The circuit was adjusted so that the output current could be zeroed for any given beam intensity with the sample cell empty. For operating convenience, a reflecting rod was so mounted that it could be swung into a fixed position in the light beam in order that a check could be maintained on the source light output by means of its effect on the output of the photronic cell. The entire unit, including batteries, was mounted in a glass-fronted metal case for convenience.

As finally evolved, the device proved capable of covering the entire range of turbidity from Delaware River water to the finest obtainable grade of triple-distilled pharmaceutical water.

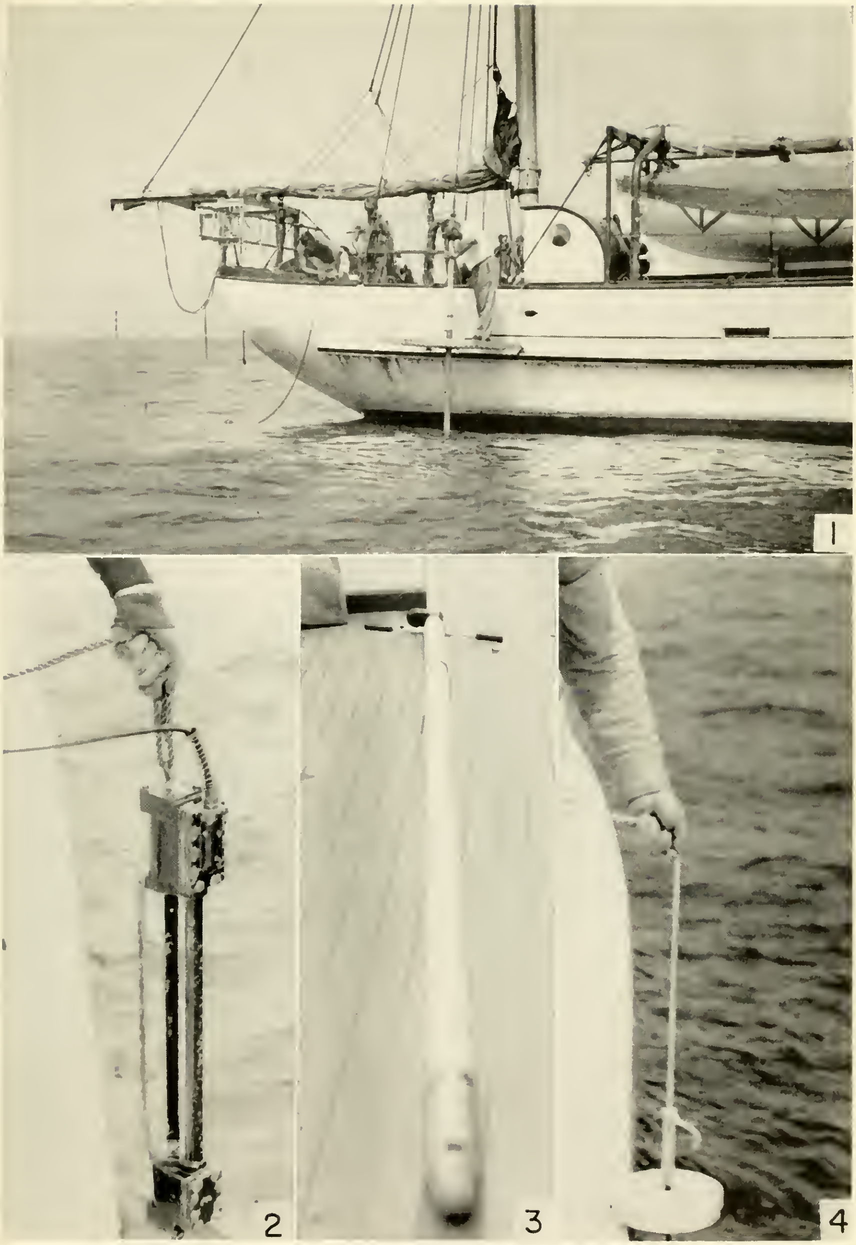
METHODS OF DATA ANALYSIS

For the sake of uniformity it seemed desirable to convert all the hydrophotometer readings to "Equivalent Secchi Disc Readings," as defined in a previous section. To do this required some relationship between actual Secchi Disc readings and hydrophotometer readings, which was not readily available. Williams, however, has developed an expression involving the extinction coefficient as a function of the Secchi Disc reading, and since the hydrophotometer transparency measurement is similar to the extinction coefficient measured under ideal conditions, it was decided to use this approach.

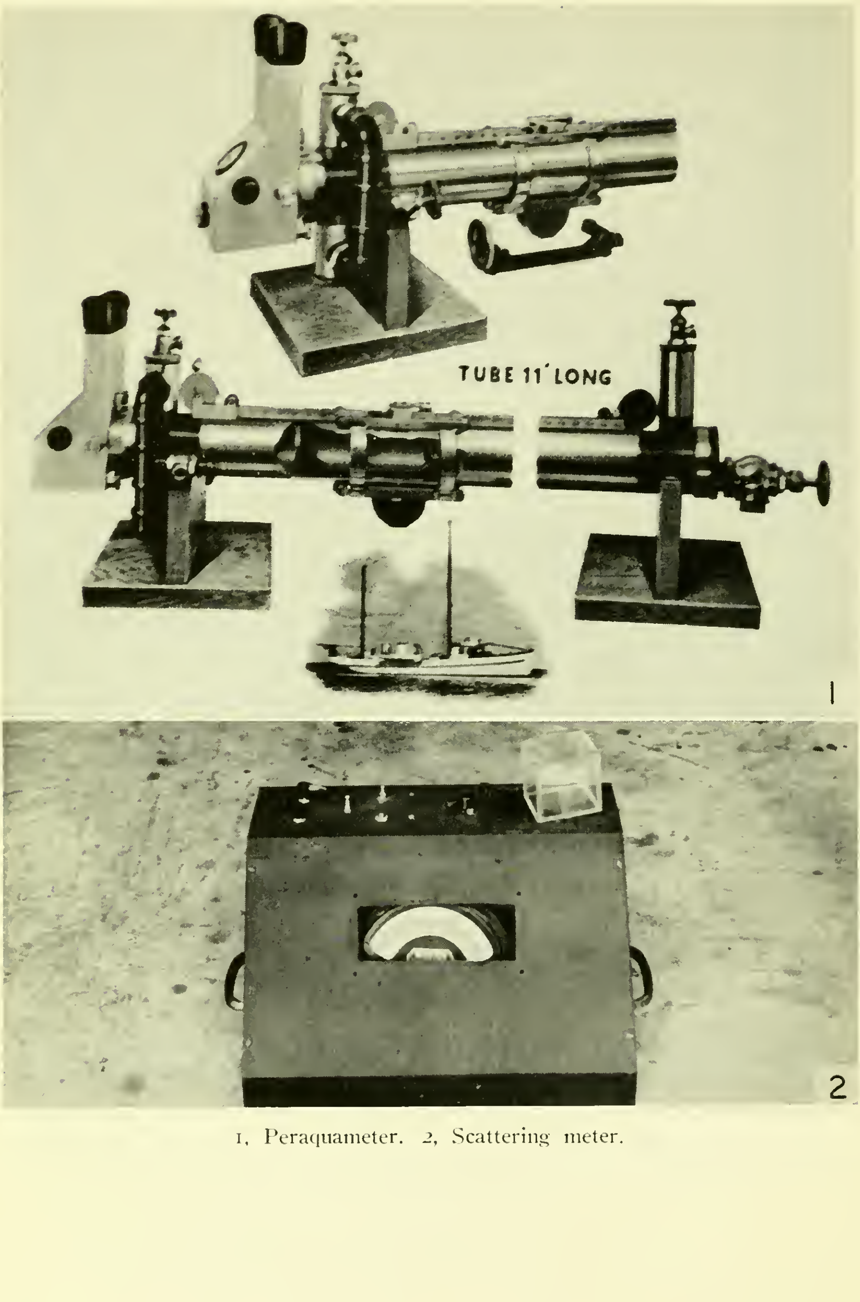
Let:

B_s = Illumination at the sea surface.

B_o = Brightness of the Secchi Disc as seen by the eye.



1, Hydroscope in use. 2, United States Navy hydrophotometer Mk II. 3, Specially designed hydroscope. 4, Secchi Disc.



1, Peraquameter. 2, Scattering meter.

B_b = Brightness of the surrounding water at the hydroscope depth. (This is the background against which the Secchi Disc is seen.)
B_{oD} = Actual brightness of the disc at the disc.
B_{bD} = Actual brightness of the surrounding water at the disc depth.
R_s = Reflectance of the sea surface.
R_d = Reflectance of the Secchi Disc.
U_w = Relative amount of light going in an upward direction compared to that going in a downward direction at the hydroscope depth.
D = Length of attenuating medium interposed between the eye and the object.
d = Depth of the glass-bottom bucket or hydroscope.
k = Extinction coefficient.

When the Secchi Disc is observed, it can be seen as long as the brightness of the disc is greater than that of its surroundings. In other words, the contrast produced by the disc against its background allows the disc to be seen as long as this contrast is above the threshold value for human visibility.

Contrast is usually defined in the following manner:

$$\text{Contrast} = \left| \frac{\text{Object brightness} - \text{Background brightness}}{\text{Background brightness}} \right|$$

where the absolute value signs are used to keep the quantity positive when contrast is produced by a dark object on a light background.

In this particular case, there are two distinct contrasts to be dealt with—the apparent contrast, or that which the eye sees, and the actual contrast, or that which actually exists at the disc level.

Using the symbols defined above, the apparent contrast C_A may be expressed as:

(1) $$C_A = \frac{B_o - B_b}{B_b}$$

and the actual contrast, C_R, by:

(2) $$C_R = \frac{B_{oD} - B_{bD}}{B_{bD}}$$

It turns out that diminutions of contrast through an attenuating medium follow this relationship:

(3) $$C_A = C_R e^{-kD}$$

or, substituting the values for C_A and C_R from (1) and (2) in (3) we get:

(4) $$\frac{B_o - B_b}{B_b} = \frac{B_{oD} - B_{bD}}{B_{bD}} e^{-kD}$$

Since B_o is the brightness of the disc at the eye, this means that only the amount of sunlight reaching the eye from the disc is involved.

Let us derive an expression for B_o in terms of some of the other variables. If there are B_s units of illumination striking the sea surface, R_sB_s units will be lost owing to reflection, and B_s $(1-R_s)$ will be the amount of light actually entering the water surface. At a depth of $(d+D)$ the light value will now be $B_s(1-R_s)e^{-k(d+D)}$.

Since only R_d of the light reaching the disc is reflected from it, the light just leaving the disc would then have a value equal to $B_s(1-R_s)e^{-k(d+D)}R_d$, which is B_{oD}.

(5) $$B_{oD}=B_s(1-R_s)e^{-k(d+D)}R_d$$

Traveling back upward, the light would be further attenuated over the distance D, so that at the bottom of the hydroscope the brightness value would now be equal to $B_s(1-R_s)e^{-k(d+D)}R_de^{-kD}$. One more reflective loss occurs at air-glass-water interface which may be assumed to be equal percentagewise to the original surface reflective loss so that the object brightness at the eye turns out to be:

(6) $$\begin{aligned} B_o &= B_s(1-R_s)e^{-k(d+D)}R_de^{-kD}(1-R_s) \\ &= B_sR_d(1-R_s)^2e^{-k(d+2D)} \end{aligned}$$

Using the same methodology for calculation of the background brightness, we get the following:

(7) $$B_b=B_sU_w(1-R_s)^2e^{-kD}$$

(8) $$B_{bD}=B_sU_w(1-R_s)e^{-k(d+D)}$$

When (5), (6), (7), and (8) are substituted back in (4), the following is obtained:

$$\frac{B_sR_d(1-R_s)^2e^{-k(d+2D)}-B_sU_w(1-R_s)^2e^{-kD}}{B_sU_w(1-R_s)^2e^{-kD}}=\frac{e^{-kD}B_sR_d(1-R_s)e^{-k(d+D)}-B_sU_w(1-R_s)e^{-k(d+D)}}{B_sU_w(1-R_s)e^{-k(d+D)}}$$

which, upon simplification becomes:

(9) $$\frac{R_de^{-2kD}-U_w}{U_w}=\left(\frac{R_d-U_w}{U_w}\right)e^{-kD}$$

Clearing fractions and transposing:

$$e^{-2kD}-\left(\frac{R_d-U_w}{R_d}\right)e^{-kD}-\frac{U_w}{R_d}=0$$

Letting $\frac{U_w}{R_d}=A$, and simplifying, gives:

$$e^{-2kD}-(1-A)e^{-kD}-A=0$$

or, multiplying by e^{2kD} to give positive exponents, we get:

$$Ae^{2kD}+(1-A)e^{kD}-1=0$$

which, when solved for e^{kD} gives:

(10) $$e^{kD}=\frac{1}{A}=\frac{R_d}{U_w}$$

or in terms of natural logarithms:

$$kD = ln \frac{R_d}{U_w}$$

(11) $$k = \frac{1}{D} ln \frac{R_d}{U_w}$$

which in common logarithms is:

(12) $$k = \frac{2.3}{D} \log \frac{R_d}{U_w} \text{ (for } D \text{ in meters)}$$

(13) $$k = \frac{7.54}{D} \log \frac{R_d}{U_w} \text{ (for } D \text{ in feet)}$$

Equations (12) and (13), then, express a relationship involving k, the extinction coefficient, D, the Secchi Disc reading, R_d, the reflectivity of the disc used, and U_w, the relative amount of light traveling in an upward direction compared to that traveling downward. Let us look at each one of these variables a little more closely.

If we define a term E, sometimes called optical density, as:

$$E = \log \frac{100}{\%T}$$

where $\%T$=percent transmission, we may express k in terms of E by:

$$k = 2.3\, E$$

since k is given in terms of natural logarithms. Since E values and $\%T$ values are conveniently tabulated in readily available tables, we may easily obtain a k value for any $\%T$ value we may have as given by the hydrophotometer. In this manner we may reduce any hydrophotometer reading to its equivalent Secchi Disc reading or vice versa by substituting the k or D value in equation (12) or (13).

The D is, of course, the Secchi Disc reading which may be either read directly or calculated from the hydrophotometer reading. For the disc used R_d was about 0.8.

The relative amount of upwelling light, U_w, however, was not measured and values were assumed for this quantity, based on other data taken by Williams in Chesapeake Bay and by the calculated values from the large number of stations where both Secchi Disc readings and hydrophotometer readings were taken.

If equation (12) is rewritten:

$$k = \frac{x}{D}$$

where

$$x = 2.3 \log \frac{R_d}{U_w}$$

or, since $R_d = 0.8$,

$$x = 2.3 - 0.1 + \log \frac{1}{U_w}.$$

A plot of x vs. D may now be made, where x is calculated from stations at which hydrophotometer readings which give k and Secchi Disc readings which give D were taken simultaneously. This plot shows a marked variation of U_w as the Secchi Disc reading is changed, and is the graph which was used to determine unknown U_w values when the S.D. readings were known, both for stations which had hydrophotometer and Secchi Disc readings and for those which had only S.D. data.

By means of this methodology, then, it was possible to calculate equivalent Secchi Disc readings for each hydrophotometer reading taken.

DISCUSSION OF DATA

In the two appended tables, all the data taken on the *Elsie Fenimore* are tabulated. Table 1 includes the hydrophotometer and Secchi Disc data presented by seasons and in geographical order from North to South. Winter is considered to include the months of January, February, and March; spring—April, May, and June; summer—July, August, and September; and fall—October, November, and December. The various stations may be easily located by number on the series of charts (figs. 1-13, preceding the tables), which show the latitude and longitude of each of the stations mentioned.

Table 2 includes all the other data taken, utilizing the various devices of Dyer plus a few others which were also used. These data are presented in simple geographical order, proceeding from north to south.

The data as a whole, although being among the most extensive available at the present time, have many limitations and shortcomings, and these should be kept in mind while any attempt at utilization is being made.

The hydrophotometer readings were taken with utmost care. However, the calibration in air was apparently not standardized, the adjustment varying from 92 to 96%T in air instead of 92 percent as previously mentioned. This would have the effect of making all readings above 90 percent highly suspect since a small change in %T at this end of the scale is associated with a large change in the Secchi Disc reading.

This is probably also the reason for the significant number of readings which are above 100 percent, and hence change from quantitative readings to qualitative. This 92 percent reading in air as being the equivalent of a 100%T reading in water was apparently unknown to the data takers, which is not surprising since the instruction book written for the U.S. Navy Hydrophotometer Mk. II specifies a calibration setting of 100 percent in air.

The Secchi Disc readings in general are undoubtedly quite reliable. However, any taken when the sun was low in the sky or in the shade of the boat are probably doubtful.

In table 2 are given the remainder of the data taken with instruments other than the hydrophotometer or Secchi Disc. These data have been tabulated separately, since their meaning is not as well understood as those in table 1.

An attempt was made to deduce some sort of a regular pattern of transparency in the area covered, but no regular pattern appears to exist. This may be due to the fact that all stations were not taken simultaneously (a physical impossibility), although this is not necessarily so. Previous experience indicates that local conditions, especially in more shallow coastal regions, almost completely determine transparency conditions at any one point in space and time. Thus the turbidity will vary from one place to another, one depth to another, one time to another with seemingly constant environmental conditions. These data seem to emphasize this seemingly unpredictable nature of transparency in natural waters.

In general, however, the data do show the following expected changes in transparency:

1. An increase in transparency with distance from the coast.
2. A seasonal change in transparency, with the winter months seeming to provide the greatest turbidity.
3. An increased turbidity around heavily industrialized areas.

These three are, of course, to be expected, as outlined by Williams [35] in a set of general rules for predicting transparency based on geographical location, weather conditions, proximity of polluting sources, etc. But there are so many variables to be considered simultaneously that these generalizations are often invalid.

This information is therefore presented not as a basic scientific study to determine the causes of transparency variations, but rather to present actual conditions existing at particular points in time and space.

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56°
55°
54°
53°
52°
51°
51°
52°
50°
49°
48°
47°
LABRADOR
Straits of Belle Isle
LOW GROUND
Hare Bay
MTS.
Fourche Bay
C. St. Johns
Bay of Exploits
NEWFOUNDLAND
Freshwater Bay
Trinity Hbr.
Fâcheux B.
Belle Bay
PLACENTIA BAY
AVALON PENINSULA
St. John's

FIG. 1.

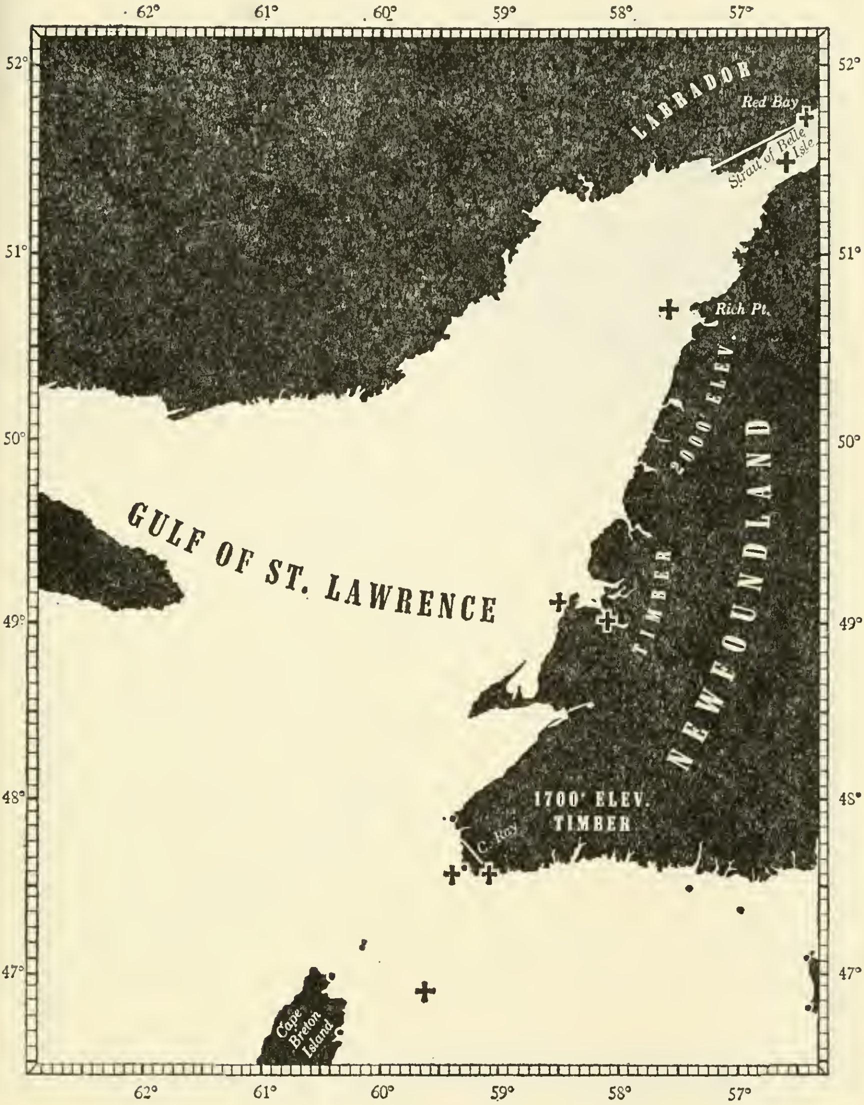
LABRADOR
Red Bay
Strait of Belle Isle
Rich Pt.
2000' ELEV.
NEWFOUNDLAND
TIMBER
GULF OF ST. LAWRENCE
1700' ELEV.
TIMBER
C. Ray
Cape Breton Island

Fig. 2.

63°
62°
61°
60°
59°
58°
46°
45°
44°
43°
42°
41°
CAPE BRETON ISLAND
Sydney
NOVA SCOTIA
TIMBER
ELEV. TO 600 FT.
Halifax
C. Canso
Sable Island

FIG. 3.


AGRICULTURAL
TIMBERED
BAY OF FUNDY
NOVA SCOTIA
LOW LANDS
Yarmouth
Halifax
GEORGES BANK
69°
68°
67°
66°
65°
64°
46°
45°
44°
43°
42°
41°
40°

FIG. 4.


75°
74°
73°
72°
71°
70°
44°
43°
42°
41°
40°
39°
38°
WOODED & AGRICULTURAL
Portland
Portsmouth
Boston
INDUSTRIAL AND AGRICULTURAL AREA
New York
Long Island
Philadelphia
Delaware Bay
Cape May

FIG. 5.


79°
78°
77°
76°
75°
74°
39°
38°
37°
36°
35°
34°
33°
CHESAPEAKE BAY
Norfolk
SWAMP AREA
Pamlico Sound
C. Hatteras
Wilmington
C. Fear

FIG. 6.

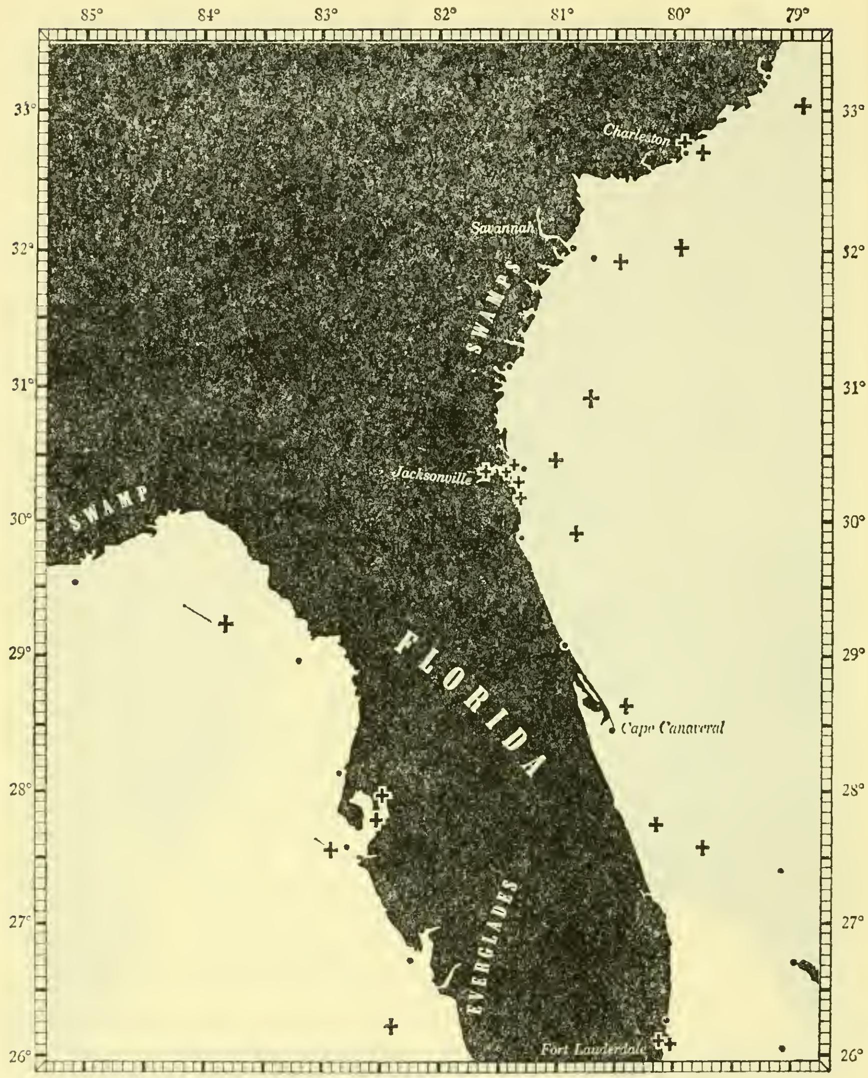
85°
84°
83°
82°
81°
80°
79°
33°
32°
31°
30°
29°
28°
27°
26°
Charleston
Savannah
SWAMPS
Jacksonville
SWAMP
FLORIDA
Cape Canaveral
EVERGLADES
Fort Lauderdale

FIG. 7.


79°
78°
77°
76°
75°
74°
28°
27°
26°
25°
24°
23°
22°
21°
BAHAMA ISLANDS
Andros Island
GREAT BAHAMA BANK
CUBA

Fig. 8.


85°
84°
83°
82°
81°
80°
79°
26°
25°
24°
23°
22°
21°
20°
19°
FLORIDA
Miami
Key West
STRAITS OF FLORIDA
Habana
CUBA

FIG. 9.


91°
90°
89°
88°
87°
86°
SWAMPY SHORE
NEW ORLEANS
Mississippi River
Pensacola
Mobile Bay
30°
29°
28°
27°
26°
25°
24°
23°
GULF OF MEXICO

FIG. 10.


91°
90°
89°
88°
87°
86°
23°
22°
21°
20°
19°
18°
17°
16°
CAMPECHE BANK
YUCATAN CHANNEL
Alacran Reef
YUCATAN PENINSULA
Campeche

FIG. 11.


97°
96°
95°
94°
93°
92°
30°
29°
28°
27°
26°
25°
24°
23°
Galveston
SWAMPY SHORELINE
Corpus Christi
Texas
Mexico
Laguna Madre
GULF OF MEXICO

FIG. 12.

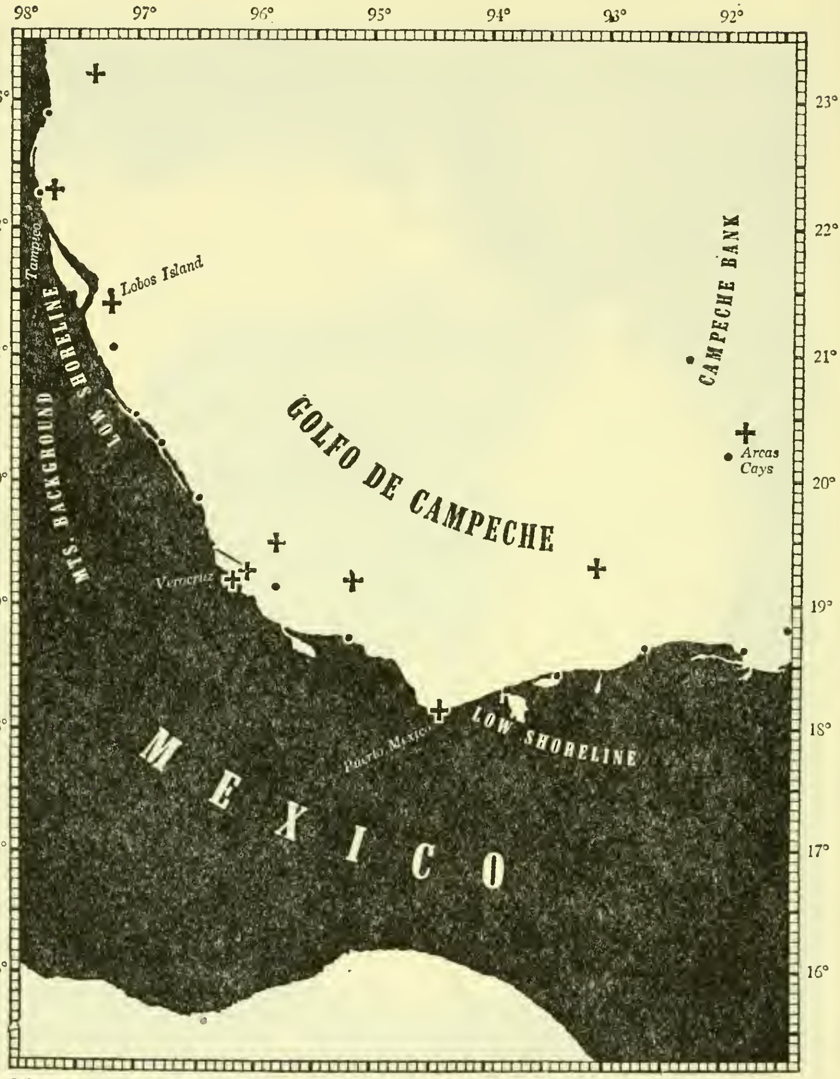
98°
97°
96°
95°
94°
93°
92°
23°
22°
21°
20°
19°
18°
17°
16°
Tampico
Lobos Island
LOW SHORELINE
MTS. BACKGROUND
GOLFO DE CAMPECHE
CAMPECHE BANK
Arcas Cays
Veracruz
Puerto Mexico
LOW SHORELINE
MEXICO

FIG. 13.

TABLE 1.—*Equation of hydrophotometer readings to equivalent Secchi Disc readings at stations studied*

A. WINTER

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Ship John Light, Delaware Bay	39°17′42″	75°23′55″	3/9/48	1700	0–B	0	<1.5	—
Cape May Harbor	38°56′47″	74°54′08″	3/7/48	—	0–B	18–20	8.3	—
Do.	38°56′47″	74°54′08″	3/1/48	1625	0	40	11.5	—
					1′	40	11.5	
					2′	40	11.5	
					3′	38	11.2	
					4′	37	11	
					5′	36	10.9	
					6′	30	10	
					7′	34	10.6	
					8′	34	10.6	
					10′	32	10.3	
Do.	38°56′47″	74°54′08″	2/23/48	—	0–8′	8–10	6.4	—
					8′–B	4–5	5.2	—
Do.	38°56′47″	74°54′08″	2/22/48	2130	0	15	7.6	—
Brown Shoal, Delaware	38°54.′5	75°06′	3/9/48	1100	0	31	10.1	—
					6′	34	10.6	
					12′	35	10.7	
					18′	34	10.6	
					24′	27	9.6	
					30′	26	9.5	
					36′	25	9.4	
					42′	20	8.5	

(*continued*)

Table 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Brown Shoal, Delaware	38°54′5	75°06′	3/9/48	1100	48′	18	8.1	
					B	15	7.6	
McCries Shoal (Occ.W)2	38°51′	74°51′	2/5/48	1000	0	60	16.3	—
					6′	60	16.3	
					12′	62	17	
					18′	62	17	
					24′	55	14.8	
					30′	55	14.8	
					36′	54	14.5	
					42′	50	13.5	
					B	50	13.5	
0.8 mile W. of Bloody Point Light, Chesapeake Bay	38°50′	76°25′	1/28/48	1312	0	20	8.5	5′
					6′	18	8.1	
					12′	18	8.1	
					18′	22	8.8	
					24′	25	9.4	
					30′	26	9.5	
					36′	22	8.8	
					42′	20	8.5	
					48′	18	8.1	
					54′	16	7.8	
					60′	13	7.2	
					66′	15	7.6	
Off Overfalls Light Ship	38°48′	75°01′5	2/5/48	1230	0	32	10.3	—
					6′	35	10.7	
					12′	37	11	
					18′	40	11.5	

					24′	38	11.2	
					30′	40	11.5	
					36′	38	11.2	
					42′	40	11.5	
					48′	45	12.4	
					54′	45	12.4	
					60′	45	12.4	
					66′	50	13.5	
2.6 miles S. of 5-Fathom Light Ship................	38°48′	74°35′.7	2/5/48	1500	0	95	61	—
					6′	95	61	
					12′	95	61	
					24′	95	61	
					36′	95	61	
					48′	95	61	
					60′	94	55	
					72′	94	55	
					78′	95	61	
					86′	94	55	
					B	94	55	
Lewes, Delaware, Breakwater Harbor..............	38°47′.75	75°06′.15	3/9/48	0900	0–B	0	<1.5	—
10.2 miles SE. of Overfalls Light Ship............	38°42′	74°52′	2/4/48	1815	0	50	13.5	—
					6′	57	15.5	
					12′	70	20	
					18′	72	20.9	
					24′	72	20.9	
					30′	74	22	
					36′	74	22	
					42′	77	24	
					48′	74	22	
					60′	75	22.7	
					66′	72	20.9	
					72′	68	19.2	

(continued)

Table 1.—*(continued)*

A. WINTER *(continued)*

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
10.2 miles SE. of Overfalls Light Ship	38°42′	74°52′	2/4/48	1815	78′	45	12.4	
					B	40	11.5	
Point Patience, Solomons Island, Md.	38°19′30″	76°28′30″	1/8/43	1325	0	—	—	5½′
Off Cedar Point	38°19′	76°20′	1/29/48	1330	0	30	10	5½′
					6′	28	9.8	
					12′	28	9.8	
					18′	31	10.1	
					24′	30	10	
					30′	30	10	
					36′	28	9.8	
					42′	27	9.6	
					48′	25	9.4	
					54′	23	9	
					60′	20	8.5	
					66′	15	7.6	
Do.	38°19′	76°20′	1/29/48	1430	0	30	10	—
					6′	29	9.9	
					12′	32	10.3	
					18′	32	10.3	
					24′	31	10.1	
					30′	29	9.9	
					36′	29	9.9	
					42′	29	9.9	
					48′	25	9.4	
					54′	23	9	
					60′	16	7.8	
					66′	12	7	

Do.	38°19′	76°20′	1/29/48	1530	0	28	9.8	—
					6′	27	9.6	
					12′	31	10.1	
					18′	31	10.1	
					24′	30	10	
					30′	30	10	
					36′	30	10	
					42′	27	9.6	
					48′	23	9	
					54′	20	8.5	
					60′	12	7	
					66′	10	6.6	
Do.	38°19′	76°20′	1/29/48	1630	0	28	9.8	—
					6′	27	9.6	
					12′	30	10	
					18′	30	10	
					24′	29	9.9	
					30′	28	9.8	
					36′	27	9.6	
					42′	29	9.9	
					48′	29	9.9	
					54′	21	8.7	
					60′	10	6.6	
					66′	3	4.6	
Do.	38°19′	76°20′	1/29/48	1730	0	30	10	—
					6′	27	9.6	
					12′	30	10	
					18′	29	9.9	
					24′	30	10	
					30′	29	9.9	
					36′	29	9.9	
					42′	29	9.9	

(continued)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Cedar Point	38°19′	76°20′	1/29/48	1730	48′	28	9.8	
					54′	23	9	
					60′	8	6.2	
					66′	2	4.1	
Off Cedar Point, (FLR) "16C"	38°19′	76°20′	1/29/48	1830	0	30	10	—
					6′	31	10.1	
					12′	30	10	
					18′	31	10.1	
					24′	31	10.1	
					30′	29	9.9	
					36′	29	9.9	
					42′	30	10	
					48′	30	10	
					54′	25	9.4	
					60′	13	7.2	
					66′	10	6.6	
Do.	38°19′	76°20′	1/29/48	1930	0	30	10	—
					6′	31	10.1	
					12′	32	10.3	
					18′	32	10.3	
					24′	30	10	
					30′	30	10	
					36′	32	10.3	
					42′	31	10.1	
					48′	31	10.1	
					54′	27	9.6	

					60'	25	9.4	
					66'	15	7.6	
Do.	38°19'	76°20'	1/9/48	2030	0	30	10	—
					6'	30	10	
					12'	32	10.3	
					18'	32	10.3	
					24'	32	10.3	
					30'	32	10.3	
					36'	32	10.3	
					42'	30	10	
					48'	29	9.9	
					54'	27	9.6	
					60'	23	9	
					66'	15	7.6	
Do.	38°19'	76°20'	1/29/48	2130	0	32	10.3	—
					6'	30	10	
					12'	31	10.1	
					18'	32	10.3	
					24'	32	10.3	
					30'	32	10.3	
					36'	32	10.3	
					42'	32	10.3	
					48'	30	10	
					54'	25	9.4	
					60'	20	8.5	
					66'	15	7.6	
Do.	38°19'	76°20'	1/29/48	2230	0	30	10	—
					6'	30	10	
					12'	30	10	
					18'	31	10.1	
					24'	29	9.9	

(continued)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Cedar Point, (FLR) "16C"	38°19′	76°20′	1/29/48	2230	30′	28	9.8	
					36′	29	9.9	
					42′	30	10	
					48′	33	10.5	
					54′	31	10.1	
					60′	28	9.8	
					66′	15	7.6	
Do.	38°19′	76°20′	1/29/48	2330	0	28	9.8	—
					6′	28	9.8	
					12′	29	9.9	
					18′	27	9.6	
					24′	31	10.1	
					30′	30	10	
					36′	30	10	
					42′	31	10.1	
					48′	29	9.9	
					54′	29	9.9	
					60′	30	10	
					66′	15	7.6	
Off Fenwick Shoal	38°17′	75°02.′8	2/4/48	1616	0	65	18	—
					6′	67	18.7	
					12′	69	19.5	
					18′	62	17	
					24′	60	16.3	
					30′	60	16.3	
					36′	40	11.5	
					42′	30	10	

Off Great Gull Bank	38°16′.4	75°00′.4	2/4/48	1435	0	55	14.8	—
					6′	57	15.5	
					12′	58	15.7	
					18′	60	16.3	
					24′	59	16	
					30′	55	14.8	
					36′	48	13	
					42′	42	11.9	
					48′	15	7.6	
5-Fathom Curve, Off Assateague Island	38°02′.6	75°10′.7	2/4/48	1215	0	30	10	—
					6′	27	9.6	
					12′	27	9.6	
					18′	27	9.6	
					24′	20	8.5	
					30′	18	8.1	
					B	15	7.6	
10-Fathom Curve, off Winter Quarter Shoal	37°57′	75°05′.5	2/4/48	1100	0	53	14.3	—
					6′	62	17	
					12′	64	17.7	
					18′	64	17.7	
					24′	64	17.7	
					30′	63	17.3	
					36′	66	18.4	
					42′	70	20	
					48′	68	19.2	
					54′	65	18	
					60′	69	19.5	
					66′	65	18	
Assateague Anchorage	37°52′	75°22′	2/4/48	0745	0	5	5.5	—
					6′	6	5.7	
					12′	3	4.6	

(continued)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Assateague Anchorage	37°52′	75°22′	2/4/48	0745	13′	2	4.1	
					14′	1	3.5	
					15′	1	3.5	
					16′	1	3.5	
					17′	1	3.5	
					18′	0	<1.5	
					19′	0	<1.5	
Off Black Fish Bank	37°47′	75°07′	2/4/48	0915	0	14	7.4	—
					6′	16	7.8	
					12′	16	7.8	
					18′	18	8.1	
					24′	16	7.8	
					30′	18	8.1	
					36′	10	6.6	
					B	5	5.5	
Off Cobb Island	37°25′	75°00′	2/3/48	1330	0	48	13	—
					6′	44	12.3	
					12′	32	10.3	
					18′	32	10.3	
					24′	38	11.2	
					30′	49	13.3	
					36′	40	11.5	
					42′	10	6.6	
					B	3	4.6	
Off Wolf Trap, Chesapeake Bay	37°20′30″	76°10′	1/9/43	1114	0	—	—	4½′
Thimble Shoal, Chesapeake Bay	37°05′36″	76°10′	1/10/43	1222	0	—	—	6½′

Do.	37°05′36″	76°10′	1/10/43	1400	0	—	—	6½′
Horseshoe Middle Grounds, Chesapeake Bay	37°05′35″	76°11′.5	2/3/48	0045	0	16	7.8	—
					6′	15	7.6	
					12′	16	7.8	
					13′	17	8	
					14′	16	7.8	
					15′	16	7.8	
					16′	14	7.4	
					17′	14	7.4	
					18′	14	7.4	
					19′	8	6.2	
					20′	5	5.5	
					21′	4	5	
					22′	2	4.1	
					23′	1	3.5	
					24′	1	3.5	
Do.	37°05′35″	76°11′.5	2/3/48	0145	0	15	7.6	—
					6′	16	7.8	
					12′	16	7.8	
					13′	16	7.8	
					14′	16	7.8	
					15′	17	8	
					16′	17	8	
					17′	17	8	
					18′	16	7.8	
					19′	16	7.8	
					20′	14	7.4	
					21′	12	7	
					22′	3	4.6	
					23′	1	3.5	
					24′	0	<1.5	

(*continued*)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station			Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Description	Latitude (N.)	Longitude (W.)						
Horseshoe Middle Grounds, Chesapeake Bay........	37°05′35″	76°11′.5	2/3/48	0245	0	18	8.1	—
					6′	17	8	
					12′	18	8.1	
					13′	18	8.1	
					14′	18	8.1	
					15′	18	8.1	
					16′	18	8.1	
					17′	16	7.8	
					18′	16	7.8	
					19′	16	7.8	
					20′	15	7.6	
					21′	14	7.4	
					22′	8	6.2	
					23′	2	4.1	
					24′	0	<1.5	
Do.	37°05′35″	76°11′.5	2/3/48	0345	0	19	8.3	—
					6′	18	8.1	
					12′	20	8.5	
					13′	21	8.7	
					14′	20	8.5	
					15′	19	8.3	
					16′	18	8.1	
					17′	16	7.8	
					18′	15	7.6	
					19′	14	7.4	
					20′	12	7	
					21′	9	6.5	

					22′	4	5	
					23′	0	<1.5	
					24′	0	<1.5	
Do.	37°05′35″	76°11′.5	2/2/48	2045	0	18	8.1	—
					6′	10	6.6	
					12′	17	8	
					18′	5	5.5	
					24′	0	<1.5	
Do.	37°05′35″	76°11′.5	2/2/48	2145	0	15	7.6	—
					6′	16	7.8	
					12′	20	8.5	
					13′	12	7	
					14′	12	7	
					15′	11	6.8	
					16′	8	6.2	
					17′	2	4.1	
					18′	2	4.1	
					19′	4	5	
					20′	5	5.5	
					21′	0	<1.5	
					22′	9	6.5	
					23′	10	6.6	
					24′	10	6.6	
Do.	37°05′35″	76°11′.5	2/2/48	2245	0	15	7.6	—
					6′	15	7.6	
					12′	14	7.4	
					17′	12	7	
					18′	8	6.2	
					19′	4	5	
					20′	3	4.6	
					21′	2	4.1	

(continued)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Horseshoe Middle Grounds, Chesapeake Bay	37°05′35″	76°11′5	2/2/48	2245	22′	1	3.5	
					23′	0	<1.5	
Do.	37°05′35″	76°11′.5	2/2/48	2345	0	16	7.8	—
					6′	14	7.4	
					12′	17	8	
					18′	3	4.6	
					24′	1	3.5	
Chesapeake Light Ship	37°00′	75°.7	2/3/48	1100	0	59	16	—
					6′	58	15.7	
					12′	57	15.5	
					18′	57	15.5	
					24′	54	14.5	
					30′	52	14	
					36′	45	12.4	
					42′	38	11.2	
					48′	32	10.3	
					54′	30	10	
Little Creek, Virginia	36°54′39″	76°10′55″	2/4/50	1030	0	27	9.6	54″
					6′	25	9.4	
					12′	25	9.4	
23½ miles E. of Currituck Sound	36°17′.5	75°19′.5	2/4/50	1900	0	93	51	—
					6′	94	55	
					12′	94	55	
					18′	92	48	
					24′–72′	93	51	
13½ miles E. of Chicamacomico Coast Guard Station	35°36′	75°11′.5	2/5/50	0200	0–B	83–85	31.7	—

Alligator and Pungo River Canal	35°30′.5	76°15′	1/13/43	1217	0	—	—	2½′
Pamlico River	35°21′	76°35′	1/13/43	1630	0	—	—	7′
Off Cape Hatteras	35°16′.75	75°22′.7	2/5/50	0600	0	76	23.3	—
					B	60	16.3	
Do.	35°08′	75°20′.5	2/5/50	0800	0–B	100+	>115	78′
Off Ocracoke Inlet	34°58′	75°57′.5	2/5/50	1334	0–48′	94	55	48′
Off Cape Lookout	34°32′.5	76°19′	2/5/50	1750	0–90′	98	88	—
Moorehead City, North Carolina coast	34°42′	76°40′	1/14/43	1555	0	—	—	8′
Wreck Buoy	33°57′.5	77°02′	2/6/50	0011	0–78′	99–94	88–55	—
Off Frying Pan Light Ship	33°27′.2	77°35′.5	2/6/50	0550	0–B	98	88	—
34.2 miles from Frying Pan Light	33°10′34″	78°10′06″	2/6/50	0940	0–B	96–99	68–103	46′
Off Cape Romain	32°59′	78°53′.5	2/6/50	1600	0–82′	94	55	—
Charleston area, off Fort Sumter	32°45′30″	79°52′	1/21/43	0847	0	—	—	2′4″
Do.	32°45′30″	79°52′	1/20/43	0935	0	—	—	2′8″
Charleston, S. C.	32°45′.2	79°54′	2/8/50	1215	0–B	2–4	4.5	16″
Charleston area, outside jetties	32°44′	79°49′	1/21/43	0915	0	—	—	10′
Charleston, S. C.	32°42′	79°46′	2/8/50	1100	0–B	36	10.9	—
Charleston Sea Buoy No. 2C	32°40′30″	79°43′	1/21/43	1005	0	—	—	20′
East of Savannah, Ga.	32°00′	79°54′	2/8/50	1945	0–B	100+	>115	—
Savannah area, Savannah Light Ship	31°57′	80°40′	1/21/43	1725	0	—	—	20′
Off Savannah Light Ship	31°53′.5	80°25′	2/8/50	2330	0–60′	93	51	—
E. of Cumberland Islands, Ga.	30°54′	80°41′.5	2/9/50	0630	0–96′	100	>115	—
Off St. Johns Light Ship	30°27′.5	81°06′.5	2/9/50	1130	0	90	42	27′
					6′	88	37.5	
					18′	85	32	
					24′	85	32	
					36′	83	29.5	
					48′	80	26.3	
					54′	75	22.7	
					60′	75	22.7	
Mayport, Fla., dockside	30°23′.5	81°26′.5	2/12/50	1845	0–16′	24–26	9.4	—

(*continued*)

TABLE I.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Jetties entrance, Mayport, Fla.	30°23′.5	81°22′	2/13/50	0915	0–30′	30	10	—
St. Johns River, Fla.	30°19′	81°38′	2/12/50	1630	0–24′	3–6	5.1	
Off Neptune Beach, Fla.	30°19′	81°22′	2/13/50	1000	6′	47	12.9	—
					12′	46	12.7	
					18′	55	14.8	
					24′	67	18.7	
					30′	69	19.5	
					36′	40	11.5	
					42′	15	7.6	
					B	3	4.6	
Off Ponte Verde, Fla.	30°14′	81°21′.5	2/13/50	1041	0	54	14.5	—
					6′	53	14.3	
					12′	57	15.5	
					18′	68	19.2	
					24′	47	12.9	
					30′	30	10	
					36′	18	8.1	
Off St. Augustine, Fla.	29°56′.3	80°48′.7	2/13/50	1600	0–98′	100+	>115	—
Galveston, Tex., Sea Buoy	29°19′	94°39′	3/28/50	1300	0	15	7.6	2′
					6′	10	6.6	
					12′	8	6.2	
					18′	9	6.4	
					24′	8	6.2	
					30′	5	5.5	
Heald Bank, off Galveston	29°05′	94°12′.5	3/30/50	1345	0–24′	68	19.2	*12′
					30′	67	18.7	
					36′	65	18	

					42′	60	16.3	
					46′	58	15.7	
Bay NW. of Mississippi entrance	29°02′	89°42′.3	3/31/50	2340	0–24′	37	11	—
					30′	50	13.5	
					36′	70	20	
					42′	67	18.7	
					48′	64	17.7	
					54′	55	14.8	
					60′	53	14.3	
					66′	50	13.5	
					78′	70	20	
					90′	92	48	
Gulf of Mexico	28°49′	92°32′	3/31/50	0130	0–72′	76	23.3	—
					78′	67	18.7	
					84′	42	11.9	
					90′	41	11.7	
					96′	41	11.7	
					102′	40	11.5	
Old Mississippi Canyon	28°39′	89°56′.5	3/31/50	2030	0–42′	90	42	—
					48′	92	48	
					54′–90′	99.5	110	
Off False Cape, Fla.	28°38′	80°20′.5	2/14/50	0515	0–54′	60	16.3	—
					60′	57	15.5	
					66′	55	14.8	
					72′	55	14.8	
15-Fathom Curve, off Freeport, Tex.	28°37′	95°01′.5	3/28/50	0750	0–36′	95	61	*43′5″
					42′	55	14.8	
					48′	13	7.2	
					54′	10	6.6	
					60′	8	6.2	
					66′	0	<1.5	

* Indicates Secchi Disc reading taken on shady side of vessel or under foggy conditions

(continued)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
10-Fathom Curve, off Ship Shoal	28°37′	90°59′.5	3/31/50	1230	0–48′	78–82	24.6–28.3	19′2″
					48′–60′	30–35	10.3	
Off Winter Beach, Fla.	27°44′	80°10′	2/14/50	1315	0–30′	97	77	—
					36′	95	61	
					42′	93	51	
					48′	93	51	
100-Fathom Curve, off Corpus Christi	27°43′.5	95°30′	3/27/50	2350	0–150′	100+	>115	—
Gulf of Mexico, off Corpus Christi	27°42′	96°35′	3/27/50	1600	0–30′	90	42	36′
					36′	94	55	
					42′	96	68	
					48′–78′	100	>115	
Gulf of Mexico	27°00′	97°00′	3/21/50	2040	0–24′	87	35.5	—
					30′	93	51	
					36′	95	61	
					42′	95	61	
					48′–110′	98–100+	88–>115	
Lauderdale area, off Hollywood, Fla.	26°31′20″	80°05′55″	1/25/43	1015	0	—	—	39′
Port Everglades Harbor, Fla.	26°05′35″	80°07′.2	2/17/50	1530	6′	10	6.6	—
					12′	10	6.6	
					18′	23	9	
					24′	35	10.7	
					30′	50	13.5	
					36′	65	18	
Do.	26°05′35″	80°07′.2	2/17/50	1645	0	12	7	—
					6′	22	8.8	
					12′	47	12.9	

					18′	58	15.7	
					24′	50	13.5	
					30′	40	11.5	
Do.	26°05′35″	80°07′.2	2/17/50	1900	0	26	9.5	—
					6′	50	13.5	
					12′	54	14.5	
					18′	54	14.5	
					24′	55	14.8	
					30′	58	15.7	
					36′	59	16	
Do.	26°05′35″	80°07′.2	2/17/50	2000	0	34	10.6	—
					6′	55	14.8	
					12′	57	15.5	
					18′	62	17	
					24′	62	17	
					30′	64	17.7	
					36′	64	17.7	
Do.	26°05′35″	80°07′.2	2/17/50	2100	0	60	16.3	—
					6′	64	17.7	
					12′	75	22.7	
					18′	73	21.5	
					24′	75	22.7	
					30′	77	24	
					36′	78	24.6	
Fort Lauderdale, Dock, N.S.B.	26°05′30″	80°07′30″	2/9/43	0840	0	—	—	8′
Do.	26°05′30″	80°07′30″	2/7/43	0841	0	—	—	6½′
Do.	26°05′30″	80°07′15″	3/18/43	1935	0	—	—	10′
Do.	26°05′30″	80°07′15″	3/13/43	1055	0	—	—	9½′
Do.	26°05′30″	80°07′15″	3/12/43	1120	0	—	—	8½′
Do.	26°05′30″	80°07′15″	3/9/43	0830	0	—	—	7′
Do.	26°05′30″	80°07′15″	3/8/43	1800	0	—	—	6′

(continued)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Fort Lauderdale, Dock, N.S.B.	26°05′30″	80°07′15″	2/13/43	1530	0	—	—	14′
Do.	26°05′30″	80°07′15″	2/12/43	1357	0	—	—	13½′
Do.	26°05′30″	80°07′15″	2/10/43	0835	0	—	—	7′
Do.	26°05′30″	80°07′15″	2/10/43	1046	0	—	—	7½′
Do.	26°05′30″	80°07′15″	2/10/43	1142	0	—	—	8½′
Do.	26°05′30″	80°07′15″	2/10/43	1245	0	—	—	10′
Do.	26°05′30″	80°07′15″	2/10/43	1456	0	—	—	10½′
Do.	26°05′30″	80°07′15″	2/10/43	1548	0	—	—	8½′
Do.	26°05′30″	80°07′15″	2/10/43	1648	0	—	—	7′
Do.	26°05′30″	80°07′15″	2/10/43	1842	0	—	—	4′
Do.	26°05′30″	80°07′15″	1/30/43	1005	0	—	—	7½′
Do.	26°05′30″	80°07′15″	1/30/43	1355	0	—	—	10½′
Do.	26°05′30″	80°07′15″	1/28/43	0955	0	—	—	8′
Do.	26°05′30″	80°07′15″	1/28/43	1140	0	—	—	9′
Do.	26°05′30″	80°07′15″	1/28/43	1447	0	—	—	12′
Do.	26°05′30″	80°07′15″	1/28/43	1615	0	—	—	11′
Do.	26°05′30″	80°07′15″	1/23/43	1415	0	—	—	7½′
Do.	26°05′30″	80°07′15″	2/8/43	0828	0	—	—	6½′
Do.	26°05′30″	80°07′15″	2/6/43	0839	0	—	—	7½′
Do.	26°05′30″	80°07′15″	2/5/43	0835	0	—	—	7′2″
Do.	26°05′30″	80°07′15″	2/5/43	1041	0	—	—	7′1″
Do.	26°05′30″	80°07′15″	2/5/43	1105	0	—	—	7′
Do.	26°05′30″	80°07′15″	2/4/43	0855	0	—	—	7′3″
Do.	26°05′30″	80°07′15″	2/4/43	1246	0	—	—	5½′
Do.	26°05′30″	80°07′15″	2/4/43	1818	0	—	—	5′
Do.	26°05′30″	80°07′15″	2/3/43	0945	0	—	—	9′
Fort Lauderdale, Turning Basin	26°05′.5	80°07′	2/16/43	0900	0	—	—	15′

Do.	26°05'.5	80°07'	2/16/43	1000	0	—	—	10½'
Do.	26°05'.5	80°07'	2/16/43	1100	0	—	—	12½'
Do.	26°05'.5	80°07'	2/16/43	1200	0	—	—	12'
Do.	26°05'.5	80°07'	2/16/43	1300	0	—	—	11'
Do.	26°05'.5	80°07'	2/16/43	1400	0	—	—	10½'
Do.	26°05'.5	80°07'	2/16/43	1500	0	—	—	9½'
Do.	26°05'.5	80°07'	2/16/43	1600	0	—	—	10'
Do.	26°05'.5	80°07'	2/16/43	1700	0	—	—	10½'
Do.	26°05'.5	80°07'	2/16/43	1800	0	—	—	10'
Do.	26°05'.5	80°07'	2/16/43	1900	0	—	—	9½
Port Everglades Harbor	26°05'.5	80°05'.2	2/17/50	1430	0	52	14	15'
					6'	55	14.8	
					12'	85	32	
					18'–54'	92	48	
Port Everglades, Fla.	26°05'.5	80°05'.2	2/17/50	1845	0	83	29.5	—
					6'	83	29.5	
					12'	83	29.5	
					18'	89	40	
					24'–54'	96–92	68–48	
Do.	26°05'.5	80°05'.2	2/17/50	2145	0	98	88	—
					6'	98	88	
					12'	98	88	
					18'	98	88	
					24'	97	77	
					30'	96	68	
					36'	95	61	
					42'	93	51	
Lauderdale area, South Ship Channel	26°05'.5	80°05'	3/13/43	1300	0	—	—	60'
Santo Brazio, Sea Buoy	26°04'.5	97°06'.5	3/21/50	1135	0–36'	92	48	34'4"
					42'	88	37.5	
					48'	70	20	
					54'	50	13.5	

(*continued*)

TABLE 1.—(*continued*)

A. WINTER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Lauderdale area, Gulf Stream	26°04′	80°07′	3/11/43	1300	0	—	—	83′
Lauderdale area, off Hollywood Beach	26°01′	80°05′.5	3/12/43	1440	0	—	—	39′
Do.	26°01′	80°05′.5	2/9/43	1130	0	—	—	55′
Do.	26°01′	80°05′.5	2/9/43	1600	0	—	—	53′
Do.	26°01′	80°05′.5	2/8/43	0918	0	—	—	37′
Do.	26°01′	80°05′.5	2/8/43	1532	0	—	—	44′
Do.	26°01′	80°04′.5	2/8/43	1618	0	—	—	55′
Off Hollywood Beach	26°00′	80°02′	2/1/43	0936	0	—	—	65′
Great Stirrup Bay	25°52′.5	77°51′.5	2/19/50	0330	0–166′	100+	>115	—
Entrance Nassau Harbor	25°05′	77°21′	2/19/50	1030	0–B	100+	>115	—
Middle Bight, Andros Island	24°20′	77°40′.7	2/22/50	1830	0–B	100+	>115	—
Tongue of the Ocean	24°07′	77°30′	2/23/50	0930	0	100+	>115	110′
Gulf of Mexico (approx.)	24°	97°	3/19/50	0230	0	100+	>115	—
Gulf of Mexico	23°09′.5	97°23′	3/18/50	2005	0	100+	>115	—
Havana Harbor, Central Port	23°09′	82°20′30″	3/3/50	1330	0	28	9.8	—
					6′	29	9.9	
					12′	48	13	
					18′	55	14.8	
					24′	75	22.7	
					30′	55	14.8	
Havana Harbor	23°09′	82°20′	3/2/50	1330	0	48	13	—
					6′	44	12.3	
					12′	57	15.5	
					18′	64	17.7	
					24′	48	13	
Off Matanzas, Cuba	23°04′.8	81°30′.2	2/25/50	0545	0	100+	>115	—
Dock at Matanzas, Cuba	23°03′.5	81°33′.4	2/27/50	1200	0–B	75–80	22.7–26.3	15′

Do.	23°03.′5	81°33.′4	2/27/50	1930	0	34	10.6	—
					6′	35	10.7	
					12′	43	12	
					18′	45	12.4	
					B	43	12	
Nicholas Channel	22°50.′1	79°10.′3	2/24/50	1400	0	100+	>115	114′
Yucatan Channel	22°49′	86°13′	3/4/50	1400	0	100+	>115	142′
Great Bahama Bank	22°49′	77°15′	2/24/50	0145	0	100+	>115	—
Campeche Bank	22°42′	89°18′	3/5/50	0830	0	100+	>115	—
Alacran Reef Anchorage	22°23.′5	89°41.′5	3/7/50	0933	6′	95	61	27′
				1030	6′	98½	95.5	
				1126	6′	98	88	
				1233	6′	99	103	
Do.	22°23.′5	89°41.′5	3/7/50	1315	6′	95	61	—
				1320	6′	95	61	
Do.	22°23.′5	89°41.′5	3/6/50	1320	0–B	99–89	103–40	24′
Off Tampico, Mexico	22°17′	97°43′	3/17/50	1440	0–84′	90–80	42–26.3	27′
Off Lobos Island	21°22′	97°14′	3/16/50	1300	0–54′	64	17.7	11′6″
					60′	50	13.5	
					66′	49	13.3	
					72′	44	12.3	
					78′	48	13	
Bay of Campeche	20°23.′5	91°50′	3/8/50	1130	0–100′	100+	>115	49′
Gulf of Campeche	19°25.′8	95°48′	3/15/50	1900	0–B	100+	>115	—
Do.	19°19′	93°03′	3/8/50	2200	0–50′	100+	>115	—
Mexico, off Vera Cruz Harbor	19°15′	96°05′	3/15/50	1530	0–24′	55	14.8	—
					24′–96′	60	16.3	
					102′–120′	61	16.7	
Vera Cruz Harbor, Mexico	19°12′05″	96°08′08″	3/12/50	1200	0	70	20	—
					6′	65	18	
					12′	65	18	
					B	60	16.3	

(*continued*)

TABLE 1.—(*continued*)

A. WINTER (*concluded*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Gulf of Campeche	19°11′.5	95°09′	3/11/50	1400	0–18′	68	19.2	12′
					24′	75	22.7	
					36′	80	26.3	
					48′	92	48	
					84′	100	>115	
Puerto Mexico Harbor	18°08′21″	94°24′43″	3/10/50	1200	0	35	10.7	6′
					6′	32	10.3	
					12′	37	11	
					18′	31	10.1	
					24′	31	10.1	
					B	23	9	
B. SPRING								
New Castle, Del.	39°38′	75°34′	4/4/47	1340	S–B	0	<1.5	10″
Off Fords Landing	39°28′36″	75°56′54″	4/5/47	0730	0–15′	0	<1.5	8″
Off Howell Point, Chesapeake Bay	39°22′.5	76°06′53″	5/28/47	0930	0–B	0–2	<1.5–4.1	18″
Howell Point, Chesapeake Bay	39°22′.5	76°06′53″	4/5/47	1030	0–B	0	<1.5	8″
Sassafras River, Grove Point	39°22′36″	76°02′24″	6/23/47	1215	0	2	4.1	18″
					6′	0	<1.5	
					12′	0	<1.5	
					B	2	4.1	
Ordinary Point Anchorage, Sassafras River	39°22′20″	75°58′15″	6/23/47	0830	0–B	10–11	6.7	2′
					0–B	12–14	7.2	3′
Do.	39°22′20″	75°58′15″	6/22/47	1930	0–B	8	6.2	2½′
				2030	0–B	10–11	6.7	2½′
				2130	0–B	6–7	5.8	2½′

Do.	39°22′20″	75°58′15″	5/28/47	0830	0	8	6.2	2½′
					6′	7	6	
					12′	7	6	
					18′	7	6	
					B	4	5	
Do.	39°22′20″	75°58′15″	5/27/47	1615	0	7	6	3½
					6′	8	6.2	
					12′	7	6	
					18′	5	5.5	
					B	0	<1.5	
				1715	0	5	5.5	—
					6′	7	6	
					12′	6	5.7	
					18′	5	5.5	
					B	3	4.6	
Do.	39°22′20″	75°58′15″	5/27/47	1815	0	5	5.5	—
					6′	5	5.5	
					12′	5	5.5	
					18′	5	5.5	
					B	40	11.5	
				1915	0	7	6	—
					6′	5	5.5	
					12′	6	5.7	
					18′	5	5.5	
					B	5	5.5	
Do.	39°22′20″	75°58′15″	5/27/47	2015	0	3	4.6	—
					6′	4	5	
					12′	5	5.5	
					18′	5	5.5	
					B	4	5	
				2115	0	5	5.5	—

(continued)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Ordinary Point Anchorage, Sassafras River	39°22′20″	75°58′15″	5/27/47	2115	6′	4	5	
					12′	5	5.5	
					18′	5	5.5	
					B	5	5.5	
Howell Point, Chesapeake Bay	39°22′18″	76°07′	6/23/47	1315	0–B	0	<1.5	8″
Ship John Light, Delaware River	39°17′42″	75°23′55″	4/19/49	1100	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
					30′	0	<1.5	
					36′	0	<1.5	
Do.	39°17′42″	75°23′55″	4/19/49	1200	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
					30′	0	<1.5	
					36′	0	<1.5	
Do.	39°17′42″	75°23′55″	4/19/49	1300	0	1	3.5	—
					6′	1	3.5	
					12′	1	3.5	
					18′	1	3.5	
					24′	1	3.5	
					30′	2	4.1	
Do.	39°17′42″	75°23′55″	4/19/49	1400	0	5	5.5	12″
					6′	3	4.6	

					12′	3	4.6	
					18′	2	4.1	
					24′	2	4.1	
					30′	2	4.1	
					36′	2	4.1	
Do.	39°17′42″	75°23′55″	4/19/49	1500	0	2	4.1	12″
					6′	2	4.1	
					12′	2	4.1	
					18′	2	4.1	
					24′	2	4.1	
					30′	3	4.6	
					36′	4	5	
Do.	39°17′42″	75°23′55″	4/19/49	1600	0	0	<1.5	15″
					6′	1	3.5	
					12′	1	3.5	
					18′	1	3.5	
					24′	0	<1.5	
					30′	0	<1.5	
					36′	1	3.5	
Do.	39°17′42″	75°23′55″	4/19/49	1700	0	1	3.5	14″
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
					30′	2	4.1	
					36′	2	4.1	
Do.	39°17′42″	75°23′55″	4/19/49	1800	0	2	4.1	14″
					6′	2	4.1	
					12′	2	4.1	
					18′	2	4.1	
					24′	3	4.6	
					30′	3	4.6	

(continued)

TABLE 1.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Ship John Light, Delaware River	39°17′42″	75°23′55″	4/19/49	1800	36′	5	5.5	
Do.	39°17′42″	75°23′55″	4/19/49	1900	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	2	4.1	
					24′	2	4.1	
					30′	2	4.1	
					36′	1	3.5	
Do.	39°17′42″	75°23′55″	4/19/49	2000	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
					30′	0	<1.5	
					36′	0	<1.5	
Do.	39°17′42″	75°23′55″	4/19/49	2100	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	2	4.1	
					30′	5	5.5	
					36′	5	5.5	
Do.	39°17′42″	75°23′55″	4/19/49	2200	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	

					30′	0	<1.5	
					36′	0	<1.5	
Do.	39°17′42″	75°23′55″	4/19/47	0800	0	0	<1.5	8″
				0815	0–B	0	<1.5	—
				0915	0–B	0	<1.5	—
				0945	0–B	0	<1.5	—
Swan Point, Chesapeake Bay	39°07′40″	76°20′	5/8/49	1400	0	22	8.8	4′3″
					6′	21	8.7	
					12′	18	8.1	
					18′	5	5.5	
					24′	2	4.1	
Do.	39°07′40″	76°20′	6/24/47	0600	0	15	7.6	3½′
					6′	14	7.4	
					12′	25	9.4	
					15′	40	11.5	
					23′	18	8.1	
				0700	0	18	8.1	4′
					6′	21	8.7	
					12′	25	9.4	
					18′	41	11.7	
					24′	15	7.6	
Do.	39°07′40″	76°20′	6/24/47	0800	0	15	7.6	3′
					6′	20	8.5	
					12′	32	10.3	
					18′	41	11.7	
					24′	10	6.6	
				0900	0	11	6.8	3′
					6′	21	8.7	
					12′	31	10.1	
					18′	35	10.7	
					24′	10	6.6	

(continued)

TABLE 1.—(*continued*)

B. SPRING (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Swan Point, Chesapeake Bay	39°07'40"	76°20'	6/24/47	1000	0	16	7.8	3½'
					6'	23	9	
					12'	36	10.9	
					18'	10	6.6	
					24'	5	5.5	
				1100	0	22	8.8	3'
					6'	26	9.5	
					12'	33	10.5	
					18'	16	7.8	
					24'	10	6.6	
Do.	39°07'40"	76°20'	6/24/47	1200	0	23	9	3½'
					6'	23	9	
					12'	31	10.1	
					18'	12½	7.1	
					24'	5	5.5	
				1300	0	30	10	4'
					6'	24	9.2	
					12'	27	9.6	
					18'	30	10	
					24'	10	6.6	
Do.	39°07'40"	76°20'	6/24/47	1400	0	24	9.2	4'
					6'	29	9.9	
					12'	37	11	
					18'	45	12.4	
					24'	10	6.6	
				1500	0	20	8.5	3½'
					6'	22	8.8	

					12′	36	10.9	
					18′	55	14.8	
					24′	24	9.2	
					B	10	6.6	
Do.	39°07′40″	76°20′	6/24/47	1600	0	20	8.5	4′
					6′	24	9.2	
					12′	42	11.9	
					18′	57	15.5	
					24′	10	6.6	
				1700	0	12	7	3½′
					6′	20	8.5	
					12′	48	13	
					18′	35	10.7	
					24′	10	6.6	
Do.	39°07′40″	76°20′	6/1/47	1030	0	12	7	1½′
					12′	6	5.7	
					18′	6	5.7	
					24′	22	8.8	
					30′	20	8.5	
					36′	20	8.5	
Do.	39°07′40″	76°20′	5/28/47	1130	0	5	5.5	2′
					6′	2	4.1	
					12′	2	4.1	
					18′	6	5.7	
					24′	4	5	
					B	4	5	
Do.	39°07′40″	76°20′	4/7/47	1215	0	4	5	—
					6′	3	4.6	
					12′	15	7.6	
					18′	22	8.8	
					24′	15	7.6	
					30′	7	6	

(continued)

TABLE 1.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Swan Point, Chesapeake Bay	39°07′40″	76°20′	4/7/47	1230	6′	0	<1.5	—
					12′	0	<1.5	
					18′	17	8	
					24′	6	5.7	
					30′	3	4.6	
					36′	3	4.6	
					42′	0	<1.5	
					48′	0	<1.5	
Do.	39°07′40″	76°20′	4/5/47	1240	6′	5	5.5	4′
					12′	10	6.6	
					18′	15	7.6	
					24′	0	<1.5	
Gibson Island, Youth Club Anchorage	39°05.′1	76°25.′6	5/29/47	0745	0	30	10	—
					6′	30	10	
					12′	27	9.6	
Do.	39°05.′1	76°25.′6	5/28/47	1430	0	35	10.7	5′
					6′	25	9.4	
					12′	20	8.5	
				1900	0	20	8.5	—
					6′	20	8.5	
					12′	20	8.5	
				2000	0	20	8.5	—
					6′	20	8.5	
					12′	20	8.5	
				2100	0	25	9.4	—
					6′	24	9.2	
					12′	20	8.5	

Gibson Island, Chesapeake Bay (Inland Bay)	39°05′	76°26′.05	5/28/47	1500	0–15′	50–55	13.9	—
Magothy River, Mountain Point	39°03′30″	76°26′05″	6/23/47	1646	0	25	9.4	5′
					6′	14	7.4	
					12′	10	6.6	
					B	8	6.2	
				1746	0	22	8.8	—
					6′	15	7.6	
					12′	10	6.6	
					B	6	5.7	
				1946	0	10	6.6	—
					6′	8	6.2	
					12′	6	5.7	
					B	6	5.7	
Do.	39°03′30″	76°26′05″	6/23/47	2046	0	4	5	—
					6′	8	6.2	
					12′	10	6.6	
					B	8	6.2	
Eastern Bay, vicinity Claybourne	38°57′24″	76°15′30″	5/29/47	1220	0	70	20	—
					6′	65	18	
					12′	50	13.5	
					18′	50	13.5	
					24′	45	12.4	
					30′	20	8.5	
Brown Shoal, Delaware River	38°54′.5	75°06′	4/20/49	1100	0	45	12.4	5½′
					6′	34	10.6	
					12′	33	10.5	
					18′	34	10.6	
					24′	38	11.2	
					30′	37	11	
					36′	28	9.8	
					42′	26	9.5	
					45′	20	8.5	

(*continued*)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Brown Shoal, Delaware River	38°54′.5	75°06′	4/20/49	1200	0	40	11.5	5′10″
					6′	25	9.4	
					12′	35	10.7	
					18′	33	10.5	
					24′	35	10.7	
					30′	25	9.4	
					36′	21	8.7	
					42′	20	8.5	
					B	15	7.6	
Do.	38°54′.5	75°06′	4/20/49	1300	0	40	11.5	5′
					6′	23	9	
					12′	24	9.2	
					18′	30	10	
					24′	33	10.5	
					30′	35	10.7	
					36′	34	10.6	
					42′	30	10	
					B	25	9.4	
Do.	38°54′.5	75°06′	4/20/49	1400	0	28	9.8	4½′
					6′	17	8	
					12′	27	9.6	
					18′	30	10	
					24′	37	11	
					30′	33	10.5	
					36′	29	9.9	
					42′	27	9.6	
					B	24	9.2	

Do.	38°54′.5	75°06′	4/20/49	1500	0	32	10.3	5½′
					6′	22	8.8	
					12′	30	10	
					18′	32	10.3	
					24′	37	11	
					30′	35	10.7	
					36′	32	10.3	
					42′	30	10	
					B	27	9.6	
Do.	38°54′.5	75°06′	4/20/49	1600	0	40	11.5	6½′
					6′	32	10.3	
					12′	34	10.6	
					18′	38	11.2	
					24′	38	11.2	
					30′	35	10.7	
					36′	27	9.6	
					42′	26	9.5	
					B	27	9.6	
Do.	38°54′.5	75°06′	4/20/49	1700	0	34	10.6	5½′
					6′	30	10	
					12′	33	10.5	
					18′	38	11.2	
					24′	38	11.2	
					30′	34	10.6	
					36′	28	9.8	
					42′	23	9	
					B	17	8	
Do.	38°54′.5	75°06′	4/20/49	1800	0	35	10.7	—
					6′	35	10.9	
					12′	33	10.5	
					18′	36	10.9	
					24′	34	10.6	

(continued)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Brown Shoal, Delaware River	38°54′.5	75°06′	4/20/49	1800	30′	36	10.9	
					36′	26	9.5	
					42′	22	8.8	
					B	20	8.5	
Tilghman Point, Chesapeake Bay	38°52′.5	76°15′.85	5/31/47	1045	0	50	13.5	9′
					6′	50	13.5	
					12′	49	13.3	
					18′	40	11.5	
					24′	40	11.5	
					30′	42	11.9	
					36′	42	11.9	
McCries Shoal Buoy	38°51′	74°51′	4/22/49	1100	0	66	18.4	13′6″
					6′	64	17.7	
					12′	63	17.3	
					18′	58	15.7	
					24′	57	15.5	
					30′	52	14	
					36′	47	12.9	
					42′	40	11.5	
					B	30	10	
1 mile W. of Bloody Point Light, Chesapeake Bay	38°50′	76°25′	6/26/47	1440	0	37	11	9′
					6′	39	11.4	
					12′	49	13.3	
					18′	50	13.5	
					24′	49	13.5	
					30′	51	13.8	
					36′	47	12.9	

					42′	53	14.3	
					48′	62	17	
					50′	65	18	
Do.	38°50′	76°25′	5/31/47	1200	0	21	8.7	4′
					6′	22	8.8	
					12′	36	10.9	
					18′	37	11	
					24′	37	11	
					30′	54	14.5	
					36′	50	13.5	
					40′	63	17.3	
					B	62	17	
Do.	38°50′	76°25′	5/29/47	1100	0	42	11.9	7′
					6′	41.5	11.8	
					12′	50	13.5	
					18′	55	14.8	
					24′	56	15.1	
					30′	52	14	
					36′	57.5	15.6	
					42′	56	15.1	
					48′	62.5	17.1	
					B	70	20	
Wye River, Chesapeake Bay	38°49′.7	76°12′.5	5/31/47	0955	0	54	14.5	10′
					6′	54	14.5	
					12′	54	14.5	
					18′	53	14.3	
					24′	50	13.5	
					B	40	11.5	
2.6 miles SE. x E. McCries Shoal	38°48′.6	74°47′.5	4/22/49	1000	0	66	18.4	10′6″
					6′	64	17.7	
					12′	62	17	

(*continued*)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
2.6 miles SE. x E. McCries Shoal	38°48.'6	74°47.'5	4/22/49	1000	18′	66	18.4	
					24′	83	29.5	
					30′	83	29.5	
					36′	83	29.5	
					42′	83	29.5	
					48′	82	28.3	
					54′	82	28.3	
					60′	80	26.3	
					66′	78	24.6	
Overfalls Light Ship	38°48′	75°01.'5	4/22/49	1230	0	55	14.8	8′
					6′	45	12.4	
					12′	32	10.3	
					18′	33	10.5	
					24′	47	12.9	
					30′	51	13.8	
					36′	51	13.8	
					42′	50	13.5	
					48′	50	13.5	
					54′	50	13.5	
					60′	50	13.5	
					66′	50	13.5	
					72′	47	12.9	
Five-Fathom Light Ship	38°48′	74°35′40″	5/15/51	1445	0	90	42	37′
					12′	91	45	
					18′	92	48	
					24′	91	45	

					30′	91	45	
					36′	89	40	
					42′	81	27.2	
					48′	77	24	
					54′	74	22	
					66′	70	20	
					72′	78	24.6	
					78′	78	24.6	
Do.	38°48′	74°35′40″	4/22/49	0730	0	85	32	18′10″
					6′	82	28.3	
					12′	82	28.3	
					18′	82	28.3	
					24′	84	30.5	
					30′	88	37.5	
					36′	92	48	
					42′	92	48	
					48′	92	48	
					54′	90	42	
					60′	91	45	
					66′	92	48	
					72′	92	48	
					78′	93	51	
Vicinity of St. Michaels..........................	38°47′18″	76°12′24″	5/30/47	0830	0	49	13.3	—
					6′	47	12.9	
					12′	46	12.7	
					B	46	12.7	
				0930	0	53	14.3	—
					6′	48	13	
					12′	48	13	
					B	46	12.7	
				1030	0	55	14.8	
					6′	52	14	

(*continued*)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Vicinity of St. Michaels	38°47′18″	76°12′24″	5/30/47	1030	12′	50	13.5	
					B	48	13	
Do.	38°47′18″	76°12′24″	5/30/47	1130	0	44	12.3	—
					6′	41	11.7	
					12′	41	11.7	
					B	40	11.5	
				1200	0	44	12.3	—
					6′	40	11.5	
					12′	40	11.5	
					B	38	11.2	
				1330	0	45	12.4	—
					6′	43	12	
					12′	42	11.9	
					B	42	11.9	
Do.	38°47′18″	76°12′24″	5/30/47	1430	0	50	13.5	—
					6′	48	13	
					12′	48	13	
					B	45	12.4	
4 miles W. Five-Fathom Light Ship	38°47′	74°40″	4/22/49	0845	0	82	28.3	16′6″
					6′	82	28.3	
					12′	82	28.3	
					18′	85	32	
					24′	85	32	
					30′	86	33.5	
					36′	87	35.5	
					42′	87	35.5	

					48′	88	37.5	
					54′	90	42	
					60′	92	48	
					66′	92	48	
					72′	92	48	
					78′	92	48	
10.2 miles SE. Overfalls Light Ship	38°42′	74°52′	4/23/47	1010	0	90	42	18′
					6′	88	37.5	
					12′	86	33.5	
					18′	84	30.5	
					24′	82	28.3	
					30′	80	26.3	
					36′	90	42	
					42′	90	42	
					48′	92	48	
					54′	92	48	
					60′	93	51	
					66′	93	51	
					72′	92	48	
Oxford, Md.	38°41′42″	76°10′30″	6/27/47	0930	0	42	11.9	6′
					6′	33	10.5	
					12′	33	10.5	
					B	33	10.5	
Off Sharps Island, Chesapeake Bay	38°38′.4	76°25′.7	5/8/49	1030	0	55	14.8	8′4″
					6′	48	13	
					12′	44	12.3	
					18′	47	12.9	
					24′	44	12.3	
					30′	50	13.5	
					36′	38	11.2	
					42′	38	11.2	
					48′	27	9.6	

(continued)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Potomac River	38°24′	77°05′	5/5/51	1600	0–B	0	<1.5	8″
Off Upper Cedar Point, Potomac River	38°24′	77°05′	5/6/49	0700	0	0	<1.5	10″
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
					30′	0	<1.5	
Do.	38°24′	77°05′	4/28/49	1400	0	4	5	4″
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
Bell (FLR) 16C	38°19′	76°20′	5/7/49	0730	0	54	14.5	9′9″
					6′	50	13.5	
					12′	49	13.3	
					18′	48	13	
					24′	48	13	
					30′	42	11.9	
					36′	45	12.4	
					42′	52	14	
					48′	50	13.5	
					54′	25	9.4	
					60′	28	9.8	
Do.	38°19′	76°20′	5/7/49	0830	0	54	14.5	8′5″
					6′	50	13.5	
					12′	47	12.9	
					18′	46	12.7	

					24′	47	12.9	
					30′	47	12.9	
					36′	40	11.5	
					42′	38	11.2	
					48′	50	13.5	
					54′	32	10.3	
					60′	28	9.8	
Do.	38°19′	76°20′	5/7/49	0930	0	56	15.1	9′4″
					6′	50	13.5	
					12′	45	12.4	
					18′	47	12.9	
					24′	50	13.5	
					30′	52	14	
					36′	44	12.3	
					42′	40	11.5	
					48′	38	11.2	
					54′	36	10.9	
					60′	30	10	
Do.	38°19′	76°20′	5/7/49	1030	0	64	17.7	9′8″
					6′	52	14	
					12′	48	13	
					18′	49	13.3	
					24′	50	13.5	
					30′	54	14.5	
					36′	50	13.5	
					42′	51	13.8	
					48′	42	11.9	
					54′	30	10	
					60′	26	9.5	
Do.	38°19′	76°20′	5/7/49	1130	0	70	20	9′9″
					6′	55	14.8	
					12′	50	13.5	

(*continued*)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Bell (FLR) 16C	38°19′	76°20′	5/7/49	1130	18′	50	13.5	
					24′	52	14	
					30′	54	14.5	
					36′	51	13.8	
					42′	53	14.3	
					48′	42	11.9	
					54′	22	8.8	
					60′	22	8.8	
Do.	38°19′	76°20′	5/7/49	1230	0	72	20.9	9′7″
					6′	58	15.7	
					12′	50	13.5	
					18′	51	13.8	
					24′	55	14.8	
					30′	57	15.5	
					36′	56	15.1	
					42′	60	16.3	
					48′	45	12.4	
					54′	35	10.7	
					60′	28	9.8	
Do.	38°19′	76°20′	5/7/49	1330	0	62	17	9′
					6′	55	14.8	
					12′	48	13	
					18′	48	13	
					24′	55	14.8	
					30′	58	15.7	
					36′	55	14.8	
					42′	58	15.7	

					48′	58	15.7	
					54′	28	9.8	
					60′	28	9.8	
Do.	38°19′	76°20′	5/7/49	1430	0	48	13	8′8″
					6′	42	11.9	
					12′	40	11.5	
					18′	45	12.4	
					24′	52	14	
					30′	55	14.8	
					36′	52	14	
					42′	56	15.1	
					48′	36	10.9	
					54′	30	10	
					60′	27	9.6	
Whistle Buoy off Fenwick Shoal	38°17′	75°02′.8	4/23/49	1300	6′	84	30.5	20′
					12′	81	27.2	
					18′	80	26.3	
					24′	78	24.6	
					30′	75	22.7	
					36′	76	23.3	
Breton Bay, Potomac River	38°14′	76°42′	4/28/49	0815	0	14	7.4	3′
					6′	10	6.6	
					12′	10	6.6	
					B	8	6.2	
Off Blackstone Island, Potomac River	38°11′.5	76°44′40″	5/6/49	1100	0	50	13.5	6′
					6′	35	10.7	
					12′	30	10	
					18′	32	10.3	
					24′	11	6.8	
					30′	10	6.6	
Do.	38°11′.5	76°44′40″	4/28/49	0915	0	22	8.8	4′
					6′	19	8.3	

(continued)

TABLE 1.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Blackstone Island, Potomac River	38°11′.5	76°44′40″	4/28/49	0915	12′	18	8.1	
					18′	3½	4.8	
					20′	3	4.6	
					24′	3	4.6	
					30′	3	4.6	
Bell "B" (FLR)	38°01′	76°21′	5/6/49	1415	0	55	14.8	8′
					6′	46	12.7	
					12′	50	13.5	
					18′	54	14.5	
					24′	57	15.5	
					30′	57	15.5	
					36′	43	12	
					42′	38	11.2	
Do.	38°01′	76°21′	4/27/49	1530	0	28	9.8	6′
					6′	26	9.5	
					12′	35	10.7	
					18′	42	11.9	
					24′	43	12	
					30′	42	11.9	
					36′	44	12.3	
					42′	20	8.5	
					48′	20	8.5	
					54′	18	8.1	
Whistle Buoy (WQS) #6	37°57′	75°05′.5	4/23/49	1715	0	—	—	15′
					6′	72	20.9	
					12′	70	20	
					18′	70	20	

					24′	70	20	
					30′	70	20	
					36′	66	18.4	
					42′	66	18.4	
					48′	69	19.5	
					54′	70	20	
					60′	69	19.5	
					66′	40	11.5	
Bell Buoy (FLW) ZTL, off Chincoteague Inlet.....	37°48′	75°18′	4/24/49	0715	0	64	17.7	12′
					6′	63	17.3	
					12′	66	18.4	
					18′	30	10	
					24′	23	9	
					B	24	9.2	
Off Wolf Trap Light, Chesapeake Bay..............	37°23′	76°10′	4/27/49	1030	0	54	14.5	7′11″
					6′	52	14	
					12′	32	10.3	
					18′	26	9.5	
					24′	23	9	
					30′	20	8.5	
Mouth York River, off Crab Neck.................	37°11′30″	76°22′	4/27/49	0815	0	65	18	12′
					6′	62	17	
					12′	65	18	
					B	65	18	
Horseshoe Middle Grounds, Chesapeake Bay.........	37°05′35″	76°09′40″	4/26/49	1000	0	40	11.5	7½′
					6′	40	11.5	
					12′	39	11.4	
					18′	60	16.3	
					24′	62	17	
					30′	50	13.5	
Do.	37°05′35″	76°09′40″	4/26/49	1100	0	47	12.9	7′
					6′	45	12.4	

(continued)

TABLE 1.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Horseshoe Middle Grounds, Chesapeake Bay.........	37°05′35″	76°09′40″	4/26/49	1100	12′	44	12.3	
					18′	65	18	
					24′	60	16.3	
					30′	53	14.3	
Do.	37°05′35″	76°09′40″	4/26/49	1200	0	42	11.9	7′
					6′	40	11.5	
					12′	47	12.9	
					18′	62	17	
					24′	62	17	
					30′	54	14.5	
Do.	37°05′35″	76°09′40″	4/26/49	1300	0	42	11.9	6½′
					6′	41	11.7	
					12′	55	14.8	
					18′	45	12.4	
					24′	45	12.4	
					30′	43	12	
Do.	37°05′35″	76°09′40″	4/26/49	1400	0	45	12.4	7′
					6′	42	11.9	
					12′	45	12.4	
					18′	54	14.5	
					24′	35	10.7	
					30′	27	9.6	
Do.	37°05′35″	76°09′40″	4/26/49	1500	0	41	11.7	6′
					6′	40	11.5	
					12′	45	12.4	
					18′	45	12.4	
					24′	40	11.5	

					30′	38	11.2	
Do.	37°05′35″	76°09′40″	4/26/49	1600	0	60	16.3	9′
					6′	60	16.3	
					12′	50	13.5	
					18′	50	13.5	
					24′	43	12	
					30′	42	11.9	
Do.	37°05′35″	76°09′40″	4/26/49	1700	0	60	16.3	11′
					6′	60	16.3	
					12′	53	14.3	
					18′	50	13.5	
					24′	45	12.4	
					30′	43	12	
Do.	37°05′35″	76°09′40″	4/26/49	1800	0	62	17	11′
					6′	63	17.3	
					12′	58	15.7	
					18′	54	14.5	
					24′	53	14.3	
					30′	38	11.2	
Do.	37°05′35″	76°09′40″	4/26/49	1900	0	58	15.7	—
					6′	60	16.3	
					12′	52	14	
					18′	50	13.5	
					24′	45	12.4	
					30′	30	10	
Do.	37°05′35″	76°09′40″	4/26/49	2000	0	57	15.5	—
					6′	55	14.8	
					12′	52	14	
					18′	47	12.9	
					24′	40	11.5	
					30′	36	10.9	

(*continued*)

TABLE I.—(*continued*)

B. SPRING (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Chesapeake Light Ship	37°00′	75°.7	4/24/49	1345	0	84	30.5	22′
					6′	82	28.3	
					12′	81	27.2	
					18′	81	27.2	
					24′	80	26.3	
					30′	82	28.3	
					36′	85	32	
					42′	84	30.5	
					48′	85	32	
					54′	84	30.5	
Dockside, Pensacola, Fla.	30°24′	87°13′	4/3/50	0930	0	53	14.3	—
					6′–B	36	10.9	
Mayport, Fla., area	30°22′	81°21′	4/28/43	1345	0	—	—	18′
Do.	30°22′	81°21′	4/28/43	1620	0	—	—	21′
SE. of Pensacola, Fla.	30°12′.6	87°10′.2	4/7/50	1845	0–B	77–83	24–29.5	—
Southward of Mobile, Ala.	29°34′.5	88°13′.5	4/1/50	1300	0–78′	75	22.7	—
					78′–120′	70–55	20–14.8	
Westward of Swannee Sound	29°16′.7	83°42′.3	4/8/50	1600	0–B	98–100	88–>115	—
Southward of Cape San Blas	29°14′	85°24′.4	4/8/50	0600	0–B	100+	>115	—
Off Mississippi Entrance	28°48′.5	89°08′	4/1/50	0445	0–6′	65	18	—
					12′–18′	75	22.7	
					24′–60′	81–88	27.2–37.5	
					66′	93	51	
					72′	97	77	
					78′	99	103	
					84′	100	>115	
					90′	100	>115	

Tampa, Fla., Harbor	27°56'.5	82°26'40"	4/11/50	0900	0–18'	12	7	—
					18'–24'	35	10.7	
					24'–B	25	9.4	
Tampa Bay, mouth of Hillsboro Bay	27°47'.5	82°30'.5	4/11/50	1015	0–18'	54	14.5	11'4"
					24'	25	9.4	
					30'	10	6.6	
Off Tampa Bay, Sea Buoy	27°35'	82°56'	4/9/50	0414	0–42'	82–87	28.3–35.5	—
Off Sanibel Island	26°13'	82°23'.5	4/11/50	2315	0–B	85–86	32–33.5	—
Fort Lauderdale, Dock, N.S.B.	26°05'30"	80°07'15"	4/22/43	1052	0	—	—	12'
Smith Shoal Light, Key West	24°43'	81°54'.5	4/12/50	1005	0–24'	57–59	15.7	9'
					28'	65	18	
Tortugas Bank in 11 fathoms	24°38'45"	83°02'50"	5/26/45	1335	18'	100+	>115	—
SW. Channel, Dry Tortugas	24°35'30"	82°57'40"	5/26/45	1440	18'	96½–100	72–>115	—
Garden Key, Dry Tortugas	24°35'10"	82°54'55"	5/27/45	0920	18'	97	77	—
				1035	18'	97½	82.5	—
				1102	18'	98	88	—
				1133	18'	97½	82.5	—
				1305	6'	96	68	—
					12'	95½	64	
					18'	96	68	
					24'	96	68	
					30'	96	68	
				1355	18'	96½	72.5	
				1420	6'	94	55	—
					12'	93	51	
					18'	93	51	
					24'	94	55	
					30'	95	61	
Do.	24°35'10"	82°54'55"	5/22/45	0800	18'	97	77	—
				1200	18'	91	45	—
				1410	18'	90	42	—
				1430	6'	91	45	—

(continued)

TABLE 1.—(*continued*)

B. SPRING (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Garden Key, Dry Tortugas	24°35′10″	82°54′55″	5/22/45	1430	12′	90	42	
					18′	90	42	
					24′	89	40	
					30′	90	42	
Do.	24°35′10″	82°54′55″	5/23/45	0925	18′	97	77	—
				1010	18′	97	77	—
				1115	18′	97	77	—
				1205	18′	96	68	—
				1330	18′	97	77	—
Do.	24°35′10″	82°54′55″	5/24/45	1000	6′	99	103	—
					12′	99	103	
					18′	$99\frac{1}{2}$	110	
					24′	99	103	
				1225	18′	$98\frac{1}{2}$	95.5	—
				1300	18′	100+	>115	—
				1330	6′	100+	>115	—
					12′	100+	>115	
					18′	100+	>115	
					24′	100+	>115	
					30′	100	>115	
				1434	18′	100	>115	—
Do.	24°35′10″	82°54′55″	5/25/45	0945	18′	100	>115	—
				1030	6′	100	>115	—
					12′	100	>115	
					18′	100	>115	
					24′	99	103	
					30′	99	103	

				1135	6′	99	103	—
					12′	99½	110	
					18′	99½	110	
					24′	100	>115	
					30′	99½	110	
Do.	24°35′10″	82°54′55″	5/25/45	1225	6′	100+	>115	—
					12′	100+	>115	
					18′	100+	>115	
					24′	100+	>115	
					30′	100+	>115	
				1340	6′	100+	>115	—
					12′	100+	>115	
					18′	100+	>115	
					24′	99–100	103–>115	
					30′	97	77	
Do.	24°35′10″	82°54′55″	5/26/45	1530	18′	92–95	48–61	—
				1540	18′	92½	49.5	—
Do.	24°35′10″	82°54′55″	5/17/45	1323	18′	100	>115	—
				1520	18′	100	>115	—
				1715	18′	95	61	—
Do.	24°35′10″	82°54′55″	5/18/45	1315	18′	94	55	—
Do.	24°35′	—	5/25/45	1530	6′	72	20.9	—
					12′	70	20	
					18′	65	18	
					22′	64	17.7	
				1700	6′	93	51	—
					12′	93	51	
					18′	93	51	
					22′	68	19.2	
					B	13	7.2	
				1702	B	55	14.8	—

(continued)

TABLE 1.—(*continued*)

B. SPRING (*concluded*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
American Shoal	24°31′	81°32′.7	4/13/50	1130	0–B	100+	>115	—
100-Fathom Curve, Garden Key, Dry Tortugas	24°19′	83°02′	5/26/45	1030	6′	100+	>115	—
					12′	100+	>115	
					18′	100+	>115	
					126′	100+	>115	
Key West, Fla.	24°	81°	5/21/45	0230	6′	63	17.3	—
					12′	58	15.7	
					18′	60	16.3	
					24′	58	15.7	
				0330	6′	59	16	—
					12′	60	16.3	
					18′	61	16.7	
					24′	55	14.8	
				0430	6′	67	18.7	—
					12′	75	22.7	
					18′	76	23.3	
					24′	72	20.9	
				0530	6′	73	21.5	—
					12′	69	19.5	
					18′	76	23.3	
					24′	67	18.7	
Do.	24°	81°	5/20/45	2230	6′	73	21.5	—
					12′	74	22	
					18′	70	20	
					24′	63	17.3	
				2330	6′	74	22	—
					12′	70	20	

					18′	61½	16.8	
					24′	56	15.1	
Do.	24°	81°	5/20/45	1930	6′	73	21.5	—
					12′	72	20.9	
					18′	66	18.4	
					24′	56	15.1	
				2030	6′	73	21.5	—
					12′	72	20.9	
					18′	69	19.5	
					24′	57	15.5	
				2130	6′	75½	23	—
					12′	75½	23	
					18′	68	19.2	
					24′	66	18.4	
Do.	24°	81°	5/20/45	1630	6′	68	19.2	—
					12′	68	19.2	
					18′	66	18.4	
					24′	68	19.2	
				1730	6′	70	20	
					12′	72	20.9	
					18′	69	19.5	
					24′	68	19.2	
				1830	6′	68	19.2	
					12′	76	23.3	
					18′	72	20.9	
					24′	56	15.1	
Rebecca Shoal, Dry Tortugas	20°34′30″	82°42′20″	5/17/45	0800	18′	96	68	—
C. SUMMER								
Red Bay, Labrador	51°45′	56°22′	8/21/48	0920	0	93	51	—
					6′	99	103	

(continued)

TABLE I.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Red Bay, Labrador	51°45′	56°22′	8/21/48	0920	12′	99	103	
					18′	99	103	
					24′	98	88	
					30′	98	88	
					36′	98	88	
					42′	98	88	
					B	97	77	
French Point, Newfoundland	51°40′	55°28′20″	8/23/48	1500	0	87	35.5	—
					6′	87	35.5	
					12′	87	35.5	
					18′	87	35.5	
					24′	87	35.5	
					30′	90	42	
					36′	90	42	
					42′	90	42	
					48′	90	42	
					54′	90	42	
					60′	90	42	
					66′	92	48	
					72′	94	55	
					78′	94	55	
Pistolet Bay	51°30′.2	55°43′	8/22/48	1600	0	67	18.7	—
					6′	68	19.2	
					12′	68	19.2	
					B	68	19.2	
Belle Isle Strait, Newfoundland	51°30′	56°37′.5	8/21/48	0600	0	90	42	58′
					6′	94	55	

					12′	94	55	
					18′	94	55	
					24′	94	55	
					30′	94	55	
					36′	95	61	
					42′	96	68	
					48′	96	68	
					54′	95	61	
					60′	96	68	
					66′	98	88	
					72′	99	103	
					78′	98	88	
Cape Fox, Newfoundland	50°51′40″	55°50′30″	8/26/48	1230	0	90	42	43′
					6′	90	42	
					12′	90	42	
					18′	88	37.5	
					24′	88	37.5	
					30′	88	37.5	
					36′	88	37.5	
					42′	88	37.5	
					48′	88	37.5	
					54′	88	37.5	
					60′	89	40	
					66′	89	40	
					72′	90	42	
					78′	90	42	
Riche Point, Newfoundland	50°43′30″	57°32′30″	8/20/48	2030	0	90	42	—
					6′	90	42	
					12′	90	42	
					18′	90	42	
					24′	90	42	
					30′	90	42	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Riche Point, Newfoundland	50°43′30″	57°32′30″	8/20/48	2030	36′	90	42	
					42′	90	42	
					48′	90	42	
					54′	90	42	
					60′	90	42	
Fouche Harbor, Newfoundland	50°31′	56°18′	8/27/48	0830	0	63	17.3	10′
					6′	65	18	
					12′	69	19.5	
					18′	77	24	
					24′	84	30.5	
					30′	87	35.5	
					36′	90	42	
					42′	91	45	
					48′	92	48	
					54′	93	51	
					60′	93	51	
					66′	94	58	
					72′	95	61	
					78′	95	61	
Do.	50°29′	56°11.2′	8/27/48	0930	0	90	42	46′
					6′	92	48	
					12′	92	48	
					18′	92	48	
					24′	92	48	
					30′	91	45	
					36′	91	45	
					42′	91	45	

					48′	91	45	
					54′	91	45	
					60′	91	45	
					66′	91	45	
					72′	91	45	
					78′	91	45	
St. Barbe Island, channel	50°12′	55°47′	8/27/48	1245	0	89	40	55′
					6′	95	61	
					12′	94	56	
					18′	93	51	
					24′	92	48	
					30′	92	48	
					36′	92	48	
					42′	92	48	
					48′	92	48	
					54′	92	48	
					60′	92	48	
					66′	92	48	
					72′	92	48	
					78′	92	48	
Gull Island	49°59′	55°22′	8/27/48	1530	0	90	42	52.5′
					6′	90	42	
					12′	90	42	
					18′	89	40	
					24′	89	40	
					30′	89	40	
					36′	89	40	
					42′	89	40	
					48′	89	40	
					54′	88	37.5	
					60′	88	37.5	
					66′	90	42	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Gull Island	49°59′	55°22′	8/27/48	1530	72′	90	42	
					78′	90	42	
Brocalhou Light, Newfoundland	49°43′40″	54°30′30″	8/28/48	1130	0	90	42	50′+
					6′	90	42	
					12′	91	45	
					18′	91	45	
					24′	90	42	
					30′	91	45	
					36′	91	45	
					42′	92	48	
					54′	92	48	
					60′	92	48	
					66′	95	61	
					72′	95	61	
					78′	96	68	
Twillingate Harbor	49°40′.5	54°46′	8/28/48	1030	0	85	32	30′
					6′	83	29.5	
					12′	82	28.3	
					18′	85	32	
					24′	87	35.5	
					30′	88	37.5	
					36′	90	42	
					42′	90	42	
					48′	90	42	
					54′	92	48	
					60′	92	48	
Offer Wadham Island	49°37′25″	53°45′	8/29/48	1100	0	94	58.5	50′

					6′	94	58.5	
					12′	94	58.5	
					18′	93	51	
					24′	92	48	
					30′	92	48	
					36′	91	45	
					42′	91	45	
					48′	91	45	
					54′	91	45	
					60′	90	42	
					66′	90	42	
					72′	91	45	
					78′	91	45	
Approx. 10 miles S. of Funk Island	49°37′	53°11′	8/29/48	1400	0	92	48	68′
					6′	93	51	
					12′	93	51	
					18′	92	48	
					24′	92	48	
					30′	92	48	
					36′	92	48	
					42′	93	51	
					48′	92	48	
					54′	92	48	
					60′	91	45	
					66′	92	48	
					72′	93	51	
Little Seldom-Come-By Harbor	49°35′45″	54°13′	8/28/48	1840	0	81	27.2	—
					6′	81	27.2	
					12′	81	27.2	
					18′	80	26.3	
					24′	79	25.5	
					30′	78	24.6	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Little Port Head Light, Newfoundland............	49°07′	58°27′	8/17/48	2115	0	89	40	—
					6′	90	42	
					12′	90	42	
					18′	89	40	
					24′	90	42	
					30′	90	42	
					36′	90	42	
					42′	92	48	
					48′	92	48	
					54′	92	48	
					60′	92	48	
					66′	93	51	
					72′	94	56	
					78′	94	56	
Humber Arm, Newfoundland......................	49°01′	58°06′30″	8/20/48	0800	0	85	32	30′
					6′	86	33.5	
					12′	90	42	
					18′	92	48	
					24′	95	61	
					30′	95	61	
					36′	96	68	
					42′	97	77	
					48′	97	77	
					54′	96	68	
					60′	96	68	
					66′	96	68	
					72′	96	68	

					78′	97	77	
Cape Bonavista, Newfoundland....................	48°42′	52°47′	8/29/48	2030	0	90	42	—
					6′	90	42	
					12′	91	45	
					18′	91	45	
					24′	92	48	
					30′	92	48	
					36′	92	48	
					42′	92	48	
					48′	92	48	
					54′	91	45	
					60′	92	48	
					66′	92	48	
					72′	94	56	
					78′	95	61	
Cape Ray, Newfoundland........................	47°34′45″	59°22′	8/17/48	0930	0	90	42	37′
					6′	90	42	
					12′	90	42	
					18′	90	42	
					24′	90	42	
					30′	91	45	
					36′	90	42	
					42′	90	42	
					48′	90	42	
					54′	90	42	
					60′	90	42	
					66′	90	42	
					72′	90	42	
					78′	90	42	
Port Aux Basque Harbor, Newfoundland...........	47°34′37″	59°08′31″	8/17/48	0715	0	76	23.3	—
					6′	73	21.5	
					12′	77	24	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Port Aux Basque Harbor, Newfoundland	47°34′37″	59°08′31″	8/17/48	0715	18′	78	24.7	
					24′	78	24.7	
					30′	78	24.7	
					B	78	24.7	
St. John's Harbor, Newfoundland	47°33′47″	52°42′27″	9/3/48	1130	0	65	18	15′
					6′	67	18.7	
					12′	65	18	
					18′	63	17.4	
					B	65	18	
Cape Spear, Newfoundland	47°33′30″	52°36′.8	9/4/48	0900	0	95	61	62′
					6′	97	77	
					12′	97	77	
					18′	97	77	
					24′	98	88	
					30′	98	88	
					36′	98	88	
					42′	97	77	
					48′	96	69	
					54′	96	69	
					60′	97	77	
					66′	98	88	
					72′	98	88	
					78′	98	88	
Cape Race, Newfoundland	46°38′.3	52°59′.5	9/4/48	1535	0	89	40	32′
					6′	88	37.5	
					12′	88	37.5	

					18′	86	32.8	
					24′	86	32.8	
					30′	85	32	
					36′	85	32	
					42′	86	32.8	
					48′	87	35.5	
					54′	89	40	
					60′	90	42	
					66′	90	42	
					72′	94	56	
					78′	94	56	
Sydney Harbor, Nova Scotia	46°08′31″	60°12′02″	8/15/48	1830	0	30	10	—
					6′	57	15.5	
					12′	60	16.3	
					18′	65	18	
					24′	64	17.7	
Bras d'Or, Nova Scotia	46°05′30″	60°41′	8/13/48	1215	0	85	32	23′
					6′	84	30.5	
					12′	83	29.3	
					18′	82	28.2	
					24′	82	28.2	
					30′	82	28.2	
					36′	83	29.3	
					42′	83	29.3	
					48′	85	32	
					54′	87	35.5	
					60′	88	37.5	
					66′	90	42	
					72′	92	48	
					78′	92	48	
Bras d'Or Lake, Nova Scotia	45°50′15″	60°50′45″	8/13/48	0930	0	88	37.5	34′
					6′	87	35.5	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Bras d'Or Lake, Nova Scotia	45°50′15″	60°50′45″	8/13/48	0930	12′	86	33.5	
					18′	86	33.5	
					24′	86	33.5	
					30′	84	30.5	
					36′	85	32	
					42′	86	33.5	
					48′	86	33.5	
					54′	87	35.5	
					60′	89	39.8	
					66′	92	48	
					72′	95	61	
					78′	97	77	
Horsehead Shoals, Nova Scotia	45°35′30″	60°52′45″	8/12/48	1700	0	75	22.7	19′
					6′	82	28.2	
					12′	82	28.2	
					18′	80	26.3	
					24′	80	26.3	
					30′	85	32	
					36′	89	39.8	
					42′	90	42	
					48′	92	48	
					54′	95	61	
					60′	92	48	
					66′	92	48	
					72′	90	42	
Saint Pierre Bank	45°34′	57°33′	9/5/48	1430	0	90	42	58′
					6′	90	42	

					12′	90	42	
					18′	90	42	
					24′	89	39.6	
					30′	89	39.6	
					36′	90	42	
					42′	92	48	
					48′	92	48	
					54′	92	48	
					60′	90	42	
					66′	92	48	
					72′	93	51	
					78′	94	58	
Cape Canso, Nova Scotia........................	45°21′07″	60°51′06″	8/12/48	1445	0	95	61	36′
					6′	94	56	
					12′	91	45	
					18′	93	51	
					24′	94	58	
					30′	94	58	
					36′	93	51	
					42′	92	48	
					48′	95	61	
					54′	95	61	
					60′	96	68	
					66′	96	68	
					72′	98	88.5	
					78′	99	103	
Country Harbor, Nova Scotia.....................	45°10′55″	61°43′10″	8/11/48	1130	0	77	24	18′
					6′	85	32	
					12′	84	30.5	
					18′	80	26.2	
					24′	79	25.5	
					30′	73	21.5	

(*continued*)

TABLE I.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Country Harbor, Nova Scotia	45°10′55″	61°43′10″	8/10/48	1730	0	78	24.7	—
					6′	78	24.7	
					12′	83	29.3	
					18′	78	24.7	
					24′	70	20	
Sea Buoy off Country Harbor	45°02′	61°32′42″	8/12/48	1915	0	91	45	*33′
					6′	91	45	
					12′	89	39.7	
					18′	89	39.7	
					24′	90	42	
					30′	90	42	
					36′	93	51	
					42′	92	48	
					48′	94	58.5	
					54′	93	51	
					60′	93	51	
					66′	94	58.5	
					72′	94	58.5	
					78′	93	51	
Yankee Jack, Nova Scotia	44°42′57″	62°28′52″	8/10/48	1020	0	96	68	60′
					6′	94	58.5	
					12′	94	58.5	
					18′	94	58.5	
					24′	94	58.5	
					30′	95	61	
					36′	95	61	
					42′	95	61	

					48′	96	68	
					54′	97	77	
					60′	98	88	
					66′	97	77	
					72′	98	88	
					78′	98	88	
Bedford Basin, Halifax	44°41′36″	63°38′24″	8/9/48	1200	0	90	42	26′
					6′	90	42	
					12′	86	33.5	
					18′	84	30.5	
					24′	85	32	
					30′	85	32	
					36′	86	33.5	
					42′	85	32	
					48′	94	56	
					54′	100	>115	
					60′	100	>115	
					66′	100	>115	
					72′	100	>115	
					78′	100	>115	
					84′	100	>115	
Halifax Harbor by Oil Dock	44°39′02″	63°34′18″	8/9/48	1020	0	—	—	24′
John Bank, Nova Scotia	44°35′30″	62°49′45″	8/10/48	0800	0	92	48	54′
					6′	90	42	
					12′	92	48	
					18′	92	48	
					24′	91	45	
					30′	90	42	
					36′	91	45	
					42′	92	48	
					48′	93	51	
					54′	95	61	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
John Bank, Nova Scotia	44°35′30″	62°49′45″	8/10/48	0800	60′	96	68	
					66′	96	68	
					72′	98	88	
					78′	98	88	
Entrance Halifax Harbor, Nova Scotia	44°31′48″	63°30′20″	8/9/48	0630	0	97	77	56′
					6′	97	77	
					12′	97	77	
					18′	97	77	
					24′	95	61	
					30′	95	61	
					36′	95	61	
					42′	95	61	
					48′	95	61	
					54′	95	61	
					60′	95	61	
					66′	97	77	
					72′	97	77	
					78′	98	88	
Blue Hill Harbor, Maine	44°24′20″	68°33′45″	7/27/48	1030	0	80	28.8	—
					6′	74	22	
					12′	71	20.5	
					18′	69	19.5	
					24′	69	19.5	
Off Long Island, Blue Hill Bay	44°18′20″	68°30′12″	7/26/48	1215	0	86	33.5	21′
					6′	83	29.3	
					12′	80	26.3	
					18′	75	22.7	

					24'	60	16.3	
					30'	65	18	
					36'	71	20.5	
					42'	74	22	
					48'	73	21.5	
					54'	74	22	
					60'	76	23.3	
					66'	78	24.7	
					72'	78	24.7	
					78'	78	24.7	
Eggemoggin Reach	44°16'12"	68°37'12"	7/25/48	1000	0	85	32	21'
					6'	85	32	
					12'	88	37.5	
					18'	82	28.2	
					24'	52	14	
					30'	52	14	
					36'	65	18	
					42'	60	16.3	
Off Long Island, Blue Hill Bay..........................	44°18'20"	68°30'12"	8/5/48	1415	0	80	26.3	17'
					6'	78	24.7	
					12'	77	24	
					18'	74	22	
					24'	69	19.5	
					30'	68	19	
					36'	69	19.5	
					42'	72	20.9	
					48'	73	21.5	
					54'	74	22	
					60'	75	22.7	
					66'	74	22	
					72'	74	22	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Frenchman's Bay	44°11′18″	68°14′54″	8/5/48	1600	0	90	42	31′
					6′	88	37.5	
					12′	89	39.8	
					18′	88	37.5	
					24′	87	35.5	
					30′	86	33.5	
					36′	87	35.5	
					42′	88	37.5	
					48′	88	37.5	
					54′	88	37.5	
					60′	89	39.8	
					66′	90	42	
					72′	90	42	
Mount Desert Rock	44°11′	68°01′30″	8/6/48	2200	0	75	22.7	—
					6′	76	23	
					12′	77	24	
					18′	75	22.7	
					24′	76	23	
					30′	79	25.5	
					36′	80	26.3	
					42′	77	24	
					48′	78	24.6	
					54′	75	22.7	
					60′	76	23	
					66′	77	24	
					72′	82	28.3	
					78′	83	29.5	

Jericho Bay	44°10′53″	68°21′12″	7/25/48	1245	0	68	19.1	14′
					6′	65	18	
					12′	62	17	
					18′	62	17	
					24′	64	17.6	
					30′	64	17.6	
					36′	64	17.6	
					42′	64	17.6	
					48′	68	19.1	
					54′	70	20	
					60′	68	19.1	
					66′	69	19.5	
					72′	68	19.1	
					78′	67	18.7	
Cross Ledge, Nova Scotia	44°10′30″	69°39′30″	8/9/48	0300	0	100	>115	—
					6′	95	61	
					12′	94	56	
					18′	95	61	
					24′	95	61	
					30′	95	61	
					36′	93	51	
					42′	93	51	
					48′	95	61	
					54′	95	61	
					60′	97	78	
					66′	100	>115	
					72′	98	88	
Swans Island Harbor	44°08′06″	68°26′42″	7/25/48	1400	0	65	18	11′
					6′	61	16.7	
					12′	60	16.3	
					18′	54	14.5	
					24′	52	14	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Swans Island Harbor	44°08′06″	68°26′42″	7/25/48	1400	30′	58	15.7	
					36′	45	12.4	
				2000	0	55	14.8	—
					6′	50	13.5	
					12′	50	13.5	
					18′	40	11.5	
					24′	42	11.9	
					30′	40	11.5	
Penobscot Bay	44°08′	69°00′18″	7/24/48	1245	0	88	37.5	28′
					6′	86	33.5	
					12′	86	33.5	
					18′	87	35.5	
					24′	82	28.3	
					30′	75	22.7	
					36′	62	17	
					42′	68	19.1	
					48′	73	21.5	
					54′	74	22	
					60′	76	23.3	
					66′	74	22	
					72′	75	22.7	
Swans Island Sea Buoy	44°07′30″	68°27′36″	7/26/48	0830	0	78	24.7	18′
					6′	78	24.7	
					12′	77	24	
					18′	78	24.7	
					24′	75	22.7	
					30′	77	24	

					36′	78	24.7	
					42′	80	26.3	
					48′	79	25.5	
					54′	80	26.3	
					60′	82	28.3	
					66′	83	29.5	
					72′	87	35.5	
					78′	85	37.5	
Emerald Bank	44°6′.5	62°20′.6	9/6/48	1230	0	100+	>115	60′
					6′	100	>115	
					12′	100	>115	
					18′	100	>115	
					24′	99	102	
					30′	99	102	
					36′	99	102	
					42′	99	102	
					48′	99	102	
					54′	99	102	
					60′	99	102	
					66′	98	88	
					72′	98	88	
					78′	97	77	
Blue Hill Bay................................	44°04′	68°25′	7/26/48	0945	0	78	24.7	20′
					6′	78	24.7	
					12′	78	24.7	
					18′	81	27.2	
					24′	80	26.3	
					30′	81	27.2	
					36′	80	26.3	
					42′	77	24	
					48′	74	22	
					54′	73	21.5	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Blue Hill Bay	44°04′	68°25′	7/26/48	0945	60′	69	19.5	
					66′	67	18.7	
					72′	65	18	
					78′	68	19.1	
Bay of Fundy	44°01′30″	67°21′30″	8/7/48	0300	0	90	42	—
					6′	91	45	
					12′	90	42	
					18′	90	42	
					24′	90	42	
					30′	89	39.8	
					36′	87	35.5	
					42′	88	37.5	
					48′	85	32	
					54′	85	32	
					60′	85	32	
					66′	82	28.3	
					72′	82	28.3	
Two Bush Channel	43°58′18″	69°00′18″	7/22/48	1215	0	89	39.8	27′
					6′	87	35.5	
					12′	82	28.3	
					18′	75	22.7	
					24′	76	23.3	
					30′	78	24.7	
					36′	78	24.7	
					42′	78	24.7	
					48′	78	24.7	
					54′	78	24.7	

					60′	78	24.7	
					66′	78	24.7	
					72′	78	24.7	
					78′	78	24.7	
Pemaquid Harbor, Maine	43°52′51″	69°31′30″	7/21/48	1545	0	68	19.2	12′
					6′	65	18	
					12′	65	18	
					18′	66	18.4	
				2100	0	55	14.8	—
					6′	55	14.8	
					12′	55	14.8	
					18′	56	15.1	
					24′	57	15.4	
Yarmouth Harbor, Nova Scotia	43°50′15″	66°07′16″	8/8/48	0800	0	11	6.8	3′
					6′	17	8	
					12′	28	9.8	
					18′	32	10.3	
					B	28	9.8	
Do.	43°50′15″	66°07′16″	8/7/48	1545	0	28	9.8	4′
					6′	21	8.7	
					12′	21	8.7	
					18′	23	9	
					B	23	9	
Johns Bay, off Pemaquid	43°50′	69°32′	7/22/48	0900	0	88	37.5	38′
					6′	88	37.5	
					12′	88	37.5	
					18′	88	37.5	
					24′	88	37.5	
					30′	83	29.5	
					36′	76	23.3	
					42′	26	9.5	
					48′	50	13.5	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Johns Bay, off Pemaquid	43°50′	69°32′	7/22/48	0900	54′	78	24.7	
					60′	85	32	
					66′	85	32	
					72′	88	37.5	
					78′	90	42	
					84′	90	42	
Lucker Light Ship, Nova Scotia	43°46′45″	66°33′40″	8/7/48	0700	0	96	68	36′
					6′	95	61	
					12′	95	61	
					18′	94	58.5	
					24′	94	58.5	
					30′	94	58.5	
					36′	94	58.5	
					42′	93	51	
					48′	93	51	
					54′	93	51	
					60′	93	51	
					66′	92	48	
					72′	94	58.5	
					78′	95	61	
Yarmouth Harbor Entrance, Nova Scotia	43°46′42″	66°09′13″	8/8/48	0900	0	78	24.7	22′
					6′	78	24.7	
					12′	78	24.7	
					18′	77	24	
					24′	77	24	
					30′	77	24	
					36′	77	24	

					42′	77	24	
					48′	75	22.7	
					54′	75	22.7	
					60′	74	22	
					66′	75	22.7	
					72′	75	22.7	
Falmouth Foreside	43°43′45″	70°12′10″	7/20/48	1730	0	69	19.5	—
					6′	66	18.3	
					12′	59	16	
					18′	50	13.5	
				2030	0	73	21.5	—
					6′	68	19.5	
					12′	70	20	
					18′	73	21.5	
					24′	70	20	
Port Joli, Nova Scotia	43°42′30″	64°42′	8/8/48	2200	0	90	42	—
					6′	83	29.5	
					12′	78	24.7	
					18′	80	26.3	
					24′	85	32	
					30′	85	32	
					36′	85	32	
					42′	85	32	
					48′	86	33.5	
					54′	87	35.5	
					60′	87	35.5	
					66′	90	42	
Off Bantam Rock	43°41′54″	69°38′06″	7/21/48	1350	0	90	42	36′
					6′	92	48	
					12′	94	55.5	
					18′	80	28.3	
					24′	62	17	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Bantam Rock	43°41′54″	69°38′06″	7/21/48	1350	30′	45	12.5	
					36′	60	16.3	
					42′	55	14.8	
					48′	60	16.3	
					54′	85	32	
					60′	90	42	
					66′	90	42	
					72′	90	42	
					78′	92	48	
					84′	94	55.5	
Portland Harbor	43°39′57″	70°14′56″	7/19/48	1930	0	57	15.4	—
					6′	62	17	
					12′	62	17	
					18′	64	17.7	
					24′	65	18	
Off Outer Green Island	43°38′	69°37′30″	7/21/48	1000	0	90	42	20′
					6′	86	33.5	
					12′	83	29.5	
					18′	80	26.7	
					24′	86	33.5	
					30′	90	42	
					36′	95	61	
					42′	95	61	
					48′	95	61	
					54′	95	61	
					60′	95	61	
					66′	96	68	

					72′	97	77	
Portland Head Light	43°32′35″	70°12′24″	7/19/48	1615	0	50	13.5	11′
					6′	50	13.5	
					12′	59	16	
					18′	65	18	
					24′	67	18.7	
					30′	70	20	
					36′	75	22.7	
					42′	76	23.3	
					48′	78	24.7	
					B	80	26.3	
Old Anthony Rock	43°27′54″	70°27′54″	7/19/48	1530	0	69	19.5	15′
					6′	75	22.7	
					12′	72	20.8	
					18′	75	22.7	
					24′	78	24.7	
					30′	82	28.3	
					36′	89	40	
					42′	91	45	
					48′	91	45	
					54′	92	48	
					60′	92	48	
					66′	92	48	
					72′	90	42	
					78′	92	48	
Whale Rock Ledge	43°26′24″	70°17′30″	7/19/48	1415	0	84	30.5	25′
					6′	84	30.5	
					12′	83	29.5	
					18′	84	30.5	
					24′	93	51.5	
					30′	95	61	
					36′	96	68	

(*continued*)

Table 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Whale Rock Ledge	43°26′24″	70°17′30″	7/19/48	1415	42′	96	68	
					48′	95	61	
					54′	97	77	
					60′	97	77	
					66′	84	30.5	
					72′	85	32	
					78′	85	32	
Cape Porpoise	43°20′18″	70°23′24″	7/19/48	1300	0	78	24.7	27′
					6′	84	30.5	
					12′	90	42	
					18′	88	37.5	
					21′	87	35.5	
					30′	85	32	
					36′	88	37.5	
					42′	90	42	
					48′	95	61	
					54′	95	61	
					60′	94	55.5	
					66′	95	61	
					72′	95	61	
					78′	95	61	
Southwest Ledge, Nova Scotia	43°20′08″	65°40′54″	8/8/48	1430	0	—	—	56′
Bald Head Cliff	43°12′06″	70°28′47″	7/19/48	1130	0	85	32	24′
					6′	92	48	
					12′	92	48	
					18′	90	42	

					24′	94	58.5	
					30′	95	61	
					36′	95	61	
					42′	94	58.5	
					48′	89	40	
					54′	85	32	
					60′	85	32	
					66′	87	35.5	
					72′	89	40	
					78′	90	42	
Portsmouth Harbor, N. H.	43°04′24″	70°43′28″	7/18/48	1530	0	82	28.3	—
					6′	80	26.3	
					12′	80	26.3	
					18′	80	26.3	
					24′	79	25.4	
					30′	80	26.3	
Do.	43°04′24″	70°43′28″	7/18/48	1830	0	73	21.5	—
					6′	74	22	
					12′	74	22	
					18′	75	22.6	
					24′	78	24.7	
					30′	79	25.5	
					36′	80	26.3	
Do.	43°04′24″	70°43′28″	7/18/48	2100	0	76	23.3	—
					6′	80	26.3	
					12′	82	28.3	
					18′	86	33.5	
					24′	86	33.5	
					30′	86	33.5	
					36′	87	35.5	
					42′	87	35.5	
York Ledge Whistle	43°04′24″	70°34′30″	7/19/48	1000	0	84	30.5	21′

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
York Ledge Whistle	43°04′24″	70°34′30″	7/19/48	1000	6′	83	29.5	
					12′	82	28.3	
					18′	81	27.3	
					24′	82	28.3	
					30′	85	32	
					36′	86	33.5	
					42′	88	37.5	
					48′	88	37.5	
					54′	91	45	
					60′	92	48	
					66′	94	55.5	
					72′	95	61	
					78′	95	61	
Off Portsmouth, N. H.	43°02′54″	70°41′24″	7/19/48	0900	0	84	30.5	23′
					6′	83	29.5	
					12′	85	32	
					18′	85	32	
					24′	86	33.5	
					30′	92	48	
					36′	95	61	
Off Newburyport, Mass.	42°50′27″	70°36′22″	7/18/48	1145	0	62	17	12′
					6′	80	26.3	
					12′	82	28.3	
					18′	90	42	
					24′	91	45	
					30′	91	45	
					36′	94	50.5	

					42′	97	77	
					48′	97	77	
					54′	98	88	
					60′	98	88	
					66′	99	102	
					72′	100	>115	
					78′	100	>115	
Off Cape Ann, Mass.	42°08′06″	70°36′18″	7/18/48	1045	0	85	32	29′
					6′	84	30.5	
					12′	82	28.3	
					18′	82	28.3	
					24′	86	33.5	
					30′	85	32	
					36′	89	40	
					42′	92	48	
					48′	92	48	
					54′	95	61	
					60′	96	68	
					66′	96	68	
					72′	97	77	
					78′	98	88	
					84′	98	88	
Gloucester Harbor, Mass.	42°36′20″	70°40′24″	7/15/48	1015	0	65	18	9′
					6′	55	14.8	
					12′	48	12.4	
					18′	41	11.7	
					24′	37	11	
				1115	0	65	18	9′
					6′	53	14.3	
					12′	46	12.7	
					18′	41	11.7	

(continued)

TABLE I.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Gloucester Harbor, Mass.	42°36′20″	70°40′24″	7/15/48	1215	0	55	14.8	9′
					6′	52	14	
					12′	47	12.9	
					18′	47	12.9	
					24′	36	10.9	
				1320	0	62	17	8′
					6′	52	14	
					12′	48	13	
					18′	50	13.5	
Do.	42°36′20″	70°40′24″	7/15/48	1415	0	40	11.5	8′
					6′	50	13.5	
					12′	45	12.4	
					18′	43	12	
					24′	40	11.5	
				1515	0	40	11.5	8½′
					6′	40	11.5	
					12′	45	12.4	
					18′	47	12.9	
					24′	42	11.9	
Off Cape Ann, Mass.	42°34′14″	70°39′14″	7/18/48	0930	0	74	22	21′
					6′	74	22	
					12′	72	20.9	
					18′	82	28.3	
					24′	82	28.3	
					30′	82	28.3	
					36′	90	42	
					42′	90	42	

					48′	92	48	
					54′	92	48	
					60′	92	48	
					66′	94	55	
					72′	92	48	
					78′	95	61	
					84′	95	61	
Off Boston Light Ship...........................	42°16′36″	70°36′36″	7/10/48	1500	0	80	26.3	23′
					6′	75	22.7	
					12′	77	24	
					18′	80	26.3	
					24′	81	27.2	
					30′	85	32	
					36′	86	33.5	
					42′	90	42	
					48′	91	45	
					54′	93	51	
					60′	95	61	
					66′	97	77	
					72′	97	77	
					78′	97	77	
					84′	97	77	
South of Browns Bank...........................	42°05′	65°47′	9/7/48	1000	0	95	61	*55′
					6′	94	55	
					12′	97	77	
					18′	97	77	
					24′	97	77	
					30′	96	68	
					36′	96	68	
					42′	96	68	
					48′	97	77	
					54′	99	103	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
South of Browns Bank	42°05′	65°47′	9/7/48	1000	66′	99	103	
					66′	100	>115	
					72′	100	>115	
					78′	100	>115	
Massachusetts Bay	42°01′39″	70°28′24″	7/10/48	1210	0	90	42	27′
					6′	90	42	
					12′	88	37.5	
					18′	88	37.5	
					24′	90	42	
					30′	90	42	
					36′	90	42	
					42′	92	48	
					48′	92	48	
					54′	94	55	
					60′	94	55	
					66′	95	61	
					72′	95	61	
					78′	98	88	
Cape Cod Canal	41°40′45″	70°40′35″	7/10/48	0915	0	60	16.3	10′
					6′	65	18	
					12′	63	17.3	
					18′	62	17	
					24′	62	17	
					30′	60	16.3	
Buzzards Bay	41°31′	75°50′30″	7/9/48	1230	0	80	26.3	13′
					6′	78	24.6	
					12′	74	22	

					18′	70	20	
					24′	65	18	
					30′	67	18.7	
					36′	62	17	
					42′	55	14.8	
					48′	52	14	
					54′	45	12.4	
					B	45	12.4	
Marthas Vineyard	41°28′25″	70°29′	7/9/48	0830	0	65	18	—
					6′	62	17	
					12′	60	16.3	
					18′	70	20	
					24′	75	22.7	
					30′	75	22.7	
					36′	72	20.9	
					42′	75	22.7	
					48′	70	20	
					54′	65	18	
Do.	41°28′25″	70°29′	7/8/48	1300	0	65	18	16′
					6′	60	16.3	
					12′	60	16.3	
					18′	62	17	
					24′	62	17	
					30′	60	16.3	
					36′	60	16.3	
					42′	62	17	
					48′	60	16.3	
					B	60	16.3	
Vineyard Sound	41°19′34″	71°14′20″	7/8/48	0215	0	70	20	—
					6′	70	20	
					12′	70	20	
					18′	70	20	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station			Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Description	Latitude (N.)	Longitude (W.)						
Vineyard Sound	41°19′34″	71°14′20″	7/8/48	0215	24′	69	19.5	
					30′	68	19.2	
					36′	69	19.5	
					42′	70	20	
					48′	70	20	
					54′	70	20	
					60′	68	19.2	
					66′	65	18	
					72′	65	18	
					78′	65	18	
Block Island Harbor	41°11′40″	71°34′30″	7/7/48	1100	0	50	13.5	12′
					6′	45	12.4	
					12′	42	11.9	
					18′	40	11.5	
				1730	0	51	13.8	—
					6′	47	12.9	
					12′	40	11.5	
					18′	40	11.5	
Vineyard Sound	41°31′40″	70°44′30″	7/8/48	1045	0	70	20	17′
					6′	70	20	
					12′	65	18	
					18′	61	16.7	
					24′	58	15.7	
					30′	57	15.5	
					36′	56	15.1	
					42′	55	14.8	
					48′	55	14.8	

					54′	55	14.8	
Block Island Sound	41°04′42″	71°44′35″	7/7/48	1730	0	30	10	—
					6′	30	10	
					12′	32	10.3	
					18′	30	10	
					24′	30	10	
					30′	30	10	
					36′	30	10	
					42′	35	10.7	
					48′	28	9.8	
					54′	30	10	
					—	64	17.7	
Off Bridgehampton	40°52′30″	72°13′30″	7/6/48	1430	0	65	18	24′
					6′	65	18	
					12′	65	18	
					18′	65	18	
					24′	65	18	
					30′	63	17.3	
					36′	65	18	
					42′	70	20	
					48′	72	20.9	
					54′	75	22.7	
Nantucket Light Ship	40°49′	69°21′	9/8/48	0800	0	93	51	*36′
					6′	93	51	
					12′	93	51	
					18′	93	51	
					24′	90	42	
					30′	88	37.5	
					36′	88	37.5	
					42′	84	30.5	
					48′	84	30.5	
					54′	85	32	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Nantucket Light Ship	40°49′	69°21′	9/8/48	0800	60′	87	35.5	
					66′	94	55	
					72′	95	61	
					78′	96	68	
Off Fire Island	40°35′33″	73°17′48″	7/6/48	0830	0	53	14.3	—
					6′	50	13.5	
					12′	62	17	
					18′	65	18	
					24′	50	13.5	
					30′	48	13	
					36′	48	13	
					42′	50	13.5	
					48′	52	14	
Off Coney Island	40°34′15″	74°00′57″	7/5/48	1345	0	0	<1.5	5½′
					6′	0	<1.5	
					12′	0	<1.5	
					18′	8	6.2	
					24′	10	6.6	
					B	10	6.6	
Off Far Rockaway	40°31′36″	73°43′40″	7/6/48	0530	0	0	<1.5	—
					6′	0	<1.5	
					12′	0	<1.5	
					18′	45	12.4	
					24′	50	13.5	
					30′	50	13.5	
					36′	45	12.4	
					42′	45	12.4	

					48′	45	12.4	
					54′	45	12.4	
					60′	45	12.4	
Scotland Light Ship	40°26′40″	73°56′	7/5/48	1000	0	25	9.4	4½′
					6′	20	8.5	
					12′	30	10	
					18′	50	13.5	
					24′	55	14.8	
					30′	65	18	
					36′	80	26.3	
					42′	82	28.3	
					48′	82	28.3	
West of Sandy Hook	40°26′40″	74°00′20″	7/5/48	0740	0–B	0	<1.5	—
Shewsbury Rock	40°20′39″	73°55′36″	7/5/48	1130	0	0	<1.5	5′
					6′	0	<1.5	
					12′	0	<1.5	
					18′	30	10	
					24′	45	12.4	
					30′	75	22.7	
					36′	65	18	
					42′	70	20	
					48′	70	20	
Barnegat Light Ship	39°46′45″	73°56′	7/4/48	1430	0	75	22.7	24′
					6′	72	20.9	
					12′	75	22.7	
					18′	70	20	
					24′	70	20	
					30′	70	20	
					36′	70	20	
					42′	70	20	
					48′	75	22.7	
					54′	80	26.3	

(continued)

TABLE I.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Barnegat Light Ship	39°46′45″	73°56′	7/4/48	1430	60′	80	26.3	
					66′	75	22.7	
					72′	70	20	
Hudson Canyon	39°36′.9	72°27′.25	9/9/48	0020	0	98	88	—
					6′	100	>115	
					12′	100	>115	
					18′	100	>115	
					24′	100	>115	
					30′	100	>115	
					36′	100	>115	
					42′	100	>115	
					48′	100	>115	
					54′	100	>115	
					60′	100	>115	
					66′	100	>115	
					72′	100	>115	
					78′	95	61	
Off Atlantic City, N. J.	39°18′	74°14′20″	7/4/48	1000	0	90	42	—
					6′	90	42	
					12′	85	32	
					18′	85	32	
					24′	85	32	
					30′	80	26.3	
					36′	85	32	
					42′	80	26.3	
					48′	80	26.3	

					54′	82	28.3	
					60′	85	32	
Ship John Light, Delaware River	39°17′42″	75°23′55″	7/1/48	1130	0	3	4.6	2′
					6′	2	4.1	
					12′	2	4.1	
					18′	9	6.5	
					24′	7	6	
					30′	0	<1.5	
Off Ship John Light, Delaware River	39°17′42″	75°23′55″	7/26/47	1300	0	2–3	4.4	14″
					6′	0	<1.5	
					12′	0	<1.5	
					18′	0	<1.5	
					24′	0	<1.5	
					30′	0	<1.5	
					36′	0	<1.5	
					B	0	<1.5	
Chesapeake Bay Bridge	38°59′.5	76°22′.7	7/31/51	1600	0	9	6.5	—
					6′	13	7.2	
					12′	18	8.1	
					18′	19	8.3	
					24′	30	10	
					30′	33	10.5	
					36′	36	10.9	
					42′	37	11	
					48′	31	10.1	
					B	30	10	
Cape May Harbor	38°56′47″	74°54′08″	7/3/48	1630	0–B	0	<1.5	—
Do.	38°56′47″	74°54′08″	7/18/47	1030	0	32	10.3	—
					6′	29	9.9	
					12′	27	9.6	
					18′	22	8.8	
					24′	24	9.2	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Cape May Harbor	38°56′47″	74°54′08″	7/18/47	1030	B	20	8.5	
				1130	0	32	10.3	—
					6′	30	10	
					12′	27	9.6	
					18′	26	9.5	
					24′	26	9.5	
					B	24	9.2	
Do.	38°56′47″	74°54′08″	7/16/47	1900	0	25	9.4	5′
					6′	25	9.4	
					12′	26	9.5	
					18′	22	8.8	
					24′	18	8.1	
					30′	18	8.1	
Brown Shoal, Delaware River	38°54′.5	75°06′	7/1/48	1700	0	25	9.4	—
					6′	32	10.3	
					12′	35	10.7	
					18′	40	11.5	
					24′	45	12.4	
					30′	45	12.4	
					36′	50	13.5	
					42′	50	13.5	
					48′	50	13.5	
Do.	38°54′.5	75°06′	7/26/47	0100	0	58	15.7	—
					6′	59	16	
					12′	54	14.5	
					18′	56	15.1	
					24′	57	15.5	

					30′	58	15.7	
					36′	60	16.3	
					42′	60	16.3	
					48′	58	15.7	
					54′	52	14	
					B	52	14	
Do.	38°54′.5	75°06′	7/26/47	0200	0	57	15.5	—
					6′	57	15.5	
					12′	55	14.8	
					18′	53	14.3	
					24′	55	14.8	
					30′	57	15.5	
					36′	55	14.8	
					42′	52	14	
					48′	45	12.4	
					54′	45	12.4	
					B	45	12.4	
Do.	38°54′.5	75°06′	7/26/47	0300	0	55	14.8	—
					6′	55	14.8	
					12′	54	14.5	
					18′	52	14	
					24′	55	14.8	
					30′	57	15.5	
					36′	58	15.7	
					42′	57	15.5	
					48′	56	15.1	
					54′	55	14.8	
					B	56	15.1	
Do.	38°54′.5	75°06′	7/25/47	1400	0	48	13	11′
					6′	52	14	
					12′	54	14.5	
					18′	52	14	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Brown Shoal, Delaware River	38°54′.5	75°06′	7/25/47	1400	24′	42	11.9	
					30′	45	12.4	
					36′	44	12.3	
					42′	42	12	
					48′	42	12	
					54′	42	12	
					B	42	12	
Do.	38°54′.5	75°06′	7/25/47	1500	0	48	13	9′
					6′	53	14.3	
					12′	54	14.5	
					18′	54	14.5	
					24′	52	14	
					30′	48	13	
					36′	49	13.3	
					42′	48	13	
					48′	42	11.9	
					54′	42	11.9	
					B	42	11.9	
Do.	38°54′.5	75°06′	7/25/47	1600	0	40	11.5	7′
					6′	38	11.2	
					12′	42	11.9	
					18′	45	12.4	
					24′	53	14.3	
					30′	56	15.1	
					36′	55	14.8	
					42′	54	14.5	
					48′	55	14.8	

					54′	55	14.8	
					B	54	14.5	
Do.	38°54′.5	75°06′	7/25/47	1700	0	38	11.2	7′
					6′	35	10.7	
					12′	43	12	
					18′	50	13.5	
					24′	56	15.1	
					30′	55	14.8	
					36′	54	14.5	
					42′	54	14.5	
					48′	52	14	
					54′	52	14	
					B	52	14	
Do.	38°54′.5	75°06′	7/25/47	1800	0	43	12	7½′
					6′	42	11.9	
					12′	42	11.9	
					18′	52	14	
					24′	54	14.5	
					30′	56	15.1	
					36′	55	14.8	
					42′	56	15.1	
					48′	56	15.1	
					54′	55	14.8	
					B	54	14.5	
Do.	38°54′.5	75°06′	7/25/47	1900	0	46	12.7	8′
					6′	46	12.7	
					12′	47	12.9	
					18′	45	12.4	
					24′	50	13.5	
					30′	56	15.1	
					36′	57	15.5	
					42′	58	15.7	

(*continued*)

TABLE I.—(*continued*)

C. SUMMER (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Brown Shoal, Delaware River	38°54′.5	75°06′	7/25/47	1900	48′	59	16	
					54′	58	15.7	
					B	56	15.1	
Do.	38°54′.5	75°06′	7/25/47	2000	0	50	13.5	—
					6′	50	13.5	
					12′	51	13.8	
					18′	56	15.1	
					24′	56	15.1	
					30′	57	15.5	
					36′	56	15.1	
					42′	59	16	
					48′	60	16.3	
					54′	61	16.7	
					B	60	16.3	
Do.	38°54′.5	75°06′	7/25/47	2100	0	53	14.3	—
					6′	53	14.3	
					12′	54	14.5	
					18′	54	14.5	
					24′	56	15.1	
					30′	58	15.7	
					36′	58	15.7	
					42′	57	15.5	
					48′	57	15.5	
					54′	60	16.3	
					B	60	16.3	
Do.	38°54′.5	75°06′	7/25/47	2200	0	46	12.7	—
					6′	42	11.9	

					12′	52	14	
					18′	55	14.8	
					24′	56	15.1	
					30′	57	15.5	
					36′	59	16	
					42′	59	16	
					48′	59	16	
					54′	58	15.7	
					B	59	16	
Do.	38°54′.5	75°06′	7/25/47	2300	0	51	13.8	—
					6′	49	13.3	
					12′	54	14.5	
					18′	57	15.5	
					24′	59	16	
					30′	63	17.3	
					36′	62	17	
					42′	59	16	
					48′	53	14.3	
					54′	52	14	
					B	50	13.5	
Do.	38°54′.5	75°06′	7/25/47	2400	0	55	14.8	—
					6′	55	14.8	
					12′	58	15.7	
					18′	61	16.7	
					24′	61	16.7	
					30′	61	16.7	
					36′	63	17.3	
					42′	59	16	
					48′	57	15.5	
					54′	56	15.1	
					B	56	15.1	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
3/10 mile off Tilghman Point Buoy	38°51'.5	76°14'.25	7/31/51	0850	0	35	10.7	6'
					6'	37	11	
					12'	36	10.9	
					18'	36	10.9	
					24'	37	11	
					30'	44	12.3	
					36'	47	12.9	
					42'	47	12.9	
Do.	38°51'.5	76°14'.25	7/29/51	1052	0	34	10.6	6'9"
					6'	31	10.1	
					12'	31	10.1	
					18'	32	10.3	
					24'	25	9.4	
					30'	15	7.6	
Shaw Bay, Eastern Bay	38°51'.5	76°11'12"	7/29/51	0945	0	18	8.1	—
					6'	14	7.4	
					12'	13	7.2	
					18'	14	7.4	
					24'	16	7.8	
					30'	17	8	
					36'	17	8	
McCries Shoal Buoy	38°51'	74°51'	7/25/47	0844	0	66	18.4	15'
					12'	62	17	
					18'	62	17	
					24'	59	16	
					30'	59	16	
					36'	59	16	

					42′	56	15.1	
McCries Shoal	38°50′.5	74°50′.3	7/16/47	1730	0	65	18	—
					12′	65	18	
					18′	68	19.2	
					24′	72	20.9	
					30′	72	20.9	
					36′	72	20.9	
					42′	70	20	
					48′	70	20	
½ mile W. of Bloody Point Light	38°50′	76°24′	7/31/51	1015	0	32	10.3	6′0″
					12′	27	9.6	
					18′	49	13.3	
					24′	54	14.5	
					30′	67	18.7	
					48′	67	18.7	
					54′	58	15.7	
					115′	45	12.4	
Off Woodland Creek entrance	38°49′50″	76°12′.25	7/31/51	0805	0	35	10.7	4′6″
					6′	35	10.7	
					12′	34	10.6	
					18′	36	10.9	
					B	34	10.6	
Miles and Wye River entrance	38°49′50″	76°72′.25	7/29/51	0900	0	29	9.9	5′11″
					6′	27	9.6	
					12′	24	9.2	
					18′	12	7	
					B	0	<1.5	
Off McCries Shoal, Delaware Bay	38°49′24″	74°50′18″	7/3/48	1500	0	70	20	—
					6′	68	19.2	
					12′	68	19.2	
					18′	72	20.9	
					24′	72	20.9	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off McCries Shoal, Delaware Bay	38°49′24″	74°50′18″	7/3/48	1500	30′	79	25.5	
					36′	79	25.5	
					42′	78	24.6	
					48′	78	24.6	
Halfway between McCries Shoal and Overfalls Light Ship	38°49′	74°56′.5	7/25/47	1030	0	60	16.3	13′
					12′	58	15.7	
					18′	63	17.3	
					24′	62	17	
					30′	62	17	
					36′	61	16.7	
					42′	60	16.3	
				—	0	55	14.8	12′
					12′	58	15.7	
					18′	61	16.7	
					24′	60	16.3	
					30′	59	16	
					36′	59	16	
					42′	59	16	
Off Overfalls Light Ship	38°48′	75°01′.5	9/9/48	1419	0	60	16.3	9½′
					6′	57	15.5	
					12′	55	14.8	
					18′	58	15.7	
					24′	58	15.7	
					30′	58	15.7	
					36′	57	15.5	
					42′	57	15.5	

					48′	58	15.7	
					54′	52	14	
					60′	42	11.9	
					66′	38	11.2	
Do.	38°48′	75°01′.5	7/25/47	1315	0	53	14.3	11′
					6′	53	14.3	
					12′	52	14	
					18′	53	14.3	
					24′	50	13.5	
					30′	47	12.9	
					36′	46	12.7	
					42′	48	13	
					48′	47	12.9	
					54′	47	12.9	
					60′	48	13	
Five-Fathom Light Ship	38°48′	74°35′.7	9/23/50	1300	0–24′	90–92	45	32′
Off Five-Fathom Light Ship	38°48′	74°35′.40″	9/9/48	1126	0	100	>115	71′
					6′	100	>115	
					12′	100	>115	
					18′	100	>115	
					24′	100	>115	
					30′	100	>115	
					36′	100	>115	
					42′	98	88	
					48′	88	37.5	
					54′	85	32	
					60′	84	30.5	
					66′	85	32	
					72′	85	32	
					78′	80	26.3	
Do.	38°48′	74°35′40″	7/4/48	0530	0	65	18	—
					6′	70	20	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Five-Fathom Light Ship	38°48′	74°35′40″	7/4/48	0530	12′	65	18	
					18′	65	18	
					24′	60	16.3	
					30′	60	16.3	
					36′	65	18	
					42′	65	18	
					48′	60	16.3	
					54′	62	17	
					60′	65	18	
					66′	65	18	
					72′	70	20	
Lewes, Del., Breakwater Harbor	38°47.′75	75°06.′15	4/22/49	1630	0	15	7.6	3′10″
					6′	14	7.4	
					12′	14	7.4	
Off Overfalls Light Ship	38°46′54″	75°01′18″	7/3/48	1200	0	60	16.3	9′
					6′	50	13.5	
					12′	64	17.7	
					18′	70	20	
					24′	74	22	
					30′	74	22	
					36′	73	21.5	
					42′	75	22.7	
					48′	76	23.3	
					54′	76	23.3	
					60′	76	23.3	
					66′	76	23.3	
					70′	76	23.3	

Off Five-Fathom Light Ship	38°44′	74°35′	7/23/47	1225	0	80	26.3	19′
					12′	78	24.6	
					18′	74	22	
					24′	70	20	
					30′	66	18.4	
					36′	64	17.7	
					42′	71	20.5	
					48′	73	21.5	
					54′	82	28.3	
					60′	84	30.5	
					72′	82	28.3	
					84′	82	28.3	
					90′	82	28.3	
					96′	82	28.3	
SE. Overfalls Light Ship	38°40′	74°52′	7/16/47	1615	0	44	12.3	—
					12′	44	12.3	
					18′	45	12.4	
					24′	49	13.3	
					30′	51	13.8	
					36′	51	13.8	
					42′	50	13.5	
					54′	50	13.5	
					60′	77	24	
					66′	70	20	
					72′	60	16.3	
					84′	60	16.3	
					96′	59	16	
Cove Point, Chesapeake Bay	38°23′12″	76°20′	7/1/47	0915	0	56	15.1	9′
					6′	48	13	
					12′	50	13.5	
					18′	46	12.7	
					24′	58	15.7	

(*continued*)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station								
Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Cove Point, Chesapeake Bay	38°23'12"	76°20'	7/1/47	0915	30'	67	18.7	
					36'	71	20.5	
					42'	67	18.7	
					48'	65	18	
					54'	65	18	
					60'	63	17.3	
					72'	62	17	
					84'	50	13.5	
					B	47	12.9	
Do.	38°23'12"	76°20'	7/1/47	1120	0	55	14.8	9'
					12'	45	12.4	
					18'	49	13.3	
					24'	65	18	
					30'	72	20.9	
					42'	68	19.2	
					54'	65	18	
					66'	64	17.7	
					78'	62	17	
					90'	58	15.7	
					B	58	15.7	
Do.	38°23'12"	76°20'	7/1/47	1220	0	62	17	9'
					12'	45	12.4	
					18'	52	14	
					30'	71	20.5	
					42'	65	18	
					54'	64	17.7	
					66'	64	17.7	

					78′	50	13.5	
					90′	55	14.8	
					B	52	14	
Do.	38°23′12″	76°20′	7/1/47	1320	0	55	14.8	9′
					12′	45	12.4	
					24′	63	17.3	
					30′	71	20.5	
					42′	67	18.7	
					54′	67	18.7	
					66′	66	18.4	
					72′	54	14.5	
					B	28	9.8	
Do.	38°23′12″	76°20′	7/1/47	1420	0	49	13.3	8½′
					12′	47	12.9	
					18′	57	15.5	
					24′	75	22.7	
					36′	64	17.7	
					48′	69	19.5	
					60′	65	18	
					66′	65	18	
					72′	63	17.3	
					78′	62	17	
					B	50	13.5	
Off Fenwick Shoal	38°17′	75°02′	7/16/47	1428	0	64	17.7	—
					12′	64	17.7	
					18′	64	17.7	
					24′	63	17.3	
					30′	65	18	
					36′	65	18	
					42′	65	18	
					48′	65	18	
					B	60	16.3	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Great Gull Bank, Whistle Buoy	38°16′.4	75°00′.4	7/16/47	1319	0	80	26.3	—
					12′	78	24.6	
					18′	78	24.6	
					24′	80	26.3	
					30′	78	24.6	
					36′	80	26.3	
					42′	80	26.3	
(FLW) Bell NE. Winter Quarter Shoal	38°03′.85	75°02′.5	7/16/47	1145	0	90	42	—
					12′	90	42	
					18′	87	35.5	
					24′	92	48	
					30′	93	51	
					36′	93	51	
					42′	90	42	
1/10 mile E. of Solomons Lump Light	38°03′	76°00′54″	7/2/47	1530	0	36	10.9	6′
					9′	32	10.3	
					15′	32	10.3	
					25′	30	10	
					B	30	10	
				1630	0	35	10.7	6′
					6′	33	10.5	
					12′	32	10.3	
					18′	32	10.3	
					24′	32	10.3	
					B	32	10.3	
Do.	38°03′	76°00′54″	7/2/47	1730	0	32	10.3	6′

					6′	35	10.7	
					12′	35	10.7	
					18′	34	10.6	
					24′	33	10.5	
					B	33	10.5	
Do.	38°03′	76°00′54″	7/2/47	1930	0	32	10.3	—
					6′	30	10	
					12′	30	10	
					18′	32	10.3	
					24′	33	10.5	
					30′	30	10	
				2030	0	32	10.3	—
					6′	32	10.3	
					12′	33	10.5	
					18′	33	10.5	
					24′	34	10.6	
					30′	32	10.3	
Do.	38°03′	76°00′54″	7/2/47	2130	0	30	10	—
					6′	30	10	
					12′	30	10	
					24′	28	9.8	
					30′	28	9.8	
					B	30	10	
				2230	0	34	10.6	—
					6′	33	10.5	
					12′	33	10.5	
					18′	32	10.3	
					24′	30	10	
					B	31	10.1	
Do.	38°03′	76°00′54″	7/2/47	2330	0	35	10.7	—
					6′	34	10.6	
					12′	33	10.5	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
1/10 mile E. of Solomons Lump Light	38°03′	76°00′54″	7/2/47	2330	18′	32	10.3	
					24′	34	10.6	
					30′	35	10.7	
5-Fathom Curve, off Assateague Island	38°02.′6	75°10.′7	7/16/47	1100	0	55	14.8	12′
					12′	54	14.5	
					18′	68	19.2	
					24′	64	17.7	
					30′	63	17.3	
					36′	60	16.3	
					B	40	11.5	
Do.	38°02.′6	75°10.′7	7/15/47	1130	0	—	—	12′
					6′	50	13.5	
					12′	48	13	
					18′	68	19.2	
					24′	65	18	
					30′	60	16.3	
					36′	77	24	
10-Fathom Curve, off Winter Quarter Shoal	37°57′	75°05.′5	7/16/47	1000	0	83	29.5	—
					12′	82	28.3	
					18′	82	28.3	
					24′	80	26.3	
					32′	82	28.3	
					36′	78	24.6	
					42′	74	22	
					48′	74	22	
					54′	72	20.9	
					60′	70	20	

Do.	37°57′	75°05′.5	7/15/47	1000	0	—	—	28′
					6′	85	32	
					12′	82	28.3	
					18′	78	24.6	
					24′	84	30.5	28′
					30′	80	26.3	
					36′	80	26.3	
					42′	75	22.7	
					48′	75	22.7	
					54′	77	24	
					B	77	24	
1 mile E. Tangier Island, Chesapeake Bay	37°48′	75°58′	7/3/47	1030	0	40	11.5	7′
					6′	40	11.5	
					12′	40	11.5	
					18′	39	11.4	
					24′	10	6.6	
					30′	4	5	
					B	3	4.6	
				1130	0	40	11.5	—
					6′	38	11.2	
					12′	38	11.2	
					18′	36	10.9	
					24′	34	10.6	
					30′	2	4.1	
Do.	37°48′	75°58′	7/3/47	1230	0	20	8.5	4′
					6′	20	8.5	
					12′	20	8.5	
					18′	30	10	
					24′	10	6.6	
					B	2	4.1	
				1330	0	25	9.4	—
					6′	20	8.5	

(continued)

TABLE 1.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
1 mile E. Tangier Island, Chesapeake Bay	37°48′	75°58′	7/3/47	1330	12′	20	8.5	
					18′	15	7.6	
					24′	10	6.6	
					B	2	4.1	
Do.	37°48′	75°58′	7/3/47	1430	0	24	9.2	—
					6′	24	9.2	
					12′	24	9.2	
					18′	23	9	
					24′	22	8.8	
					30′	10	6.6	
Bell Buoy (FLW) ZTL, off Chincoteague Inlet	37°48′	75°18′	7/16/47	0755	0	75	22.7	—
					12′	75	22.7	
					18′	40	11.5	
					24′	40	11.5	
					30′	35	10.7	
					B	20	8.5	
Off Black Fish Bank	37°47′	75°07′	7/16/47	0845	0	85	32	—
					12′	85	32	
					18′	85	32	
					24′	85	32	
					30′	80	26.3	
					36′	83	29.5	
					42′	78	24.6	
					48′	87	35.5	
					54′	75	22.7	
					60′	75	22.7	
Off Chincoteague Inlet	37°46′	75°25′	7/15/47	—	0	33	10.5	6′

					6′	24	9.2	
					12′	16	7.8	
					18′	8	6.2	
					B	2	4.1	
Chesapeake Bay Buoy............................	37°41′	76°12′.5	7/4/47	1330	0	45	12.4	8′
					6′	37	11	
					12′	36	10.9	
					18′	37	11	
					24′	38	11.2	
					30′	40	11.5	
					36′	38	11.2	
					42′	2	4.1	
					B	2	4.1	
Off Wolf Trap Light, Chesapeake Bay.............	37°23′	76°10′	7/5/47	1300	0	32	10.3	—
					6	20	8.5	
					12′	19	8.3	
					18′	29	9.9	
					24′	27	9.6	
					30′	22	8.8	
					36′	22	8.8	
					42′	19	8.3	
Horseshoe Middle Grounds, Chesapeake Bay.........	37°05′35″	76°09′40″	7/12/47	1000	0	53	14.3	10′
					6	49	13.3	
					12′	46	12.7	
					18′	45	12.4	
					24′	54	14.5	
					32′	50	13.5	
					B	50	13.5	
				1100	0	57	15.5	10′
					6′	51	13.8	
					12′	50	13.5	
					18′	52	14	

(*continued*)

TABLE I.—(*continued*)

C. SUMMER (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Horseshoe Middle Grounds, Chesapeake Bay	37°05′35″	76°09′40″	7/12/47	1100	24′	42	11.9	
					32′	45	12.4	
Do.	37°05′35″	76°09′40″	7/12/47	1200	0	54	14.5	10′
					6′	47	12.9	
					12′	45	12.4	
					18′	50	13.5	
					24′	42	11.9	
					32′	46	12.7	
				1400	0	58	—	10′
					6′	45	12.4	
					12′	46	12.7	
					18′	49	13.3	
					24′	42	11.9	
					32′	20	8.5	
Do.	37°05′35″	76°09′40″	7/12/47	1500	0	53	14.3	10′
					6′	52	14	
					12′	43	12	
					18′	47	12.9	
					24′	30	10	
					32′	30	10	
				1600	0	50	13.5	—
					6′	50	13.5	
					12′	42	11.9	
					18′	42	11.9	
					24′	20	8.5	
					32′	12	7	
Do.	37°05′35″	76°09′40″	7/12/47	1700	0	49	13.3	—

					6′	48	13	
					12′	46	12.7	
					18′	40	11.5	
					24′	27	9.6	
					32′	20	8.5	
					B	18	8.1	
				1800	0	46	12.7	—
					6′	46	12.7	
					12′	44	12.3	
					18′	37	11	
					24′	28	9.8	
					32′	35	10.7	
					B	30	10	
Do.	37°05′35″	76°09′40″	7/12/47	1900	0	45	12.4	—
					6′	44	12.3	
					12′	35	10.7	
					18′	25	8.1	
					24′	33	10.5	
					32′	30	10	
				2000	0	48	13	—
					6′	44	12.3	
					12	42	11.9	
					18′	30	10	
					24′	28	9.8	
					32′	26	9.5	
Do.	37°05′35″	76°09′40″	7/12/47	2100	0	47	12.9	—
					6′	45	12.4	
					12	38	11.2	
					18′	36	10.9	
					24′	38	11.2	
					32′	38	11.2	
				2200	0	48	13	—

(continued)

TABLE I.—(*continued*)

C. SUMMER (*concluded*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Horseshoe Middle Grounds, Chesapeake Bay	37°05′35″	76°09′40″	7/12/47	2200	6′	49	13.3	
					12′	47	12.9	
					18′	40	11.5	
					24′	38	11.2	
					32′	37	11	
Chesapeake Light Ship	37°00′	75°.7	7/14/47	1300	0	84	30.5	30′
					12′	82	28.3	
					18′	92	48	
					24′	95	61	
					30′	95	61	
					36′	94	55	
					42′	94	55	
					48′	90	42	
					B	78	24.6	
Do.	37°00′	75°.7	7/14/47	1400	0	84	30.5	26½′
					18′	92	48	
					24′	95	61	
					30′	95	61	
					36′	94	55	
					42′	95	61	
					48′	82	28.3	
					B	80	26.3	
Do.	37°00′	75°.7	7/14/47	1500	0	84	30.5	—
					18′	87	35.5	
					24′	95	61	
					30′	94	55	
					36′	94	55	

					42′	92	48	
					48′	86	33.5	
					54′	80	26.3	
					B	80	26.3	
Do.	37°00′	75°.7	7/14/47	1600	0	82	28.3	—
					12′	84	30.5	
					18′	95	61	
					24′	94	55	
					30′	92	48	
					36′	92	48	
					42′	94	55	
					48′	80	26.3	
					B	80	26.3	
D. AUTUMN								
Swan Point, Chesapeake Bay	39°07′40″	76°20′	11/1/47	1445	0	28	9.8	5′
					6′	25	9.4	
					12′	23	9	
					18′	20	8.5	
					24′	5	5.5	
Chesapeake Bay Bridge	38°59′.5	76°22′.7	11/11/51	1410	0	48	13	8′
					6′	44	12.3	
					12′	46	12.7	
					18′	53	14.3	
					24′	57	15.5	
					30′	47	12.9	
					36′	40	11.5	
					42′	42	11.9	
					48′	38	11.2	
Cape May, Sea Buoy	38°56′47″	74°54′08″	11/5/51	0950	0	9	6.5	35″
					6′	7	6	

(continued)

TABLE 1.—(*continued*)

D. AUTUMN (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Cape May, Sea Buoy	38°56′47″	74°54′08″	11/5/51	0950	12′	8	6.2	
					18′	6	5.7	
					24′	6	5.7	
Cape May Harbor, dock	38°56′47″	74°54′08″	11/4/51	1240	0	13	7.2	60″
					6′	13	7.2	
					12′	12	7	
					B	13	7.2	
Do.	38°56′47″	74°54′08″	11/4/51	1210	0	15	7.6	—
					6′	16	7.8	
					12′	13	7.2	
					B	14	7.4	
Do.	38°56′47″	74°54′08″	11/4/51	1205	0	20	8.5	44″
					6′	20	8.5	
					12′	12	7	
					B	12	7	
Do.	38°56′47″	74°54′08″	10/31/51	0820	0	27	9.6	4′9″
					6′	27	9.6	
					12′	27	9.6	
					18′	27	9.6	
					22′	24	9.2	
					B	17	8	
Do.	38°56′47″	74°54′08″	10/31/51	0650	0	22	8.8	4½′
					6′	24	9.2	
					12′	20	8.5	
					B	10	6.6	
Do.	38°56′47″	74°54′08″	10/29/51	2030	0	20	8.5	5′
					6′	20	8.5	

					12′	12	7	
					B	5	5.5	
Brickhouse Bay, Chesapeake Bay	38°55′.2	76°22′.75	11/7/49	0930	0–B	52–55	14.4	10′
Brown Shoal, Delaware River	38°54′.5	75°06′	11/5/51	1150	0	34	10.6	6′
					6′	34	10.6	
					12′	48	13	
					18′	33	10.5	
					24′	36	10.9	
					30′	39	11.4	
					36′	27	9.6	
					42′	23	9	
					48′	24	9.2	
					54′	17	8	
Off Tilghman Point, Eastern Bay, Chesapeake Bay	38°51′.5	76°14′.25	11/13/51	1613	0	52	14	15′5″
					6′	52	14	
					12′	57	15.5	
					18′	69	19.5	
					24′	70	20	
					B	70	20	
Do.	38°51′.5	76°14′.25	11/12/51	1505	0	64	17.7	12′
					6′	63	17.3	
					12′	65	18	
					18′	70	20	
					24′	72	20.9	
					30′	73	21.5	
					B	73	21.5	
Do.	38°51′.5	76°14′.25	11/12/51	1130	0	61	16.7	14′
					6′	65	18	
					12′	62	17	
					18′	66	18.4	
					24′	74	22	
					30′	78	24.6	

(*continued*)

TABLE 1.—(*continued*)

D. AUTUMN (*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Shaw Bay, Eastern Bay	38°51'.5	76°11'12"	11/15/51	0845	0	68	19.2	15'8"
					6'	66	18.4	
					12'	71	20.5	
					18'	74	22	
Do.	38°51'.5	76°11'12"	11/14/51	1459	0	67	18.7	14+
					6'	69	19.5	
					12'	60	16.3	
					18'	60	16.3	
Overfalls Shoal vicinity	38°51'.5	74°56'.5	11/5/51	1050	0	20	8.5	58"
					6'	19	8.3	
					12'	13	7.2	
					18'	17	8	
					24'	11	6.8	
					30'	9	6.5	
McCries Shoal	38°51'	74°51'	10/30/51	1200	0–B	60–64	17	14'
East of Kent Point, Chesapeake Bay	38°50'11"	76°21'15"	11/15/51	1635	0	49	13.3	10'
					6'	58	15.7	
					12'	59	16	
					18'	61	16.7	
					24'	61	16.7	
					30'	62	17	
Do.	38°50'11"	76°21'15"	11/15/51	1505	0	50	13.5	8'4"
					6'	52	14	
					12'	62	17	
					18'	64	17.7	
					24'	58	15.7	
					B	58	15.7	

Do.	38°50′11″	76°21′15″	11/15/51	1329	0	45	12.4	10′2″
					6′	49	13.3	
					12′	56	15.1	
					18′	64	17.7	
					24′	66	18.4	
					30′	66	18.4	
1.3 miles W. of Bloody Point Light, Chesapeake Bay	38°50′	76°25′	11/2/47	1200	0	48.5	13.1	14′
					6′	47	12.9	
					12′	46	12.7	
					18′	46	12.7	
					24′	46	12.7	
					30′	47	12.9	
					36′	47	12.9	
					42′	55	14.8	
					48′	30	10	
Chesapeake Bay, Choptank	38°39′.5	76°12′.3	11/6/47	1150	0	66	18.4	13′
					6′	65	18	
					12′	61	16.7	
					18′	68	19.2	
					24′	64	17.7	
				—	0	60	16.3	—
					6′	60	16.3	
					12′	60	16.3	
					18′	66	18.4	
					24′	63	17.3	
Cambridge, Md., Harbor	38°34′.35	76°04′.4	11/6/47	1530	0	35	10.7	6′
					6′	25	9.4	
					12′	25	9.4	
					B	25	9.4	
Choptank off Cambridge, Md	38°34′.85	76°03′.7	11/2/47	1640	0–B	37	11	—
Do.	38°34′.85	76°03′.7	11/6/47	1500	0–B	52–53	14.1	10′

(*continued*)

TABLE 1—(*concluded*)

D. AUTUMN (*concluded*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Date	Time	Depth	Hydro. reading	Equiv. S.D.	Actual S.D.
Off Mouth of Popes Creek, Potomac River	38°20′	77°00′35″	11/30/42	1458	0	—	—	3½′
Point Patience, Solomons Island, Md.	38°19′30″	76°28′30″	11/29/42	0835	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/29/42	1035	0	—	—	8′
Do.	38°19′30″	76°28′30″	11/28/42	1000	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/28/42	1055	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/28/42	1153	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/28/42	1303	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/28/42	1400	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/28/42	1445	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/27/42	0803	0	—	—	8′2″
Do.	38°19′30″	76°28′30″	11/27/42	0902	0	—	—	8′4″
Do.	38°19′30″	70°28′30″	11/27/42	0958	0	—	—	8′
Do.	38°19′30″	76°28′30″	11/27/42	1055	0	—	—	9′
Do.	38°19′30″	76°28′30″	11/27/42	1155	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/27/42	1300	0	—	—	9′
Do.	38°19′30″	76°28′30″	11/27/42	1404	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/27/42	1449	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/27/42	1555	0	—	—	8½′
Do.	38°19′30″	76°28′30″	11/26/42	1053	0	—	—	8′
Do.	38°19′30″	76°28′30″	11/26/42	1239	0	—	—	9′4″
Do.	38°19′30″	76°28′30″	11/26/42	1310	0	—	—	9′
Off Cedar Point, Potomac River	38°18′36″	76°20′	11/29/42	1445	0	—	—	8′
Off Piney Point, Potomac River	38°08′	76°30′45″	11/30/42	0940	0	—	—	7½′
Do.	38°08′	76°30′45″	11/30/42	1055	0	—	—	8½′

TABLE 2.—*Various types of information concerning transparency of water at stations listed*

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Paraquameter	Scattering (units of scatter matter)
Harbor, Red Bay, Labrador................	51°45′	56°22′	0	39′2″	57′				
			6′						5
			30′						6
Off French Point, Newfoundland............	51°40′	55°28′20″	0	20′7″	36′2″				
			6′						8
			36′						14
			72′						12
Pistolet Bay, Newfoundland................	51°30′.2	55°43′.0	0	13′3″	21′10″	32′			
			6′						12
Belle Isle Strait, Newfoundland............	57°30′.0	56°37′.5	0	33′10″	65′	114′	4200		
			6′						3
			36′						3
			72′						3
Off Cape Fox, Newfoundland..............	50°51′10″	55°50′30″	0	26′2″	46′4″	105′	1500		
			6′						6
			42′						7
			72′						6
Off Riche Point, Newfoundland............	50°43′30″	57°32′30″	6′						4
Fouche Harbor, off NE. Cove, Newfoundland.	50°31′.0	56°18′.0	0	6′2″	14′	21′2″	900		
			6′						14
			36′						7
			72′						5
Off Fouche Harbor, Newfoundland.........	50°29′.0	56°11′.2	0	29′3″	49′6″	110′	1000		
			6′						5
			36′						5
			72′						6

(continued)

TABLE 2.—(*continued*)

Location of station									
Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Channel beween St. Barbe Islands..........	50°12.′0	55°47.′0	0	39′4″	59′		1200		
			6′						6
			36′						8
			72′						8
Off Gull Island, 1 mile S. of Newfoundland..	49°59.′0	55°20.′0	0				2000		
			6′						6
			36′						7
			72′						6
Off Brocalhou Light, Newfoundland.........	49°43′40″	54°30′30″	0				1500		
			6′						6
			72′						5
Twillingate Harbor, Newfoundland..........	49°40.′5	54°46.′0	0	18′9″	31′2″	52′6″	1800		
			6′						9
			36′						10
			54′						7
Off Offer Wadham Island, Newfoundland...	49°37′25″	53°45.′0	6′						4
			36′						5
			72′						4
Approx. 10 miles S. of Funk Island, Newfoundland	49°37.′0	53°11.′0	0				6300		
			6′						5
			36′						5
			72′						5
Little Seldom-Come-By Harbor, Newfoundland	49°35′45″	54°13.′0	0	17′6″	32′	66′			
			6′						7
Off Little Port Head Light, Newfoundland..	49°07′00″	58°27′00″	0		45′2″	84′			
			6′						5

			36′					6
			72′					6
Off Fox Point, Humber Arm, Newfoundland.	49°01′00″	58°06′30″	0	18′5″	36′6″	74′	625	
			6′					7
			36′					5
			72′					4
Off Cape Bonavista, Newfoundland..........	48°42′.0	52°47′.0	6′					3
			36′					5
			72′					4
Off Cape Ray, Newfoundland...............	47°34′45″	59°22′00″	0	18′7″	38′2″	77′	2000	
			6′					10
			36′					8
			72′					8
Port Aux Basque Harbor, Newfoundland....	47°34′37″	59°08′31″	0		25′	37′11″		
			6′					12
			24′					9
St. John's Harbor, Newfoundland...........	47°33′47″	52°42′27″	0	10′10″	18′1″	34′	7200	
			18′					14
Cape Spear, bearing 217°T—distant 1.3 miles, Newfoundland	47°33′.5	52°36′.8	0				7000	
			6′					3
			36′					3
			72′					3
Cabot Strait, Newfoundland................	46°55′58″	59°38′00″	0	46′10″	89′			
			6′					4
			36′					5
			72′					4
Cape Race, bearing 288°T—distant 11.3 miles, Newfoundland	46°38′.3	52°59′.5	0				1800	
			6′					8

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Paraquameter	Scattering (units of scatter matter)
Cape Race, bearing 288°T—distant 11.3 miles Newfoundland	46°38′.3	52°59′.5	36′						8
			72′						6
10 miles off Sydney Harbor, Sea Buoy, Nova Scotia	46°27′00″	60°01′30″	0	35′	77′8″				
			6′						8
			36′						5
			72′						6
Sydney Harbor, Sea Buoy, Nova Scotia	46°18′12″	60°08′00″	0	19′6″	22′5″				
			6′						10
			30′						10
Sydney Harbor, Nova Scotia	46°08′31″	60°12′02″	0		17′3″	24′4″			
			6′						16
Bras d'Or Lake, Nova Scotia	46°05′30″	60°41′00″	0	11′7″	23′8″	34′2″			
			6′						11
			36′						8
			72′						15
Bras d'Or, Nova Scotia	55°50′15″	60°50′45″	0	17′10″	28′5″	41′2″	6000		
			6′						5
			36′						6
			72′						5
Off Horsehead Shoals, Nova Scotia	45°35′30″	60°52′45″	0	13′1″	23′6″	36′4″			
			6′						15
			36′						10
			66′						6
St. Pierre Bank, Nova Scotia	45°34′	57°33′	0				7800		
			6′						5
			36′						6
			72′						4

Off Cape Canso, Nova Scotia..............	45°21'07"	60°51'06"	0	23'11"	34'	50'2"	5200	
			6'					5
			36'					4
			78'					4
Country Harbor, Nova Scotia.............	45°10'55"	61°43'10"	0	16'5"	26'4"	39'	7000	
			6'					11
			24'					5
Do.	45°10'55"	61°43'10"	0		38'8"	49'2"		
			6'					12
			24'					4
Sea Buoy off Country Harbor, Nova Scotia..	45°02'00"	61°32'42"	0	22'11"	38'4"	53'7"	2500	
			6'					12
			36'					12
			72'					10
Off Yankee Jack, Nova Scotia, Sheet Harbor, Sea Buoy	44°42'57"	62°28'52"	0	44'2"	53'5"	85'	5800	
			6'					4
			36'					7
			72'					4
Bedford Basin, Halifax, Nova Scotia.......	44°41'36"	63°38'24"	0	11'6"	19'1"	35'1"	8200	
			6'					12
			36'					13
			72'					3
Halifax Harbor, Nova Scotia, by oil dock....	44°39'02"	63°34'18"	0					5
Whst'l John Bank, Nova Scotia............	44°35'30"	62°49'45"	0	34'11"	52'9"	over 98'	8200	
			6'					3
			36'					4
			72'					6
Entrance Halifax Harbor, Nova Scotia......	44°31'48"	63°30'20"	6'					3
			36'					3
			72'					3

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Blue Hill Harbor, Maine	44°24′20″	68°33′45″	0	8′3″	14′4″	23′3″	4200		
			6′						19
Off Long Island, Blue Hill Bay	44°18′20″	68°30′12″	0	12′2″	20′10″	31′1″	4200		
			6′						6
			24′						8
			72′						7
Eggemoggin Beach, Spar 12	44°16′12″	68°37′12″	0	9′11″	21′6″	37′4″	8800		
			6′						7
			30′						22
Off Long Island, Blue Hill Bay	44°18′20″	68°30′12″	0	9′9″	17′7″	29′8″	7400		
			6′						8
			36′						7
			72′						15
Off Little Duck Island, Frenchman's Bay	44°11′18″	68°14′54″	0	22′	31′	55′	6800		
			6′						6
			36′						11
			72′						4
14 miles N. of Mt. Desert Rock Lighthouse	44°11′00″	68°01′30″	0		21′6″	33′5″			
			6′						16
			36′						14
			72′						16
Jericho Bay, off Sunken Egg Rock	44°10′53″	68°21′12″	0	7′11″	13′6″	23′11″	5000		
			6′						12
			36′						8
			72′						6
Off Cross Ledge, Nova Scotia	44°10′30″	63°39′30″	6′						3
			36′						2
			72′						3

Swan's Island Harbor	44°08′36″	68°26′42″	0	8′5″	11′8″	18′9″	7200	
			6′					15
			24′					14
Do.	44°08′36″	68°26′42″	0		13′1″	19′1″		
			6′					14
Penobscot Bay Buoy Whst'l "CIA" Ref.	44°08′00″	69°00′18″	0	15′8″	28′3″	49′2″	8400	
			6′					6
			36′					8
			72′					9
Swan's Island Sea Buoy	44°07′30″	68°27′36″	0	8′6″	17′6″	27′8″	6200	
			6′					15
			36′					13
			72′					12
30 miles N. of Emerald Bank	44°06′.5	62°20′.6	0				7000	
			6′					3
			36′					3
			78′					4
Off Long Island, Blue Hill Bay	44°04′00″	68°25′00″	0	11′5″	17′5″	27′6″	5400	
			6′					14
			36′					14
			72′					8
Mouth, Bay of Fundy	44°01′30″	67°21′30″	0		40′4″	62′6″		
			6′					5
			48′					7
Two Bush Channel Whst'l. (S-L FLW) "TBI"	43°58′18″	69°00′18″	0	19′4″	27′7″	42′4″	6000	
			6′					9
			36′					18
			72′					10
Pemaquid Harbor, Maine	43°52′51″	69°31′30″	0	7′9″	8′11″	13′4″		
			6′					20

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Pemaquid Harbor, Maine	43°52′51″	69°31′30″	0		21′11″	24′2″			
			6′						10
Yarmouth Harbor, Nova Scotia	43°50′15″	66°07′16″	0	2′	4′4″	8′2″			
			6′						37
Do.	43°50′15″	66°07′16″	0	4′6″	4′6″	9′1″			
			6′						30
John's Bay, off Pemaquid Light	43°50′00″	69°32′00″	0	15′10″	30′	46′8″	7200		
			6′						3
			42′						5
			78′						4
Off Lucker Light Ship, Nova Scotia	43°46′45″	66°33′40″	0	33′4″	38′5″	70′+	6400		
			6′						9
			54′						8
Yarmouth Harbor entrance, Nova Scotia, Bell #11.34 Cat Rock	43°46′42″	66°09′13″	0	13′4″	20′	31′5″	8200		
			6′						13
			36′						15
			66′						13
Falmouth-Foreside, Maine	43°43′45″	70°12′10″	0	5′2″	12′7″	19′7″			
			6′						14
			0		11′3″	20′4″			
			6′						16
Southeast of Port Joli, Nova Scotia	43°42′30″	64°42′00″	0		46′	97′			
			6′						3
			36′						5
			66′						5

Off Bantam Rock, Whst'l (FLW) "16 BR"	43°41'54"	69°38'06"	0	14'1"	21'7"	39'3"	7200	
			6'					13
			30'					11
			72'					4
Portland Harbor Anchorage	43°39'57"	70°14'56"	0		11'7"	19'5"		
			6'					12
			18'					11
Off Outer Green Island	43°38'00"	69°37'30"	0	9'2"	14'4"	30'3"	8800	
			6'					10
			36'					11
			72'					6
Off Portland Head Light	43°32'35"	70°12'24"	0	3'4"	9'1"	13'1"	6000	
Old Antony Rock (FLW) "22" Whst'l	43°27'54"	70°27'54"	0	6'1"	12'6"	21'4"	2200	
			6'					18
			30'					23
Off Whale Rock Ledge	43°26'24"	70°17'30"	0	9'10"	18'8"	33'2"	2200	
			6'					13
			42'					24
			72'					8
Cape Porpoise Buoy (FLW) "2CP"	43°20'18"	70°23'24"	0	8'	17'5"	35'5"	3400	
			6'					15
			48'					11
			78'					14
Whst'l (FLR) off Southwest Ledge, Nova Scotia	43°20'08"	65°40'54"	0	40'2"	44'	92'	7000	
			6'					3
			36'					3
			72'					4
Off Bald Head Cliff	43°12'06"	70°28'47"	0	11'4"	21'10"	43'4"	4800	
			6'					6

(*continued*)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aquameter	Scattering (units of scatter matter)
Off Bald Head Cliff	43°12′06″	70°28′47″	54′						7
			78′						5
Portsmouth Harbor, N. H.	43°04′24″	70°43′28″	0	7′5″	11′	21′4″			
			6′						14
			24′						15
Do.	43°04′24″	70°43′28″	0	9′	16′9″	28′10″			
			6′						18
			30′						17
Do.	43°04′24″	70°43′28″	0		26′9″	42′8″			
			6′						7
			30′						10
York Ledge Whst'l (FLR) "24 YL"	43°04′24″	70°34′30″	0	9′4″	16′5″	30′2″	7200		
			6′						12
			42′						21
			78′						27
Kitts Rock Whst'l Buoy "2 KR," off Portsmouth, N. H.	43°02′54″	70°41′24″	0	12′9″	25′	36′3″	8800		
			6′						11
			30′						6
9.2 miles off Newburyport, Mass.	42°50′27″	70°36′22″	0	3′6″	6′9″	15′4″			
			6′						13
			36′						15
			78′						24
Off Cape Ann, Mass., Whst'l (FLO) "2"	42°38′06″	70°36′18″	0	11′	20′8″	39′7″	7800		
			6′						9
			42′						8
			84′						5

Gloucester Harbor, Mass., Can No. 5........	42°36′20″	70°40′24″	0					25
			18′					22
			0					23
			18′					21
Do.	42°36′20″	70°40′24″	0					24
			18′					21
			0					20
			18′					22
Do.	42°36′20″	70°40′24″	0					20
			18′					15
			0					22
			18′					13
Off Cape Ann, Mass., 3 miles E. of (FLR) "2 A"	42°34′14″	70°39′14″	0	5′2″	12′2″	22′10″	7200	
			6′					13
			48′					8
6.6 miles E. of Boston Light Ship...........	42°16′36″	70°36′36″	0	10′3″	18′0″	32′8″	7200	
			6′					13
			42′					11
			78′					4
? S. of Brown's Bank......................	42°05′	65°47′	6′					3
			36′					5
			72′					4
Whst'l Buoy, Massachusetts Bay............	42°01′39″	70°28′24″	0	9′9″	17′10″	37′3″	8200	
			6′					12
			36′					10
			72′					12
Buzzards Bay entrance, Cape Cod Canal.....	41°40′45″	70°40′35″	0	3′3″	12′10″	18′9″	7500	
			6′					9
			24′					9

(*continued*)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
(FLW) "5," Buzzards Bay, off New Bedford.	41°31′00″	70°50′30″	0	5′9″	11′11″	20′5″	7900		
			6′						13
			30′						14
			54′						22
(FLW) "16" Gong, off Edgartown Harbor, Marthas Vineyard	41°28′25″	70°29′00″	0	6′4″	10′	16′2″	8200		
			6′						25
			24′						25
			42′						30
(FLW) "16" Gong, off Edgartown Harbor, Marthas Vineyard	41°28′25″	70°29′00″	0		13′7″	21′5″	7000		
			6′						23
			30′						20
			48′						26
Between Block Island and Vineyard Sound..	41°19′34″	71°14′20″	0	5′8″	35′8″	72′5″			
			6′						6
			30′						6
			72′						5
Harbor (Great Salt Pond), Block Island...	41°11′40″	71°34′30″	0			20′3″			
			6′						14
			0		12′5″	17′5″			
			6′						15
Off Nashawena Island, Vineyard Sound.....	41°31′40″	70°44′30″	0		14′6″	21′4″	9000		
			6′						6
			30′						7
			48′						10

Off (FLG) "3" Gong, 2½ miles SE. entrance Block Island Sound	41°04'42"	71°44'35"	0	17'11"	27'10"		
			6'				14
			30'				15
			54'				17
(FLW) "2A" Bell, off Bridgehampton	40°52'30"	72°13'30"	0	18'10"	28'8"		
			6'				5
			30'				6
			54'				5
6 miles off Nantucket Light Ship	40°49'	69°21'	42'				10
			78'				12
Whst'l Buoy (FLW) "4," off Fire Island	40°35'33"	73°17'48"	0	13'6"	23'11"		
			6'				8
			36'				10
New York Harbor Narrows, off Coney Island	40°34'15"	74°00'57"	0	4'7"	6'6"		
			6'				30
			24'				20
Whst'l Buoy "4," off Far Rockaway	40°31'36"	73°43'40"	0	7'11"	11'6"		
			6'				21
			30'				10
			54'				11
New York Harbor approach, South Channel, vicinity Scotland Light Ship	40°26'40"	73°56'00"	0	3'5½"	5'7"	7200	
			6'				30
			30'				10
			48'				7
Anchorage W. of Sandy Hook	40°26'40"	74°00'20"	0	2'0"	4'6"		
			15'				32
Off Shewsbury Rock Light Buoy (FLW) Bell "1"	40°20'39"	73°55'36"	0	3'11"	5'4"		
			6'				35

(*continued*)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Off Shewsbury Rock Light Buoy (FLW) Bell "I"	40°20′39″	73°55′36″	24′						10
			42′						7
Barnegat Light Ship	39°46′45″	73°56′00″	0	12′	21′3″	40′8″			
			6′						15
			36′						18
Hudson Canyon	39°36′.9	72°27′.25	6′						1
			36′						1
			78′						3
1½ miles E. of (QK FLR) Gong, off Atlantic City	39°18′00″	74°14′20″	0			43′10″			
			6′						13
			36′						10
			54′						12
Sta. 1, off Ship John Light, Delaware River	39°17′42″	75°23′55″	18′						35
Do.	39°17′42″	75°23′55″	0						62
			6′						63
			18′						62
			30′						60
Do.	39°17′42″	75°23′55″	0						56
			18′						53
			36′						54
Do.	39°17′42″	75°23′55″	0						50
			18′						47
			30′						53
Do.	39°17′42″	75°23′55″	0				2500		49
			18′						68
			30′						72

Do.	do.	do.	0				6500	48
			18′					61
			30′					59
Do.	do.	do.	0				4800	43
			18′					56
			30′					47
Do.	do.	do.	0				3600	42
			18′					53
			30′					40
Do.	do.	do.	0		23′	25′	1100	42
			18′					42
			30′					38
Do.	do.	do.	0		23″			52
			18′					39
			30′					38
Do.	do.	do.	0					45
			18′					32
			30′					35
Do.	do.	do.	0					65
			18′					39
			30′					55
Do.	do.	do.	0					70
			18′					52
			30′					49
Do.	do.	do.	0		22″	46″		
Do.	do.	do.	0		0	4″		
Sta. 10, off Swan Point, Chesapeake Bay....	39°07′40″	76°20′	0				6400	11
			18′					22
Do.	do.	do.	0	27″				
Do.	do.	do.	0	48″				
Chesapeake Bridge	38°59′.5	76°22′.7	0				4900	

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Cape May Harbor (Rafferty Marina Dock)	38°56′47″	74°54′08″	0				4200		16
Do.	38°56′47″	74°54′08″	0				4500		17
Do.	do.	do.	0				600		9
Do.	do.	do.	0				8		2.1
Do.	do.	do.	0						22½
Do.	do.	do.	0–B						40
			5′		5′7″	8′			
Do.	do.	do.	0		64″	78″			19
Do.	do.	do.	0	73″					12
Do.	do.	do.	0	38″					32
Buckhouse Bar, Chesapeake Bay	38°55′.2	76°22′.75	0–B					152″	4
Sta. 2, Brown Shoal, Delaware Bay	38°54′.5	75°06′	0				6800		13
			24′						12½
			42′						18
Do.	do.	do.	0				6600		12½
			24′						13
			42′						20½
Do.	do.	do.	0				5400		11
			30′						14
			42′						17
Do.	do.	do.	0				5400		13½
			24′						12
			42′						18
Do.	do.	do.	0				4400		13
			24′						10
			42′						17

Do.	do.	do.	0			5400		10
			24′					13
			42′					18½
Do.	do.	do.	0			4100		11
			24′					14
			42′					18
Do.	do.	do.	0	11′3″	16′9″			10
			24′					11
			42′					18
Do.	do.	do.	0	50″	7′9″			
			6′					19
			24′					25
			42′					26
Do.	do.	do.	0	79″	130″			24
			12′					23
			30′					39
			42′					41
Do.	do.	do.	0			6200		
Do.	do.	do.	0			3000		
Do.	do.	do.	0			180		
Do.*	do.	do.	0					
Off Tilghman Point, Eastern Bay, Chesapeake Bay	38°51′.5	76°14′.25	0			420		
Do.	do.	do.	0			2800		
Do.	do.	do.	0			4200		7
3/10 mile off Tilghman Point Buoy	38°51′.5	76°14′.25	0			4400		
			12′				116″	

* Screen Point, 11′8″.

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Paraquameter	Scattering (units of scatter matter)
Shaw Bay, Eastern Bay, Chesapeake Bay....	38°51'.5	76°11'12"	0				650		5
Do.	do.	do.	0				280		
Do.	do.	do.	0					80"	
McCries Shoal	38°51'	70°51'	0–B						10
Do.	do.	do.	0				1400		6½
			18'						9
			36'						14
Do.	do.	do.	0	74"		94"			
E. of Kent Point 16 miles E. of Eastern Bay, Chesapeake Bay	38°50'11"	76°21'15"	0				320		
Do.	do.	do.	0				3000		4½
Do.	do.	do.	0				1600		5½
½ mile W. of Bloody Point Light, Chesapeake Bay	38°50'	76°24'	0				4400		
Bloody Point Light, Chesapeake Bay (0.8 mile W. of)	38°50'	76°25'	0	41"					22
			30'						24
			60'						26
Do.	do.	do.	0	5'					
Off Woodland Creek entrance, Eastern Bay, Chesapeake Bay	38°49'50"	76°12'.25	0				5000		
Miles and Wye River entrance , Eastern Bay, Chesapeake Bay	38°49'50"	76°72'.5	0				1800	102"	
			6'					112"	
			12'					104"	
			18'					90"	
			Bot.					60"	

Off McCries Shoal, Delaware Bay..........	38°49′24″	74°50′18″	0	5′	127′	200″		
			6′					15
			24′					14
			42′					12
2.6 miles SE. x E. of McCries Shoal Buoy...	38°48′.6	74°47′.5	0	13′4″	16′6″	25′10″	1800	
			6′					6½
			36′					4
			60′					4
Overfalls Light Ship......................	38°48′	75°01′.5	0	9′4″	15′1″	26′7″	900	6½
			36′					12
			66′					11½
			0	5′	10′	18′		
Off Overfalls Light Ship..................	do.	do.	6′					15
			54′					21
Five-Fathom Light Ship....................	38°48′	74°35′40″	0					5
			0		27′8″	43′3″	1300	
Do.	do.	do.	6′					5
			36′					3½
			66′					4
Off Five-Fathom Light Ship...............	do.	do.	0	57′		>125′	5200	
			6′					1
			36′					3
			78′					10
Do.	do.	do.	0	5′		36′		
			6′					7
			36′					7
			60′					8
Five-Fathom Light Ship....................	38°48′	74°35′.7	0					10
Lewes, Del., Breakwater Harbor...........	38°47′.75	75°06′.15	0				500	
			6′					23
Do.	do.	do.	0–B		28″	35″		85

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
4 miles W. of Five-Fathom Light Ship......	38°47′	74°40′	0	26′1″	40′11″		1800		
			6′						4
			36′						3½
			72′						4
Off Overfalls Light Ship, Delaware Bay...	38°46′54″	75°01′18″	5′	88″	10′3½″				
			6′						23
			30′						18
			60′						19
Off Delaware Capes......................	38°42′	74°52′	0						15
			42′						4
			72′						8
10.2 miles SE. of Overfalls Light Ship.......	38°42′	74°52′	0				400		
			6′						4
			36′						3½
			72′						3½
Chesapeake Bay, Choptank (off Spar WS "G")	38°39.′5	76°12.′3	0		15′1½″				
			0				7000		4
			30′						4
Chesapeake Bay, Cambridge, Md. Harbor...	38°34.′35	76°04.′4	0	6′8″					
Potomac River, off upper Cedar Point (Maryland Point Light)......................	38°24′	77°05′	0						66
Do.	do.	do.	0				1200		65
			24′						76
Do.	do.	do.	0				5000		
			6′						60
Cove Point, Chesapeake Bay...............	38°23′12″	76°20′00″	0	56″					

Off mouth Popes Creek, Potomac River......	38°20'00"	77°00'36"	0			3200	
Point Patience, Solomons Island, Md.........	38°19'30"	76°28'30"	0			600	
Do.	do.	do.	0			2000	
Do.	do.	do.	0			4000	
Do.	do.	do.	0			3200	
Do.	do.	do.	0			4000	
Do.	do.	do.	0			3200	
Do.	do.	do.	0			2400	
Do.	do.	do.	0			3200	
Do.	do.	do.	0			3200	
Do.	do.	do.	0			2400	
Bell (FLR) "16C," off Patuxent River, Chesapeake Bay	38°19'	76°20'	0	11'4"	17'6"	1800	5
			30'				6
			54'				11
Do.	do.	do.	0	10'7"	16'7"	2900	4
			30'				4½
			54'				8½
Do.	do.	do.	0	9'10"	16'7"	5400	4
			30'				5
			54'				8
Do.	do.	do.	0	9'3"	14'	4000	3
			30'				5
			54'				11
Do.	do.	do.	0	7'8"	13'6"	3800	4
			30'				5
			54'				13
Do.	do.	do.	0	7'8"	12'7"	4500	4
			30'				4
			54'				10

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Paraquameter	Scattering (units of scatter matter)
Bell (FLR) "16C," off Patuxent River, Chesapeake Bay	38°19′	76°20′	0	6′	7′5″		4400		3½
			30′						5
			54′						7
Do.	do.	do.	0				3000		5
			30′						4
			54′						7½
Off Cedar Point, Chesapeake Bay, (FLR) "16C"	38°19′	76°20′	0	60″					16
			30′						16
			66′						27
Do.	do.	do.	0		51″	95″			
Whistle Buoy (IFIS), Fenwick Island Shoal	38°17′	75°02′.8	0				6400		
			6′						3
			24′						4
Off Fenwick Shoal (FLW) "IFIS" Whst'l.	do.	do.	0						4
			24′						5
			36′						12
Off Great Gull Bank (FLW) "H" Whst'l.	38°16′.4	75°00′.4	0						11
			24′						8
			36′						14
Breton Bay, Potomac River	38°14′	76°42′	0				7000		
			6′						12
Potomac River, off Blackstone Island	38°11′.5	76°44′40″	0				5400		4
			24′						13
Do.	do.	do.	0				2000		11
			24′						37

Off Piney Point, Potomac River	38°08′00″	76°36′45″	0			4000	
Bell "B" (FLR), mouth of Potomac River	38°01′	76°21′	0			5000	3
			24′				5
Do.	do.	do.	0	7′7″	10′7″	600	7
			30′				7
			54′				14
Whistle Buoy (WQS) #6 Winter Quarter Shoal	37°57′	75°05′.5	6′				4
			30′				3½
			54′				6
10-Fathom Curve off Winter Quarter Shoal (WQS) 6 Whst'l	do.	do.	0				11
			42′				5
			60′				5
Bell Buoy (FLW) "2TL," off Chincoteaque Inlet	37°48′	75°18′	0	14′10″	22′4″	5200	6
			18′				11
Off Wolf Trap Light, Chesapeake Bay	37°23′	76°10′	0	11′10″	19′9″	1050	5
			18′				14
			30′				17
Off Wolf Trap, Chesapeake Bay	37°20′30″	76°10′	0			1300	
Mouth York River, off Crab Neck	37°11′30″	76°22′	0	17′9″	26′1″	850	
			6′				4
Thimble Shoals, Chesapeake Bay	37°05′36″	76°10′	0			1600	
Do.	do.	do.	0			800	
Horseshoe Middle Grounds, Chesapeake Bay	37°05′35″	76°11′.5	0				30
			6′				36
			12′				31
			18′				97
Do.	37°05′35″	76°09′40″	0			7200	8
			24′				5

(*continued*)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Horseshoe Middle Grounds, Chesapeake Bay..	37°05′35″	76°09′40″	0				5800		7
			24′						5
Do.	do.	do.	0				5200		7
			24′						6
Do.	do.	do.	0				5000		7
			24′						11
Do.	do.	do.	0				6000		6
			24′						17
Do.	do.	do.	0				5700		5
			24′						10
Do.	do.	do.	0				6400		3½
			24′						10
Do.	do.	do.	0				5000		4
			24′						8
Do.	do.	do.	0		16′	21′4″	2800		2½
			24′						5
Do.	do.	do.	0		20′3″	28′4″			5
			24′						8
Do.	do.	do.	0		19′5″	26′9″			5
			24′						8
Do.	do.	do.	0	52″		58″			
Chesapeake Light Ship....................	37°	75°.7	0				1200		
			6′						3
			30′						3
			54′						4
Do.	do.	do.	0						11
			30′						13
			48′						17

Little Creek, Va., Amphut East Annex Training Base, Pier 1	36°54'39"	76°10'55"	0			7200	62"	5
East of Curituck Sound, 23½ miles	36°17'.5	75°19'.5	0	30'	66'			2
East of Chicamacomico C. G. Station, 13½ miles	35°36'.0	75°11'.5	0		43'		20'	2½
Pamlico River	35°21'.0	76°35'.0	0			800		
Off Cape Hatteras, Cape Hatteras Lighthouse, bearing 263°T—distant 8 miles	35°16'.75	75°22'.7	0				9'6"	4
Off Cape Hatteras (QK FLW) R & B Whst'l, bearing 039°T—distant 2 miles	35°08'	75°20'.5	0			4000		½
Off Ocracoke Inlet	34°58'.0	75°57'.5	0			7000		1
Off Cape Lookout	34°32'.5	76°19'	0					1
Moorehead City, N. C. Coast	34°42'.0	76°40'.0	0			2400		
Wreck Buoy (QK FLR) "W2" dis. ½ mile	33°57'.5	77°02'	0					½
Off Frying Pan Light Ship, Edge of 10-Fathom Curve	33°27'.2	77°35'.5	0					½
Frying Pan Light Ship, bearing 246°T—distant 34.2 miles	33°10'34"	78°10'06"	0			5800		½
Off Cape Romain (FLW) "2CR" Whst'l, bearing 180°T—distant 0.2 mile	32°59'	78°53'.5	0					1
Charleston area, off Fort Sumter	32°45'30"	79°52'	0			125		
Do.	do.	do.	0			1100		
Charleston, S. C., Harbor	32°45'.2	79°54'	0			2000	14"	10
Charleston, S. C., off entrance	32°42'	79°46'	0				68"	5
Charleston Sea Buoy No. 2C	32°40'30"	79°43'	0			250		
East of Savannah, Ga	32°00'	79°54'	0					3
Savannah area, Savannah Light Ship	31°57'	80°40'	0			1000		
Off Savannah Light Ship	31°53'.5	80°25'	0				13'	1½
East of Cumberland Island, Ga	30°54'	80°41'.5	0					½
Off St. Johns Light Ship	30°27'.5	81°06'.5	0	20'6"		4000		1½

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Dockside, Pensacola, Fla..................	30°24′	87°13′	0					6′8″	3
			14′					4′2″	4
Mayport, Fla., dockside..................	30°23′.5	81°26′.5	0	4′		1½′		6′2″	3
St. Johns River..........................	30°19′	81°38′	0				3200		2
			18′					2′3″	
SE. of Pensacola, Fla.....................	30°12′.6	87°10′.2	25′					14′10″	1
Southward of Mobile, Ala.................	29°34′.5	88°13′.5	0–78′						1
			78′–120′					>22′	
Galveston, Texas, Sea Buoy, 2/10 mile NE. (FLW) "1" Whst'l......................	29°19′	94°39′	0				6200		
			20′					36″	5
Westward Swannee Sound.................	29°16′.7	83°42′.3	0				4000		
			0–B					>22′	
			30′						1¼
Southward of Cape San Blas..............	29°14′	85°24′.4	0				3000		
			30′					>22′	½
Heald Bank off Galveston, Tex., about 0.8 mile E. of (OCCW) "2" Whst'l.........	29°05′	94°12′.5	0				7000		
			20′					17′3″	1
Bay NE. of Mississippi entrance............	29°02′	89°42′.3	12′					9′6″	2
			36′					14′	¾
Gulf of Mexico...........................	28°49′	92°32′	0			40′			
			20′					17′2″	¾
			90′					18′8″	½
Off Mississippi entrance..................	28°48′.5	89°08′	6′					15′10″	1
			80′						½
Old Mississippi Canyon, off False Cape, Fla...	28°38′	89°56′.5	0			61′		>22′	⅔

Hetzel Shoal Buoy (FLW) "8" Whst'l close by	28°38′	80°20′.5	0			6′11″	½
15-Fathom Curve, off Freeport, Tex.	28°37′	95°01′.5	0		4600		
			20′				1
			60′			4′5″	4
10-Fathom Curve, off Ship Shoal (FLW) "2" Whst'l close by	28°37′	90°59′.5	0		6400		
			25′				1
			55′			17′	½
Tampa Bay, mouth Hillsboro Bay, off NW. end of Quarantine Anchorage	27°47′.5	82°30′.5	0		5600		
			12′				2
			25′				3
Off Winter Beach, Fla. (FLW) Whst'l close by Bethel Shoal Buoy	27°44′	80°10′	0			12′6″	⅔
100-Fathom Curve, off Corpus Christi	27°43′.5	95°30′	0	298′			
			40′				½
Gulf of Mexico, off Corpus Christi	27°42′	96°35′	0		4800		
			20′				1½
			60′				½
Off Tampa Bay Sea Buoy dist. ½ mi. (S.-L FLW) Whst'l	27°35′	82°56′	20′			14′	⅔
Gulf of Mexico	27°	97°	18′				½
			48′				½
Lauderdale area, off Hollywood Beach, Fla.	26°31′20″	80°05′55″	0		3000		
Off Sanibel Island	26°13′	82°23′.5	25′	60′		18′6″	¾
Port Everglades Harbor, turning basin	26°05′35″	80°07′.2	6′			3′8″	3
			35′			10′8″	1½
Fort Lauderdale, Fla., Dock, N.S.B.	26°05′30″	80°07′30″	0		1120		
Do.	do.	do.	0		650		
Do.	26°05′30″	80°07′15″	0		6400		

(continued)

TABLE 2.—(*continued*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Fort Lauderdale, Fla., Dock, N.S.B.	26°05′30″	80°07′15″	0				500		
Do.	do.	do.	0				5120		
Do.	do.	do.	0				6400		
Do.	do.	do.	0				8000		
Do.	do.	do.	0				6400		
Do.	do.	do.	0				5100		
Do.	do.	do.	0				4800		
Do.	do.	do.	0				215		
Do.	do.	do.	0				200		
Do.	do.	do.	0				6400		
Do.	do.	do.	0				1900		
Do.	do.	do.	0				5600		
Do.	do.	do.	0				4800		
Do.	do.	do.	0				6000		
Do.	do.	do.	0				400		
Do.	do.	do.	0				300		
Do.	do.	do.	0				288		
Do.	do.	do.	0				4800		
Do.	do.	do.	0				4800		
Do.	do.	do.	0				1280		
Do.	do.	do.	0				6400		
Do.	do.	do.	0				1200		
Do.	do.	do.	0				3200		
Port Everglades Harbor, off harbor entrance, C "1 A" close by	26°05′.5	80°05′.2	0				6800		
			6′					13′8″	1
			35′						¼

Do.	do.	do.	25′					½
Santa Brazio, Sea Buoy	26°04′.5	97°06′.5	0			4200		¾
Lauderdale, Fla., area off Hollywood Beach	26°01′	80°05′.5	0			3200		
Do.	do.	do.	0			5600		
Do.	do.	do.	0			3200		
Do.	do.	do.	0			5600		
Lauderdale, Fla., area, 2 miles off Hollywood Beach	26°01′	80°04′.5	0			4800		
Great Stirrup Bay	25°52′.5	77°51′.5	0		336′			
			50′					¼
Dock, Brownsville, Texas	25°50′	97°.5	0		21′			
Nassau, N. P., B. W. I.	25°05′	77°22′	0			5200		
			6′	81′4″				
			18′	92′5″				
			0			2200		
			6′	76′				
			18′	62′				
			0			3800		
			6′	74′				
			22′	74′				
			0			2200		
			6′	41½′				
			22′	47′				
Entrance Nassau Harbor, close by Sea Buoy	25°05′	77°21′	0					¼
Smith Shoal Light, Key West	24°43′	81°54′.5	0			5000	8′10″	½
Garden Key, Dry Tortugas, Fla.	24°35′10″	82°54′55″	0	50′				
Do.	do.	do.	B	20′				
Do.	do.	do.	0	48′				
			0	40′				
Do.	do.	do.	0	108′				
			0	108′				
			0	42′				

(continued)

TABLE 2.—(*concluded*)

Location of station: Description	Latitude (N.)	Longitude (W.)	Depth	Nat. lt. (Ball)	Letter	Lamp (point source)	Photometer (incident light) ft.-candles	Par-aqua-meter	Scattering (units of scatter matter)
Garden Key, Dry Tortugas, Fla.	24°35′10″	82°54′55″	0	46′					
Do.	do.	do.	0	38′					
American Shoal	24°31′	81°32′.7	0				6200		
Middle Bight, Andios Island	24°20′	77°40′.7	0						1½
Tongue of the ocean off Long Bay Cays	24°07′	77°30′	0				3000		2
Gulf of Mexico	24°	97°	0						½
Do.	23°09′.5	97°23′	0						½
Havana Harbor	23°09′	82°20′	0					7′8″	4
			6′					11′2″	2
			12′					10′8″	1
Off Matanzas, Cuba	23°04′.8	81°30′.2	0			275′			1½
Dock at Matanzas, Cuba	23°03′.5	81°33′.4	0				6400	14′	1
Do.	do.	do.	0			12′9″		7′8″	3
Nicholas Channel	22°50′.1	79°10′.3	0	122′			6000		1
Yucatan Channel	22°49′	86°13′	0				6200		⅓
Great Bahama Bank	22°49′	77°15′	0						1
Campeche Bank	22°42′	89°18′	0						¼
Alacran Reef Anchorage	22°23′.5	89°41′.5	0	36′			5050		
			6′						2
			0	35′			2450		
			6′						1¾
			0	29′6″			2200		
			6′						1½
			0	26′			3400		
			6′						1

Do.	do.	do.	0	28′6″		5000		
			6′					2
			0	22′		3800		
Do.	do.	do.	0			6600		3
Off Tampico, Mexico	22°17′	97°43′	0	15′		5000		1
Off Lobos Island	21°22′.0	97°14′	0	9′8″		5200	15′	1
Bay of Campeche	20°23′.5	91°50′	0			7000		1½
Gulf of Campeche	19°25′.8	95°48′	0		>300′			½
Do.	19°19′	93°03′	0					1½
Mexico, off Vera Cruz Harbor	19°15′	96°05′	0	9′6″		4000	14′	4
Vera Cruz, Mexico, Harbor, dockside	19°12′.05″	96°08′08″	0	15′		4000	19′2″	1
Gulf of Campeche, off Roca Partida, 5 miles	19°11′.5	95°09′	0			3000	19′8″	5
			24′					1½
Puerto Mexico, Harbor Pier #2, Coatzacoalcos River	18°08′21″	94°24′45″	0				5′10″	2½

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THE LORD BALTIMORE PRESS, INC.
BALTIMORE, MD., U. S. A.

A CLASSIFICATION FOR THE BIRDS OF THE WORLD

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The principal additions to current information that affect the arrangement of the family and higher groups in birds since the previous paper on this subject by the author was published (1951, pp. 1-22) have come in the fossil field and deal in part with the earliest known forms of the Jurassic and Cretaceous periods. While there has been much discussion of family limits among the Passeriformes, with considerable spread of opinion as to family limitations, in the main these have been expressions of individual viewpoint, without completely firm support in the new information offered. Valuable new data that are accumulating from many sources relative to this order, where they are completely decisive, in the main suggest better alignment of existing families through shift of genera from one group to another. The great majority of the many species still require detailed anatomical study.

Under the revision of the International Code of Zoological Nomenclature as adopted at the Fifteenth International Zoological Congress held in London in July 1958, now in press, a new rule provides that family names are to be based on strict priority in publication. There is no attempt to follow this requirement in the classification presented herewith since the final draft of the Code was not yet in print when the paper was under preparation. It is apparent, however, that acceptance of this new proviso, while intended to establish stability, in the beginning will bring many changes in current family and higher group designations in the class Aves.

The following notes that discuss the more important changes are added to material from the introductory section of the revision of 1951 where this remains pertinent. In the classification at the end of the text the fossil groups are enclosed in brackets to enable their ready recognition on the part of students familiar mainly with the family and other categories of living kinds.

Archaeornithes.—The recent careful study of the specimen of *Archaeopteryx* in the British Museum (Natural History) by Sir

Gavin de Beer has added greatly to knowledge of this bird through application of modern methods of examination. De Beer (1954, pp. 39-41) has outlined clearly the resemblances found in the two nearly complete specimens preserved in London and in Berlin and has shown that most of the differences between them that have been described either have been misinterpreted or do not rate the value that has been assigned to them. His conclusion is that "proposed generic and even specific distinction between them calls for very critical examination." In his final statement on this part of his study (l.c., pp. 50, 57) he unites both under the name "*Archaeopteryx lithographica* Meyer."

In brief review, formal recognition of the two specimens as representative of separate species came when Dames (1897, p. 829) named the one in Berlin *Archaeopteryx siemensii.* Petronievics (*in* Petronievics and Woodward, 1917, p. 5) considered that differences between the two were of sufficient weight to separate *siemensii* tentatively as the type of a new genus, *Archaeornis.* In a later study Petronievics (1921, p. 10), after further consideration, was definite in establishing the two in distinct genera and added that they might "vielleicht sogar zu zwei verschiedenen Familien gehören." In a more detailed account (1925, pp. 67-69) he placed the two in separate families, which he maintained later in a further review (1950, pp. 118-120).

The major points on which Petronievics based his two families have disappeared through the information supplied by de Beer. There remain, however, distinctions of size and relative proportion, the London specimen being about 10 percent larger in general dimension, with the foot about 25 percent greater. De Beer regards these size characters as individual, to be attributed either to age or to sex. Steiner (1938, p. 292), who also has considered the two identical, says that in his opinion the Berlin specimen was a young individual and a female, in contrast to the London example which he believes was a mature male.

While my personal study of this problem has been confined to views of the London fossil and the nearby cast from Berlin in the British Museum, additional comparisons of casts of the two in the U.S. National Museum, and examination of published figures, it appears to me that the foot of the Berlin bird not only is smaller but also has the toes of different proportion in relation to one another and to the tarsometatarsus. The wing elements in the two specimens appear quite similar, but the entire leg in the Berlin bird seems more slender. It is possible that these ancient birds, like some reptiles, continued to grow in size for a longer period than is true with modern species, a factor, however, which must remain hypothetical. Steiner's supposition that the London specimen is male and the Berlin fossil female is equally speculative, since if sex is assumed, the reverse might be true. While the male is larger than the female in most living birds, this is not the universal rule, and as reptilian characteristics persist in these earliest known avian forms it must be remembered that in reptiles it is common for the female to be larger than the male. As a further contribution to available information there should be noted the analysis of the primary wing feathers by Savile (1957, pp. 99-101), which points out an apparent difference in wing formula between the London and the Berlin birds. This recent observation if accepted would indicate rather wide separation, but, on the other hand, if denied would serve to bolster the conclusions of de Beer.

A third specimen found in 1956 near the point where the first example was discovered shows mainly wing and leg bones and vertebrae, in addition to feather impressions. It has been described in detail by Heller (1959, pp. 1-25), who finds that it agrees in size and characters with the one in London, so that there are now two of the larger form known.

It is important to have a modern study, like that of de Beer, of the Berlin specimen, to add to the data assembled by Dames. As matters stand, the three known skeletons present an appearance of differences sufficient to mark them as two distinct species on the basis of criteria found in the osteology of living birds. These data, for the present, appear to warrant recognition of two genera, *Archaeopteryx* represented by two specimens and *Archaeornis* by one, which, however, should be united in one family, the Archaeopterygidae.

Ichthyornithes.—A recent study by Gregory (1952, pp. 73-88) has severed the long-standing association of *Hesperornis* and *Ichthyornis* in a superorder separated from all other birds known from the New World through the possession of teeth. In brief, Dr. Gregory has shown that the toothed lower jaw fragments allocated to the skeleton of *Ichthyornis dispar* Marsh, unduly large in proportion to the rest of the skull and the skeleton with which they have been associated, in reality are not avian but are those of a small mosasaur. Two other jaw fragments placed by Marsh with *Ichthyornis anceps* and *I. victor* are similar, so that all these specimens, which have the teeth in sockets, are identified as reptilian. This leaves *Hesperornis* as the only group of Cretaceous age in which teeth are known. To give a balanced treatment that will emphasize the important characters of the birds concerned it has seemed appropriate to establish a suborder Ichthyornithes for the Ichthyornithiformes, separated from all other birds by the possession of biconcave vertebrae. I have given a somewhat more detailed discussion of this matter elsewhere (Wetmore, 1956, p. 2).

The penguins.—The question of the weight to be given the peculiarities of uniform pterylosis, extreme specialization of the wing as a flipper for submarine progression, and incomplete fusion in the metatarsal elements, as well as such other details as erect posture in standing and walking and the anatomical adjustments involved, found in the penguins, is one that has merited careful review. It seems reasonable after this examination to retain the Impennes as a superorder, at least until we have further evidence through fossils as to their line of evolution. It is necessary, however, to remove the fossil family Cladornithidae, since Simpson (1946, pp. 24-25) has found that the two genera *Cruschedula* and *Cladornis* placed in this family have no apparent relationship to the Sphenisciformes. These two, described by Ameghino from the Deseado formation of Patagonia, now placed in the Oligocene, are based on fragmentary, considerably flattened metatarsi. The descriptions and figures that have appeared thus far are not sufficiently definite to demonstrate characters of importance in classification. However, from what we now know these ancient birds cannot be considered as ancestral penguins of terrestrial habit, as has been supposed. The only suggestion that has come to me is that possibly they may belong in the order Pelecaniformes, in which I have placed the family tentatively in a suborder Cladornithes (see p. 25).

The Neognathae.—One important result of recent studies has been the allocation to the Neognathae of the orders formerly separated as the Palaeognathae. For years I have felt that recognition of the Palaeognathae, as a separate group apart from other birds, on the basis of a supposed peculiarity in the palate, stood on flimsy ground. The studies of McDowell (1948, pp. 520-549) demonstrate that the structure of the palaeognathous palate, in which the palatine and pterygoid bones are articulated by a squamous suture, is variable from order to order and that in fact the details of this union differ considerably in the several groups. For example, McDowell points out that in *Dromiceius* the palatine and pterygoid are not in contact, while in a number of families placed in the Neognathae, as in the Anatidae, to name only one, the two bones are in articulation. As there is no clear-cut separation, the former Palaeognathae must be combined with the Neognathae.

The supposed bird *Caenagnathus collinsi* described by R. M. Sternberg (1940, p. 81) from the Belly River series of beds of Upper Cretaceous age in Alberta has been carried tentatively in our avian classification, though it has been my belief from the beginning that it was reptilian. It is known from a lower jaw, beautifully preserved, without appreciable deformation and practically complete except for part of the lower section of one ramus. The resemblance to birds is found in the lack of teeth, fused symphysis, and the considerable size of the mandibular foramen. While these are characters found in birds, there is nothing peculiar included since all are duplicated in some of the groups of the Reptilia. The fossil resembles Reptilia in the form of the articular surface, the forward position of the coronoid area, the conformation at the symphysis, especially on the upper surface, the upward curvature in that area, and in the general texture of the bone. In none of these is there exact duplication in Aves, except partially in the form of the symphyseal region. The whole appearance of the bone strongly suggests a species related to the Ornithomimidae among the therapod dinosaurs. In view of this the "Order Caenagnathiformes" is now omitted from the avian classification, since it is felt that its continued tentative inclusion may promote misunderstanding as to its status.

The family Eleutherornithidae is introduced for the fossil *Eleutherornis helveticus* Schaub, from the Eocene of Switzerland, described from a fairly well preserved pelvis. Apparently this is representative of an ancestral group from which the living ostriches may have come. Its greatest importance is found in its indication of relationship with carinate groups though of unquestioned ratite stock. It is thus important as definite indication that the struthious birds are descended from flying ancestors, not from some distinct cursorial line that always has been flightless, as some have contended.

The genus Podiceps.—The differences of opinion that prevailed for years as to the application of the generic name *Colymbus* have been adjusted currently by an arrangement under which *Gavia* has been accepted for the loons and *Podiceps* for the grebes. There is, however, discussion still as to the proper spelling of the ordinal and familial names for which *Podiceps* is the base. The uncertainty arises from misunderstanding of the derivation of this generic term. The colloquial name applied to these diving birds in the English of the 16th to the 18th centuries (and later) was "arse foot," or "arsfoot," from the posterior position of the leg. The term is found in the early dictionaries of Johnson, was carried in the later editions of Todd and Walker, and is still found in a footnote in Webster's 1953 volume, with indication there that the word now is obsolete. Some early authors who wrote in Latin rendered this term appropriately as "Podicipes," as for example Willughby (1676, p. 258), and Ray (1713, pp. 125, 190), where the horned grebe is listed as "Colymbus sive Podicipes minor." Catesby (1731, p. 91) wrote of the pied-billed grebe under the heading *"Prodicipes Minor* Rostro vario," but he corrected the spelling of the first word in the legend for the plate that faces the text, which is labeled "Podicipes &c." This account by Catesby was the sole basis on which Linnaeus (1758, p. 136) established his specific name for the pied-billed grebe. And it is here that present-day confusion has its beginning, since Linnaeus called the bird *"Colymbus Podiceps,"* and in citing the reference to Catesby wrote it "Podiceps minor, rostro vario." While he corrected Catesby's error in spelling he thus made another of his own, which remains in our current name *Podilymbus podiceps* (Linnaeus) for the pied-billed grebe. Following Linnaeus, John Latham (1787, p. 244) proposed the genus *Podiceps,* in which he included several species of grebes, with basis for the name on Linnaeus, as he makes reference to "Colymbus Lin." The error in spelling was recognized by several early authors, as in a note attributed to Oken (1839, p. 674) and one by Gloger (1854, p. 430). Correct usage for a family name based on *Podiceps* (=*Podicipes*) was indicated by Newton (1896, p. 381). That this history, well known up to 40 years or so ago, has been forgotten by many is shown by recent action of the International Commission on Zoological Nomenclature (1957, pp. 300-304) which it appears should have further review. The data supplied by the Committee to Dr. Grensted, as classical adviser, were misleading, as there was no indication for his information that "Podiceps" had been derived from "Podicipes."

As the terminal root in *Podiceps* is a contraction of the Latin pes, pedis, it would appear that the correct form for the family name is Podicipedidae (not Podicipidae or Podicipitidae), and for the order Podicipediformes (not Podicipitiformes or Podicipidiformes).

The Procellariiformes.—Family segregation in this order has been oversimplified in some recent discussions, probably through misunderstanding of the group characters, possibly also through somewhat confusing names that have been applied to familial and generic categories. Verheyen (1958, pp. 11-14) has placed the Pelecanoididae in an order with the Alcidae, as indicative that the auk group is allied rather closely to the Procellariiformes. The resemblances that he cites appear due to convergence, as the basic form of the diving petrels is definitely that of the shearwater-petrel group. Aside from this, the Diomedeidae and the Pelecanoididae have been accepted without apparent question, but the remaining species have been combined by some under a single family name. Lowe (1925, pp. 1436-1443) has shown that the genera included in the Hydrobatidae have a simplified condition in the quadrato-tympanic region of the skull in which the opening of the upper tympanic recess is small, and is so located that it separates the squamosal and opisthotic facets. In addition, the posterior border of the sternum is truncated and entire, and basipterygoids are absent or are represented only by small spines. In the Procellariidae, on the other hand, the foramen of the upper tympanic recess is greatly enlarged and lies anterior to the two facets for the quadrate, which are joined by a bridge of bone; the posterior border of the sternum is notched; and basipterygoid processes are present. These constitute distinctive characters at the family level.

The Pelecaniformes.—In the arrangement of suborders in the order Pelecaniformes we encounter in marked degree the standard difficulty of logical placement in linear alignment of groups that really stand in three-dimensional relationship. Lanham (1947, pp. 65-70) has made a summary of the major anatomical characters of the group in which he points out the differences that set off the Phaëthontes and the Fregatae from the Pelecani. There is no question that the first two carry primitive characters, which may be presumed to be similar to those found in ancient ancestral stocks, since in these resemblances they are more like other types of birds, notably the Procellariiformes. From this style the families of the suborder Pelecani have become widely divergent. Although the tropicbirds and the frigate-birds both have retained a part of what may be regarded as a basic pattern, they are so distinct in other respects that it appears to be more reasonable to relate them individually as branches from a common stock rather than to combine the two on one line, separate from the Pelecani. The Phaëthontes possibly may have separated earlier than the Fregatae. Among interesting differences other than those of internal anatomy, it may be noted that the tropicbirds have the young covered with down at birth and that the adults possess series of air cells under the skin on the forepart of the body like those found in pelicans and boobies. The frigate-birds have young almost naked at hatching, and the emphysematous condition is mainly lacking. In view of this I prefer to continue to align these groups on either side of the Pelecani.

Though there is no question that the cormorants and snake-birds are closely allied, they differ in such degree that they should be retained in separate family status. The snake-birds are marked by a peculiar conformation of the cervical vertebrae through which the beak becomes a triggered spear in feeding. The bridge of Dönitz on the ninth vertebra is an important part of this arrangement. The stomach also is unusual in possessing a curious pyloric lobe, lined with a mat of hair-like processes. And there is only one carotid artery while in cormorants there are two.

The description of *Osteodontornis orri* by Hildegarde Howard (1957a, pp. 1-23) from the Monterey formation in the Miocene of California adds a third species to the strange Odontopteryges, whose common character is found in the sharply pointed, dentate projections developed on the margins of upper and lower mandibles as continuous parts of the bony structure of the jaws. This suborder was placed tentatively (Wetmore, 1930, p. 3), following Lydekker (1891, pp. 57-58), in the Pelecaniformes, but this was not definite, as the characters of *Odontopteryx* have been interpreted by some as indicating closer alliance to the petrel–albatross group. In July 1956, at the British Museum (Natural History), through the kind attention of Dr. W. E. Swinton, I had the privilege of studying the type skull of *Odontopteryx toliapica* Owen, which came from the London clay of the lower Eocene, on the Isle of Sheppey, Kent, England. It was possible thus to ascertain certain details not clear from the published accounts. As a result of this study it is my opinion that the characters clearly indicate relationship with the Pelecaniformes.

Without repeating unnecessary detail, available in Lambrecht's great volume (1933, pp. 304-307), it was interesting to note the strongly marked craniofacial hinge at the base of the bill, like that of gannets and cormorants, and also the impressed line along the side of the premaxilla, and the definite closure of the external narial opening, as in the Sulidae. The distal articular end of the quadrate suggests that of *Phaëthon,* though somewhat more flattened, with the whole articular surface narrower, and the separate segments more nearly in line than in any living species of the various pelecaniform families. The lachrymal appears to have been slender and is firmly anchylosed on its upper margin to the frontal as in *Phalacrocorax.* The rounded cranium suggests that of pelicans, rather than the more flattened form of other families of the order. The sum of the characters indicates a bird of gannetlike diving habit that, when slippery aquatic prey was seized, could hold it firmly in the sharp dentations of the mouth.

Dr. Howard in her interesting study of *Osteodontornis* has elevated the group to the rank of an order, on the consideration that it "may represent an early connection with procellariiform–pelecaniform stock" (1957a, p. 22). It has seemed to me appropriate to emphasize the evident pelecaniform character by retaining the two families recognized in subordinal status in that group, since the resemblances that point toward the Procellariiformes appear to be much less definite and possibly may be subject to other interpretation. It is desirable now to place the Odontopteryges at the beginning of the order because of their antiquity. The known history of the group, which begins in the early Eocene, indicates probable ancestry in Paleocene time. The pointed projections on the jaws, assumed to have been sheathed in the integument of the bill, were without question used in seizing prey. The disappearance during Miocene time of such a holding apparatus may indicate that the bony projections were not completely successful for their purpose, perhaps because of their hollow centers, as accidental breakage in them would not be restored. The fine serrations restricted entirely to the ramphotheca, found in the straight-billed species of the pelecaniform order (tropicbirds, gannets, boobies, and anhingas), may be regarded as a functional replacement.

The change in position made to the beginning of the order covers only the Odontopterygidae and the Pseudodontornithidae and leaves *Cladornis* and *Cruschedula* still unsettled as to relationship. As explained above (p. 4), Ameghino described both as forms of penguins, but Simpson says that they have no connection with this group. As the suborder Cladornithes, they are located in their former uncertain position at the end of the Pelecaniformes.

Suborder Ardeae.—The general resemblance of the boat-billed heron (*Cochlearius cochlearius*) to the night herons has been the occasion of differences in allocation of its rank in classification from that of a subgenus of *Nycticorax* to full family status. In a recent review of the Ardeidae, Bock (1956, pp. 31-35) has treated it as a separate genus in a "Tribe Nycticoracini" allied to *Nycticorax*. Superficially the boatbill is like a black-crowned night heron, but in detail there are outstanding differences. The enlarged bill is obvious, and there are four pairs of powder-down patches, instead of the three found in the other herons. In the skull, the bill has been changed from the spear point usual in herons to a broad scoop with the roof of the mouth smoothly arched. The lower jaw is widely bowed to fit this change, and the symphysis is greatly reduced in length. The palatines are so greatly broadened, and so inflated on the outer posterior margin, that they have little resemblance to the ordinary heron form. The quadrate has the orbital process shorter and thicker and the mandibular articulation narrowed; the lachrymal is small; the eye opening considerably enlarged to house the exceptionally large eye; and the external nasal opening considerably reduced. The palatal musculature is decidedly stronger than in the true herons.

In life boatbills act like night herons, as they roost and nest in groups and are mainly nocturnal. When hunting at night, I have found them feeding in shallow waters, often in riffles where they scoop at their living prey, rather than spear at it as is the custom with the typical herons. The eyes, wood brown by day, at night reflect the jacklight with a faint orange sheen, which I have not observed in other herons. The eggs are pale, nearly white, and often are lightly speckled with brown, so that they resemble those of the tiger bittern, *Tigrisoma lineatum,* rather than those of the night herons, which are deep blue.

While there is no fossil record for the boatbill, I regard it as an ancient sideline from the typical herons that, judged from its present restricted range in the American Tropics, has not been too successful. It may seem attractive to unite *Cochlearius* with the true herons, but from long acquaintance I regard their characters, briefly outlined above, sufficient to maintain a separate family status.

In view of the fact that the structural characters of the Balaenicipitidae have been summarized clearly by Stresemann (1934, p. 809), it seems strange that the status of this family has been a matter of question. The single species shows affinity both with storks and with herons, in addition to outstanding peculiarities of its own. Miss Cottam (1957, pp. 51-71) has made a careful summary of the osteology from which she deduces a pelecaniform relationship, but this appears to be due to convergence rather than to actual relationship. The great enlargement of the skull has occasioned superficial resemblances to pelicans, but these, and others seen elsewhere in the skeleton, are subordinate to the general sum of all characters, which is ciconiiform.

Phoenicopteri.—The position of the modern flamingos, which show characters that point on one hand to the Ciconiiformes and on the other to the Anseriformes, has been a matter of some variance in allocation. Mayr and Amadon (1951, pp. 7, 33), with only brief discussion, have set them up as a distinct order, but general opinion has carried them as a suborder allied to the herons, storks, and their relatives. The latter course remains justified when the fossil genera *Palaelodus* and *Elornis* of the upper Eocene to Miocene of western Europe are considered (Wetmore, 1956, p. 3). This group of flamingo relatives was identified in North America when Alden Miller (1944, p. 86) described *Megapaloelodus connectens* from the lower Miocene of South Dakota, a species to which remains from the upper Miocene of California also are referred (Loye Miller, 1950, pp. 69-73; 1952; pp. 296-298). The group may be recognized as the family Palaelodidae, on the generic name *Palaelodus* Milne-Edwards (1863, pp. 157, 158). (There has been confusion relative to the proper spelling, since Milne-

Edwards in his important later work [1868, p. 58] used the form *Paloelodus*.)

Howard (1955, pp. 3-23) has described a still different form of the flamingo group as *Telmabates antiquus* from the lower Eocene (Casamayor formation) of Chubut in Patagonia. While this species resembles the Palaelodidae in shortness and other details of form in the leg, it may prove to be representative of a separate family on characters found in the vertebrae and wing, as suggested in the original description. It is regarded for the present as of subfamily status in the Palaelodidae.

Suborder Cathartae.—The superfamily Neocathartoidea, and family Neocathartidae, for the curious vulture *Neocathartes grallator* (Wetmore), discovered in the Upper Eocene fossil beds of Wyoming, introduced a new element in our known avifauna in the form of a small-winged, strong-legged vulture that evidently was terrestrial with limited powers of flight. It had about the same relation to the other American vultures that the secretarybird has to the hawks and falcons. Its inclusion also requires a separate superfamily, the Cathartoidea, for the previously known cathartine families.

Galliformes.—The Numididae, which have been placed by some as a subfamily of the Phasianidae, differ in completely lacking the tuberosity or plate on the inner side of the second metacarpal that is so prominent in pheasants and grouse. It should be recorded, however, that Hudson, Lanzilloti, and Edwards (1959, p. 64) note that *Numida* shows no peculiarities in the leg musculature when compared with the Phasianidae. The Tetraonidae, in contrast with the Phasianidae, have the pelvis relatively much broader and different in proportion, and the tarsus relatively shorter in relation to the length of the tibiotarsus. With these differences in mind it seems reasonable to retain the three groups in family status, at least until more detailed knowledge of their anatomy as a whole warrants change.

Gruiformes.—In the Turnices the two genera of bustardquails, *Turnix* and *Ortyxelus*, have no hind toe, the wing is eutaxic, only the left carotid is present, and the eggs are rounded oval. The plain-wanderer of Australia, *Pedionomus*, has a small hind toe, the wing is diastataxic, right and left carotids are found, and the large eggs are pyriform. It seems desirable to continue these as separate families, rather than as subfamilies of one group, an arrangement that Stresemann (1933, p. 760) has accepted.

It has long been known that *Mesites* Geoffroy for the curious roatelos of Madagascar is antedated by the same name used by Schönherr for a group of beetles. It has been in error, however, to replace this with *Mesoenas* Reichenbach 1862, since the conflict had been noted seven years earlier by Prince Bonaparte who gave the group the name *Mesitornis* (Bonaparte, 1855, p. 484). The suborder becomes Mesitornithides and the family Mesitornithidae.

In the course of study of the fossil *Andrewsornis abbotti* from the Oligocene of Patagonia, Bryan Patterson (1941, pp. 50-53) has reviewed related groups to the end that he has added the family Psilopteridae for the South American fossil genera *Psilopterus* and *Smiliornis*. Further, he has placed *Phororhacos* and its allies as a superfamily Phororhacoidea under the suborder Cariamae. His further observations on these matters are to appear later in a more comprehensive paper.

The family Cunampaiidae, for the fossil *Cunampaia simplex*, named by Rusconi (1946, p. 1) from the Oligocene of western Argentina, while placed in the Cariamae, still remains of uncertain status.

The allocation of the phororhacid group to its new position and its demotion from subordinal status requires recognition of a superfamily Cariamoidea for the living Cariamidae and the fossil group Hermosiornithidae. The common name for the Cariamidae in most English writings has been "Cariama," being the form instituted by Marcgrave in 1648 in his Historiae rerum naturalium Brasiliae, when he rendered the Tupí name "çariama" as cariama. This was copied by subsequent authors, including Linnaeus in his twelfth edition, and so came finally into English usage, beginning with Ray's translation of Willughby's Ornithologiae in 1678. Seriema, a modification of the Indian word çariama, is used in Brazil, and with that spelling has come into the Engish language, where it should replace the other form.

Charadriiformes.—Differences of treatment at present are found mainly in the superfamily Charadrioidea and the suborder Lari, in which the groups have been regarded by some as of family value and by others have been allocated to the rank of subfamilies. The various studies that have been made have not been complete from a taxonomic point of view except for part of the species, and the conclusions derived from the data available appear in the main more philosophical than concrete. The picture therefore still remains confused.

In view of the diverse specializations that are apparent, and the obvious long evolutionary history, it appears better to me to continue to acknowledge the main segregations as families, at least until the subjects involved have been more thoroughly investigated. A family, Rhegminornithidae, covers the fossil *Rhegminornis calobates* Wetmore, described from the lower Miocene of Florida. This was as large as a medium-sized curlew, of peculiar form as regards the foot, the only part of the skeleton known, which shows certain characters that seem to point toward the jaçanas, though the bird is to be placed in the Charadrioidea.

It should be noted that the family affinity of the turnstones and the surfbird, long considered members of the plover family, is not certain as some studies (Lowe, 1931, pp. 747-750) place them in the Scolopacidae. (See also Bock, 1958, pp. 85-86.)

In the Lari the terns and the gulls are regarded as one family, though there are some reasons that make further examination of this treatment desirable. The Stercorariidae possess a 2-notched sternum, large caeca, a cere, and a complex rhamphotheca. In the Laridae ambiens and biceps slip are present, the sternum is 4-notched, there is no cere, and the rhamphotheca is simple in form.

In further discussion of proposals relative to this group it is pertinent to observe that a logical scheme of classification should attempt to outline relationships in living and fossil species through examination of all available data, considerations in which modern studies of behavior find increasingly useful part. There are pitfalls and hidden traps, however, when attempt is made to establish affiliation through any single method of approach, as inevitably inconsistencies appear. I fully agree with Martin Moynihan (1959, pp. 22-23, 35-38) that the skimmers (*Rynchops*) represent an early separation in the ancestry of the gull-like birds and find it pertinent that this is shown in their behavior pattern. At the same time these birds present outstanding peculiarities that should be considered in assigning them appropriate status in relation to their relatives. The bill, compressed to knifelike form, with great elongation of the ramphotheca of the lower jaw, is unique, and the method of feeding, where the lower mandible cuts the water surface with the bird in flight, is equally strange. The structural modifications in the form of the skull from that found in skuas, gulls, and terns also are too extensive to be ignored. The elongated blade of the lower mandible anterior to the symphysis of the rami is intriguing but less important than the profound changes elsewhere. The palatine bones are greatly expanded, the orbital process of the quadrate is reduced to a short, pointed spine, the impression for the nasal gland is much reduced, the frontal area is inflated and produced posteriorly, with compression of the lachrymal, and consequent reduction in size of the cavity for the eye, to enumerate the most outstanding differences in the osteology. Externally, the pupil of the eye is a vertical slit similar to that of a cat, and thus unlike that of any other group of birds (Wetmore, 1919,

p. 195). Other peculiarities have been described in the musculature. The sum of these characters justifies treatment of the Rynchopidae as a distinct family in their suborder.

The fossil humerus, type of *Mancalla californiensis* Lucas, that was the first intimation of a flightless auk on the west coast, while unique for many years, now has been supplemented by abundant material from which an additional, smaller species, *Mancalla diegense* (L. H. Miller), is recognized. It has been possible also to construct a composite skeleton of the larger one that is sufficiently complete to give a clear picture of its form and characters. The evident peculiarities of the genus *Mancalla* are found in the wing, as elsewhere the skeleton resembles that of other alcids, except for differences of a generic and specific nature. In comparison of the wing with that of the great auk, now extinct, that formerly ranged the coasts of the North Atlantic, the humerus of *Mancalla* is generally similar, the forearm appears proportionately shorter, and the hand more elongated. Ulna, radius, metacarpal, and phalanges so far as present are more slender. The head of the humerus in *Mancalla* differs decidedly in the relative angles of different elements, and also in the conformation of the distal articular surface. The general indication in the west-coast bird is of a proportionately longer wing, with the slighter bones to be expected in a form of lesser bulk. Loye Miller (1946, pp. 34-36) and Loye Miller and Howard (1949, pp. 222, 225) have likened the specialization seen in the wing to that found in penguins and explain any similarity to the great auk, *Pinguinis impennis,* as due to convergence. On this basis they have separated *Mancalla* from the other auks in the family Mancallidae. While I followed this, with some reservation, in the last revision of the fossil list (Wetmore, 1956, pp. 3, 80-81), a further review of the subject raises definite doubt, since, except for some specialization in the wing, *Mancalla,* as said above, is like other alcids. The change in the wing is no greater than that of *Pinguinis,* though the divergence is in a different direction. It would seem sufficient to place *Mancalla* in a well-marked subfamily, rather than in a separate family.

Finally, the proposals of several authors to separate the auks in a distinct order appear to require further study.

Strigiformes.—Old World ornithologists in the main regard the owls as belonging to a single family, but while all are deceivingly similar in general aspect, Ridgway (1914, p. 598) years ago summarized the considerable structural characters that separate the Tytonidae and the Strigidae. It is necessary here only to point out the more outstanding differences of the barn owls in lack of the manubrium, the different form of the posterior margin of the sternum, which is entire or 2-notched, the straight outline of the palatines, and in the ventral pteryla where the outer branch joins posteriorly to the main tract. The Strigidae possess a manubrium, the sternum is 4-notched, the palatines are greatly expanded posteriorly, and the posterior end of the ventral pteryla does not join the main tract at the posterior end.

Apodiformes.—Lucas (1889, pp. 8-13; 1895, pp. 155-157) long ago demonstrated the differences between the true swifts and the crested swifts, though his work seems latterly to have been overlooked, in view of the recent inclusion of the two in one group, as by Stresemann and by Mayr and Amadon. The skull in the Hemiprocnidae is quite distinct in the general form of the cranium and in the development of the nasals, vomer, and palatines. The hypotarsus has a tendinal foramen (like that found in hummingbirds), and the plantar tendons have the flexor longus hallucis connected with the branch of the flexor perforans digitorum, which extends to the fourth digit. Coupled with this there may be noted the curious nest, which, fastened to the side of a branch, is barely large enough to contain one egg, and the further fact that these birds perch regularly on branches and twigs in trees.

As *Apus* Scopoli, published in 1777, is recognized now in place of *Micropus* Meyer and Wolf, 1810, for the type genus of the swifts, the terms in the classification change to order Apodiformes, suborder Apodi, and family Apodidae, which replace the former terms Micropodiformes, Micropodi, and Micropodidae, respectively.

Coraciiformes.—The proposal of Mayr and Amadon (1951, p. 35) to include the rollers in one family, the Coraciidae, with three subfamilies, goes back to the arrangement of Dresser in his monograph of the group (1893, pp. xviii, 85, 101). Sclater (1865, pp. 682-688), however, many years ago, pointed out the pelvic powder-down tracts, the small manubrium, and other peculiarities of *Leptosoma*, and set it apart in a distinct family. The anatomy of the syrinx and feet was further elaborated by Forbes (1880, pp. 464-475). The family Leptosomatidae therefore should be recognized.

The groundrollers, *Brachypteracias, Atelornis,* and *Uratelornis,* usually have been included as a subfamily of the Leptosomatidae, but Stresemann (1934, p. 829) places them in a separate family, the Brachypteraciidae. There seems to be reason for this in their general appearance, though their anatomy is not well known. *Brachypteracias,* in its skeleton, differs from *Coracias* and *Eurystomus* in the much greater depth of the outer notch on the posterior border of the sternum, in the much broader and stronger pelvis, the heavier femur, and the greater curvature of the shaft and reduction of the crista superior of the humerus. I have not seen the skull. The habit of life is markedly different. Although anatomical material of the other genera is not presently available, it seems reasonable to accept Stresemann's proposal. These peculiar birds certainly are not closely allied to *Leptosoma.*

Lack of information on the anatomy of the woodhoopoes must be the reason for recent nonrecognition of the Phoeniculidae as a family separate from the Upupidae, since the two are quite distinct and have been so recognized for many years. The external differences are readily apparent. In the skeleton in *Phoeniculus* (of which I have seen several examples) the posterior part of the nasal area is ossified, there being only a small, narrow, elongated nasal opening; the ectethmoid is much reduced; the anterior end of the pterygoid is broadly expanded; the sphenoidal rostrum is swollen at the anterior end, where the expanded ends of the pterygoids join it; the quadrates are decidedly larger; the keel of the sternum is greatly reduced, being only half as high as in *Upupa;* the furculum is broader; the pelvis is narrowed, and considerably enlongated posterior to the acetabulum, with the ischio-pubic fenestra greatly enlarged; and the tarsus is heavier and broader, with two definite fenestra below the head. There are other minor details. In all of the above the characters of *Upupa* are directly opposite. The two groups appear to me to be sharply set off as distinct families.

Passeriformes.—This order, with more living species than all the others combined, and far fewer fossil forms known, presents many difficult problems in logical arrangement. The major groups are clear, whether we rank them as suborders or superfamilies being a matter of opinion. But the limits and status of numerous families contained in these larger categories are uncertain since the internal anatomy is known for so few kinds that details of difference are poorly understood. Superficial resemblances, on the other hand, are so obvious in many cases that they cause confusion. Under the circumstances it continues to seem appropriate to me to accept the family grouping that has been current for many years, except in those cases where acceptable studies clearly indicate change. Supposition in these matters has led to various proposals for changes, some part of which undoubtedly will prove correct. It is equally probable that a part, possibly the considerably larger part, may prove to be unfounded when details are more clearly known. If change is accepted under these circumstances it may prove unwarranted, necessitating further shift, perhaps a return to the original status. Since this can only prove confusing I prefer the conservative course. In the remarks that follow I shall discuss only a few matters on which I have more or less concrete ideas.

In the superfamily Furnarioidea, von Ihering (1915, pp. 145-153) united the Furnariidae and the Dendrocolaptidae, since he was unable to separate two groups on the basis of the form of the posterior border of the nasal opening. The variation that he showed seems valid, but there are numbers of other points of supposed difference in the osteology and other structural details, so that his suggestion is far from established. Pycraft (1906, pp. 133-159), though seemingly uncertain in the beginning, finally retained the two families. It may prove that some genera are wrongfully allocated at present between the two groups, so that their shift, when we have sufficient information, will clear our understanding.

In the Tyrannoidea, the family Oxyruncidae is known through external characters that seem to warrant separation. If the sharpbills have other affinities it is doubtful that these are within the family Tyrannidae, where some have placed them.

In the family Cracticidae, recognized by Australian ornithologists, the skull, according to Pycraft (1907, pp. 355-365), mainly from examination of *Gymnorhina,* has the zygomatic process of the squamosal bifurcate, the postorbital process large, the orbitosphenoid ossified, the interorbital septum with a single opening, the prefrontals unusually large, and the form of the palate peculiar. In his phylogenetic tree Pycraft places the group on a common stem with the Artamidae, and not far from the Paradisaeidae. His account is difficult to summarize in concrete form.

The family Grallinidae is likewise recognized officially by Australian ornithologists for *Grallina cyanoleuca,* the magpie-lark. The principal study of the osteology is that of Shufeldt (1923, pp. 16-19, pl. 6) but his account is mainly descriptive and without definite conclusion. Amadon (1950, pp. 123-127) has placed *Corcorax* and *Struthidea* here tentatively, though this seems subject to further proof.

Stonor (1937, pp. 475-490) has outlined excellent reasons for recognition of the Ptilonorhynchidae, finding that they differ from Paradisaeidae, with which they have been united, in having an apterium in the center of the dorsal feather tract, the tip of the vomer convex, larger, more developed maxillo-palatines, the margin of the palatines angular, smaller ectethmoid, much larger lachrymal, and slender, greatly elongated orbital ramus of the quadrate. The genera *Loria* and *Loboparadisea,* usually included here, he transfers to the Paradisaeidae. His conclusion is that "the Ptilonorhynchidae constitute a singularly complete and isolated family of the acromyodian passerine birds and show no special relationship to any other, being sharply marked off by the structure of the skull, the colour-pattern, and the bower-building habit." (It should be noted that the names on Stonor's figs. 6 and 8 have been transposed, fig. 6 being *Semioptera wallacei,* and fig. 8 *Amblyornis subalaris,* not the reverse as printed on pp. 481 and 483.)

Oberholser (1917, pp. 537-539) has set up a distinct family Irenidae for the fairy bluebirds (*Irena*), and Delacour (1946b, p. 3) a family Aegithinidae for the leafbirds, which would cover *Irena, Aegithina,* and *Chloropsis.*

The proper allocation of the genus *Chamaea* for the wrentits, at present accepted by the A. O. U. Committee on Classification and Nomenclature as a separate family, the Chamaeidae, is one of considerable uncertainty. Delacour (1946a, pp. 18, 25, 35) has suggested that the group be located in the family Timaliidae in a special subfamily in which he includes also such diverse genera as *Chrysomma* (*Moupinia*), *Panurus, Conostoma,* and *Paradoxornis* (combining under this name *Suthora, Psittiparus, Neosuthora,* and *Cholornis*). This is an obviously heterogeneous assemblance, in which *Chamaea* has slight resemblances to the first only. From *Moupinia poecilotis* (placed in *Chrysomma* by Delacour) the wrentit differs definitely in weaker, less arched bill and in differently proportioned feet. It has no close similarity to any of the others that are mentioned. Although the relationships of *Chamaea* are obviously uncertain, it is retained as a family pending other information.

In consultation with Herbert Deignan, expert in matters that relate to the birds of eastern Asia, the Campephagidae have been placed near the Pycnonotidae, an arrangement that agrees with that adopted by Charles Vaurie in his recent volume on the palearctic region (1959, p. 181), and the Paradoxornithidae are brought nearer the Timeliidae.

The fossil family Palaeoscinidae, proposed by Hildegarde Howard (1957b, p. 15) for the species *Palaeoscinis turdirostris,* has been inserted provisionally near the Pycnonotidae. The specimen on which this name is based is a skeleton found in Santa Barbara County, Calif., compressed in a slab of Miocene limestone of the Monterey formation. The type, in which most of the bones are outlined, is one of those attractive silhouette impressions that delight the eye but that often pose difficulties in classification through lack of clear-cut characters on which to judge relationship. In the present instance Dr. Howard has concluded that "affinities of the Palaeoscinidae lie with the Pycnonotidae, Bombycillidae, Corvidae and Cinclidae" of the suborder

Passeres. Affinity with the Bombycillidae may be queried, as the fossil differs from *Bombycilla* in the proportions found in the hind limb, where both metatarsus and femur are longer in comparison with the tibiotarsus, and the toes appear longer, as well as of different proportion. The corvid affiliation also seems uncertain because of the slender form of *Palaeoscinis,* since the skeleton of the crows and their relatives is strong and robust.

Separation of the two genera of leafbirds, *Aegithina* and *Chloropsis,* in a family distinct from the Pycnonotidae is justified on the basis of characters found in the skull. The entire palatal structure is slighter than in *Pycnonotus* and allied genera, with the central plate of the palatine reduced in area, and the transpalatine produced posteriorly. The sphenoidal rostrum is slender, as is the orbital process of the quadrate. In *Pycnonotus* the palatine is broad, the transpalatine process distally is only slightly angular without posterior projection, and both the rostrum and the orbital process of the quadrate are strong and heavy. Herbert Deignan informs me that the group, recognized by several authors, seems to have been first separated by Cabanis (1847, p. 326), who designated it as the subfamily "Phyllornithinae" based on *Phyllornis* Temminck, 1829. This generic term is antedated by *Chloropsis* Jardine and Selby, 1826, so the family name based on this genus will be Chloropseidae, rather than Aegithinidae which dates from G. R. Gray in 1869 (p. 312).

The fairy bluebirds, genus *Irena,* often have been placed with the leafbirds but have no close connection with that group. The main external peculiarity of *Irena* is found in the smooth, enamel-like tipping found in adult males on the feathers of the central dorsal area from the center of the crown back over hindneck, back, rump, and upper tail coverts, and on the elongated under tail coverts. As this is a secondary sexual character, not present in females, it has no value at the family level. In the osteology, the skull differs from *Chloropsis* and *Aegithina* in the completely open external narial opening, the ossification of the vertical plate between the nares, the more inflated lachrymal, and the more elongate maxillo-palatines. In the sternum the depth of the notch on either side of the posterior margin relatively is decidedly less, and in the pelvis the antitrochanter has the dorsal margin much produced laterally. The general resemblance in these matters is to species of the genus *Oriolus.* It may be observed further that the feathers of breast and back in the aberrant species *Oriolus traillii* and *O. mellianus* have smooth exposed ends that suggest the condition found in male *Irena.* In view of these resemblances, and in lack of important differences, it seems sufficient to include the fairy bluebirds in the family Oriolidae, as the subfamily Ireninae, which incidentally dates from G. R. Gray (1869, p. 288) and not from the name Irenidae set up later by Oberholser (1917, pp. 537-539).

Suggestions for the union of the Bombycillidae, Ptilogonatidae, and the Dulidae in one family are not substantiated by examination of the skeleton. *Dulus,* the palmchat, is widely different from the other two, a structural distinction that is further emphasized by its curious communal nesting habits. The first two seem more closely related but are separated clearly by characters found in the ectethmoid region of the skull, and in the manubrium, to mention only two points that are easily apparent. Delacour and Amadon (1949, pp. 427-429) consider *Hypocolius* closely allied to *Ptilogonys.*

While Zimmer (1942, p. 10) believed that the family Vireolaniidae should be included in the Vireonidae, separate family rank in my opinion is definitely justified. In addition to characters assigned by Pycraft (1907, pp. 378-379) for the shrike-vireos I have found that in the pterylosis the dorsal tract on the lower back is divided, the arms being broad at the ends, and separated from the narrowed line that continues onto the caudal area. This is completely different from the usual rhomboid in the vireos, and may indicate that the family eventually should be removed from the vicinity of the Vireonidae.

The family characters of the peppershrikes, likewise outlined by Pycraft in the reference given above, are easily apparent on examination of the skeleton.

The family Callaeidae has been separated by Stonor (1942, pp. 1-18) on the weakened keel of the sternum, the great development of the lower limb coupled with reduced powers of flight, and the presence of a mouth wattle, for three peculiar genera, *Callaeus, Heterolocha,* and *Philesturnus* of New Zealand.

Continuing discussion relative to the group of families to be placed in elevated position at the end of the list has led to publication of several useful studies and interesting statements. Beecher (1953, pp. 270-333) from examination of the musculature of the jaw, aided by other anatomical features, has proposed two major divisions of the suborder of the song birds, within which he has diagramed radiating lines of family and subfamily relationship. While he shows a variety of connections that in many cases vary widely from ideas current at present, he places the crow group in the assemblage with simpler muscle development in the area of the jaw, in contrast to those of higher status with a more complicated arrangement.

Tordoff (1954a, 1954b) in a study of the skull, particularly the palatal structure, of species allied to the Fringillidae, has proposed the union of part of the honeycreepers and the wood warblers in one family, the tanagers, with part of the coerebine assemblage with some of the fringillids in the Fringillidae, and removal of the cardueline finches to the Ploceidae, placing that family at the end of his list. His detailed studies afford much valuable information. I agree with him that shifting of certain genera to families in which they are not classified at present will lead to better alignment, but I am not prepared from present information to completely dismember the Coerebidae without further study. *Coereba,* for example, has a stomach peculiar in its small size; *Diglossa* differs in the form of the bill, in which the gonys is extended posteriorly behind the level of the nostril, so that it differs from all other oscinine species, to cite only two easily seen characters.

Mayr and Greenway (1956, pp. 2-5, 8-9) discuss problems of sequence in some detail and cite the approval of a committee appointed at the International Ornithological Congress held in Basel in 1954 to allocation of the Corvidae at the higher end of the list, as has been long customary among most ornithologists of Europe. In further consideration of these matters, I published a note on the humerus of the Corvidae (Wetmore, 1957, pp. 207-209), which called attention particularly to the proximal end of the bone, where the pneumatic fossa in *Corvus,* for example, has a form not only generally similar to that of the New World flycatchers and their allies, which are recognized as low down in the linear classification, but also to the woodpeckers, the Coraciiformes, and the trogons. There is transition from this simpler form to the style found in such groups as the Icteridae, Thraupidae, and Fringillidae, where the fossa is enlarged, and is more complex, as it is partly divided by a bladelike process projecting from the internal tuberosity. (In the paper cited I neglected to refer to an earlier study by James T. Ashley [1941] on the humerus of the Corvidae, which outlined the same differences, and on which Ashley considered the crow group to have more primitive status.)

Amadon (1957) recently has outlined the three major groups of oscinine families, with the conclusion that the one most highly advanced includes the 9-primaried New World groups, while the section containing the crows is placed low at the beginning. There is general agreement with this in the classification outlined by Delacour and Vaurie (1957).

Storer (1959) in a clearly stated summary of these recent contributions, in which he includes a more recent statement by Mayr (1958), writes that in a classification for a text on the biology of birds now in preparation he has placed the 9-primaried groups in the highest place, and indicates that this is the procedure that is gaining in acceptance in parts of the world other than America.

The former family Melithreptidae becomes the family Meliphagidae, since the name of the type genus is now accepted as *Meliphaga* Lewin, 1808.

In a similar way the family Compsothlypidae for the wood warblers becomes the family Parulidae, since the former *Compsothlypis* Cabanis, 1851, is replaced by the older *Parula* Bonaparte, described in 1838.

The order of arrangement in the Passeriformes as said above is in part necessarily arbitrary, through the easily perceptible and often-remarked fact that we are required to list the groups in linear order in a two-dimensional alignment when actually they stand in three-dimensional relationship to one another. A further element that may be regarded almost as a fourth dimension is found in some of the extinct groups known only as fossils that have no close relatives alive today. The sequence in the following pages is the one that best represents my present understanding, based on personal studies over a period of more than 50 years. I continue to place the Fringillidae at the end of the list, because of my feeling that this group is the modern expression of a main core or stem that through the earlier Tertiary periods has given rise to more specialized assemblages that we now recognize as distinct families. Further specialization is apparent in some parts of the existing fringilline assemblage that, if undisturbed, may lead to further differentiation, should these variants be able to persist for the necessary millenniums in our rapidly changing world. Adjacent to the Fringillidae I place the other groups that obviously are closely allied to them. Attempts to arrange the avian families with the Corvidae and their allies in the terminal position, because of supposed more advanced development of the brain, appear to me quite uncertain, particularly in view of our decidedly limited information in this field. Should this idea be coupled with belief in superior mental reactions in the corvine assemblage, I would consider this more an anthropomorphic interpretation than one supported by scientific fact.

In the formation of group names the suffixes -idae and -inae for families and subfamilies are accepted rather universally so that they do not require examination. In view of the limited number of species covered in ornithology I see no point in the introduction of tribes as another category between the subfamily and the genus. This may be useful to entomologists with their tens of thousands of species but seems unnecessary and cumbersome with birds. In some of the more comprehensive avian genera there are groups of species more closely allied to one another than to their fellows, but the taxonomist may discuss these at need as groups without imposing another burden on a classification that now is highly divided. For the group names above the family level, I believe it preferable to use suffixes that allow immediate identification of the rank, coupled with a stem that, like the family name, is based on a current generic term. Where ordinal and subordinal names are both formed as Latin plurals there is possibility of confusion.

SYSTEMATIC LIST

Fossil groups in brackets

Class Aves, Birds.
  [Subclass Archaeornithes, Ancestral Birds (fossil).]
    [Order Archaeopterygiformes, Archaeopteryx, Archaeornis (fossil).]
      [Family Archaeopterygidae, *Archaeopteryx, Archaeornis* (fossil).]
  Subclass Neornithes, True Birds.
    [Superorder Odontognathae, New World Toothed Birds (fossil).]
      [Order Hesperornithiformes, Hesperornithes (fossil).]
        [Family Hesperornithidae, *Hesperornis* (fossil).]
          [Enaliornithidae,[1] *Enaliornis* (fossil).]
          [Baptornithidae, *Baptornis* (fossil).]
    [Superorder *Ichthyornithes*, Ichthyornis and Allies (fossil).]
      [Order Ichthyornithiformes, Ichthyornithes (fossil).]
        [Family Ichthyornithidae, *Ichthyornis* (fossil).]
          [Apatornithidae, *Apatornis* (fossil).]
    Superorder Impennes, Penguins.
      Order Sphenisciformes, Penguins.
        Family Spheniscidae, Penguins.
    Superorder Neognathae, Typical Birds.
      Order Struthioniformes, Ostriches.
        [Family Eleutherornithidae, *Eleutherornis* (fossil).]
          Struthionidae, Ostriches.
      Order Rheiformes, Rheas.
        Family Rheidae, Rheas.
      Order Casuariiformes, Cassowaries, Emus.
        Family Casuariidae, Cassowaries.
          Dromiceidae, Emus.
          [Dromornithidae, *Dromornis* (fossil).]

[1] Position provisional.

[Order Aepyornithiformes, Elephantbirds (fossil and subfossil).]
[Family Aepyornithidae, *Aepyornis* (fossil and subfossil).]
[Order Dinornithiformes, Moas (fossil and subfossil).]
[Family Dinornithidae, *Dinornis* (fossil and subfossil).]
[Anomalopterygidae, *Anomalopteryx, Emeus,* and Allies (fossil and subfossil).]
Order Apterygiformes, Kiwis.
Family Apterygidae, Kiwis.
Order Tinamiformes, Tinamous.
Family Tinamidae, Tinamous.
Order Gaviiformes, Loons.
Family Gaviidae, Loons.
Order Podicipediformes, Grebes.
Family Podicipedidae, Grebes.
Order Procellariiformes, Albatrosses, Shearwaters, Petrels, and Allies.
Family Diomedeidae, Albatrosses.
Procellariidae, Shearwaters, Fulmars.
Hydrobatidae, Storm Petrels.
Pelecanoididae, Diving Petrels.
Order Pelecaniformes, Tropicbirds, Pelicans, Frigate-birds, and Allies.
[Suborder Odontopteryges, Odontopteryx, and Allies (fossil).]
[Family Odontopterygidae, *Odontopteryx* (fossil).]
[Pseudodontornithidae, *Pseudodontornis, Osteodontornis* (fossil).]
Suborder Phaëthontes, Tropicbirds.
Family Phaëthontidae, Tropicbirds.
Suborder Pelecani, Pelicans, Boobies, Cormorants, Snakebirds.
Superfamily Pelecanoidea, Pelicans and Allies.
Family Pelecanidae, Pelicans.
[Cyphornithidae, *Cyphornis, Palaeochenöides* (fossil).]
Superfamily Suloidea, Boobies, Cormorants, and Allies.
Family [Pelagornithidae, *Pelagornis* (fossil).]
Sulidae, Boobies, Gannets.

[Elopterygidae, *Elopteryx, Eostega, Actiornis* (fossil).]
Phalacrocoracidae, Cormorants.
Anhingidae, Snake-birds.
Suborder Fregatae, Frigate-birds.
Family Fregatidae, Frigate-birds.
[Suborder Cladornithes, Cladornis and Cruschedula (fossil).]
[Family Cladornithidae, *Cladornis, Cruschedula* (fossil).]
Order Ciconiiformes, Herons, Storks, and Allies.
Suborder Ardeae, Herons, Bitterns.
Family Ardeidae, Herons, Bitterns.
Cochleariidae, Boatbilled Herons.
Suborder Balaenicipites, Whale-headed Storks.
Family Balaenicipitidae, Whale-headed Storks.
Suborder Ciconiae, Storks, Ibises, Spoonbills.
Superfamily Scopoidea, Hammerheads.
Family Scopidae, Hammerheads.
Superfamily Ciconioidea, Storks.
Family Ciconiidae, Storks, Jabirus.
Superfamily Threskiornithoidea, Ibises.
Family Threskiornithidae, Ibises, Spoonbills.
Suborder Phoenicopteri, Flamingos.
[Family Agnopteridae, *Agnopterus* (fossil).]
[Scaniornithidae, *Scaniornis, Parascaniornis* (fossil).]
Phoenicopteridae, Flamingos.
[Palaelodidae, *Palaelodus, Megapaloelodus, Telmabates* (fossil).]
Order Anseriformes, Screamers, Ducks, Geese, Swans.
Suborder Anhimae, Screamers.
Family Anhimidae, Screamers.
Suborder Anseres, Ducks, Geese, Swans.
[Family Paranyrocidae, *Paranyroca* (fossil).]
Anatidae, Ducks, Geese, Swans.
Order Falconiformes, Vultures, Hawks, Falcons.
Suborder Cathartae, New World Vultures.
[Superfamily Neocathartoidea, Neocathartes (fossil).]
[Family Neocathartidae, *Neocathartes* (fossil).]

Superfamily Cathartoidea, New World Vultures.
Family Cathartidae, New World Vultures.
[Teratornithidae, *Teratornis, Cathartornis* (fossil).]
Suborder Falcones, Secretarybirds, Hawks, Falcons.
Superfamily Sagittarioidea, Secretarybirds.
Family Sagittariidae, Secretarybirds.
Superfamily Falconoidea, Hawks, Falcons, and Allies.
Family Accipitridae, Hawks, Old World Vultures, Harriers.
Pandionidae, Ospreys.
Falconidae, Falcons, Caracaras.
Order Galliformes, Megapodes, Curassows, Pheasants, Hoatzins.
Suborder Galli, Megapodes, Curassows, Grouse, Pheasants.
Superfamily Cracoidea, Megapodes, Curassows.
Family Megapodiidae, Megapodes.
[Gallinuloididae, *Gallinuloides* (fossil).]
Cracidae, Curassows, Guans, Chachalacas.
Superfamily Phasianoidea, Grouse, Pheasants, Turkeys.
Family Tetraonidae, Grouse.
Phasianidae, Quails, Pheasants, Peacocks.
Numididae, Guineafowl.
Meleagrididae, Turkeys.
Suborder Opisthocomi, Hoatzins.
Family Opisthocomidae, Hoatzins.
Order Gruiformes, Cranes, Rails, and Allies.
Suborder Mesitornithides, Roatelos, Monias.
Family Mesitornithidae, Roatelos, *Monias.*
Suborder Turnices, Bustardquails, Hemipodes.
Family Turnicidae, Bustardquails.
Pedionomidae, Plainwanderers.
Suborder Grues, Cranes, Limpkins, Trumpeters, Rails.
Superfamily Gruoidea, Cranes, Limpkins, Trumpeters.
[Family Geranoididae, *Geranoides* (fossil).]
[Eogruidae, *Eogrus* (fossil).]
Gruidae, Cranes.
Aramidae, Limpkins.
Psophiidae, Trumpeters.

Superfamily Ralloidea, Rails.

[Family Orthocnemidae,[2] *Orthocnemus, Elaphrocnemus* (fossil).]

Rallidae, Rails, Coots, Gallinules.

Suborder Heliornithes, Sungrebes.

Family Heliornithidae, Sungrebes.

Suborder Rhynocheti, Kagus.

Family Rhynochetidae, Kagus.

Suborder Eurypygae, Sunbitterns.

Family Eurypygidae, Sunbitterns.

Suborder Cariamae, Seriemas and Allies.

[Superfamily Phororhacoidea, Phororhacos and Allies (fossil).]

[Family Phororhacidae, *Phororhacos* and Allies (fossil).]

[Psilopteridae, *Psilopterus* and Allies (fossil).]

[Brontornithidae, *Brontornis, Liornis,* and Allies (fossil).]

[Opisthodactylidae, *Opisthodactylus* (fossil).]

[Cunampaiidae, *Cunampaia* (fossil).]

Superfamily Cariamoidea, Seriemas and Allies.

[Family Bathornithidae, *Bathornis* (fossil).]

[Hermosiornithidae, *Hermosiornis, Procariama* (fossil).]

Cariamidae, Seriemas.

Suborder Otides, Bustards.

Family Otididae, Bustards.

[Order Diatrymiformes, Diatryma, Omorhamphus, and Allies (fossil).]

[Family Diatrymidae, *Diatryma* (fossil).]

[Gastornithidae, *Gastornis, Remiornis* (fossil).]

Order Charadriiformes, Shore Birds, Gulls, Auks.

Suborder Charadrii, Shore Birds.

Superfamily Jacanoidea, Jaçanas.

Family Jacanidae, Jaçanas.

Superfamily Charadrioidea, Plovers, Sandpipers, and Allies.

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[2] Position provisional.

[Family Rhegminornithidae, *Rhegminornis* (fossil).]
Rostratulidae, Painted Snipe.
Haematopodidae, Oystercatchers.
Charadriidae, Plovers, Turnstones, Surfbirds.
Scolopacidae, Snipe, Woodcock, Sandpipers.
Recurvirostridae, Avocets, Stilts.
[Presbyornithidae, *Presbyornis* (fossil).]
Phalaropodidae, Phalaropes.
Superfamily Dromadoidea, Crabplovers.
Family Dromadidae, Crabplovers.
Superfamily Burhinoidea, Thick-knees.
Family Burhinidae, Thick-knees.
Superfamily Glareoloidea, Pratincoles, Coursers.
Family Glareolidae, Pratincoles, Coursers.
Superfamily Thinocoroidea, Seedsnipe.
Family Thinocoridae, Seedsnipe.
Superfamily Chionidoidea, Sheathbills.
Family Chionididae, Sheathbills.
Suborder Lari, Gulls, Terns, Skimmers.
Family Stercorariidae, Skuas, Jaegers.
Laridae, Gulls, Terns.
Rynchopidae, Skimmers.
Suborder Alcae, Auks.
Family Alcidae, Auks, Auklets, Murres.
Order Columbiformes, Sandgrouse, Pigeons, Doves.
Suborder Pterocletes, Sandgrouse.
Family Pteroclidae, Sandgrouse.
Suborder Columbae, Pigeons, Doves.
Family Raphidae, Dodos, Solitaires.
Columbidae, Pigeons, Doves.
Order Psittaciformes, Lories, Parrots, Macaws.
Family Psittacidae, Lories, Parrots, Macaws.
Order Cuculiformes, Plantain-eaters, Cuckoos.
Suborder Musophagi, Plantain-eaters.
Family Musophagidae, Plantain-eaters, Touracos.
Suborder Cuculi, Cuckoos, Roadrunners, Anis.
Family Cuculidae, Cuckoos, Roadrunners, Anis.
Order Strigiformes, Owls.
[Family Protostrigidae, *Protostrix* (fossil).]
Tytonidae, Barn Owls.
Strigidae, Typical Owls.

Order Caprimulgiformes, Oilbirds, Goatsuckers.
Suborder Steatornithes, Oilbirds.
Family Steatornithidae, Oilbirds.
Suborder Caprimulgi, Frogmouths, Goatsuckers.
Family Podargidae, Frogmouths.
Nyctibiidae, Potoos.
Aegothelidae, Owlet-frogmouths.
Caprimulgidae, Goatsuckers.
Order Apodiformes, Swifts, Hummingbirds.
Suborder Apodi, Swifts.
[Family Aegialornithidae,[3] *Aegialornis* (fossil).]
Apodidae, Swifts.
Hemiprocnidae, Crested Swifts.
Suborder Trochili, Hummingbirds.
Family Trochilidae, Hummingbirds.
Order Coliiformes, Colies.
Family Coliidae, Colies.
Order Trogoniformes, Trogons.
Family Trogonidae, Trogons.
Order Coraciiformes, Kingfishers, Bee-eaters, Rollers, Hornbills.
Suborder Alcedines, Kingfishers, Todies, Motmots.
Superfamily Alcedinoidea, Kingfishers.
Family Alcedinidae, Kingfishers.
Superfamily Todoidea, Todies.
Family Todidae, Todies.
Superfamily Momotoidea, Motmots.
Family Momotidae, Motmots.
Suborder Meropes, Bee-eaters.
Family Meropidae, Bee-eaters.
Suborder Coracii, Rollers, Hoopoes.
Family Coraciidae, Rollers.
Brachypteraciidae, Groundrollers.
Leptosomatidae, Cuckoo-rollers.
Upupidae, Hoopoes.
Phoeniculidae, Woodhoopoes.
Suborder Bucerotes, Hornbills.
Family Bucerotidae, Hornbills.

[3] Position provisional.

Order Piciformes, Jacamars, Barbets, Toucans, Woodpeckers.
Suborder Galbulae, Jacamars, Barbets, Toucans.
Superfamily Galbuloidea, Jacamars, Puffbirds.
Family Galbulidae, Jacamars.
Bucconidae, Puffbirds.
Superfamily Capitonoidea, Barbets, Honeyguides.
Family Capitonidae, Barbets.
Indicatoridae, Honeyguides.
Superfamily Ramphastoidea, Toucans.
Family Ramphastidae, Toucans.
Suborder Pici, Woodpeckers.
Family Picidae, Woodpeckers, Piculets.
Order Passeriformes, Perching Birds.
Suborder Eurylaimi, Broadbills.
Family Eurylaimidae, Broadbills.
Suborder Tyranni, Ovenbirds, Tyrant Flycatchers, and Allies
Superfamily Furnarioidea, Ovenbirds, Woodhewers, and Allies.
Family Dendrocolaptidae, Woodhewers.
Furnariidae, Ovenbirds.
Formicariidae, Ant-thrushes.
Conopophagidae, Antpipits.
Rhinocryptidae, Tapaculos.
Superfamily Tyrannoidea, Tyrant Flycatchers, Pittas, and Allies.
Family Cotingidae, Cotingas.
Pipridae, Manakins.
Tyrannidae, Tyrant Flycatchers.
Oxyruncidae, Sharpbills.
Phytotomidae, Plantcutters.
Pittidae, Pittas.
Acanthisittidae, New Zealand Wrens.
Philepittidae, Asities, False Sunbirds.
Suborder Menurae, Lyrebirds.
Family Menuridae, Lyrebirds.
Atrichornithidae, Scrubbirds.
Suborder Passeres, Songbirds.
Family Alaudidae, Larks.
[Palaeospizidae, *Palaeospiza* (fossil).]
Hirundinidae, Swallows.
Dicruridae, Drongos.

Oriolidae, Old World Orioles.
Corvidae, Crows, Magpies, Jays.
Cracticidae, Bell Magpies, Australian Butcher-birds.
Grallinidae, Magpie-larks.
Ptilonorhynchidae, Bowerbirds.
Paradisaeidae, Birds of Paradise.
Paridae, Titmice.
Sittidae, Nuthatches.
Hyposittidae, Coralbilled Nuthatches.
Certhiidae, Creepers.
Paradoxornithidae, Parrotbills, Suthoras.
Chamaeidae, Wrentits.
Timaliidae, Babblers.
Campephagidae, Cuckoo-shrikes.
Pycnonotidae, Bulbuls.
[Palaeoscinidae,[4] *Palaeoscinis* (fossil).]
Chloropseidae, Leafbirds.
Cinclidae, Dippers.
Troglodytidae, Wrens.
Mimidae, Thrashers, Mockingbirds.
Turdidae, Thrushes.
Zeledoniidae, Wrenthrushes.
Sylviidae, Old World Warblers.
Regulidae, Kinglets.
Muscicapidae, Old World Flycatchers.
Prunellidae, Accentors.
Motacillidae, Wagtails, Pipits.
Bombycillidae, Waxwings.
Ptilogonatidae, Silky Flycatchers.
Dulidae, Palmchats.
Artamidae, Woodswallows.
Vangidae, Vanga Shrikes.
Laniidae, Shrikes.
Prionopidae, Woodshrikes.
Cyclarhidae, Peppershrikes.
Vireolaniidae, Shrike-vireos.
Callaeidae, Wattled Crows, Huias, Saddlebacks.
Sturnidae, Starlings.
Meliphagidae, Honey-eaters.

[4] Allocation to this position is tentative.

Nectariniidae, Sunbirds.
Dicaeidae, Flowerpeckers.
Zosteropidae, White-eyes.
Vireonidae, Vireos.
Coerebidae, Honeycreepers.
Drepanididae, Hawaiian Honeycreepers.
Parulidae, Wood Warblers.
Ploceidae, Weaverbirds.
Icteridae, Blackbirds, Troupials.
Tersinidae, Swallowtanagers.
Thraupidae, Tanagers.
Catamblyrhynchidae, Plushcapped Finches.
Fringillidae, Grosbeaks, Finches, Buntings.

December 31, 1959.

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