Lower Tertiary Crinoids from Northwestern Oregon

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By RAYMOND C. MOORE *and* HAROLD E. VOKES

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LOWER TERTIARY CRINOIDS FROM NORTHWESTERN OREGON

By Raymond C. Moore and Harold E. Vokes

ABSTRACT

The occurrence of numerous remains of crinoids, including nearly complete crowns, in the middle member of the Keasey formation, early Tertiary, of northwestern Oregon is of more than ordinary paleontological interest. Most of the marine Tertiary formations of North America are notably lacking in crinoids, although in a few places abundant fragmentary remains of free-swimming crinoids (comatulids) have been reported. Only five species have been described from North America, exclusive of the West Indies. Five more species, distinguished on the basis of stem fragments, are reported from Eocene rocks of Trinidad and Miocene deposits of Haiti and Cuba.

The Oregon crinoids here described are stem-bearing forms, assigned to the genus *Isocrinus*. They constitute the first-reported occurrence of this type of crinoid in the Tertiary of the continent. It is especially interesting to find nearly complete crowns that rival some of the well-known pentacrinid crowns from Jurassic localities in Europe. However, the Oregon fossils generally have the hard parts poorly preserved, and some of the best preparations for study of their structure consist of external molds. A few of the molds were formed by natural weathering, but most have been prepared by etching the partly decomposed calcite with acid.

On the basis of more than a dozen crowns, some fairly complete, and innumerable fragments of stems, arms, and pinnules, two species are recognized. They are named *Isocrinus oregonensis* and *I. nehalemensis*. Some fossils, preserved as calcite, are assigned to each species, but most of the specimens are molds.

The Keasey formation includes deposits belonging to the uppermost Eocene and lower Oligocene. Analysis of the molluscan fauna, which is associated with the crinoids in the middle member of the Keasey formation, indicates that the crinoid-bearing beds are probably of early Oligocene age.

The matrix in which the fossils are embedded is a highly tuffaceous, mostly fine-grained, hard, massive siltstone. Locally, it contains scattered ash "pebbles" ¼ in. or more in diameter. The articulated condition of most of the crinoid material indicates very quiet water sedimentation, which certainly does not belong in a wave-agitated, near-shore zone. That land was not far away from the sites where crinoids were buried during Keasey sedimentation, however, is indicated by the ash "pebbles" and especially by occurrence of well-preserved land plants, which are mingled with the mollusks and crinoids. The environment of deposition, accordingly, is interpreted to denote moderately deep water adjacent to a land on which explosive-type volcanic activity existed during at least middle and late times of deposition. That the area in which the crinoids lived and were buried was a sound seems more likely than that it was open ocean.

INTRODUCTION

DISCOVERY OF CRINOID REMAINS IN OREGON

The remarkable crinoid specimen, which constitutes the holotype of the new species *Isocrinus oregonensis*, was collected in 1944 by Walter C. Warren and Rex M. Grivetti, at that time members of a field party of the United States Geological Survey engaged in preparation of a reconnaissance geologic map of northwestern Oregon (Warren, Grivetti, and Norbisrath, 1945). The specimen was found in a stratum of the Keasey formation (figs. 27, 28) exposed a short distance above the level of the Nehalem River in a prominent bluff located on the west side of that river approximately 3,500 feet south of the junction of Oregon State highways 47 and 202 at Mist, Columbia County, Oreg. (U. S. Geol. Survey locality 15318). This site has long been known as a fossil locality, first described by Diller in 1896 (pp. 469–470). Schenck (1936, p. 58) recognized it as being probably the type locality of *Acila* (*Truncacila*) *nehalemensis* G. D. Hanna, one of the principal guide fossils of the Keasey formation.

Crinoid material is not uncommon in a thin zone at this outcrop, and crinoid specimens are known to be in the hands of amateur collectors from the Portland area. A few fragmentary specimens are in the collections at Oregon State College, Corvallis, Oreg.

In view of the absence of known stem-bearing crinoids in Tertiary deposits of North America outside of Oregon, and of the fact that the occurrence of crinoids at the Columbia County locality was fairly well known locally some time before collection of specimens by the U. S. Geological Survey party, it is rather surprising that these fossils have not been reported earlier. If west coast paleontologists knew of the Keasey crinoids they must not have apprehended the extreme rareness and fragmentary condition of described stem-bearing crinoids elsewhere in Tertiary deposits of the world. The fossils are important because of the very meager record of stem-bearing crinoids in North America between Late Cretaceous and the present time.

In addition to the relatively complete crowns described from the locality near Mist, crinoid stem segments occur at four other localities in the Keasey formation. The material from three of them agrees with the more abundant stem segments found in association with the crowns at U. S. Geological Survey locality 15318 and is referred to *Isocrinus oregonensis*. Columnals from the fourth locality are unlike the common ones in the other collections and are considered to represent a different form, here called *I. nehalemensis*. Stem fragments were found also in coarse sandstones of the

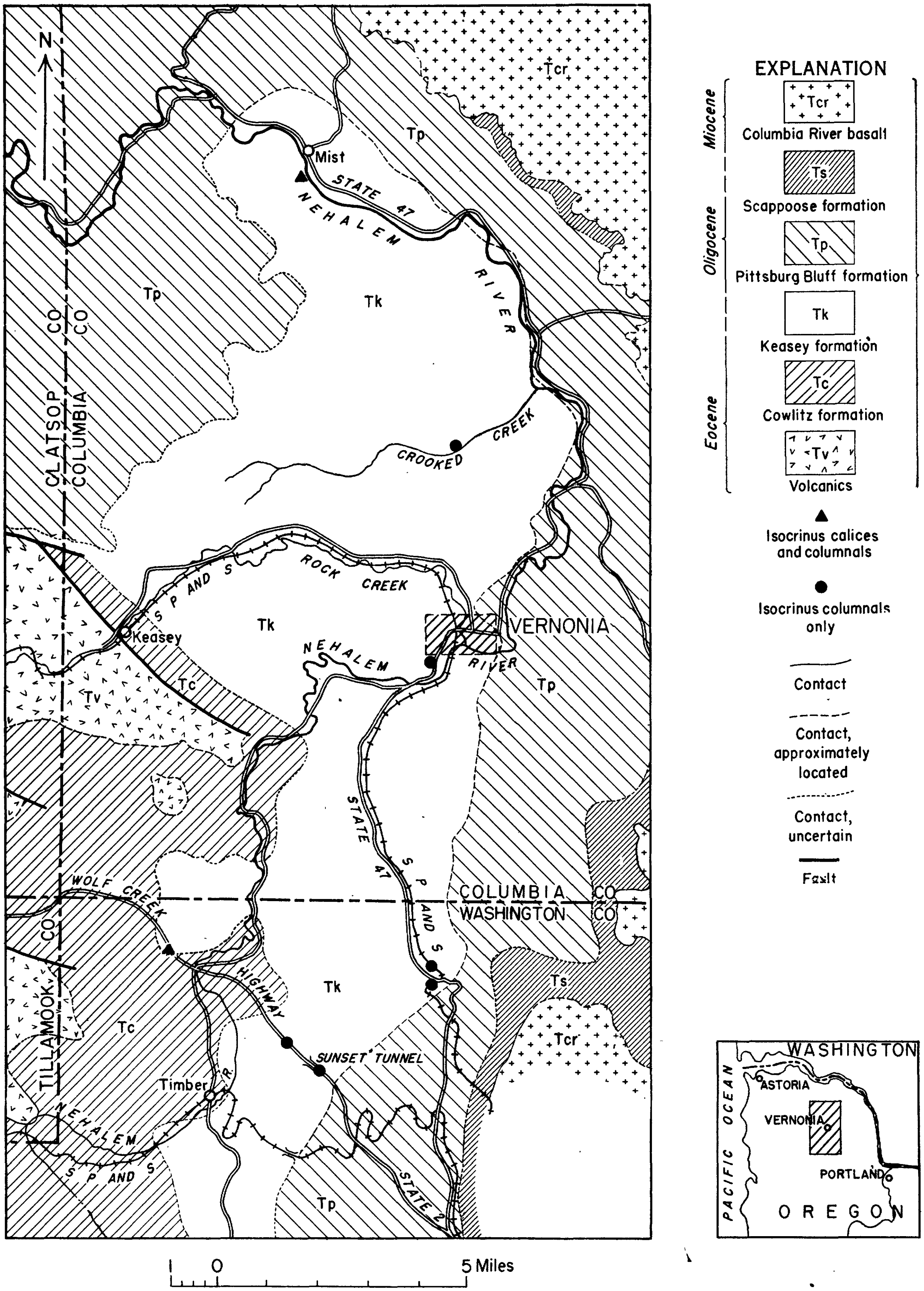


FIGURE 27.—Map of upper Nehalem basin, northwestern Oregon, showing localities that yielded crinoids.

Member	*Thickness (feet)*	*Description*
Upper	120	Interbedded gray tuffaceous shale and fine-grained tuffaceous sandstone with a few thin beds of fine tuff; sparingly fossiliferous; fauna includes *Lima (Acesta) oregonensis* Clark, *Nemocardium lorenzanum* (Arnold), *Porterius gabbi* (Dickerson). *Turcicula* n. sp., *Gyrineum jeffersonensis* Durham.
Middle	335	Approximate horizon of occurrence of crinoid calyces at Mist, Oregon. Gray tuffaceous mudstone with a few thin tuff beds, and scattered bands of fossiliferous calcareous concretions. Scattered fossils; fauna includes *Acila (Truncacila) nehalemensis* Hanna, *Nemocardium weaveri* (Anderson and Martin), *Thracia* n. sp., *Tellina* n. sp., *Olequahia schencki* Durham, *Nekewis* n. sp., *Flabellum hertleini* Durham, *Eumorphocorystes naselensis* Rathbun, etc.
	125	Gray, firm, well-stratified tuffaceous shale with thin tuff bands. Fauna includes *Acila (Truncacila) nehalemensis* Hanna, *Nemocardium weaveri* (Anderson and Martin), *Tellina* n. sp., *Echinophoria "dalli var."* Durham, *Epitonium condoni* (Dall) n. var., etc.
	100	Gray, unstratified, tuffaceous mudstone with thin tuff bands. Fauna includes *Acila (Truncacila) nehalemensis* Hanna, *Nemocardium weaveri* (Anderson and Martin), *Tellina* n. sp., *Epitonium keaseyense* Durham, *"Gemmula" bentsonae* Durham, etc.
	480	Gray, unstratified, tuffaceous and sandy mudstone, (mostly concealed) with occasional thin tuff beds, and scattered bands of dark, calcareous concretions, many containing large numbers of *Delectopecten* n. sp. A large and heterogeneous fauna includes *Acila (Truncacila) nehalemensis* Hanna, *Nemocardium weaveri* (Anderson and Martin), *Thracia* n. sp., *Tellina* n. sp., *Epitonium keaseyense* Durham, *Epitonium condoni* (Dall), n. var., *Echinophoria "dalli* var." Durham, *Bruclarkia* n. sp. *Nekewis* n. sp. *"Gemmula" bentsonae* Durham, *Eumorphocorystes naselensis* Rathbun.
	250	Gray, unstratified, tuffaceous mudstone with occasional concretionary bands. A large fauna includes *Acila (Truncacila) nehalemensis* Hanna, *Crenella porterensis* Weaver, *Nemocardium weaveri* (Anderson and Martin), *Thracia* n. sp., *Tellina* n. sp., *Echinophoria "dalli* var." Durham, *Olequahia schencki* Durham, *Bruclarkia* n. sp., *Cancellaria* n. spp., *"Gemmula" bentsonae* Durham, *Turritella* n. sp., *Nekewis* n. sp., *Isocrinus* columnals.
	120	Gray tuffaceous shale with a few concretionary bands. Sparsely fossiliferous.
	250	Gray, unstratified, tuffaceous mudstone. Fossiliferous; fauna includes *Acila (Truncacila) nehalemensis* Hanna, *Delectopecten* n. sp., *Nemocardium weaveri* (Anderson and Martin), *Thracia* n. sp., *Tellina* n. sp., *"Gemmula" bentsonae* Durham.
Lower	40–500	(Thicker toward north). Dark gray, glauconitic sandy shales and siltstones. A thin pebble conglomerate at base. Fossiliferous; fauna includes *Acila (Truncacila) nehalemensis* Hanna (rare), *Solemya willapaensis* Weaver, *Thyasira* n. sp., aff. *T. disjuncta* Gabb, *Pitar clarki* (Dickerson), *Turcicula columbiana* Dall, *Conus* n. sp. *"Zanthopsis" vulgaris* Rathbunn.

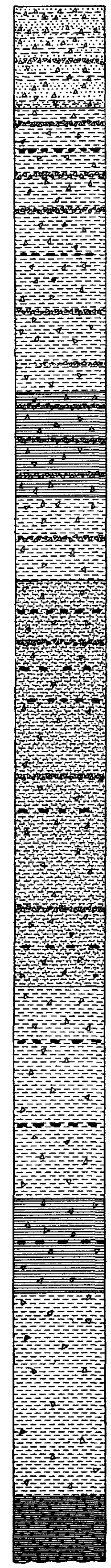


FIGURE 28.—Composite columnar section of the Keasey formation, Washington and Columbia Counties, Oregon. It is based mainly on exposures of the formation in cuts along the Wolf Creek Highway (Oregon route no. 2) in the vicinity of Sunset Tunnel.

Toledo formation exposed in sea cliffs north of Yachats, Lincoln County, Oreg. Both kinds of columnals occur at the Mist and Yachats localities.

In 1946, the junior author and Mr. P. D. Snavely, Jr., visited the locality on the Nehalem River and collected several large chunks of rock showing traces of crinoids along the edges. At least 50 pounds of the material was shipped to the senior author at the University of Kansas.

During the 1949 field season, Oregon fossil localities in the Keasey formation were visited by the junior author with Dr. J. Wyatt Durham of the University of California. Crinoid material collected at the Mist outcrop on Nehalem River (U. S. Geological Survey locality 15318) consisted mostly of unaltered calcite embedded in hard unweathered rock. At least four dorsal cups and attached lower parts of the arms were obtained, together with blocks containing arm and stem fragments. Efforts made at the University of California to prepare these fossils by breaking down the matrix with caustic potash were only partly successful, as it was found almost impossible to avoid some corrosion of the calcite of the fossils. Therefore, the potash method was abandoned. Through kindness of Dr. Durham, eight University of California specimens (marked Loc. A5018) were loaned to the senior author for study, with permission to make further preparation of the material. This has been done, working with sharp tools under the binocular microscope, but much time was required, owing to hardness of the matrix. The fossils, which are preserved as calcite, importantly supplement studies previously made on external molds, but many details of structure, such as the syzygial union of various brachials, are less readily and reliably determinable on the University of California specimens than on the molds belonging to the U. S. Geological Survey collection. Results of study of the University of California specimens have been incorporated in the report.

Casts of portions of the stem of *Isocrinus oregonensis* are very abundant at U. S. Geological Survey locality 15314; some attain lengths up to 60 mm, and many exhibit cirri. An excellently preserved specimen showing a nodal segment and seven interodals of various orders (pl. 23, figs. 1–3) was collected at U. S. Geological Survey locality 15282, and a single concretion, from U. S. Geological Survey locality 15508, yielded several disassociated stem segments (pl. 23, figs. 5, 6, 8–10).

Specimens of columnals referred to *Isocrinus nehalemensis* (pl. 23, figs. 4, 7, 11) were collected from U. S. Geological Survey locality 15268, from beds approximately 40 feet stratigraphically above those at 15508 that yielded stem segments of *I. oregonensis.*

OCCURRENCE OF TERTIARY CRINOIDS ELSEWHERE IN WESTERN HEMISPHERE

The almost complete absence of known crinoid remains from Tertiary deposits of the Americas has been indicated by Springer (1925, pp. 4–6). In this paper, describing a few crinoid stems from Miocene deposits of Haiti (*Balanocrinus haitiensis* Springer), he writes:

> That which does give to our species a very special interest is the fact that its occurrence in the Miocene of the West Indies furnishes a notable addition to the extremely small number of Tertiary crinoids that are known. When we consider the vast extent of Eocene and Miocene sedimentaries of marine origin in Europe, Asia, Africa, Australia, the United States, West Indies, Central and South America, many of them thousands of feet in thickness and richly fossiliferous, abounding in crustaceans, corals, mollusks, and other organisms everywhere associated with crinoids, in ages preceding the Tertiary as well as in the present seas, it is remarkable how few are the remains of crinoids which they have yielded. About 40 species, embraced in 8 or 9 genera, will cover all that have been described, most of them from very imperfect material, such as isolated columnals of pentacrinites and centrodorsals of comatulids, among which are doubtless a number of synonyms. Well-preserved specimens, such as are so frequent in the Jurassic and Cretaceous, are almost unknown in the Tertiary, about all we know of the crinoid life of that age being derived from the fragmentary remains above mentioned, and even these are of rare occurrence.
>
> Of the restricted number of species hitherto known, only a single one has been derived from American rocks [true at the time of Springer's writing], namely, the cup of a small comatulid belonging to the Thalassometrinae from the Eocene of North Carolina, described by Emmons [1858, p. 311, figs. 246, 247] as *Microcrinus conoideus.* A few other fragmentary remains, not hitherto noted or described, occur in the same beds, and specimens of a species of comatulid, *Nemaster*, have been found in the Eocene of South Carolina—all fragmentary and extremely rare amid a profusion of other fossils.

Up to the present time, 12 species of crinoids have been described from Tertiary rocks of the Western Hemisphere. Five of these are diminutive comatulids, described on the basis of specimens consisting of radials and centrodorsal or of brachial plates. The other 7 described species are stem-bearing forms, and all but one of these are known only from isolated stem fragments. The names of these crinoids, together with their stratigraphic occurrence and known geographic distribution, are indicated in the following list.

Tertiary crinoids reported from Western Hemisphere

Comatulids

- *Glenotremites (Palaeantedon) caroliniana* Gislén (1934, pp. 57–59, figs. 49–59, 61), Eocene (Jackson), near Baldock, S. C.
- *Himerometra bassleri* Gislén (1934, pp. 14, 49–52, figs. 1–36), Eocene (Jackson), near Baldock, S. C.
- *Cypelometra iheringi* (de Loriol, 1902, p. 22, pl. 2, figs. 3–4; Gislén, 1924, pp. 107, 116, 159, 191), Eocene, Oligocene, or Miocene, Patagonia, South America.
- *Microcrinus conoideus* Emmons (1858, p. 311, figs. 246, 247). Trent marl, Miocene, Craven County, N. C.

Microcrinus sp. cf. *M. conoideus* Emmons (Gislén, 1934, pp. 54–56, figs. 38–47), Eocene (Jackson), near Baldock, S. C.
Unnamed and undescribed comatulids (Howe, 1942, pp. 1194–1195, figs. 10–11, 19–20), Eocene (Jackson), Alabama; Oligocene (Red Bluff), Alabama, Mississippi.

Stem-bearing articulates

"*Pentacrinus*" *obtusus* Guppy (1874, p. 444, pl. 18, fig. 26), isolated columnals only, Eocene, Trinidad.
"*Pentacrinus*" *rotularis* Guppy (1874, p. 444, pl. 18, fig. 25), isolated columnals only, Eocene, Trinidad.
"*Pentacrinus*" *bryani* Gabb [?=*Balanocrinus*] (1876, p. 178, pl. 5, fig. 18b), isolated stem fragments only, Vincentown limesand, Eocene (Wilcox?), New Jersey.
Balanocrinus haitiensis Springer (1925, pp. 2–8, pl. 1, figs. 1–10), articulated groups of columnals only, lower Miocene, Haiti.
Balanocrinus cubensis Valette (in Sanchez-Roig, 1926, pp. 19–20, pl. 1, figs. 4–5), isolated columnals only, lower Miocene, Cuba.
Austinocrinus cubensis Valette (in Sanchez-Roig, 1926, pp. 21–22, pl. 1, fig. 3), isolated columnals only, Miocene (?), Cuba.
Bourgueticrinus cylindricus (Weller) (1907, pp. 275–276, pl. 6, fig. 1), dorsal cup, Vincentown limesand, Eocene (Wilcox?), New Jersey.

The above list of crinoid species contains two stem-bearing forms from the Vincentown sand of the Rancocas group of New Jersey. This stratigraphic unit has been classed during many years as uppermost Cretaceous. Clark and Twitchell (1915) described and figured Vincentown crinoids as Cretaceous fossils. These include stem fragments of "*Pentacrinus*" *bryani* Gabb (Clark and Twitchell, pp. 35–36, pl. 6, fig. 2a, b), Weller's type of *Rhizocrinus cylindricus*, and several columnals inferred to belong to this species (Clark and Twitchell, p. 40, pl. 7, figs. 5a–g). Characters of the articular facets indicate that Gabb's species probably belongs to *Balanocrinus* (proximal columnals), and according to Gislén (1938, p. 7, fig. 6), Weller's species should undoubtedly be assigned to *Bourgueticrinus*. Canu and Bassler (1933), in describing the rich bryozoan fauna (some 65 species) of the Vincentown beds, reported close resemblance of this assemblage to abundant bryozoans occurring in the Danian rocks (presumed to be uppermost Cretaceous) of Denmark, and accordingly they affirmed judgment of the Cretaceous age of the Vincentown deposits.

The Vincentown sand was assigned to the Eocene by Cooke and Stephenson (1928) largely on the presence of *Venericardia*. Greacen (1941), from a review of the stratigraphy and fauna of this formation, concludes that it should be assigned to the Paleocene or possibly the Eocene. Cooke, Gardner, and Woodring (1943, pl. 1) adopt the view of Cooke and Stephenson in correlating the Vincentown with Wilcox group of the Eocene. This age determination is accepted, but whatever its age, the crinoid remains are an extremely rare element of its fauna.

It is of interest now to review briefly what is known of crinoid remains of undoubted Tertiary age elsewhere in the Western Hemisphere.

The first reported crinoid is the small comatulid called *Microcrinus conoideus* Emmons (1858). This is the only Cenozoic crinoid listed in the Clark and Twitchell (1915) memoir, but because they were unable to find a specimen, no illustration was given. They reported it (p. 112) as occurring in the "Trent marl (middle Eocene) of Craven County, N. C." This deposit is classed by Cooke, Gardner, and Woodring (1943) as lowest Miocene. Until additional specimens of this fossil from a known horizon and locality are collected, its nature and stratigraphic significance must be in doubt. Clark and Twitchell (1915, p. 112) designated it as *Zenometra* (?) *conoideus*.

Beds of Eocene (Jackson) age near Baldock, S. C., are rich in comatulid ossicles, which include centrodorsals, radials, and brachials. Gislén (1934) sorted out some 23,000 comatulid ossicles during his study of this material. Mainly from examination of the types of arm branching, Gislén was able to differentiate and reconstruct three species—one designated as *Microcrinus* cf. *conoideus* Emmons and two new species, *Glenotremites* (*Palaeantedon*) *caroliniana* and *Himerometra bassleri*.

Howe (1942) reports abundant comatulid remains in Eocene and Oligocene rocks of the Gulf Coastal Plain from Alabama to Mississippi, and he figures a number of specimens, but without description or designation by name. All are microcrinoids. Howe notes that forms occurring in different zones can readily be differentiated.

Other Tertiary crinoids known from the Western Hemisphere are all reported from areas south of the United States. De Loriol (1902) described a comatulid, *Cypelometra iheringi*, from rocks doubtfully referred to Eocene, Oligocene, or Miocene in Patagonia. This fossil is discussed by Gislén (1924, pp. 107, 116, 159, 191).

Isolated columnals of a pentacrinid were collected from Eocene rocks of Trinidad and described as *Pentacrinus* [?=*Isocrinus*] *obtusus* Guppy (1874) and *Pentacrinus* [?=*Isocrinus*] *rotularis* Guppy (1874).

Springer (1925) described and figured half a dozen stem fragments, which he named *Balanocrinus haitiensis* from lower Miocene rocks of Haiti, West Indies.

Stem fragments referred to a new species called *Balanocrinus cubensis* Valette (in Sanchez-Roig, 1926) have been described from lower Miocene rocks of Cuba. In the same paper, other types of stem fragments were named *Austinocrinus cubensis* Valette, from rocks in Cuba doubtfully identified as Miocene.

This review reveals that nowhere in North or South America have Tertiary crinoid fossils been found that are comparable to those described in this paper from the Tertiary rocks of Oregon. Also, the Oregon crinoids are the only undoubted representatives of *Isocrinus* yet recorded in the Western Hemisphere. The stem fragments described from Trinidad by Guppy may belong to *Isocrinus*, but this is uncertain. Furthermore, a survey of Tertiary crinoids from other parts of the world fails to show comparable specimens, excepting a nearly complete crown of *Balanocrinus subbasaltiformis* Sowerby, described by Sieverts-Doreck (1943) from the Eocene (London clay) of England.

ACKNOWLEDGMENTS

Special thanks are expressed to Dr. J. Wyatt Durham, University of California, at Berkeley, for the opportunity to study specimens of Keasey crinoids from Oregon in the collections of the Museum of Palaeontology of that institution.

Suggestions received from Dr. Hertha Sieverts-Doreck, of Stuttgart, Germany, have been very helpful and are much appreciated. Her presence at the University of Kansas at the time the present manuscript and illustrations were being reviewed was fortunate, for few specialists in the study of fossil articulate crinoids have wider knowledge and experience in research on these forms.

THE OREGON CRINOID-BEARING BEDS

LITHOLOGIC AND PALEONTOLOGIC CHARACTERS OF THE KEASEY FORMATION

Warren and Norbisrath (1946, pp. 213–237) have summarized the stratigraphy of the Upper Nehalem Basin in northwestern Oregon, including a description of the Keasey formation from which crinoid remains have been collected. They divide the Keasey strata, which are named from outcrops on Rock Creek in the Nehalem area, into three lithologically and faunally distinct members.

(1) A lower member, 500 feet thick at the type locality of the formation, but thinner toward the south, consists of dark-gray, generally glauconitic, fossiliferous shales. A fauna of approximately 50 species has been obtained from these beds. The most characteristic forms confined to this member are *Turcicula columbiana* Dall, *Fimbria washingtoniana* (Clark), and a new species of *Conus*. A new species of *Thyasira*, which is very abundant here, is rarely present also in the fauna of the middle member.

(2) The middle member is marked faunally by *Nemocardium weaveri* (Anderson and Martin), *Olequahia schencki* Durham, *Thracia* n. sp., *Nekewis* n. sp., and a new variety of *Epitonium condoni* Dall, which are confined to this part of the Keasey formation. The member is distinguished also by an abundance of *Acila* (*Truncacila*) *nehalemensis* G. D. Hanna, which is rare in the lower member. The middle member of the Keasey consists of light- to medium-gray, relatively unstratified to massive, harsh, tuffaceous siltstone, which is associated with some hard calcareous beds and a few layers of ashy tuff. The most nearly continuous exposures of this member are along the Wolf Creek Highway in the vicinity of Sunset Tunnel, where the member is about 1,700 feet thick.

(3) The upper member of the Keasey formation, like the middle member, is highly tuffaceous, but it is somewhat more sandy and generally is thinner bedded than the middle member of the Keasey. It is one or two hundred feet thick. The fauna of the upper member is characterized especially by *Lima* (*Acesta*) *oregonensis* Clark, but, among other elements, it contains a new species of *Turcicula*, which is quite distinct from *T. columbiana* Dall of the lower member of the formation. Other characteristic elements of the fauna from the upper part of the Keasey are *Nemocardium lorenzanum* (Arnold), *Porterius gabbi* (Dickerson), and *Gyrineum jeffersonensis* Durham. *Porterius gabbi* was described from the type locality of the Gries Ranch formation in Washington and *Gyrineum jeffersonensis* from the lower part of the Quimper sandstone of Durham on the Olympic Peninsula of Washington, where it occurs in strata containing a typical Gries Ranch fauna. The occurrence of these species in the Nehalem area suggests that the upper member of the Keasey formation may be the deeper water equivalent of the predominantly conglomeratic shallow-water Gries Ranch formation. This suggestion is strengthened by the fact that the fauna of the upper portion of the Quimper sandstone, which overlies beds containing a fauna having Gries Ranch affinities, is that of the *Molopophorus gabbi* zone of Durham. The fauna of this zone is the well-known Pittsburgh Bluff assemblage, occurring in the lower part of the Pittsburgh Bluff formation, the type section of which directly overlies Keasey strata in the Nehalem Basin area.

The crinoid remains here described occur in the upper half of the middle member of the Keasey formation. The tuffaceous material, which is dominant in the sediments, is mostly rather fine grained, but the random occurrence of ash "pebbles," one-quarter inch or more in diameter, suggests that the source of volcanic debris, which is so prominent a constituent of the Keasey sediments, was not far distant. No evidence of submarine volcanic activity has been seen at any outcrop of the Keasey formation, and thus it is reasonable to assume that the tuffaceous materials were derived from sources somewhere on the landward side of the Keasey shoreline, probably not more than a few miles away.

The invertebrate fauna associated with the crinoids in upper part of the middle members of the Keasey formation consists mostly of mollusks, which are judged to have lived and been buried in relatively deep water. Among fossils collected with the crinoid remains at U. S. Geological Survey locality 15318 are the following species:

Invertebrates associated with crinoids in middle Keasey beds near Mist, Oreg.

Solemya (Acharax) willapaensis Weaver
Ennucula n. sp.
Acila (Truncacila) nehalemensis G. D. Hanna
Nuculana washingtonensis (Weaver), n. subsp.
Yoldia (Portlandella) chehalisensis (Arnold)
Minormalletia n. sp.
Propeamussium n. sp.
Delectopecten n. sp.
Tellina n. sp.
Polinices n. sp.
Fulgurofusus n. sp.
"Cancellaria" n. sp.
Exilia lincolnensis Weaver
Scaphander stewarti Durham
Flabellum hertleini Durham

AGE OF THE KEASEY FORMATION

The Keasey formation was described by Schenck (1927, p. 457) as the Keasey shale and was considered the lowest Oligocene exposed in the Columbia County area of Oregon. Recent correlations suggest its equivalence to Ludian and lower Tongrian strata of the standard European section (Weaver, *et al.*, 1944, pl. 1), indicating that it is upper Eocene and lower Oligocene. Schenck and White (in Weaver, *et al.*, 1944, pp. 573–574) add: "We know of no convincing evidence to prove the precise correlation of any Tertiary formation in California with formations in Europe." In terms of the molluscan faunas, the Keasey fauna is clearly delimited from that of the upper Eocene Cowlitz formation and much more closely allied to that of the higher Oligocene horizons of Oregon and Washington. It is marked by the first appearance of a number of genera that are characteristic of the Oligecene and younger horizons and by a general absence of typical Eocene elements. The fauna of the lower zone witnesses the first appearance, on the west coast of North America at least, of such genera as *Turcicula*, *Thyasira*, *Bruclarkia*, and *Cochlodesma*, all of which range throughout the Oligocene section in this region.

The general Oligocene element in the fauna is well illustrated by the following table showing range of species known from the Keasey formation and adjacent horizons.

Stratigraphic distribution of invertebrates from the Keasey formation

[X=specific identity, XU=upper faunal zone only, S=new subspecies in the Keasey fauna.]

	Cowlitz	Keasey	Gries Ranch	Pittsburgh Bluff	Lincoln	Blakeley	Twin Rivers
"Nuculana" washingtonensis (Weaver)		S	X	X	X		
Yoldia chehalisensis (Arnold)		X		X	X	X	
Porterius gabbi (Dickerson)		XU	X				
Isognomon clarki (Effinger)		XU	X				
Crenella porterensis Weaver		X		X	X	X	
Fimbria washingtoniana (Clark)		X			X		
Nemocardium lorenzanum (Arnold)		XU	X		X	X	X
Pitar (Lamelliconcha) clarki (Dickerson)	[1]	X	X	X			
Epitonium (Boreoscala) condoni Dall		S	X	X			
Natica (Tectonatica) weaveri Tegland		X	X	X			
Sinum obliquum (Gabb)	X	X	X	X	X		
Calyptraea diegoana (Conrad)	X	X	X	X	X	X	
Echinophoria dalli (Dickerson)		S	X				
Gyrineum jeffersonensis Durham		XU	X				
"Spirotropis" kinkaidi (Weaver)		S	S?	S?	X		
"Gemmula" bentsonae Durham		X	X	X			
Knefastia washingtoniana (Weaver)		S	S?	X	X		
Exilia lincolnensis Weaver		X	X	X	X		
Nekewis washingtonensis (Weaver)	X	S					
Scaphander stewarti Durham		X	X	X			
Dentalium stramineum Gabb	X	X?					
Number of species or subspecies in common with Keasey fauna	4	21	16	13	10	4	1

[1] Weaver's reference (1943, pp. 184, 636) of this species to the Cowlitz formation is clearly a *lapsus*, since he correctly states that it was described from the Gries Ranch, then fails to list it from that horizon.

The implied indication that the Keasey fauna is no more closely related to the fauna of the Cowlitz formation than it is to that of the upper Oligocene Blakeley formation of Weaver (*Echinophoria rex* zone) is a reflection of the extent to which new Oligocene elements enter the fauna of the Keasey formation. The only species the Keasey and Cowlitz faunas have in common are forms that range throughout middle and upper Eocene on the west coast, and two of the three that are so found range on up into the middle Oligocene. All three forms, furthermore, are relatively generalized types without many characteristics suitable for close specific discrimination.

As noted by Schenck and White (loc. cit.), there is no evidence suggesting a precise correlation of the Keasey formation with the standard European section; nevertheless, in terms of the fossil molluscan faunas of the west coast, the Keasey is clearly much more of Oligocene aspect and relationship than Eocene.

OUTCROPS OF THE KEASEY FORMATION FROM WHICH CRINOID REMAINS HAVE BEEN COLLECTED

U. S. Geol. Survey loc. 15268: Large cut at south end of high overpass of United Railroad crossing Oregon Highway 47 (Buxton-Vernonia highway): 6,400 feet west of grid 815,000 and 11,300 feet south of grid 2,645,000, Veronona quadrangle, U. S. Army Engineers, 1943 edition.

U. S. Geol. Survey loc. 15282: Prominent road cuts on opposite sides of the Wolf Creek Highway (Oregon Highway 2) 0.90 to 1.0 mile northwest of western end of the Sunset Tunnel, Timber quadrangle, U. S. Army Engineers, 1941 edition.

U. S. Geol. Survey loc. 15985: On coast about 1.25 miles (air line) north of Yachats, Lincoln County, Oregon. South 64°30′′ West of fire lookout tower on Blodgett Peak, Waldport quadrangle, U. S. Army Engineers.

U. S. Geol. Survey loc. 15314: Cut in low banks on south side of abandoned logging railroad that paralleled Crooked Creek. Outcrop is at west end of "Ross Siding," 2.55 miles (direct) west-northwest of Pittsburgh Bluff; 3,000 feet west of grid 815,000, on the line of grid 2,660,000, Verononia quadrangle, U. S. Army Engineers, 1943 edition.

U. S. Geol. Survey loc. 15318 (also Univ. California loc. A5018): Prominent bluff on west side of Nehalem River, immediately south of bridge for small side road and approximately 3,500 feet south of junction of Oregon State Highways 47 and 202 at Mist, Oreg.

U. S. Geol. Survey loc. 15508: Prominent cut on north side of horseshoe bend on United Railroad with high overpass over Oregon Highway 47. Locality is in second cut beyond the north end of trestle. (Loc. 15268 is first cut at south end of same trestle.)

DESCRIPTION OF CRINOIDS

MATERIAL AVAILABLE FOR STUDY

Initially available crinoid specimens collected from the Keasey formation in northwestern Oregon consisted of the remarkable crown that is here designated as the holotype of *Isocrinus oregonensis* Moore and Vokes, n. sp., collected by Messrs. Warren and Grivetti from the locality on the Nehalem River near Mist, Oreg. (U.S.G.S. locality 15318), and a few fragments of columnals from this and other localities in the area. Associated with several of the stem segments were portions of attached cirri. Most of these stems consist of fairly well preserved calcite, free of matrix or partly imbedded in the rock. The latter specimens proved very difficult to prepare because the matrix is so much harder than the calcite of the fossils. Several specimens are external molds of individual columnals and segments of the stem consisting of articulated series of columnals and of cirri. The molds had been formed by weathering and solution of the calcite so as to leave nearly perfect impressions of the form of the fossil in the essentially noncalcareous matrix. Such specimens clearly show the crenellae of articular surfaces of columnals and features of the lateral surfaces of stem segments, including especially the pattern made by edges of crenellae between individual columnals and sockets for attachment of cirri.

As previously noted, during the field season of 1946 Vokes and Snavely visited the locality from which the holotype of *Isocrinus oregonensis* had been obtained and were successful in collecting from the thin crinoid-bearing zone of the Keasey formation about 50 pounds of rock. When this material was unpacked by Moore, he was much disappointed at its extremely unpromising nature. Although he did not expect duplication of such finds as the exceptional crown first collected by Warren and Grivetti, he hoped that additional search at the fossil locality might yield fairly well-preserved crinoid arms, stems, and possibly one or two dorsal cups that would aid importantly in understanding features of the specimens first studied. Stem and arm fragments were, in fact, found to be fairly common in the material shipped in the matrix, but the more or less rotted calcite of most fossils had been broken through so as to reveal only the gross pattern of crinoid structures. The presence of abundant crinoidal material along some bedding planes was indicated by cross sections of fragments visible on sides of the blocks. Efforts to break the rocks along such bedding planes, however, so as to expose crinoids were not successful, because fractures carefully made along chosen bedding planes broke through the fossils rather than between the crinoids and adhering matrix. Considerable time was spent on the most promising specimens in efforts to remove the matrix so as to expose crinoid remains with unmarred surface. Most of this work was done under a binocular microscope so as to watch the preparation closely. Power tools, both abrasion- and percussion-types, were useful for preliminary stages of cutting, but, because of the softness of the calcite, these proved unsuitable for work close to the specimen. Very sharp chisel-edged needles, operated by hand, did good work, but progress was painfully slow, and hardness of the matrix as compared with the fossils made it almost impossible, even with greatest care, to expose crinoid remains without damaging their surface.

Decision was made at length to test removal of the mostly soft, partly decomposed calcite by etching fragments of crinoid-bearing rock in weak acid. It was found that the tuffaceous material of the matrix is not at all affected by the acid or only imperceptibly etched, whereas the calcite of the crinoids was quickly eaten away. As a result of this treatment, beautifully sharp external molds were obtained that permitted definite identification of many structural features not otherwise observable. A disadvantage, which shortly became evident in this method of preparation, however, was the almost uncontrollable tendency of the rock when wet in acid to break apart unpredictably. This fragmentation evidently is induced by swelling of disseminated bentonitic material in the rock. By treating surfaces with an acid-resistant plastic, such as ambroid or alvar, not too much thinned, it was possible to hold most specimens together or to cement in position pieces of the rock that broke loose.

This method of treatment was ultimately applied to nearly all of the shipment of bulk rock material from the crinoid locality, and it yielded innumerable specimens of parts of the stem, arms, and pinnules. Also, it led to discovery of several additional crowns of various size and completeness—all this from material that initially seemed to be almost valueless. The prepared fossils are extremely fragile, for efforts to harden the molds by soaking in a thin solution of plastic generally produce further decrepitation.

After completion of a report, based on specimens collected by U. S. Geological Survey parties in Oregon, eight pieces of crinoid-bearing rock fragments from the Keasey formation at the Mist locality (U. S. Geological Survey loc. 15318) were borrowed from the Museum of Palaeontology, University of California, at Berkeley. The specimens bear University of California locality number A5018 and for purpose of individual identification have been lettered A to H, respectively. Incomplete crowns occur on specimens A, B, and C (two crowns on C being designated as C1 and C2); the other specimens (D to H) bear only stem and arm fragments. The calcite of the fossils on all specimens is firm and the rock in which they are embedded is very hard, unweathered tuffaceous siltstone. After preparation, the fossils stand out in relief. Some have about the same hue as the light greenish-gray matrix, but others are stained pink or brown, and some show a very dark greenish-brown color, which makes them strikingly conspicuous. At first glance, these last resemble various Ordovician and Mississippian crinoids, such as those from the Trenton group of New York and the Crawfordsville beds of Indiana. The four crowns in the University of California collection are of *Isocrinus oregonensis*, and are especially valuable in clearly showing characters of the dorsal cup. Among numerous stem fragments, both *I. oregonensis* and *I. nehalemensis* are recognized, the former being much the most common. Specimen C carries three sections of cirrus-bearing stems 32, 35, and 55 mm long.

Altogether, the specimens studied in preparing this report consist in only very minor degree of completely dissociated crinoid fragments. Most of them are segments of stem and cirri made up of many adhering segments or arm fragments in which many brachials are arranged in unbroken series, generally with pinnules in attached position. Elements of the crowns are mostly not broken apart. Uncompressed or with only little flattening, they lie in positions in which the animals were buried. The more or less accidental way in which the crowns are exposed in preparation and the difficulty of exploring structures by removing matrix where desired are the main handicaps in working with these fossils.

SUPRAFAMILIAL PLACEMENT OF THE OREGON CRINOIDS

The fossil crinoids from lower Tertiary deposits of Oregon described in this report give complete enough morphological information to warrant using them as basis for a review of questions of major taxonomic divisions among post-Paleozoic crinoids. The Keasey crinoids clearly belong to the group called pentacrinoids. These are a stock of relatively large-crowned, pentagonal-stemmed, cirriferous crinoids which have special importance by reason of their abundance, cosmopolitan distribution, longevity, and (not least) inclusion among them of the ancestors of the Comatulida—the dominant group among modern crinoids. They are far removed from other stalked and unstalked crinoids of Mesozoic and Cenozoic age, such as the eugeniacrinids, bourgueticrinids, thiolliericrinids, comatulids, and others. Suprafamilial allocation of the Oregon crinoids may be indicated in terms of assemblages of decreasing magnitude, as Phylum Echinodermata, Class Crinoidea, Subclass Articulata, and Order Pentacrinoidea.

FAMILY ISOCRINIDAE GISLÉN, 1924

This family comprises Mesozoic and Cenozoic genera, including among forms known as fossils, *Isocrinus*, *Cainocrinus*, *Balanocrinus*, and *Austinocrinus*, and living genera of stalked crinoids, such as *Metacrinus*, *Saracrinus*, *Cenocrinus*, *Teliocrinus*, *Endoxocrinus*, *Diplocrinus*, *Annacrinus*, *Neocrinus*, and *Hypalocrinus*. The assemblage was differentiated independently by Matsumoto (1929, p. 31) under the same family name, seemingly without knowledge of Gislén's publication.

In genera assigned to the Isocrinidae, the infrabasals are hidden or they may have vanished; the basals are small and generally, in external view, not in lateral contact with one another; and the radials are normal, without downward pointing processes. Branching of the rays is isotomous, bifurcation occurring once or as many as four or five times. Pinnulation is complete, except on proximal brachials. The tegmen is small. Columnals belonging to isocrinid genera are stellate, pentagonal, quinquelobate, or circular in section, with articular facets marked by short to moderately long crenellae at borders of five variously shaped floor areas. The maximum number of internodals (mostly 5 to 15) is attained not far below the dorsal cup. Cirri of subcircular cross section are attached to nodals in whorls of five, or with alternating position on successive nodals, they may be reduced to three, two, or one.

The range of the Isocrinidae is from Triassic to Recent.

The Oregon material confirms Gislén's (1924) view that *Pentacrinus* and *Isocrinus* stand well apart, belonging to different families, Pentacrinidae and Isocrinidae. The former comprises *Pentacrinus* and *Seirocrinus*, and the latter includes (among fossil forms) *Isocrinus*, *Balanocrinus*, and *Austinocrinus* (Sieverts-Doreck, 1943). The Oregon crinoids help fill a great gap in paleontological knowledge of Tertiary crinoids in general and Isocrinidae in particular. The search for relatives of the Oregon forms has been hampered by the fact that many Tertiary Isocrinidae are poorly known, insufficiently described and illustrated, and ranged under *Pentacrinus*, to which genus they surely do not belong; they may represent *Isocrinus*, *Balanocrinus*, or the predecessor of a Recent genus.

GENUS ISOCRINUS VON MEYER, 1837

Genotype: *Isocrinus pendulus* von Meyer, 1837 (by monotypy).

Isocrinites von Meyer (as *Isocrinites pendulus* von Meyer), L'Institut, (December 30, 1835), 1836, p. 435 (*nomen nudum*).

Isocrinus L. Agassiz (based on *Isocrinites pendulus* von Meyer), Soc. Sci. Nat. Neuchâtel Mém., vol. 1, p. 195, 1836 (invalid because based on *nomen nudum*).

Isocrinus von Meyer (as *Isocrinus pendulus* von Meyer, n. sp.), Mus. Senckenberg, vol. 2, p. 260, pl. 16, figs. 1–5, 1837.

The crinoid generally known as *Isocrinus* and attributed to Louis Agassiz (1836) cannot be recognized by this name, author, and date, inasmuch as no described species was then attributable to it. Clark (1908, p. 526) cites von Meyer (1836) as originator of the generic name *Isocrinites* (based on *Isocrinites pendulus* nomen nudum), but this also surely is erroneous. The crinoid named and described by von Meyer in 1837 as *Isocrinus pendulus* must be taken as the basis both of the specific and the generic names, for prior to that time it had no status in scientific literature. Accordingly, the generic name here recognized is *Isocrinus*, and von Meyer is regarded as the nomenclator.

The Oregon crinoids described in this report are assigned to *Isocrinus* because of (1) the nature of their columnals, including stellate shape in cross section, petaloid pattern of the articular facets, number of internodals, and presence of five elliptical cirrus sockets on nodals, and (2) structure of the rays, including the isotomous mode of branching, union of the two primibrachs of each ray by synarthry, and the nature of pinnulation.

Isocrinus is the most important genus of the Pentacrinoidea. Although *Pentacrinus* is very commonly cited in literature, Bather (1898) showed that many fossil species assigned to *Pentacrinus* really belong to *Isocrinus*. It is appropriate to define characters which distinguish *Isocrinus*.

CHARACTERS OF ISOCRINUS

Isocrinus is a medium-sized to large pentacrinoid that has a long cirrus-bearing stem of pentagonal or stellate cross section, diminutive dorsal cup, and generally long pinnulate arms, which bifurcate isotomously. The crown typically flares upward so as to attain greatest width at or near the arm trips. Distinguishing features are found in structures and ornament of the stem, dorsal cup, and arms, including especially the nature of branching in the rays, articulation of brachials, and placement of proximal pinnules. The genus has a greater stratigraphic range than that of any other articulate crinoid, for it is recorded from Lower Triassic to Recent.

Column.—The stem is composed of more or less even-sized pentagonal or stellate columnals having diameter several times greater than their thickness. They are divisible into nodals, which bear cirri, and internodals, which lack cirri. The contact between columnals is marked by crenulate sutures, except on the distal side of nodals, where a straight suture occurs. The articular surfaces are characterized by strongly petaloid floor areas, bordered by short crenellae, but the distal face of nodals and the apposed face of hypozygal internodals are nearly smooth. Radial pores may be present at re-entrant angles of the stem between internodals, at least in proximal parts of the column. The cirri generally occur in whorls of five. As in other genera of the Isocrinidae, the sockets for cirrus attachment are subcircular to elliptical in outline.

Dorsal cup.—The dorsal cup of *Isocrinus* is very inconspicuous. It is shallow basin-shaped and not much greater in diameter than the stem—almost invariably less than twice the stem diameter. Infrabasal plates, which are recorded in some species, are reduced to diminutive size and entirely concealed by the proximal columnal. Basals are externally visible as widely separated small projections of the cup above angles of the stem, but actually they adjoin beneath overlapping parts of the radials and the proximal columnal. The radials are relatively thick and extend outward in nearly horizontal or slightly up-flaring direction; their proximal portions may form part of a basal concavity of the cup. The articular facets are equal in width to the radials.

Arms.—Two primibrachs occur in each ray of *Isocrinus*, the second being an axilliary that supports equal-sized branches. Two or more bifurcations occur in each ray. Articulation between the two primibrachs (and generally between the first two secundibrachs) is synarthrial, but between the primaxil and first secundibrach of each branch articulation is muscular. Union between secundibrachs and higher series of brachials normally is by muscular articulation, but some pairs of brachials are joined by syzygy. Generally, as first noted by Biese (1930, p. 715), the third and fourth secundibrachs are syzygially united; study of the Oregon specimens indicates that the second and third tertibrachs and quartibrachs are likewise connected by syzygies. The most proximal pinnules of each ray normally appear on the second secundibrach, as in most articulate crinoids. They are directed toward the outer sides of the ray. Pinnules are moderately stout and long, the proximal pinnular being typically much shorter than others.

COMPARISON WITH RELATED GENERA

Some authors have classed *Isocrinus* as a synonym of *Pentacrinus* Blumenbach, of Jurassic age, despite the fact that these genera, as now understood, stand rather widely apart, being assigned to different families. Bather (1898) and Gislén (1924) have pointed out distinguishing features, among which the most readily observed is the rhombic cross section of the cirri of *Pentacrinus*, as contrasted to the elliptical or subcircular cross section of cirri belonging to *Isocrinus*. Also, the heterotomous bifurcations of the rays and downward projecting prominences on radials of *Pentacrinus* differ from the isotomous branching and smoothly rounded radials of *Isocrinus*.

Cainocrinus Forbes (1852, p. 33, figs. 1–5) was described on the basis of a small dorsal cup with attached portion of stem and some isolated fragments of columns from the London clay (Eocene) of southern England. It is an isocrinid characterized by a moderately elevated bowl-shaped cup with upflaring radials and externally visible contacts between the gently curved basals. The column is pentalobate, somewhat like that of *Isocrinus* and *Balanocrinus;* it has widely spaced nodals which bear a whorl of five cirri with subcircular cross section. The nature of articular facets is not described or figured, and accordingly, relationships to *Isocrinus* are indeterminate. *Cainocrinus occurs* in rocks of nearly the same age as deposits containing the Oregon crinoids, but the genus obviously differs from *Isocrinus* in features of the dorsal cup.

Balanocrinus de Loriol, which ranges from the Middle Triassic to the Miocene, was originally described as a subgenus of *Isocrinus*, distinguished solely on the basis of characters of columnals. Proximal parts of the stem of *Balanocrinus* may be quinquelobate or pentagonal in section, and articular surfaces of columnals may bear a strongly petaloid pattern, indicating similarity to *Isocrinus*, its probable ancestor. Typical *Balanocrinus* columnals, however, have a rounded outline, crenellae restricted mainly to the periphery, and obtusely triangular floors separated by reduced crenellae, line of granules, or radial ridges that define a star-shaped rosette centered on the minute round lumen. Nodals bear one to three cirrus attachment sockets, rather than five, as normally in *Isocrinus*, and the reduced number of cirri seen in *Balanocrinus* accompanies an alternation in arrangement of the cirri on successive nodals. Discovery of a crown belonging to *Balanocrinus subbasaltiformis* (Sowerby) in Eocene (Ypresian) beds of southeastern England has permitted the observation (Sieverts-Doreck, 1943, p. 152) that *Balanocrinus* resembles *Isocrinus* in having only two primibrachs, but they are joined by synostosis instead of synarthry. Also, unlike *Isocrinus*, the first and second secundibrachs are united by synostosis; neither synarthrial articulations nor syzygies between any brachials are recognized. The dorsal cup of *B. subbasaltiformis* is nearly identical to that of the Oregon species of *Isocrinus* described in this report.

Another genus of Isocrinidae is *Austinocrinus* de Loriol, which is distinguished on characters of columnals, other parts being unknown. According to Springer (1913, p. 233), *Austinocrinus* corresponds to *Isocrinus* except in having finer crenellae along borders of the petaloid floor areas of the columnal facets. Actually, *Austinocrinus* resembles *Balanocrinus* more closely than *Isocrinus*, especially in the pattern of articular surfaces of the columnals, rounded cross section of the stem, and reduced number of cirri attached to nodals. As in many species of *Balanocrinus*, the cirri may be reduced and disposed in alternating position on successive nodals. *Austinocrinus* is widely distributed in Upper Cretaceous rocks of both hemispheres but is unknown in other systems.

Among living Isocrinidae are two genera that correspond to the Oregon species of *Isocrinus* in characters of the column and dorsal cup, and in having only two primibrachs which are joined by synarthry. They are *Neocrinus* Wyville Thomson, 1864, and *Hypalocrinus* A. H. Clark, 1908. These genera, however, are characterized by strongly interlocking immovable articulations between certain brachials, of a sort quite foreign to typical *Isocrinus* and not observed in the Oregon crinoids from the Keasey formation. Thus, *Neocrinus* and *Hypalocrinus* evidently represent a separate tribe of Isocrinidae.

Occurrence of a syzygial union between first and second primibrachs in *Metacrinus* P. H. Carpenter, *Teliocrinus* Döderlein, *Cenocrinus* Wyville Thomson, *Annacrinus* A. H. Clark, *Endoxocrinus* A. H. Clark, and *Diplocrinus* Döderlein distinguishes these genera from *Isocrinus* (Döderlein, 1912, p. 22; Clark, 1923). There are other differences, such as greater length of the primibrach series (normally 4 to 8 brachials) in *Metacrinus*. *Saracrinus* A. H. Clark also differs from *Isocrinus* in having four primibrachs in each ray.

To summarize, *Isocrinus* is most closely related to *Balanocrinus*, among fossil crinoids, and to *Hypalocrinus* and *Neocrinus* among living forms. It is distinguished from *Balanocrinus* especially by characters of the columnals and the articulation between brachials. *Hypalocrinus* and *Neocrinus* are distinguished by the interlocked type of union of some of their brachials.

ISOCRINUS OREGONENSIS MOORE AND VOKES, N. SP.

Pls. 14–18; pl. 19, figs. 2–5; pl. 20, fig. 3; pl. 22, fig. 3; pl. 23, figs. 1–3, 5–6, 8–10; pl. 24; text figs. 29–35, 36A, 36D–E, 39D.

SUMMARY OF DESCRIPTION

Crown unusually tall, expanding upward, consisting of small, discoid dorsal cup and rays that bifurcate isotomously three times, so as to terminate in as many as 40 long, slender arms.

Dorsal cup subpentagonal in outline, having approximately twice the diameter of the column. Infrabasals not observed. Basals small, bulbous, externally visible only above angles of stem, but adjoining laterally beneath the proximal columnal. Radials stout, strongly curved in longitudinal profile, directed horizontally, forming lower side walls and floor of cup. Radial facets wide, with broad area for dorsal ligament.

Primibrachs two, united by synarthry, laterally adjoined to neighboring primibrachs in relatively immovable manner. Secundibrachs 6 to 7, with a syzygy normally uniting $IIBr_{3+4}$. Tertibrachs 9 to 16, with syzygial union between $IIIBr_{2+3}$. Quartibrachs more than 60 (at least 88 in some arms), with syzygy between IVB_{2+3} and sporadically between some higher pairs. Pinnules relatively long and stout; proximal pinnule shorter than others. The most proximal pinnule occurs on $IIBr_2$, directed toward outer side of the ray.

Column long, stellate in section, nearly equal in width throughout. Columnals relatively thin, nearly uniform in diameter, nodals only a little larger than internodals, which normally number 7 in each series, except near the dorsal cup. Sides of columnals smooth, slightly carinate. Joint faces marked by long narrow floors and short crenellae. Nodals bear elliptical sockets for attachment of 5 long, stout cirri, which are directed upward in their proximal region. The distal articular face of nodals is nearly smooth, denoting synostosial union with the adjoining internodal, which also has a smooth facet.

DESCRIPTION OF SPECIMENS

HOLOTYPE

The superb fossil crinoid (U.S.N.M. 560790D[1]), which is the holotype of *Isocrinus oregonensis*, consists of a crown and attached proximal portion of the stem from the outcrop of the Keasey formation at U.S.G.S. loc. 15318. It occupies most of one surface of a slab measuring roughly 8 by 10 inches (pl. 14, text fig. 29). The arms spread out radially from the dorsal cup, like spokes of a wheel, so as to reveal portions of almost every arm. Most of the arms are bordered on one or both sides by outstretched pinnules. It is as though the specimen had been laid out by a botanist for pressing in his herbarium. Maximum dimension across the outstretched arms is 210 mm. The diameter of the dorsal cup is barely 10 mm. An outstanding feature of the holotype specimen is the remarkable length of the unbranched arms, forming terminal portions of the rays. Several of these are at least 90 mm in length. The height of the crown, as represented by this specimen, may be given as approximately 125 mm.

The specimen is mostly an external mold, for the original calcite of the dorsal cup, arms, and column is gone. The somewhat discolored and decomposed calcite of some pinnules remains in place. Although the holotype of *Isocrinus oregonensis* shows general structure of a nearly complete crown, the nature of articulations between ray plates is generally obscure or lacking. In this respect the holotype is decidedly inferior to most of the paratype specimens prepared by etching with acid.

It has not been possible to determine orientation of the holotype specimen—that is, to ascertain which is the anterior ray and where the posterior interradius belongs. Accordingly, in order to facilitate reference to individual parts of the specimen, the rays are numbered in arbitrary manner (fig. 29) starting at the left and proceeding in clockwise manner around the spread-out arms (the terminal parts of each ray being lettered *a* to *h*, inclusive).

Enlargements of portions of the holotype specimen are illustrated in plates 15–17.

PARATYPES

Ten paratype specimens, all but one consisting of more or less complete crowns, are illustrated or used in

[1] All catalogue numbers cited are those of the United States National Museum unless stated otherwise.

preparation of diagrams in this paper. Stem fragments, classed as paratypes, also are figured. Much additional paratype material is not illustrated. Most of the figured crowns are acid-etched preparations of rock collected from the crinoid bed at the Mist, Oregon locality (U.S.G.S. 15318) in 1946. Although none of the paratypes is comparable in perfection and beauty to the holotype, they have thrown much light on the structure of the dorsal cup, arms, and stem, and they have been particularly useful in indicating the nature of articulations between the plates of the rays.

Paratype A (U.S.N.M. 560791A) is a crown viewed from the ventral side, the arms being spread out in radial manner around the cup. The greatest dimension across the exposed arms is about 110 mm. At one side are portions of the stem and cirri that evidently belong to this crown. As clearly shown in the figures (pl. 18; text fig. 31), the proximal part of the column is strongly stelliform in outline. The proximal columnals are centrally placed at the base of the cup. Seemingly, only a small part of the normally very long quartibrach portion of the arms is preserved in this specimen. It is probable that these outer parts of the arms were present originally, and they may be represented in some of the fragmentary material that became separated during preparation. The very robust nature of proximal pinnules belonging to some of the rays is well shown.

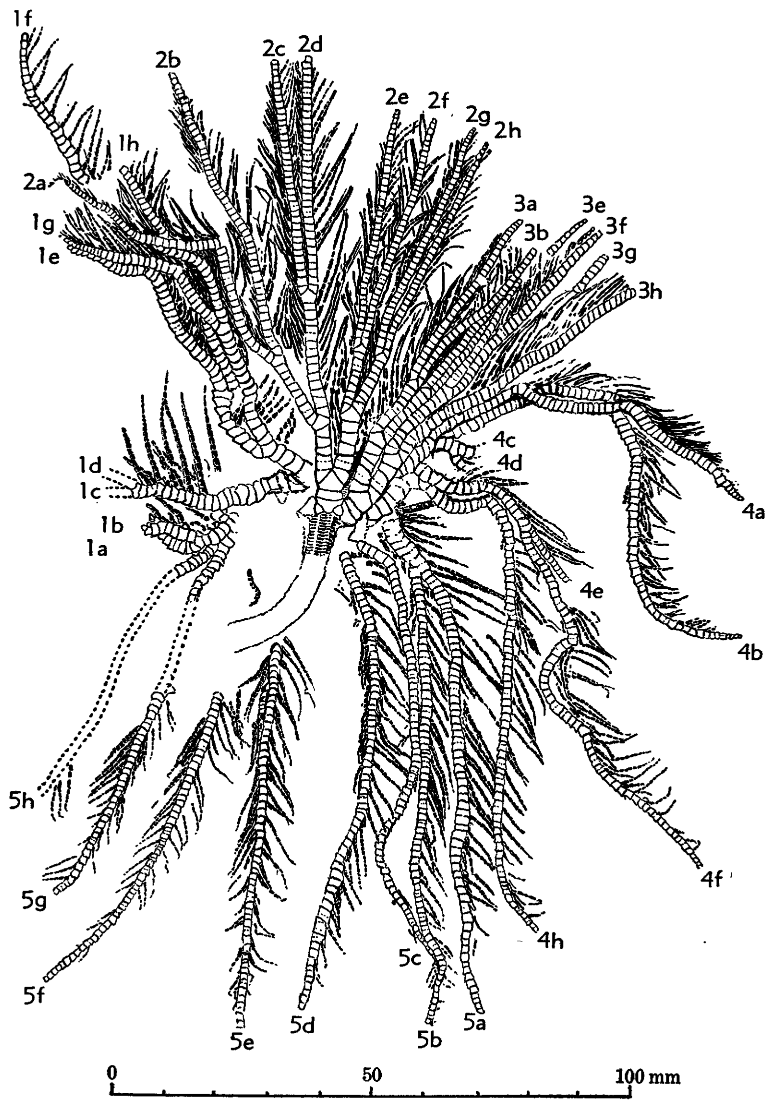


FIGURE 29.—Holotype of *Isocrinus oregonensis*. The drawing corresponds to the photographic illustration reproduced in plate 14, with enlargements as given in plates 15–17. For purpose of identifying parts of the crown, arms are designated by numbers to denote rays, and letters to denote individual arms; the assignment of these designations proceeds clockwise, beginning at the left. Thus, the eight arms of ray number 2 (enlarged in plate 16) are indicated by 2a to 2h.

Paratype B (U.S.N.M. 560791B) is a fairly robust, well-preserved crown in which the arms of the lower part of the crown are closely crowded together. The distal part of the arms is mostly missing. The nature

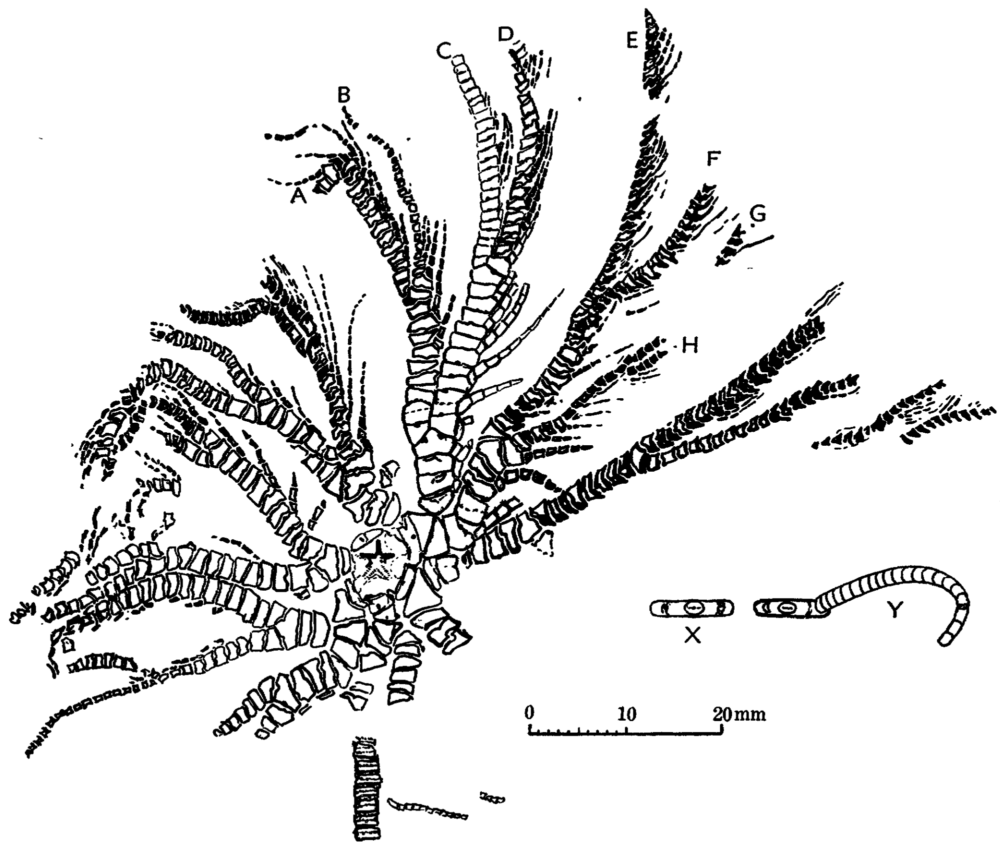


FIGURE 30.—Paratype A of *Isocrinus oregonensis*. The drawing corresponds to the photographic illustration reproduced in plate 18 The structure of arms lettered A–H is represented in text figure 31. X, Y show side views of nodal columnals and part of attached cirrus, probably belonging to paratype A.

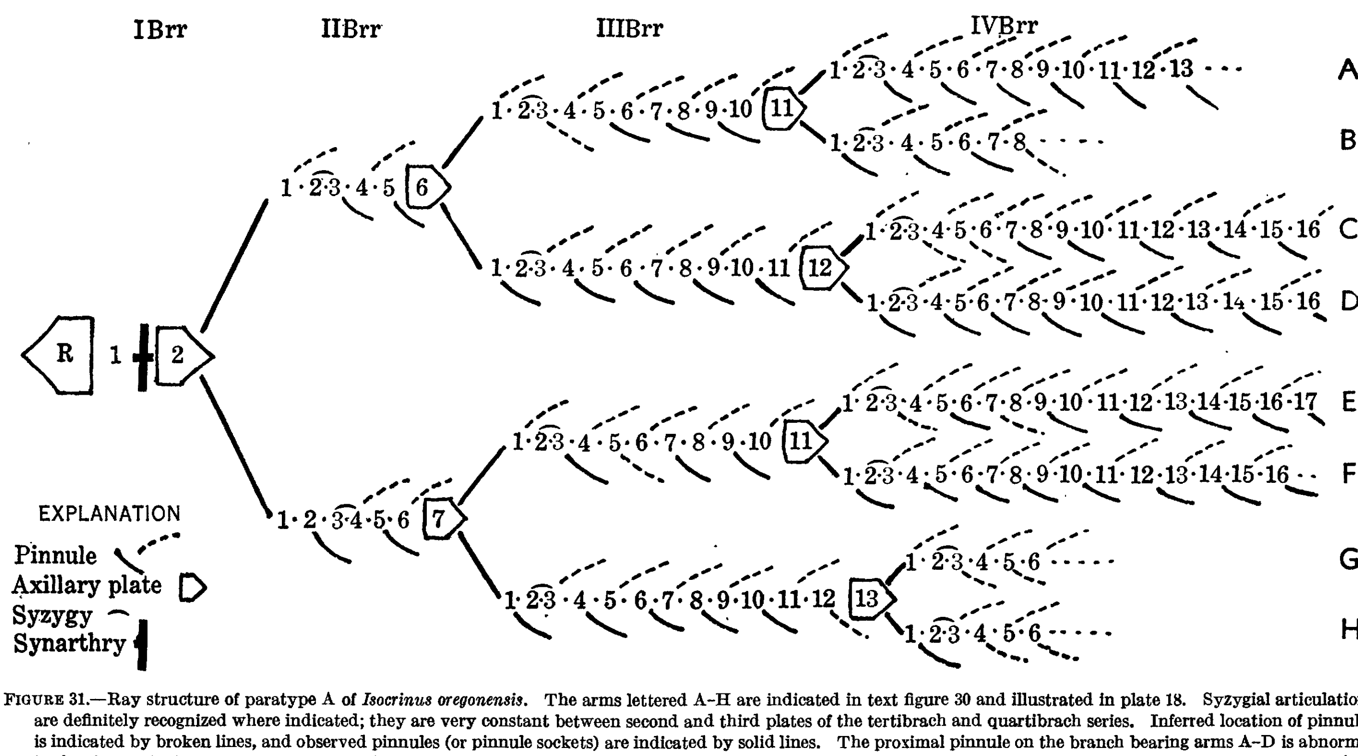


FIGURE 31.—Ray structure of paratype A of *Isocrinus oregonensis*. The arms lettered A–H are indicated in text figure 30 and illustrated in plate 18. Syzygial articulations are definitely recognized where indicated; they are very constant between second and third plates of the tertibrach and quartibrach series. Inferred location of pinnules is indicated by broken lines, and observed pinnules (or pinnule sockets) are indicated by solid lines. The proximal pinnule on the branch bearing arms A–D is abnormal in that it seemingly occurs on $IIBr_1$ instead of on $IIBr_2$.

of articulations between the radials and first primibrachs and between plates of the rays is well shown, and most of the structure for at least four of the rays can be determined (text fig. 32). The arms are too closely appressed to show well the arrangement of pinnules, except in one of the arms that is somewhat separated from the remainder of the crown. This arm bears unusually coarse, long pinnules. An intact part of the stem, which evidently belongs to this crown, lies close to its base but disposed in a transverse manner. It comprises seven groups of nodal and internodal columnals, several of the nodals bearing cirri in attached position. This specimen measures about 100 mm across its largest part.

Paratype D (U.S.N.M. 560791D) consists of a group of arms and the lower part of a crown, the total length of exposed arms being about 90 mm (pl. 19, fig. 4). Fairly complete regularly spaced pinnules appear at the side of the arms.

Paratype E (U.S.N.M. 560791E) is a crown spread out so as to show all of the rays radiating from the centrally placed dorsal cup. The specimen measures

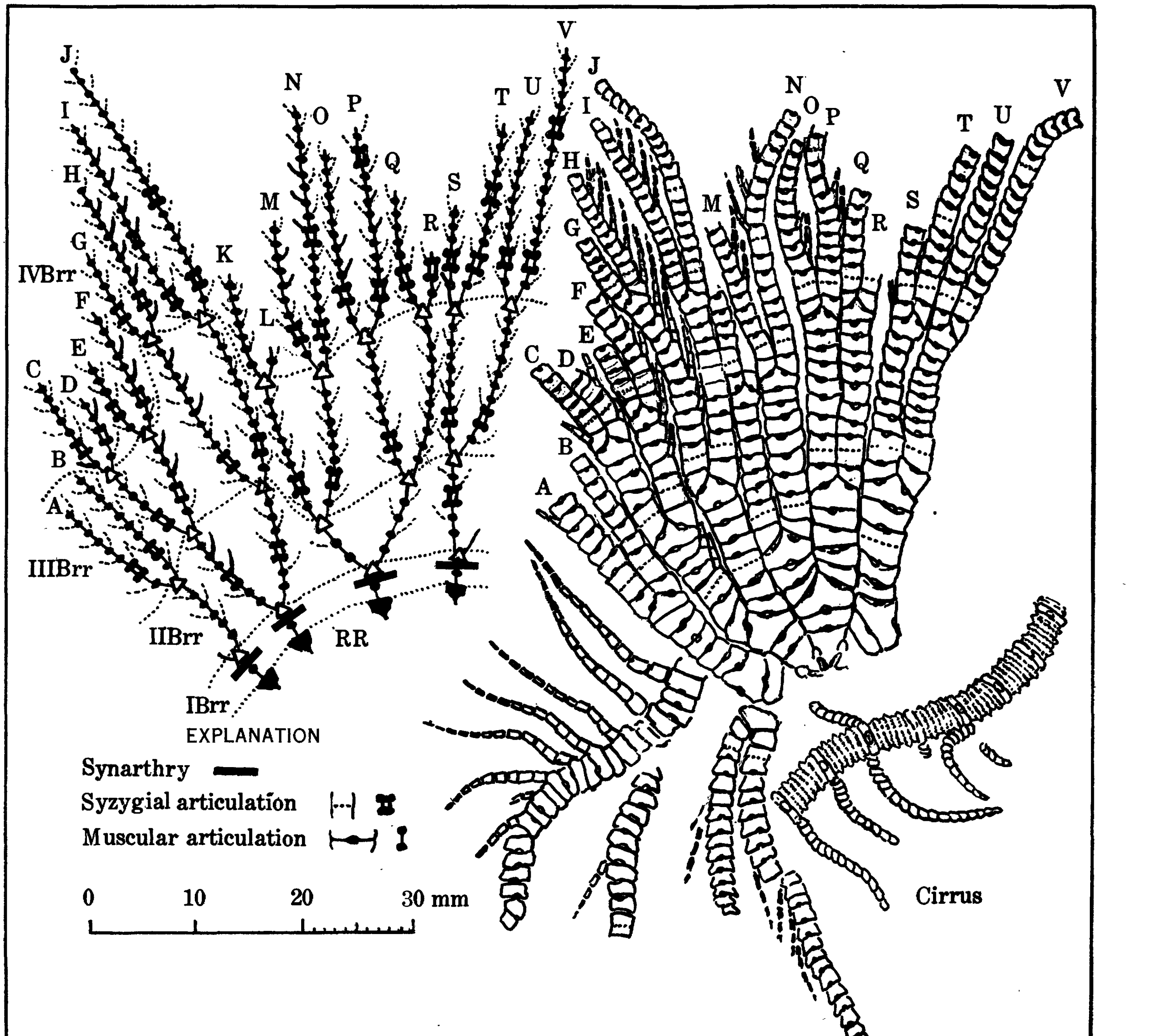


FIGURE 32.—Paratype B of *Isocrinus oregonensis* and diagram of ray structure. Subdivisions of the rays are correspondingly lettered on the drawing of this paratype and the diagram showing structure. Syzygies are irregular in the secundibrach series of this specimen in that some branches lack them, others are normal in showing syzygial union of $IIBr_{3+4}$. With one exception, $IIIBr_{2+3}$ and $IVBr_{2+3}$ are joined by syzygy. Union between IBr_{1+2} is synarthrial.

about 150 mm across its widest part (pl. 19, figs. 2, 5). Several very robust pinnules belonging to lower parts of the ray are well shown.

Paratype L (U.S.N.M. 560791L) clearly shows the arrangement of plates of the dorsal cup, and structure of the lower parts of the crown (pl. 20, fig. 3).

Several lots of stem fragments and isolated columnals are included among paratypes of *Isocrinus oregonensis*, illustrated specimens appearing in plate 23, figs. 1–3, 5–6, 8–10 (U.S.N.M. 560903A-C).

Paratype U.C.M.P. (University of California Museum of Palaeontology) A5018A is a completely exposed dorsal cup with remnants of proximal columnals attached and, spread out around the cup, arms representing all of the rays. The structure of the lower part of the arms in some of the rays is determinable but only in one ray is all of the tertibrach series visible, and pinnules are not very well shown. This specimen is illustrated in Plate 24, figure 4 and text figure 35E. Measurement across the crown in one direction is 100 mm and at right angles about 60 mm; the evenly pentagonal dorsal cup has a diameter of 10 mm and height of 4 mm.

Paratype U.C.M.P. A5018B is a crown having a maximum length of some of the arms of 60 mm. (pl. 24, fig. 1). The primibrach series of all rays are preserved, but secundibrach and tertibrach series can be seen in only three of the rays. Although a small part of the dorsal cup is lost, some of the radials and basals are complete and all plates of the cup are represented. A couple of the strongly stellate proximal columnals are joined to the base of the cup (pl. 24, fig. 3). The fracture which obliquely intersects one side of the cup (lower part of text figure 35*D*) reveals the suture between two basals toward the edge of the stem, where normally this suture is covered by the proximal extremity of a radial plate. This dorsal cup, which lies on the edge of a rock fragment 100 mm long and 45 mm wide is completely visible from the base and on all sides. It has a diameter of 10 mm and a height of 4 mm.

Paratypes U.C.M.P. A5018C1 and A5018C2 are on a block of rock 220 mm long and 120 mm wide. One of the surfaces of this block also shows three relatively long articulated pieces of stem (to 60 mm) and smaller sections of joined columnals, all belonging to *Isocrinus oregonensis* (Paratype U.C.M.P. A5018C3, pl. 22, fig. 3). One of the stems has many attached cirri, regularly spaced in whorls surrounding the column. Paratype U.C.M.P. A5018C1 is a good specimen that lies on its side, one half projecting above the surface of the block and the other half buried in hard matrix. Preparation of the dorsal cup has revealed most of it, only one radial being entirely covered, and joined to the base of the cup are several columnals. The highest part of the arms in any of the preserved rays belongs to the tertibrach series. The crown is 40 mm wide and 35 mm high, with the dorsal cup 10 mm across and 4 mm high. Paratype U.C.M.P. A5018C2 is unimportant. It is an incompletely exposed basal part of a crown about 25 mm high and 18 mm wide. The dorsal cup probably is present, buried in the matrix, because the first primibrachs are visible on two of the sides. No effort to expose the base of the crown has been made. Paratype U.C.M.P. A5018C1 is illustrated in Plate 24, figure 2, and in text figure 35*A*, *B*.

Of other University of California paratypes, only a stem fragment on U. C. M. P. A5018H is here described and figured (text figs. 35 *F–I*). It consists of the epizygal cirrus-bearing nodal and seven proximally succeeding internodals which normally remain joined together. The distal articulating surface of the epizygals is nearly smooth, so that rupture of the stem at this point is easy. Cirrals are attached to this stem fragment on all sides of the nodal. The figured fragment is 6.8 mm long and the stem is 6 mm in diameter.

DORSAL CUP

Identifiable plates of the dorsal cup consist of radials and basals, which are joined to form a relatively stout structure having a width slightly less than twice the diameter of the stem attachment and height nearly one-half of the width. The part of the base of the cup which is covered by the proximal columnal and composed of proximal surfaces of the radials is a flat horizontal plane. The basals project below this plane, however. Total height of the cup is most readily and accurately measured at the angles occupied by the bulging basals going upward from their lower extremity to the summit of an interradial suture.

Infrabasals occur in other species of *Isocrinus* but are not observable in any of the Oregon specimens.

The basals are small, moderately to strongly bulbous plates having a rhomboidal outline as seen in oblique view from below. They rejoin the outer angles of the column, and on some specimens they protrude like short blunt spines. The bulbous basals project downward rather than sideward, and accordingly they tend to produce a concave outline of the cup base. They are not laterally in contact externally but are separated by proximal extensions of the radials, which reach to the base of re-entrant angles of the proximal columnals. The proximal parts of the basals extend beneath the stemward tips of the radials, however, so as to join one another laterally, not only in the area covered by the stem but outside of this (text fig. 35*D*, lower part).

The circlet of radials comprises most of the cup; these plates are somewhat wider than long, laterally in contact with one another on the exposed side of the cup, and very strongly convex in longitudinal profile.

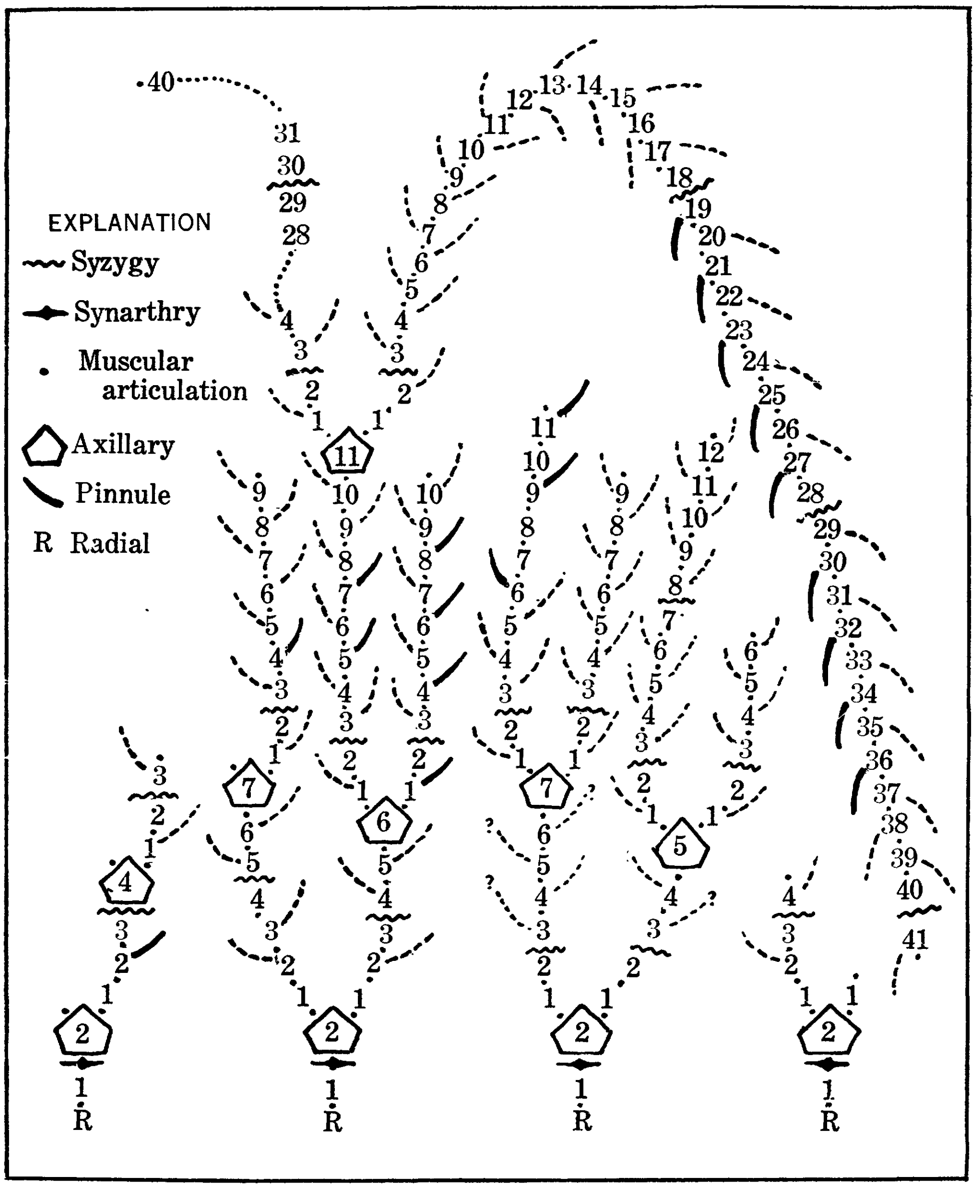


FIGURE 33.—Ray structure of paratype L of *Isocrinus oregonensis*. This specimen is distinguished by unusual variability in location of syzygies in the secundibrach series.

Sutures between the radial plates are well defined but not impressed. The entire distal margin is occupied by an articular facet for support of the base of a ray. The margin of the facet appears straight in slightly upward oblique side view of the cup but is actually curved, for the very broad outer ligament area of the facet reaches downward in the midportion of the radials. Characters of the articular surface of the radials are not shown by the holotype but are partly discernible on some of the paratypes (text fig. 35 *A-C*, *E*). They seem to be identical to the facet of *I. nehalemensis*, some specimens of which show the facet clearly.

No differences in size of the five radials of any cup have been discerned, and no evidence for placement of the posterior interradius has been found. Hence, orientation of the cup is unknown.

In longitudinal profile, the pointed proximal part of radial plates that projects to the re-entrant angles of the stem is nearly plane and is approximately horizontal in position—that is, disposed at right angles to the axis of the stem. The middle and distal parts of the outer surface are very strongly and evenly curved so as to form half a circle between the plane of the base and the margin of the outer ligament area. The transverse profile of radial plates at their midlength is also very strongly curved, and the lateral portions of adjoining radials meet so as to form a shallow, re-entrant angle. The outline of the cup in dorsal view is that of a regular pentagon having slightly rounded sides (text fig. 35*D*).

The general shape of the radial plates and nature of the articular facets of radials belonging to *Isocrinus* *oregonensis* seem to be wholly similar to those of *I. nehalemensis* except that they are larger. Inasmuch as the nature of the facets is much better shown in the latter species, detailed description is given in discussing specimens referred to *I. nehalemensis.*

RAYS EXCLUSIVE OF RADIALS

Arms.—Each of the rays in which the structural plan is clearly determinable shows a threefold isotomous branching, so that there are eight outer branches to the ray. At least 30 arms can be differentiated with certainty, and it seems probable that the total number of arms belonging to the species is 40. Bifurcations are relatively near the cup, with the unbranched distal portion of the rays beyond the last bifurcation more than twice as long as the part between this bifurcation and the cup. The arms are strongly rounded transversely and fairly slender. Most of the sutures between brachials are oblique, with the proximal and distal articular surfaces sloping in opposed directions; thus, most brachials are distinctly wedge shaped.

Primibrachs.—There are two primibrachs in each observed ray. The first primibrach is a very short quadrangular arm segment that is broader along its contact with the radial than at its distal margin. The nature of the articular surfaces is not determinable definitely in the holotype, except that their external appearance indicates a nonsyzygial articulation. Paratype L (text fig. 33) of *Isocrinus oregonensis* and specimens of *I. nehalemensis* (text fig. 38) clearly show that the articulations between the first and second primibrachs are synarthrial. Presumably, all of the Oregon specimens possess this character, which is a distinguishing feature of *Isocrinus.* The second primibrach is a large axillary plate having steeply inclined distal facets of even width that support equal branches.

Secundibrachs.—Six or seven secundibrachs occur in each main branch. The lowest brachial of this series is a short, slightly wedge shaped plate that bears no pinnule; the edge on the outside of the ray is not sufficiently longer than that on the inside of the ray to compensate the strongly inclined attitude of the distal surface of the adjoining axillary primibrach. The second segment of the secundibrach series is a larger plate that also has a longer edge on the outside of the ray, its distal articular surface sloping toward the inside of the ray. As in all species of *Isocrinus*, this brachial normally bears a stout pinnule at its upper angle, directed toward the outside of the ray. This is the most proximal pinnule observed in any specimen, and its position is determined clearly in at least seven rays belonging to different paratypes. Seemingly, this placement of the proximal pinnules is a nearly constant character (an exception is indicated in text fig. 31, paratype A). The third and fourth secundibrachs normally are united by close suture, forming a syzygial pair; the third segment has no pinnule, but the fourth supports one that grows toward the inside of the ray. Succeeding secundibrachs are joined by muscular articulation and (excepting axillaries) bear pinnules. Syzygies between the second and third secundibrachs, or between the fourth and fifth secundibrachs are rarely seen. The axillary secundibrachs have evenly sloping distal margins of approximately equal width, supporting subequal branches. The structure of rays observed in the holotype and two paratypes of *Isocrinus oregonensis*, showing distribution of syzygies and pinnules, is indicated in text figures 31–33.

Tertibrachs.—The number of tertibrachs in different branches ranges from 9 to 16. These brachials are like those of preceding series except for their smaller size and the fact that the second and third tertibrachs (instead of the third and fourth) are joined as a syzygial pair; this occurrence of syzygy is almost invariable in the tertibrach series, for only one instance of deviation, in which the first and second tertibrachs are thus joined, has been seen. The first tertibrach (except where it forms the hypozygal of a syzygial pair), like succeeding ones which are not hypozygals, is pinnule bearing.

Quartibrachs.—Arm segments of the quartibrach series are nearly uniform in size, and have the length approximately equal to the width. Articulation between segments is mostly muscular, but there is indication that syzygial pairs occur at intervals of 10 to 12 segments in some branches (text figs. 31–33). Joints cross the branches obliquely, and pinnules are borne on opposite sides of the branch by alternate segments.

Bifurcation of the rays.—Three bifurcations are found in each of the rays of *Isocrinus oregonensis.* No specimen has been observed in which a ray bears more than three bifurcations. This signifies that the terminal part of the arms consists of quartibrachs and the total number of arms belonging to a complete crown is 40. A distinguishing feature of the species seems to be the unusual length of the unbranched quartibrach series of plates. Several arms of the holotype specimen have more than 60 quartibrachs in the preserved portion of these arms. Although tertaxils are not certainly identified in some rays, count of quartibrachs of various arms are 72 (text fig. 29, arm 5d), 74 (arm 5a), 76 (arm 5c), 84 (arm 4h), and 88 (arm 5b).

Each ray invariably divides first on the second primibrach. These primaxils are comparatively large plates of pentagonal outline.

Bifurcations above the primaxils most commonly occur on the fifth to eighth plates of the secundibrach series and tenth or eleventh plates of the tertibrach series. This is indicated by the following table and illustrated in text figures 31–33. One paratype (U.C.M.P. A5018A) exhibits unusual irregularity in length of the secundibrach series, for in four adjacent arms the number of these brachials (including secundaxils) is 10, 5, 4, and 8. This specimen shows one complete tertibrach series composed of 20 brachials, followed by several quartibrachs beyond the tertaxil. An adjoining incomplete tertibrach series contains 20 brachials, no tertaxil being present, signifying that this branch must have at least 21 plates in the tertibrach series.

Distribution of bifurcations in secundibrach and tertibrach series of Isocrinus oregonensis

Axillary	Number of examples	Axillary	Number of examples
$IIBr_3$	1	$IIIBr_7$	1
$IIBr_4$	2	$IIIBr_8$	2
$IIBr_5$	3	$IIIBr_{10}$	6
$IIBr_6$	4	$IIBr_{11}$	7
$IIBr_7$	3	$IIIBr_{12}$	3
$IIBr_8$	3	$IIIBr_{13}$	2
$IIBr_{10}$	1	$IIIBr_{20}$	1
$IIIBr_6$	1	?$IIIBr_{21}$	1

The complete unbranched quartibrach series are very long, but on most of the paratypes only fragments of this part of the rays can be seen. However, paratype L (U.S.N.M. 560791L) shows 40 and 41 quartibrachs, respectively, in two of the arms (text fig. 33).

Articulation of brachials.—Types of articulation recognized in the rays of *Isocrinus oregonensis* include muscular, syzygial, and synarthrial.

Muscular articulation is much the most common. It is distinguished by the presence of a strongly marked articular ridge, an outer ligament area containing a deep ligament pit, inner ligament depressions, and inner shallow muscular areas, situated on either side of the ventrally located muscular notch. An alternating shift toward left and right in the position of the ligament pit in the muscular articulations indicates obliquity of position of the articular ridges, but generally not enough of the molds of the facets are preserved to determine clearly the orientation of the articular ridges.

Syzygial sutures are distinguished by fine radiating crenellae that are developed on the part of the articular surface adjoining the exterior of the brachials (pl. 19, fig. 3). Syzygially joined brachials are perforated centrally by a canal, and the ventral part of the articular facet is nearly smooth.

Synarthrial articulation is characterized by a ridge running dorso-ventrally so as to separate broad, shallow ligament areas on the two lateral parts of the adjoining facets; ligament pits are lacking. The first primibrach and the primaxil are united by synarthry, but this type of union is not definitely observed higher in the rays, although a tendency in this direction is noted in the articulation of the first two brachials following axillary plates or following a syzygial articulation.

Distribution of syzygial articulation.—Most commonly, syzygial articulation occurs between the second and third brachials of the tertibrach and quartibrach series, but in the secundibrach series union of the third and fourth plates is generally more common than that between the second and third secundibrachs.

Observable distribution of syzygial articulations in specimens of *Isocrinus oregonensis* is summarized in the following tabulation, and it is partly illustrated in text figures 31–33. In three complete secundibrach series and one tertibrach series, no syzygial pairs of brachials are present.

The University of California paratypes, which are not included in the foregoing table, mostly permit identification of syzygial sutures without difficulty, and in general, these specimens follow the pattern discerned in study of the external molds belonging to the United States Geological Survey collection. The second and third brachial of each tertibrach and quartibrach series are invariably united by a syzygy, and this applies to two of the secundibrach series of paratype U. C. M. P. A5018A. Other secundibrach series show syzygial union of the third and fourth brachials, as is the rule.

Distribution of syzygial articulations in Isocrinus oregonensis

Brachials united	Number of examples	Brachials united	Number of examples
$IIBr_{2+3}$	3	$IVBr_{9+10}$	1
$IIBr_{3+4}$	6	$IVBr_{10+11}$	1
$IIIBr_{1+2}$	1	$IVBr_{13+14}$	2
$IIIBr_{2+3}$	22	$IVBr_{18+19}$	1
$IIBr_{7+8}$	1	$IVBr_{28+29}$	1
$IVBr_{2+3}$	28	$IVBr_{29+30}$	1
$IVBr_{8+9}$	1	$IVBr_{40+41}$	1

Pinnules.—Branchlets that are classifiable as pinnules are borne by all brachials except axillaries, hypozygals, and possibly distal quartibrachs, occurring above the non-pinnule-bearing first secundibrach (text figs. 31–33). The pinnules are mostly long and moderately stout. Those attached to secundibrachs and proximal tertibrachs are somewhat larger than pinnules growing from the unbranched arms, and the smallest, weakest pinnules are seen near the extremities of the arms (plates 1–4). The tendency toward "rat tail" appearance of the distal portion of arms, such as characterizes several species of modern stalked crinoids, is evident in *Isocrinus oregonensis*, but it is hardly more than incipient. Proximal pinnulars are distinctly shorter and stouter than distal segments of these branchlets (text fig. 34).

Many pinnules reveal the presence of covering plates in erect position along sides of the ambulacral groove, although these plates are visible only on pinnules that happen to be properly oriented (plate 17; text fig. 34). If the ambulacral groove is along an edge of the pinnule nearly in the plane of bedding on which the crinoid is spread out, the erect covering plates may be seen in profile; there are four such plates to each pinnular of normal size. In recumbent position the covering plates are not distinguishable.

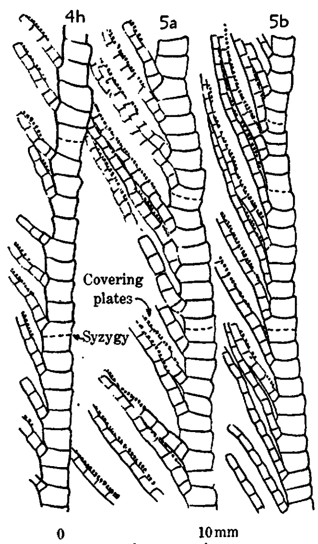


FIGURE 34.—Brachials and pinnules of the holotype of *Isocrinus oregonensis*. Compare with text figure 29 for determining position of the arms 4h, 5a, and 5b (mid-portion of quartibrach series). The small covering plates are in erect position.

COLUMN

The nature of the stalk of *Isocrinus oregonensis* is determined from study of the mold of the proximal part of the stem of the holotype specimen, nearly 40 mm of which is preserved in its position of attachment to the calyx. In addition, it is shown by observation of several long segments of the column associated with paratype crowns and numerous isolated stem fragments that have characters seemingly identical with those of the type specimen. The majority of these specimens are molds, but several show the well-preserved calcite of the stem, which could be removed from the matrix; the calcite specimens reveal characters of the articular surfaces of both nodal and internodal columnals, as well as features of the sides.

The stem is distinctly stellate in cross section, having five sharply pointed angles and a corresponding number of re-entrants midway between the angles. At first glance, the columnals seem to be very even in width, so that the stem is straight-sided and uniform; there is hardly a perceptible difference in thickness of the columnals; nodals are not prominent. Closer observation indicates an unevenness of alternating columnals, not only in width and thickness but in the profile of the sides; these variations are persistent and regular in arrangement, and they are judged to be diagnostic specific features.

Nodal segments of the stem are distinguished by the presence of five elliptical scars representing places of attachment of cirri or they bear adherent segments of the cirri; these branches of the stem are arranged in whorls, the attachments being located in each re-entrant between points of the nodal. The occurrence of five cirri on each nodal is a feature indicating lack of specialization, and this character of the column of *Isocrinus oregonensis* constitutes an easily recognized distinction from species of *Balanocrinus*. The cirri are directed slightly upward, but the scar of attachment, located nearer to the proximal margin than to the distal edge of the nodal, does not encroach appreciably on the adjoining internodal. The surface of the scar is plane or gently concave transversely (horizontally) and nearly plane in a direction parallel to the axis of the stem. The angle between the upward tilted plane of the cirrus socket and axis of the column is about 30 degrees (text fig. 35*H–I*). A well-defined articular ridge divides the scar unequally into upper and lower ligament areas, of which the latter is the larger and is marked by faint radiating crenellae (plate 23). The transverse ridge of the cirrus sockets does not extend to their margins but terminates at each end in a rounded boss that is slightly steeper on the proximal side (text figs. 35*G-I*; 36*A*, *D-E*; 39*D*). Nodals are slightly thicker than internodals and the angles project 0.2 mm or so laterally beyond the edges of larger internodals.

The proximal articular surface of nodal columnals, as in modern pentacrinoids, is marked by strong crenellae that surround and run nearly normal to five lanceolate or ovoid ligament areas; this surface is like the normal articular surfaces of internodals. The distal (lower) articular surfaces of a number of nodals are revealed, for pentacrinoid stems normally break readily at the contact of nodals with the subjacent internodal, owing to the nearly smooth nature of the articulation, termed a synostosis. The under side of the nodal carries five gently hollowed areas that extend outward to the angles, and each hollow is bordered by faint crenellae. The surface of the contiguous internodal bears five gently convex areas that fit into hollows of the nodal; this columnal next below the cirrus-bearing nodal has been classed as infranodal or hypozygal element of a so-called nodal pair (P. H. Carpenter, 1884, p. 4), but actually it is an internodal.

Internodal segments are slightly thinner and smaller in diameter than the nodals. Typically, there are seven columnals of this type between each pair of neighbor-

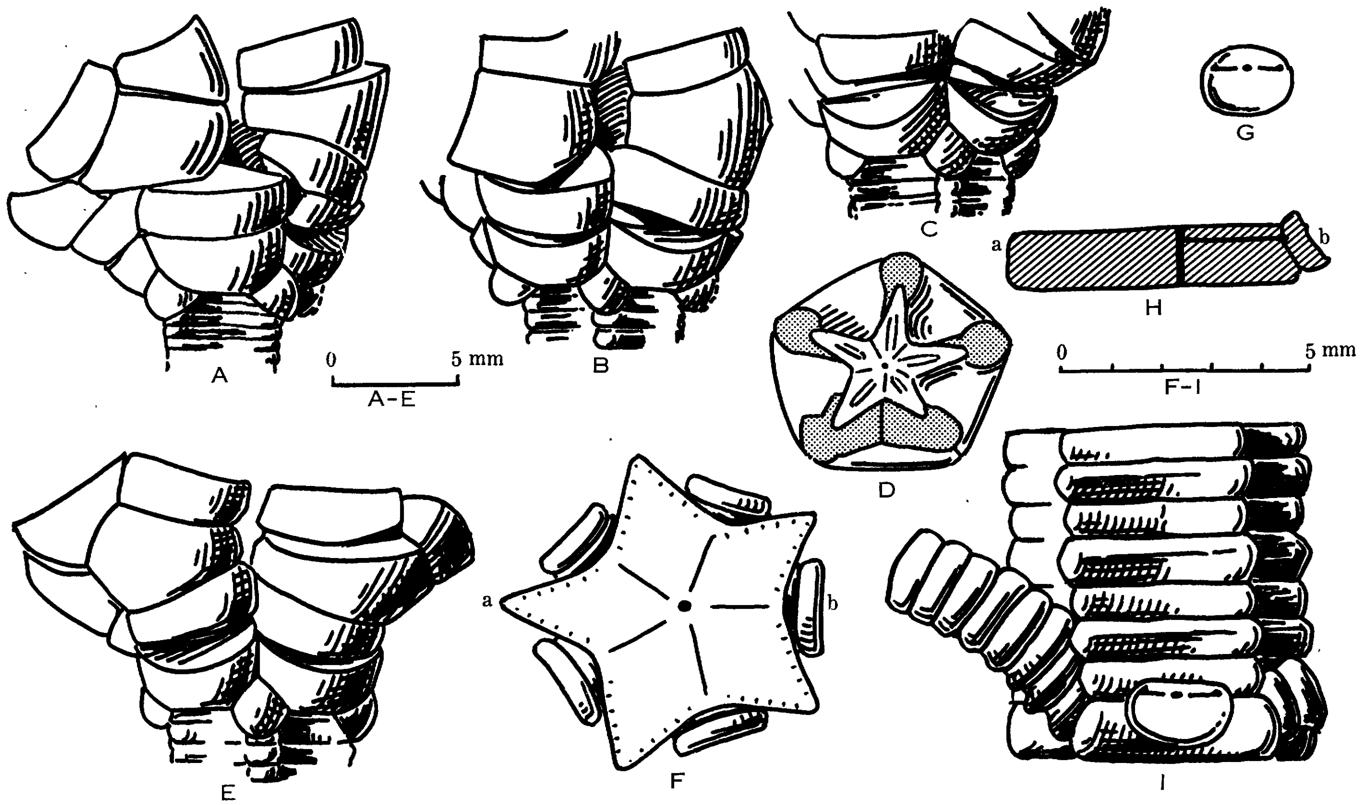


FIGURE 35.—Paratypes of *Isocrinus oregonensis* in collections of the University of California Museum of Palaeontology. *A, B,* Side views of paratype A5018C1, showing dorsal cup and two primibrachs in each ray. *C, D,* Side and dorsal view of paratype A5018B; the shaded areas in *D* are basal plates, which appear enlarged in the lower part of the figure owing to an oblique fracture that has resulted in loss of the proximal part of the radial above the basals in this region; the strongly stellate outline of proximal columnals (the point at lower right partly broken off) is indicated. *E,* Side view of paratype A5018A. *F,* Distal surface of the nodal columnal shown at base of the stem fragment illustrated in *I*; the five pentameres of the articular face are gently concave and smooth, except for faint marginal crenellae; proximal cirrals are attached to each re-entrant side of the nodal. *G,* An articular facet for attachment of a cirral. *H,* Cross section of the nodal shown in *F* along the line *a-b*, intersecting an inclined proximal cirral and showing axial canals penetrating the columnal and cirral. *I,* A stem fragment, paratype A5018H, consisting of an epizygal nodal with attached cirrals and seven internodals, the uppermost of which adjoins the base of another nodal and is thus identified as a hypozygal plate; the cirrals near the stem are much shorter than those of middle and distal parts of the cirri.

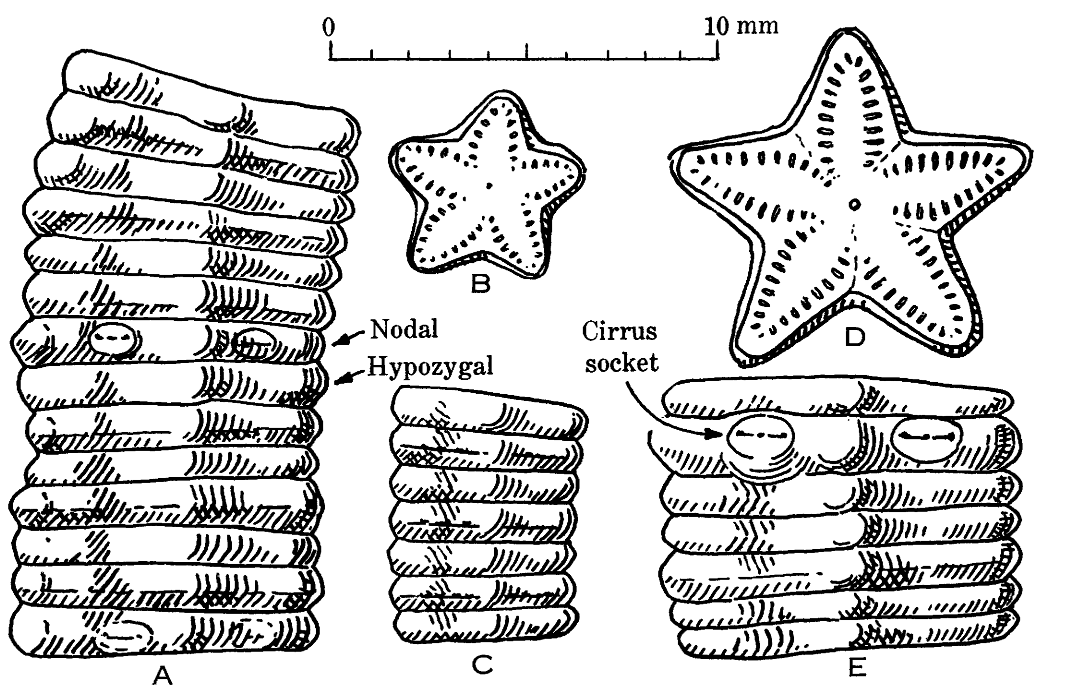


FIGURE 36.—*Isocrinus* columnals. *A, E,* Side views of two stem fragments of *Isocrinus oregonensis,* showing nodals and internodals. *D,* Articular face of the internodal shown at top (proximal extremity) of the fragment illustrated in *E*. *B, C,* Articular face and side view of columnals belonging to *I. nehalemensis.*

ing nodals; the internodal midway between the nodals is the largest of the group, and the centrally located internodals (one above and the other below the dominant internodal) in the remaining space between two nodals are next in size; the four other internodals of a group are smallest. These differentiated internodals represent successive orders of appearance in growth, the middle internodal being the first order (that is, initially developed columnal between nodals), the two slightly smaller internodals being second order (in time of making appearance), and the others constituting a third order (final segments in growth succession). It is noteworthy that internodals of *Isocrinus oregonensis* belonging to the first and second orders have flaring sides that join in a median angulation at midheight of the columnals, whereas internodals of the third order are straight-sided and lack an angulation; also, the first and second order internodals project beyond those of the third order at points of the star-shaped stem.

Presumably, nodals are more closely spaced near the dorsal cup, in the proximal part of the column of *Isocrinus oregonensis* and internodals are fewer and thinner, but this is not well demonstrated. The well-preserved segments of columns referred to this species show nearly uniform internodalia composed of seven internodals.

The slightly wavy sutures that are seen in side view of columnals having crenellate articular surfaces can be distinguished from the perfectly plane suture occurring at the distal border of nodal segments. Thus, any fragments of the stem that include a nodal can be oriented according to position of the column in the living crinoid. Amplitude of the crenellae is greatest midway between the outer and re-entrant angles of the columnals and in a zone located about 0.5 mm inward from the margin. Here amplitude of the crenellae (height from crest of ridge to adjacent furrow) increases to 0.3 mm. These features are excellently shown by many specimens preserved as external molds.

The articular surfaces of internodals (except the proximal face of an internodal next below a nodal) are marked by five lense-shaped, gently hollowed, smooth-floored ligament areas that extend radially outward from the tiny circular lumen nearly to the points of the stellate columnal; each ligament area is bordered by short, strongly marked crenellae running normal to the border of the area, but crenellae near the lumen are shorter and less distinct than those bordering the outer edeg of the stem. A very fine line resembling a suture extends from the lumen to each re-entrant of the margin of the columnals, thus defining pentameres that are comparable to those of some Paleozoic stems of primitive type.

Cirri.—The cirri extend outward and slightly upward from the column and then curve downward. They are nearly uniform in diameter (about 1.5 mm) from the base of attachment to their distal extremity, and the most nearly complete example has a length of 25 mm. Proximal cirrals are relatively thin, about nine occurring in 5 mm, whereas segments of the medial and distal regions are notably thicker, only five cirrals in 5 mm. A terminal segment, presumably clawlike in form, has not been seen.

Measurements.—A stem fragment having relatively large diameter (from loc. 15282) has dimensions as follows: greatest width of nodal 9.0 mm. (pl. 23, fig. 1), width across re-entrant angles 5.5 mm, distance from lumen to one of the outer angles 4.8 mm, thickness 1.5 mm; greatest width of internodal 8.0 mm (pl. 23, fig. 2), width across re-entrant angles 4.5 mm, distance from lumen to outer angle 4.2 mm, thickness 0.8 to 1.2 mm; a group of eight columnals (nodal and seven internodals) measures 8.8 mm in aggregate thickness (pl. 23, fig. 3). The very small lumen has a diameter of 0.1 to 0.2 mm. Cirrus scars on this fragment are 1.5 by 2.0 mm in width. A smaller stem (loc. 15508, pl. 23, fig. 9) has maximum width of 6.5 mm, thickness of nodals 1.3 mm, internodals 0.7 to 1.0 mm; a group of eight columnals measure 7.5 mm in thickness.

DISCUSSION

Discrimination of *Isocrinus oregonensis*, n. sp., from associated crinoid remains that are referred to *I. nehalemensis*, n. sp., is based on seemingly constant differences in features of the dorsal cup, arms, and stem, as well as by the greater average size of specimens belonging to *I. oregonensis*. Plates of the dorsal cup of *I. oregonensis* are generally less bulbous and more nearly confluent with the lower arm plate than in *I. nehalemensis*. Three bifurcations of the rays occur in *I. oregonensis*, whereas only two have been observed in *I. nehalemensis*. This distinction is not certainly valid inasmuch as the longest unbifurcated tertibrach series observed in the latter species (text fig. 36*K*) is 17. Syzygial sutures of the secundibrach series rather constantly occur between brachials 3 and 4 in *I. nehalemensis*, whereas these are much less regular in *I. oregonensis*. The stem of *I. oregonensis* is distinctly larger on the average than that of *I. nehalemensis*, and alternating columnals are different in size in contrast to the evenness of columnals belonging to *I. nehalemensis*. Also, columnals of *I. nehalemensis* are comparatively straight-sided rather than horizontally ridged, as in *I. oregonensis*. Closely crowded short cirri in the proximal part of the stem of *I. nehalemensis* are well shown in some specimens (pl. 19, fig. 1; pl. 22, fig. 1; text fig. 37) but are not evident in *I. oregonensis;* this seeming distinction cannot be affirmed, however, as a reliable basis for discriminating the two species.

A Jurassic crinoid from Wyoming described by Springer (1909) as *Isocrinus knighti*, corresponds to *I.*

oregonensis in having the first primibrach joined to the axillary second primibrach by synarthry, in the generally oblique disposition of the muscular articular ridges of brachials, distribution of syzygies in the secundibrach and higher arm series, and in its slender long arms, but all of these are characters of the genus *Isocrinus*. This Jurassic species differs from *I. oregonensis* in its steeper-sided dorsal cup, the presence of only two bifurcations to each ray, and in noteworthy differences of the stem, which is pentagonal rather than stellate in outline. Except near the crown, internodal series of *I. knighti* range up to 14 columnals, whereas the greatest normal number in *I. oregonensis* is 7 columnals to a single internodal series.

Jurassic crinoid columnals from Utah described by Clark (1893, p. 51; 1893a, p. 27, pl. 3, figs. 2*A–D*) as *Pentacrinus whitei*, correspond to columnals of *Isocrinus oregonensis* in size, general nature of the articular surfaces, and appearance in side view. Clark's species, which probably belongs to *Isocrinus*, was redescribed and figured by Clark and Twitchell (1915, p. 27, pl. 3, figs. 3*A–C*). A stem segment consisting of 10 attached columnals (Clark and Twitchell, pl. 3, fig. 3*C*) seemingly consists only of internodals.

From Normandy (near Caen, Département du Calvados) have come several specimens of a Middle Jurassic species of *Isocrinus*, which from 1845 to 1898 was known as *Pentacrinus nicoleti* Desor. This form resembles *I. oregonensis* rather closely in most respects but is much smaller. Shape of the dorsal cup, proportions of the radial and basal plates and their attitude, the closely juxtaposed arrangement of the primibrach series in a manner which makes them seem to be part of the dorsal cup, and repeated isotomous bifurcations of the rays are all nearly identical in Desor's species from France and the Oregon specimens described from the Keasey formation. Likewise in the column, the nodals, internodals, and cirri, are little different in the two forms. Figures and description of *I. nicoleti* by Bigot (1938) show that the Jurassic species mainly differs from *I. oregonensis* in that the dorsal cup more nearly matches the proximal columnals in diameter, a synarthry occurs between the first and second secundibrachs, and at least five bifurcations occur in some rays. Syzygies typically occur between the third and fourth plates of the tertibrach and quartibrach series, instead of the second and third, as in *I. oregonensis*. Some of the specimens of *I. nicoleti* clearly reveal very diminutive infrabasal plates, and in one (Bigot, 1938, pl. 1, fig. 13), the tegmen is almost complete.

From Danian rocks in the type area of Denmark, Nielsen (1913, pp. 76–99, pls. 6–10) has described and figured 11 species of crinoids, referred to *Pentacrinus*. The Danian deposits commonly are classed as belonging at the top of the Upper Cretaceous succession, but some paleontologists consider them to be of Tertiary age. Diagnostic Cretaceous invertebrates are lacking, whereas the gastropods (Ravn, 1933, p. 9), some other mollusks (Vincent, 1930), and bryozoans (Canu and Bassler, 1933) indicate affinities with deposits elsewhere that are classed as Paleocene or Eocene. Except for stem segements consisting of several articulated columnals, Nielson's pentacrinoid specimens are all dissociated fragments. Some of them clearly belong to *Balanocrinus*, as noted by Sieverts-Doreck (1943, p. 150), but none are surely assignable to *Isocrinus* and none closely resemble parts of *I. oregonensis*.

Isocrinus holsaticus Jaekel (1904) from Upper Cretaceous rocks of northern Germany has a dorsal cup and compact, laterally adjoined lower brachials similar to corresponding parts of *I. oregonensis*, except for the proportionally larger basals and steeply upsloping attitude of the radials; characters of the column (except for the stellate proximal segment) are unknown.

Isocrinus crassitabulatus Biese (1930, p. 702, pl. 51) from Upper Cretaceous (Senonian) rocks of Germany possesses infrabasal plates, and has plates of the basal circlet laterally in contact. The arms are much thicker and the brachials very much shorter than in *I. oregonensis*. Other features, such as the marked median thinning externally of the first primibrach, distinguish this Cretaceous species. Biese (1930, p. 716) considered his species similar to *Cainocrinus beaugrandi* de Loriol, which he erroneously defined as the type species of *Cainocrinus* Forbes (1852) and which Bather (1898, p. 253) referred to *Isocrinus*. De Loriol's species, from Upper Jurassic strata of France, is too unlike *I. oregonensis* to merit comparison.

Occurrence—Middle member of the Keasey formation, lower Oligocene(?), northwestern Oregon; most abundantly at U. S. Geological Survey locality 15318, on Nehalem River, near Mist, Oregon.

ISOCRINUS NEHALEMENSIS MOORE AND VOKES, N. SP.

Pl. 19, fig. 1; pl. 20, figs. 1, 2; pl. 21, fig. 2; pl. 22, fig. 1; pl. 23, figs. 4, 7, 11; text figs. 35–38, 39A–C.

Description of this species is based on three fairly complete lower portions of crowns and numerous stem fragments. All of the crowns and many of the stem fragments come from the locality near Mist, Oreg., that has yielded most of the material referred to *Isocrinus oregonensis*. Isolated columnals and stem fragments assigned to *I. nehalemensis* occur in at least two other northwestern Oregon localities. The crowns are external molds prepared by removing the more or less decomposed calcite of the fossils by etching in acid. Several segments of the column are also external molds. A few stem fragments are well-preserved specimens composed of calcite that were obtained free from matrix.

SUMMARY OF DESCRIPTION

Isocrinus nehalemensis is a relatively small species, which has strongly bulbous cup plates. Infrabasals not observed. Basals protrude at the interradial corners, in some specimens projecting downward as bluntly rounded spines. Radials thick, strongly rounded near the facets, which occupy the full distal extremity of these plates and bear a broad dorsal ligament area.

Arms slender, probably four in each ray, making a total of twenty at summit of the crown. Syzygies rare, except between the third and fourth secundibrachs and the second and third tertibrachs.

Stem stellate to pentagonal in section. Radial pores occur between columnals, which are very uniform in most characters. Nodals are only slightly thicker than internodals and they do not project laterally; they bear large elliptical cirrus sockets, which tend to impinge on the proximally adjoining internodal. Articular facets have long narrow floors bordered by conspicuous short crenellae. Seven internodals normally occur between each neighboring pair of nodals, except in the proximal part of the stem, where internodals are fewer. Cirri are comparatively short, directed upward, and arranged in whorls of five.

DESCRIPTION OF SPECIMENS

HOLOTYPE

One of the crowns (U.S.N.M. 560792K) that has longest attached arms is selected as the holotype of *Isocrinus nehalemensis*. The proximal part of the stem is attached to the dorsal cup. The height of the preserved part of the crown of the holotype specimen is 40 mm and the width about 60 mm. The dorsal cup is 10 mm in diameter, and the stem is 4 mm across at its proximal extremity (pl. 21, fig. 2).

PARATYPES

Paratype C (U.S.N.M 560793C) consists of the lower part of a crown in which the dorsal cup, seen from the side, is fairly well shown, together with an attached proximal part of the stem bearing numerous short cirri (pl. 19, fig. 1).

Paratype G (U.S.N.M. 560793G) is the lower part of a crown 30 mm high and about 25 mm wide (pl. 20, fig. 2). The dorsal cup is 7.5 mm in diameter.

Paratype H (U.S.N.M. 560793H) (not figured) is like the other specimens except that it is a little more completely imbedded in the matrix and the available fragment is more than a half specimen. The greatest width of the exposed part of the crown is 25 mm, and its height is 18 mm. The attached proximal part of the stem is 20 mm long, and its greatest width is 5 mm. Diameter of the dorsal cup is 8 mm, and its height 2½ mm.

An external mold of a relatively long stem segment

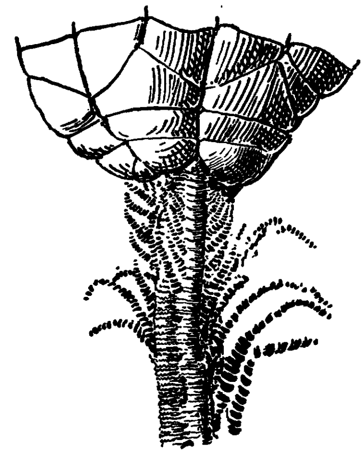


FIGURE 37.—Paratype C of *Isocrinus nehalemensis*. This drawing corresponds to the photographic illustration given in plate 19, figure 1. Lower brachials abut one another laterally in manner indicating that they are virtually parts of the dorsal cup. The proximal part of the stem contains closely spaced nodals, which bear whorls of five short, upwardly directed cirri.

(52 mm) is not associated with a crown; this fossil, designated as paratype I (U.S.N.M. 560793I), shows regularly distributed nodal- and inter-nodal sequences and the proximal part of a few cirri attached to nodals (pl. 20, fig. 1). Other paratypes consisting of stem fragments preserved as calcite (U.S.N.M. 560904A, B) are illustrated in plate 23, figs. 4, 7, 11.

Paratype J (U.S.N.M. 560793J) is the mold of a dorsal cup with attached lower arms and about 40 mm of the attached proximal part of the stem, bearing numerous cirri. The height of the attached crown is 30 mm, its width is 28 mm, and the diameter of the dorsal cup is 10 mm. Greatest width of the preserved part of the column is 5 mm.

DORSAL CUP

The dorsal cup of *Isocrinus nehalemensis* generally corresponds to that of *I. oregonensis* except for its slightly more bulbous plates. This greater convexity of the plates applies both to radials and basals. In paratype H, the basals project downward distinctly as short, bluntly rounded spines, but in other specimens these plates appear as subtriangular convex protrusions between the lower parts of the radials.

RAY STRUCTURE

No specimen referable to *Isocrinus nehalemensis* has been observed in which there are more than two successive bifurcations in a ray. The available material, however, is insufficient to establish whether this is a characteristic feature of the species. The longest preserved portion of the arms is seen in the holotype specimen (U.S.N.M. 560792K) (pl. 21, fig. 2; text fig. 38), which in one ray has 11 and 12 tertibrachs and in another 14 and 17 tertibrachs. The last-mentioned numbers belong to the regenerated right branch of one of the rays.

Occurrence of syzygial articulations is rather constant between the third and fourth brachials of the secundibrach series (fig. 38) and between the second and third brachials of the tertibrach series. All twelve observed tertibrach series show syzygies between the second and third tertibrachs. Two arms (fig. 38*K*) show 11 and 14 tertibrachs respectively, without a syzygial union. The distal articular surface of typical hypozygals, showing the fine crenellae along the external edge of brachials, is illustrated in text fig. 39*C*.

The articular facet of the radials is nearly as long as wide (text figs. 39*A*, *B*). It is divided into two parts by a straight articular ridge running from one upper angle of the radial to the other. On the external side of this ridge is the outer ligament area, consisting of a very broad gentle concavity, bounded on its curved outer edge by abrupt bending into confluency with the outer face of the radial. This border of the ligament area is not sharply defined. The maximum width of the outer ligament area and of the articular ridge of a radial 5 mm in width is 5 mm, and its greatest length, in the middle, measured from the articular ridge to the abrupt bending at the outer border is 1.3 mm. A very sharply defined, deep ligament pit, semicircular in plan,

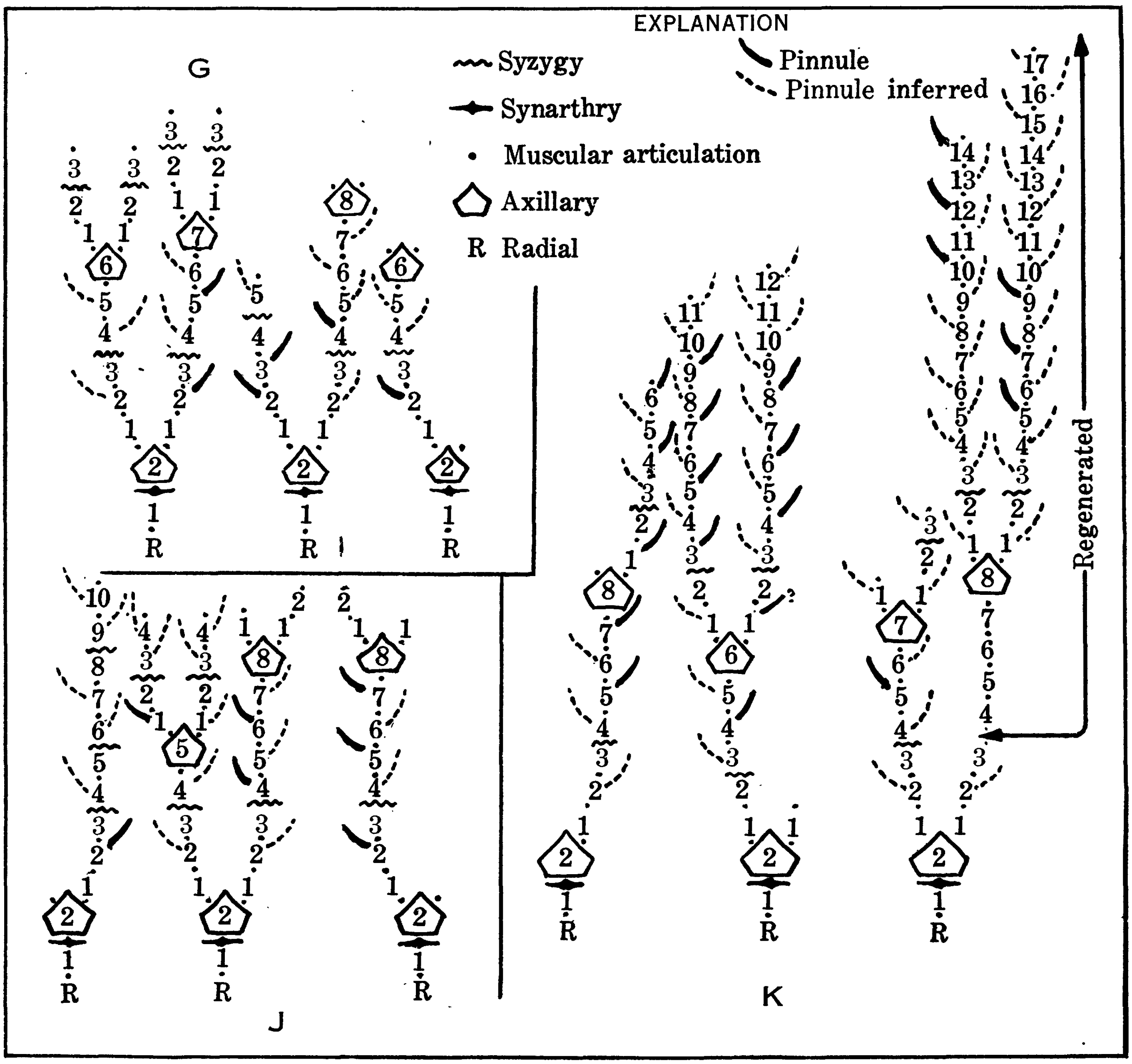


FIGURE 38.—Ray structure of holotype and two paratypes of *Isocrinus nehalemensis*. The holotype is represented by the letter K. Paratypes G and J are shown at the left of the figure. The regenerated branch belonging to one of the rays of the holotype is of interest, because the beginning of regenerated parts of the ray is located at the point of normal syzygial union in ossicles of the secundibrach series, that is, between $IIBr_3$ and $IIBr_4$.

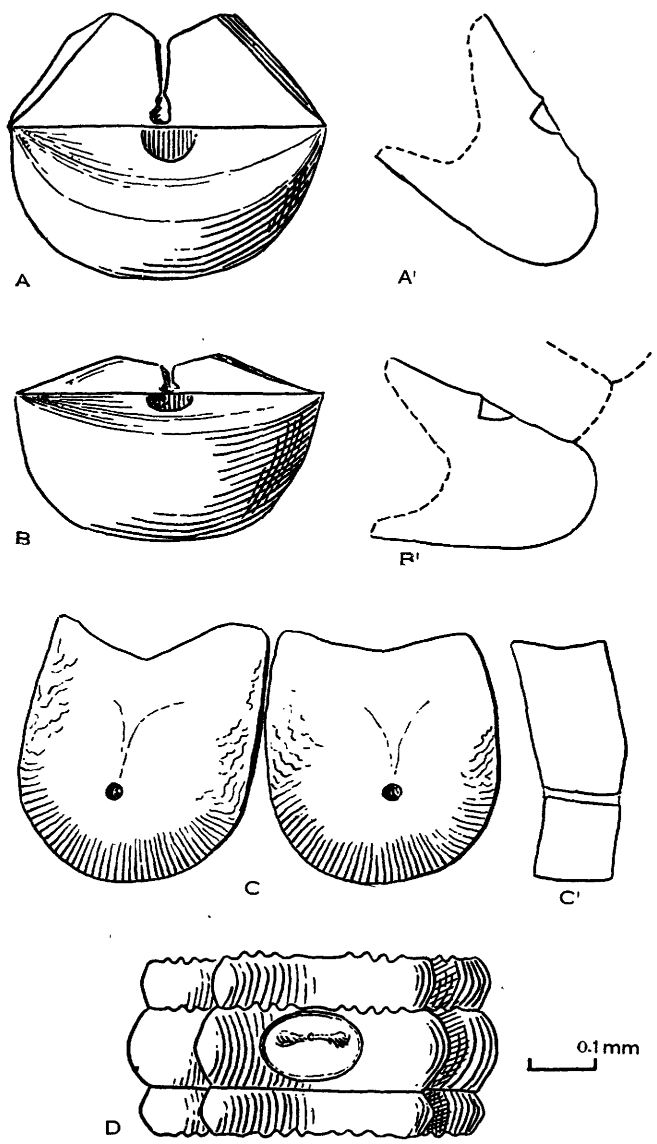


FIGURE 39.—Radial plates and syzygial articulation of *Isocrinus nehalemensis*, and cirrus socket of *I. oregonensis*. *A*, *B*, Views from two slightly different angles of a radial plate of paratype G of *I. nehalemensis*, showing outer curvature and features of the articular facet. *A'*, *B'*, profile views, indicating longitudinal curvature and showing the deep ligament pit. *C*, Distal surface of two hypozygals. *C'*, Cross section of one of these plates. *D*, Nodal and two adjoined internodals of *I. oregonensis*, showing cirrus socket on nodal.

is centrally located near the inner edge of the outer ligament area. The straight side of the pit that adjoins the transverse ridge is vertical and is finely striated, whereas the curved outer border slopes steeply toward the base of the pit about 0.5 mm below the surface of the area. On the average, the pit is 0.5 mm by 0.85 mm. The inner ligament area is subtrapezoidal in outline, and lies nearly in the same plane as the outer ligament area, from which it is separated by the articular ridge. Its lateral margins are elevated in a low but sharp ridge, outside of which is a slope to the interradial suture. The inner margin of the area is deeply indented by an intermuscular notch and strong furrow that lead to a central perforation in the position of the central canal close to the articular ridge and opposite to the outer ligament pit. Muscle areas on the two sides of the furrow are shallowly concave and are not marked by oblique ridges. The plane of the whole articular facet, including outer and inner ligament areas, slopes outward at an angle of 30 to 40 degrees to the plane of the base of the cup or that formed by the five articular ridges of the radials.

COLUMN

The column of *Isocrinus nehalemensis* is distinguished mainly by its relatively small diameter and by the uniformity in size of successive columnals. In these respects, the column (pl. 23, figs. 4, 7, 11; text figs. 36B, C) is readily distinguished from that of *I. oregonensis* (pl. 20, fig. 1; pl. 23, figs. 1–3, 5–6, 8–10; text figs. 35I, 36A, D, E). The sides of the columnals of *I. nehalemensis* are relatively straight longitudinally, the horizontally ridged appearance of the columnals of *I. oregonensis* in side view being conspicuously absent. *I. nehalemensis* typically has seven internodals in each group of columnals occurring between the nodal segments except in the proximal part of the stem, where nodals are closely spaced (text fig. 37). Both nodals and internodals are characterized by the presence of a pit at re-entrant angles of the stem in the position of the articular sutures.

Nodal segments.—The nodal columnals of *Isocrinus nehalemensis* are only slightly thicker than the internodals (pl. 23, fig. 11). For this reason, and because they do not project laterally, they are less conspicuous than in stem segments of *I. oregonensis.* Each of the five re-entrant angles of the nodals bears a large elliptical cirrus socket that is perforated slightly above the center by the small opening leading to the axial canal of the stem. A short articular ridge extends laterally from the central opening of the socket, terminating in a rounded elevation. The socket occupies nearly the entire thickness of the nodal but tends to impinge slightly more on the proximal than the distal margin. The upper or proximal articular surfaces of the nodals bear crenellae like those borne by all internodals except one that adjoins a nodal on the distal side. The crenellate edge of the articulations can be seen clearly in side view of the stem. The distal surfaces of the nodals are smooth and very gently convex. The articulation along this surface is a synostosis, along which the stem parts readily.

Internodal segments.—Internodal series of columnals belonging to *Isocrinus nehalemensis* are uniformly about 5.5 to 6 mm in aggregate thickness. Individual internodals range in thickness from 0.8 to 1.0 mm, except near the crown, where all columnals are thinner than in mature portions of the stem. The articular surfaces of the internodals are strongly petaloid and marked by prominent short crenellae, which, as in *I.*

oregonensis, reach inward almost to the small round lumen (pl. 23, fig. 7; text fig. 36B). The proximal surface of the most proximal internodal of each group carries a smooth articular surface, which is slightly concave and matches the synostosial articular surface of the adjoining nodal plate (pl. 23, fig. 4). Carpenter (1884, p. 18) notes that re-entrant angles of the proximal part of the column belonging to some modern pentacrinoids contain "interarticular pores." Similar pores are observed in the column of *I. nehalemensis*. These radial pores are produced by apposition of faint grooves radiating from the center of columnals along the articular surfaces. The grooves are largest near the lumen and shallow near the margin, but they do not reach the lumen and have no connection with it. The radial pores of the column of *I. nehalemensis* seemingly are not confined to youthful (proximal) parts of the column, for they are clearly evident on mature stem segments having the normal full number of evenly sized internodals (pl. 23, fig. 11). Radial pores are not observed even in the proximal region of well-preserved stem segments of *I. oregonensis*. This feature, along with other characters of the column, distinguishes *I. nehalemensis* from *I. oregonensis*.

Cirri.—In *Isocrinus nehalemensis*, the cirri are numerous but comparatively short. They are directed upward and seemingly do not tend to become pendent, as is common in *I. oregonensis*. Proximal cirrals are distinctly shorter than those in the middle and near the extremity of cirri. Adjacent to the stem, the cirri are elliptical in section but become subcircular a short distance outward from the socket. The shape of terminal cirrals is not known.

DISCUSSION

Comparison of *Isocrinus nehalemensis* with *I. oregonensis* has been given in the discussion of the latter species. In the study of *I. nehalemensis*, attention has been given to the possibility that this group of crinoids represents the young of *I. oregonensis*. This is a reasonable postulate in view of their association together and various structural resemblances. Information derived from additional specimens may modify conclusions which seem to be well supported by characters observed on the specimens now available for study. *I. nehalemensis* is judged to be distinguishable from *I. oregonensis* on features both of the crown and of the column.

Characters of the articular surfaces and sides of the columnals of *Isocrinus nehalemensis* are rather closely similar to those of *I. californicus* Clark (in Clark and Twitchell, 1915, p. 21, pl. 1, figs. 2a-c from the Upper Triassic of California. The diameter of the columnals of *I. californicus* is reported to be 2 to 5 mm and the thickness of 0.5 to 1 mm. Only a few internodal series of Clark's species are known. Despite their similarity to typical specimens of the stem of *I. nehalemensis*, the two forms are not thought to be allied specifically.

Occurrence—Middle member of the Keasey formation, lower Oligocene(?), northwestern Oregon. Most abundant remains are recognized in material collected at U. S. Geological Survey locality 15318 near Mist, Oregon. Columnals from Survey localities 15268 and 15985 are also referred to this species.

SPECIES OF ISOCRINUS DESCRIBED FROM TERTIARY ROCKS IN OTHER PARTS OF THE WORLD

Five species that seem referable to *Isocrinus* have been described from Tertiary rocks of areas outside of North America, and another species, assigned to *Isocrinus*, is recorded from undifferentiated Tertiary deposits. The five species are *Isocrinus d'archiaci* Pasotti (1929, pp. 80–82, 84–86, pl. 2, figs. 12–15), from Paleogene rocks of Gassino, Italy; *Isocrinus gastaldi* (Michelotti) (described as *Pentacrinus gastaldi* Michelotti, 1847, p. 59, pl. 16, fig. 2), from Eocene, Oligocene (Tongrian), and Miocene rocks of northern Italy and from Miocene of southern France; *Isocrinus hungaricus* Vadasz (1915, pp. 85, 92–93, pl. 7, figs. 33–35), from Miocene beds of Hungary; *Isocrinus stellatus* Szalai (1926, p. 341), also from the Miocene of Hungary; and *Isocrinus tridactylus* (Quenstedt) (1874–76, p. 268, pl. 99, fig. 170), from Tertiary rocks of Spain. Crinoid remains referred to *Isocrinus gastaldi* are illustrated also by de Loriol (1897, p. 115, pl. 4, figs. 15–18), Noelli (1900, p. 19, pl. 1, figs. 1–32), and Albus (1931, p. 279, pl. 10, figs. 1, 4–5, 7, 11, 14–15). All of these reported species are represented by fragments of the column only.

Additional Tertiary forms referred to *Pentacrinus* (27 species) probably belong in other genera. Some of these are referable certainly to *Balanocrinus*, and others may be assignable to *Isocrinus* or other genera of the Isocrinidae. Definite generic identification seems to be impossible for the fragments of columns represented among these fossils. Only two of the Tertiary species of "*Pentacrinus*" merit individual notice here by reason of their occurrence in the Pacific province. There are "*P.*" *ariakensis* Yokoyama (Nagao, 1928, p. 100, pl. 18, fig. 17), from lower Tertiary (Paleogene) rocks of Kyushu, in southern Japan; and "*P.*" *stellatus* Hutton (Tate, 1894, p. 122), from deposits of undetermined position in the Tertiary succession of New Zealand and southeastern Australia. The generic classification of the Japanese columnals cannot be defined from a study of the description and figures, but they are not conspecific with either of the Keasey crinoids. Illustrations of the New Zealand species or of specimens from Australia referred to it, have not been published. Consequently, "*P.*" *stellatus* Hutton is not now recognizable. If the species proves to belong to *Isocrinus* and *I. stellatus* Szalai, from Hungary, is rightly placed generically, the latter is a homonym of Hutton's species.

Comparison of illustrations of other Tertiary crinoids with the fossils here described from Oregon brings to light some that have more or less resemblance to *Isocrinus oregonensis* or *I. nehalemensis;* others are obviously different in one or more characters. Because of geographic remoteness of those described species based on fragments of columnals, and because most of them differ in age from the Oregon fossils, there is very little possibility that the crinoids here described as new species may actually represent already described forms occurring in Tertiary rocks of some other part of the world. Even where fragments of the column seem to correspond closely, as in specimens of *Isocrinus californicus* Clark, from the Triassic of California, and *I. nehalemensis* from lower Oligocene rocks of Oregon, possibility of specific identity is very unlikely.

PALEOECOLOGY OF THE KEASEY CRINOIDS

GENERAL STATEMENT

The local abundance of well-preserved remains of stem-bearing crinoids in the Keasey formation of northwestern Oregon is a highly exceptional paleontological record. Except for two or three species that are represented by cups, all described forms of Tertiary crinoids in the world are identified on the basis of fragments of the stem or arms or both. Preservation of the Keasey crinoids, among which several specimens show stem and arms attached to the dorsal cup and in which articulated groups of brachials and columnals are the rule rather than the exception, indicates burial of these organisms in very quiet water. It is desirable to make such observations as are possible on the environment of Keasey sedimentation in the area where the fossil crinoids have been found.

Paleoecological evidence relating to occurrence of the Keasey crinoids includes lithologic features, the nature of bedding, and other physical characters of the rocks containing the crinoids and the nature of organic remains associated with the fossil crinoids.

As pointed ou the description of the lithology of the middle member of the Keasey formation in which the crinoids occur, dominance of tuffaceous volcanic materials is an obviously important physical character. The sediment in which the crinoids and other fossils are imbedded is noncalcareous, medium to fine-textured, and, although bedded, is not well laminated. Scattered small "pebbles" of ashy material are observed in the rock, and the manner in which it swells on wetting and breaks into conchoidally shaped fragments suggests the mixture of a good deal of bentonitic material. It seems appropriate to ask whether the volcanic detritus was carried to the point of deposition on the sea floor by marine currents or whether much of it may have been carried through the air so that on falling into the water it could settle quietly to the bottom. Whether carried in this manner or transported by currents, we wish to know whether the sea bottom was shallow, of intermediate depth, or very deep. By "shallow" we mean anything from the strand line to the commonly accepted lower limit of wave agitation at 100 fathoms. "Intermediate depths" may be designated for present purposes as ranging from 100 to 500 fathoms (600 to 3,000 feet). As "deep water" we designate all depths of the coastal area of early Tertiary sedimentation in the Oregon region lying below 500 fathoms. As indicated by Shepherd (1948) and others, all of these depth conditions exist today close to the Pacific border of the continent, and in many areas there is very abrupt local variation in depth environment. Accordingly, in studying the Keasey deposits, one may reasonably postulate deep-water conditions as somewhat arbitrarily defined above as well as intermediate and shallow-depth waters.

PHYSICAL FEATURES

Pertinent physical features bearing on interpretation of sedimentation at the crinoid localities in the Keasey formation include not only the texture and bedding of the deposits in these areas but regional thickness, variation in thickness, and texture of the deposit as known throughout the Nehalem Basin. The recorded total thickness of the Keasey formation is 1,800 to 2,200 feet (Warren and Norbisrath, 1945, p. 220), although satisfactory measurement has been made at only one locality. The comparatively great thickness of the Keasey deposits, coupled with the strongly tuffaceous nature of the middle and upper members, indicates that if the site of sedimentation was in moderately deep, or deep water, the area was not far removed from land on which a number of explosive volcanic vents were recurrently active. The middle member of the Keasey is described as unstratified siltstone. Lack of bedding and general uniformity through considerable thicknesses of the deposit are not features to be expected in the littoral zone and suggest offshore conditions where the bottom was not agitated by waves or affected by currents. Analysis of all known physical characters associated with the crinoid-bearing part of the Keasey formation therefore indicates nearness (at most a few tens of miles) to land and a sea bottom ranging from intermediate depth to greater than 500 fathoms. A considerable fraction of the volcanic materials including light ashy constituents may have been carried through the air or in shallow currents so as to sift down through the moderately deep water to the surface of sedimentation.

ORGANIC EVIDENCE

The nature of the crinoid remains has already been cited as indicative of quiet, fairly deep water. Agitation on the bottom by waves or currents, which would surely have resulted in disarticulation of the crinoid remains, is inconsistent with nearly all the observed crinoid fossils.

Associated with the crinoids are common, well-preserved mollusks, including pelecypods and gastropods, Foraminifera, and various other invertebrates. One nearly complete specimen of a spinose ophiuroid was found resting against crinoid arm fragments. Rather unexpected is occurrence of fairly large, well-preserved leaves, which, in unweathered condition, appear black by reason of the film of carbon derived from tissue of the leaves. Two such leaves are illustrated in plate 22, figure 2. These have been identified by Dr. R. W. Brown, who states:

Several fragmentary, dicotyledonous leaves of land plants were found with the crinoid. One represents an oak, *Quercus consimilis* Newberry, a species common in the Oligocene and Miocene floras of Oregon, Washington, and Idaho. The others are probably a species of bayberry, *Myrica* sp. These leaves were tough enough to resist complete destruction while being swept out to burial in the sea.

Referring to the mollusks, we note that temperature control is an important factor in the depth distribution of many species, for the same species are found in relatively shallow waters at high latitudes and in deep waters in tropical regions. Thus, *Lima* (*Acesta*) *excavata* (Fabricius), the type of *Acesta*, occurs at depths of 150 to 300 fathoms off the coast of Norway and at 1,450 fathoms off the Azores Islands; and *Turcicula bairdii* Dall, the modern equivalent of the principal guide to the lower faunal zone of the Keasey, occurs at 27 fathoms in the Behring Sea and from 238 to 822 fathoms off the coast of Washington to the Coronado Islands.

It is difficult at the present stage of the study of the Keasey molluscan fauna to make any certain valuations of its modern equivalents; however, there is a general absence of forms that may be considered as wholly confined to the tropical regions, although some subtropical types are present. Hence, it seems most probable that the general equivalents of the Keasey fauna will be found in the southern portion of the California faunal province as defined by Bartsch (1921, p. 507) or of the Californian province (restricted) of Schenck and Keen (1936). Within this area, *Solemya* (*Acharax*) *johnsoni* Dall, the type of the subgenus *Acharax*, is reported as ranging from 200 to 1,100 fathoms; *Delectopecten randolphi* (Dall) from 300 to 1,100 fathoms; and *D. randolphi tillamookensis* (Dall) from 100 to 1,100 fathoms (Woodring, 1938, pl. 3). *Minormalletia*, a rather abundant form in the Keasey fauna, is known in Recent faunas only from two species dredged from 493 fathoms off the Pacific coast of Mexico. The presence of these types, together with large, thin-shelled gastropods, such as *Olequahia schencki* Durham, and dominance of Turridae, if not strictly in numbers of individuals, certainly in number and diversity of genera and species, all suggest that the Keasey formation was deposited in relatively deep waters. This is even more strongly indicated by the complete absence of the common shallow-water molluscan types present in the normal west coast Tertiary marine sequence. Such common genera as *Ostrea*, *Mytilus*, *Volsella*, *Macrocallista*, *Spisula*, *Macoma*,[2] *Solen*, *Crepidula*, and many others that are represented in the faunas of both the underlying Cowlitz and the overlying Pittsburgh Bluff formations are wholly absent in the Keasey fauna. The only essentially shallow-water type so far noted is represented by a single, rather large, and thin-shelled *Acmaea;* it may well have been carried into the area on a large alga.

This concept of relatively deep waters over the area during the deposition of the Keasey formation also seems to receive a measure of confirmation in the fact that the great majority of the pelecypods have the valves in association, even such weakly hinged types as *Solemya*, *Delectopecten*, and *Lima* (*Acesta*) being usually not markedly disturbed. Furthermore, the several crinoid specimens here described, as well as the others that have been recovered from this locality, show no evidence of strong disturbance such as would result from even moderately weak wave or current action. Likewise, a highly spinose ophiuroid specimen, which was found between arms of a crinoid crown at U. S. Geol. Survey locality 15318, shows no signs of disarticulation. The lack of disarticulation of so many crinoid crowns seems to negate the suggestion that the crinoids and associated invertebrates are relatively deep- or cool-water types that lived in a zone marked by an upwelling of cool waters such as occur at a number of localities along the California coast. Furthermore, many of the shallow-water genera, which are absent in the Keasey fauna here discussed, are represented in the modern Aleutian cool-water faunas. They would be expected to occur in the Keasey fauna if its presumably deep-water elements were present as a result of such upwelling.

The organic evidence, therefore, seems to point to deposition in relatively deep waters, below the limit of effective wave or current action, in a region not far from the old coast line.

[2] A form previously identified and listed as "*Macoma* n. sp." has proved to be an unusually *Macoma*-like form of *Tellina*.

REFERENCES

AGASSIZ, LOUIS, 1836, Prodrome d'une monographie des radiaires ou echinodermes: Soc. sci. nat. Neuchâtel, Mém. (1835), tome 1, pp. 168–199.

ALBUS, LUIGINA, 1931, Nuove ricerche sui Crinoidi miocenici della Collina di Torino: Soc. geol. italiana Boll., vol. 49, fasc. 2, pp. 279–296, pls. 10, 11.

BARTSCH, PAUL, 1921, Ocean currents, the prime factor in the distribution of the marine mollusks on the west coast of America: Bernice P. Bishop Mus., Spec. Pub. 7, pt. 2, pp. 505–526.

BATHER, F. A., 1898, *Pentacrinus:* a name and its history: Nat. Sci. vol. 12, no. 74, pp. 245–256, figs. 1–10.

——— 1917, British fossil crinoids—XI. *Balanocrinus* of the London Clay: Annals and Mag. Nat. History, ser. 8, vol. 20, pp. 385–407, figs. 1–7.

BIESE, WALTER, 1930, Über *Isocrinus* H. v. Meyer and *Cainocrinus* Forbes: Preuss. geol. Landesanstalt Jahrb. für 1929, Band 50, Teil 2, pp. 702–719, pl. 51.

BIESE, WALTER, and SIEVERTS-DOBECK, HERTHA, 1939, Crinoidea caenozoica: Fossilium Catalogus, 1: Animalia, pars 80, pp. 1–151.

BIGOT, A., 1938, Les Crinoides du Bathonien du Calvados: Annales Paleont., vol. 27, pp. 3–38, pls. 1–4.

CANU, FERDINAND, and BASSLER, R. S., 1933, The bryozoan fauna of the Vincentown limesand: U. S. Nat. Museum Bull. 165, pp. 1–108, pls. 1–21, fig. 1.

CARPENTER, P. H., 1884, Report on the Crinoidea collected during the voyage of H. M. S. *Challenger* during the years 1873–76: Report on the scientific results of the voyage of H. M. S. Challenger during the years 1873–76, Zoology, vol. 11, pp. i–xii, 1–442, pls. 1–62, figs. 1–21.

CLARK, A. H., 1908, The nomenclature of the Recent crinoids: U. S. Nat. Museum, Proc., vol. 34, pp. 435–542.

——— 1923, A revision of the Recent representatives of the crinoid family Pentacrinidae, with the diagnoses of two new genera: Washington Acad. Sci., Jour., vol. 13, pp. 8–12.

CLARK, W. B., 1893, The Eocene of the United States: Johns Hopkins Univ. Circ. 12, pp. 50–51.

——— 1893a, The Mesozoic Echinodermata of the United States: U. S. Geol. Survey, Bull. 97, pp. 1–207.

CLARK, W. B. and TWITCHELL, M. W., 1915, The Mesozoic and Cenozoic Echinodermata of the United States: U. S. Geol. Survey, Mon. 54, pp. 1–341, pls. 1–108.

COOKE, C. W., and STEPHENSON, L. W., 1928, The Eocene age of the supposed late Upper Cretaceous greensand marls of New Jersey: Jour. Geology, vol. 36, pp. 139–148.

COOKE, C. W., GARDNER, JULIA, and WOODRING, W. P., 1943, Correlation of the Cenozoic formations of the Atlantic and Gulf Coastal Plain and the Caribbean region: Geol. Soc. America Bull., vol. 54, pp. 1713–1723, pl. 1 (chart).

DILLER, J. S., 1896, A geological reconnaissance in northwestern Oregon: U. S. Geol. Survey 17th Ann. Rept., pt. 1, pp. 441–520, pls. 4–16, text figs. 4–17.

DÖDERLEIN, LUDWIG, 1907, Die gestielte Crinoiden der Siboga-Expedition: Uitkomsten op zool., botan., oceanograph., en geol. gebied. Nederl. Oost-Indië, 1899–1900, Mon. 42a, pp. 1–53, pls. 1–23 (E. J. Brill, Leiden).

——— 1912, Die gestielten Crinoiden der Deutschen Tiefsee-Expedition: Wiss. Ergebn. Deutschen Tiefsee-Expedition, 1898–1899, Band 17, Heft 1, pp. 1–34, pls. 1–12, figs. 1–9.

DURHAM, J. WYATT, 1944, Megafaunal zones of the Oligocene of northwestern Washington: California Univ., Dept. Geol. Sci., Bull., vol. 27, no. 5, pp. 101–212, pls. 13–18, 7 text figs., 1 map.

EMMONS, EBENEZER, 1858, Agriculture of the eastern counties, together with descriptions of the fossils of the marl beds: North Carolina Geol. Survey Rept., pp. i–xvi, 1–314, text figs.

FORBES, EDWARD, 1852, Monograph of the Echinodermata of the British Tertiaries: Paleontograph. Soc. Mon., pp. 1–36, pls. 1–4.

GABB, W. M., 1876, Note on the discovery of representatives of three orders of fossils new to the Cretaceous formation of North America: Acad. Nat. Sci. Philadelphia, Proc., vol. 28, pp. 178–179, pl. 5.

GISLÉN, TORSTEN, 1924, Echinoderm studies: Zoologiska Bidrag från Uppsala, Band 9, pp. 1–316, figs 1–355.

——— 1934, A reconstruction problem. Analysis of fossil comatulids from N. America with a survey of all known types of comatulid arm-ramifications: Lunds Univ. Arsskr., N. F., Avd. 2, Band 30, Nr. 11, pp. 1–59, figs. 1–63.

——— 1938, A revision of the Recent Bathycrinidae: Lunds Universitets Arsskr., N. F., Avd, 2, Bd. 34, Nr. 10. (Kungl. Fysiogr. Sällsk. Handl. N. F. Bd. 49, Nr. 10), pp. 1–30, figs. 1–18.

GREACEN, K. F., 1941, The stratigraphy, fauna and correlation of the Vincentown formation: New Jersey Dept. Cons. and Devel., Geol. Ser., Bull. 52, pp. 1–83, pl. 1.

GUPPY, R. J. L., 1874, On the West Indian Tertiary fossils: Geol. Mag., new ser., dec. 2, vol. 1, pp. 433–454, pls. 16–18.

HOWE, H. V., 1942, Neglected Gulf Coast Tertiary microfossils: Am. Assoc. Petroleum Geologists Bull., vol. 26, no. 7, pp. 1188–1199, figs. 1–25.

JAEKEL, O., 1904, Ueber einen Pentacriniden der deutschen Kreide: Sitz-ber. Gesell. naturf. Freunde, Jg. 1904, no. 9, pp. 191–196, figs. 1–11.

LORIOL, PERCIVAL DE, 1897, Description de quelques Echinodermes: Soc. géol. France, Bull., ser. 3, vol. 25, pp. 115–129, pl. 4.

——— 1902, Notes pour servir a l'étude des échinodermes, 2d ser., fasc. 1, pp. 1–52, pls. 1–3.

MEYER, HERMANN VON, 1836, Mittheilungen, an Professor Bronn gerichtet: Neues Jahrb., 1836, pp. 55–61.

——— 1837, *Isocrinus* and *Chelocrinus,* zwei neue Typen aus der Abtheilung der Crinoideen: Mus. Senckenbergianum Abh., Band 2, pp. 249–263, pl. 16.

MICHELOTTI GIOVANNI, 1847, Précis de la faune miocène [supérieure] de la haute Italie: Hollandsche Maats. Wetensch. Haarlem Naturk. Verh., Verz. 2, Deel 3, Stuck 2, p. 59, pl. 16, fig. 2.

NAGAO, TAKUMI, 1928, Palaeogene fossils of the island of Kyushu, Japan: Sci. Rep. Tôhoku Univ., vol. 9, geol., pp. 97–128, pl. 18–22.

NIELSEN, K. B., 1913, Crinoiderne i Danmarks Kridtaflejringer: Danmarks Geol. Undersøgelse, Raekke 2, no. 26, pp. 1–120, pls. 1–12, text figs. 1–34, Copenhagen.

NOELLI, ALBERTO, 1900, Contribuzione allo studio dei crinoidi terziari del Piemonte: Soc. italiana sci. nat. Atti, vol. 39, pp. 19–49, pl. 1.

PASOTTI, PIERINA, 1929, Di alcuni Crinoidi paleogenici con particolare riguardo a quelli di Gassino: Soc. geol. italiana Boll., vol. 48, pp. 71–89, pls. 1, 2.

QUENSTEDT, F. A., 1874–1876, Petrefactenkunde Deutschlands. Teil 4. Asteriden und Encriniden: pp. 1–724, pls. 90–114 (Leipzig).

RAVN, J. P. J., 1933, Études sur les pélécypodes et gastropodes daniens du Calcaire de Faxe: K. danske vidensk. Selsk., Naturv.-math. Afd., Raekke 9, vol. 2, pp. 1–74, pls. 1–7, text figs. 1–8.

SANCHEZ-ROIG, MARIO, 1926, Los equinodermos fosiles de Cuba: Cuba, Direccion de montes y minas, pp. 1–134, pls. 1–43.

SCHENCK, H. G., 1927, Marine Oligocene of Oregon: California Univ., Dept. Geol. Sci., Bull., vol. 16, no. 12, pp. 449–460, 1 text fig.

——— 1936, Nuculid bivalves of the genus *Acila;* Geol. Soc. America Spec. Paper 4, pp. i–xiv, 1–149, pls. 1–18, figs. 1–15.

SCHENCK, H. G., and KEEN, A. M., 1936, Marine molluscan provinces of western North America: Am. Philos. Soc. Proc., vol. 76, pp. 921–938.

SHEPARD, F. P., 1948, Submarine geology, Harper, New York, pp. i–xvi, 1–348, illus.

SHEPARD, F. P., and EMERY, K. O., 1941, Submarine topography off the California coast: Canyons and tectonic interpretation: Geol. Soc. America Spec. Paper 31, pp. i–xiii, 1–171, pls. 1–18, charts 1–4, figs. 1–42.

SIEVERTS, HERTHA, 1932, Jungertiäre Crinoiden von Seran und Borneo: Neues Jahrb, Beilage-Band 69, Abt. B, pp. 145–168, figs. 1–12.

SIEVERTS-DORECK, HERTHA, 1943, Zur Morphologie und systematischen Stellung von *Balanocrinus:* Neues Jahrb., Beilage-Band 88, Abt. B, pp. 136–155, pl. 15, text figs. 1–10.

SIEVERTS-DORECK, HERTHA, and BIESE, WALTER, 1939, Supplementum ad Crinoidea triadica, jurassica, cretacea et caenozoica: Fossilium Catalogus, 1: Animalia, pars. 88, pp. 1–81.

SPRINGER, FRANK, 1909, A new American Jurassic crinoid: U. S. Nat. Museum Proc., vol. 36, pp. 179–190, pl. 4.

——— 1913, Crinoidea: in Zittel-Eastman, Textbook of Palaeontology, vol. 1, pp. 173–243, figs. 267–346, MacMillan, London.

——— 1918, A new species of fossil *Pentacrinus* from the East Indies. Nederlandsche Timor-Expeditie II: Jaarb. mijnwezen, Jaarg. 45, 1916, pp. 1–8, pl. 1.

——— 1925, A Tertiary crinoid from the West Indies: U. S. Nat. Museum Proc., vol. 65, art. 3, pp. 1–8, pl. 1.

——— 1925a, Occurrence of the crinoid genus *Apiocrinus* in America: U. S. Nat. Museum Proc., vol. 67, art. 18, pp. 1–5, pl. 1.

——— 1925b, The genus *Pentacrinus* in Alaska: U. S. Nat. Museum Proc., vol. 67, art. 5, pp. 1–7, pl. 1.

SZALAI, TIBOR, 1926, Daten zur Frage der Tertiärcrinoideen: Földtani Közlöny, Band 55, 1925, pp. 169–174 (Hungarian), 339–341 (German), pl. 1.

TATE, RALPH, 1894, Critical list of the Tertiary Mollusca and Echinodermata of New Zealand in the collection of the Colonial Museum: Rept. Geol. Survey New Zealand, 1892–93, pp. 121–127.

VADÁSZ, M. E., 1915, Die mediterranen Echinodermen Ungarns: Geologica Hungarica, tomus 1, fasciculus 2.

VINCENT, E., 1930, Études sur les Mollusques montiens du Poudengue et du Tuffeau de Ciply: Mus. royal histoire nat. Belgique Mem. 46, pp. 1–115, pls. 1–6, text figs. 1–37.

WANNER, J., 1938, *Balanocrinus sundaicus* n. sp. und sein Epöke aus dem Altmiocän der Insel Madura: Neues Jahrb., Beilage Band 79, Abt. B, pp. 385–402, pls. 10, 11.

WARREN, W. C., GRIVETTI, R. M., and NORBISRATH, HANS, 1945, Geology of northwestern Oregon west of Willamette River and north of latitude 45°15′: U. S. Geol. Survey Oil and Gas Invs. Prelim., Map 42.

WARREN, W. C., and NORBISRATH, HANS, 1946, Stratigraphy of upper Nehalem River Basin, northwestern Oregon: Am. Assoc. Petroleum Geologists Bull., vol. 30, pp. 213–237.

WEAVER, C. E., 1943, Paleontology of the marine Tertiary formations of Oregon and Washington: Washington Univ. [Seattle] Pub. in Geology, vol. 5, pts. 1–3, pp. i–xiii, 1–789, pls. 1–104.

WEAVER, C. E., *et al.*, 1944, Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America Bull., vol. 55, no. 5, pp. 569–598.

WELLER, STUART, 1907, A report on the Cretaceous paleontology of New Jersey: New Jersey Geol. Survey, pp. 275–305, pls. 6–18.

WOODRING, WENDELL P., 1938, Lower Pliocene mollusks and echinoids from the Los Angeles Basin, California, and their inferred environment: U. S. Geol. Survey Prof. Paper 190, pp. 1–67, pls. 1–9, figs. 1, 2.

YOKOYAMA, MATAJIRO, 1911, Some Tertiary fossils from the Miike coal field: Jour. Coll. Sci., Imp. Univ. Tokio, vol. 27, art. 20, pp. 1–16, pls. 1–3.

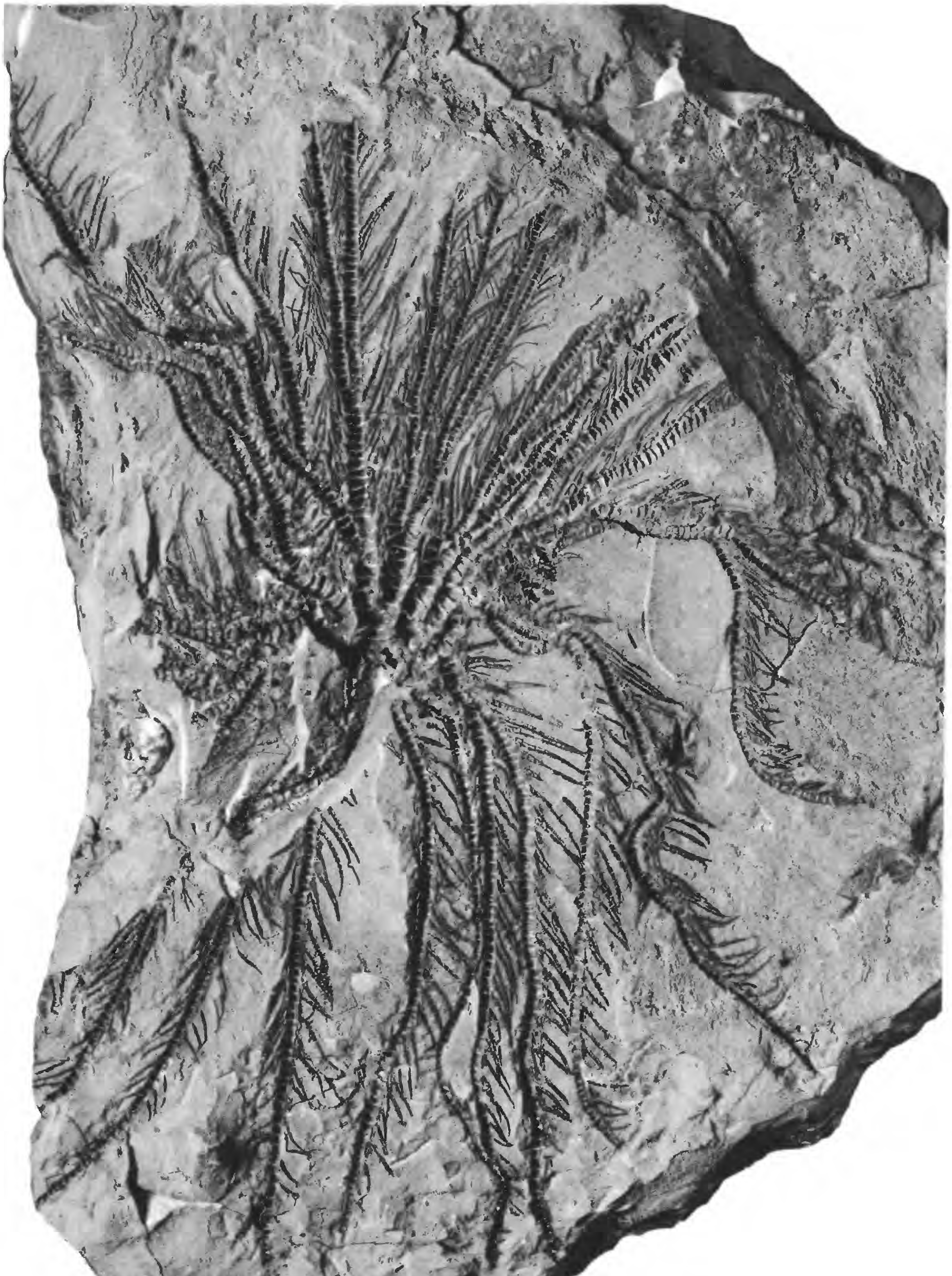
INDEX

[Italic numbers indicate descriptions

PLATES 14–24

Plate 14

Isocrinus oregonensis Moore and Vokes, n. sp. Holotype (U.S.N.M. 560790), × 1, U.S.G.S. Tertiary loc. 15318. From Keasey formation, upper Eocene and lower Oligocene, Columbia County, Oreg. Compare with text fig. 29.



ISOCRINUS OREGONENSIS

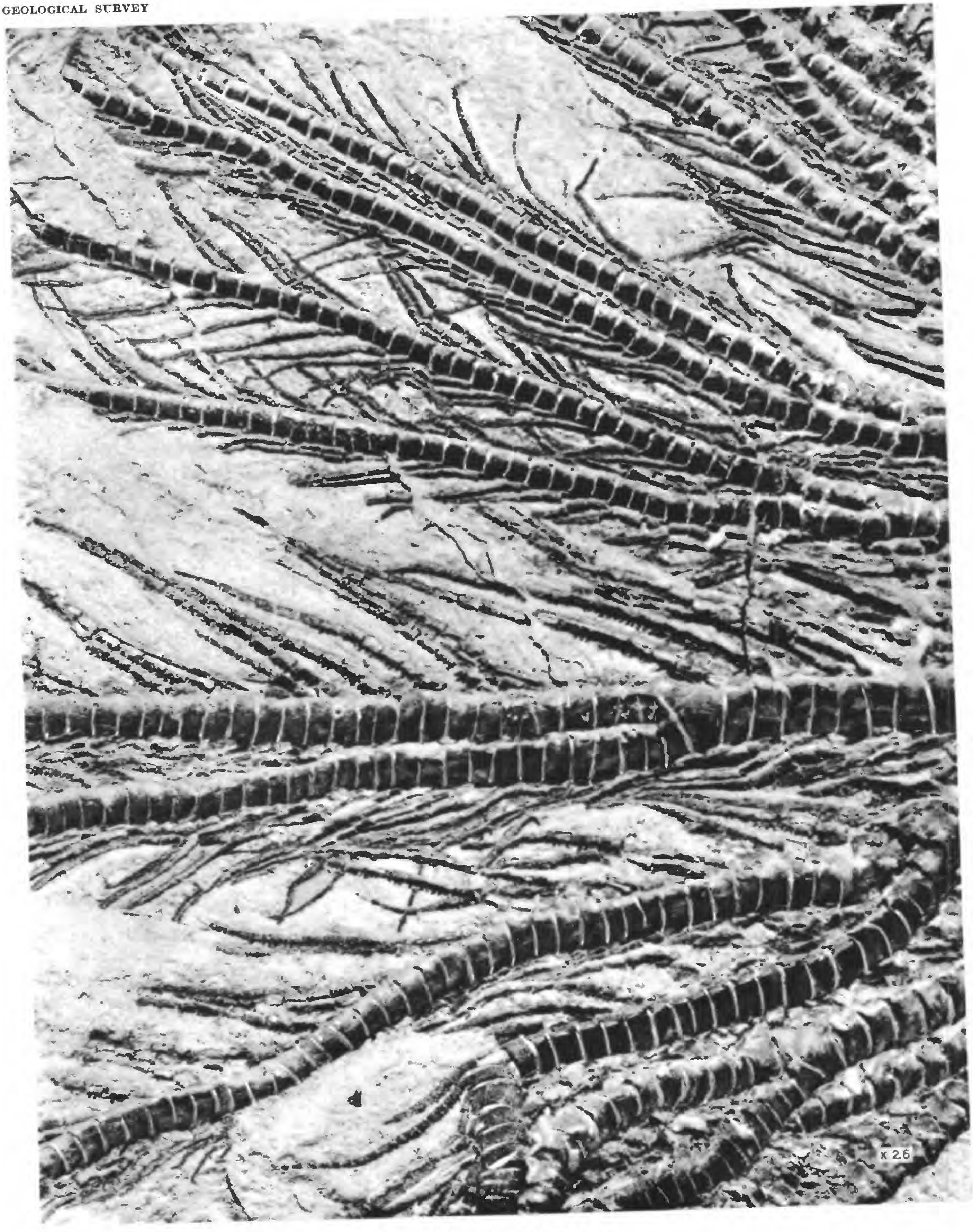
Plate 15

Isocrinus oregonensis Moore and Vokes, n. sp. Cup and lower part of the crown; portion of the holotype (U.S.N.M. 560790), × 2.6, U.S.G.S. Tertiary loc. 15318. From Keasey formation, upper Eocene and lower Oligocene, Columbia County Oreg.

ISOCRINUS OREGONENSIS

Plate 16

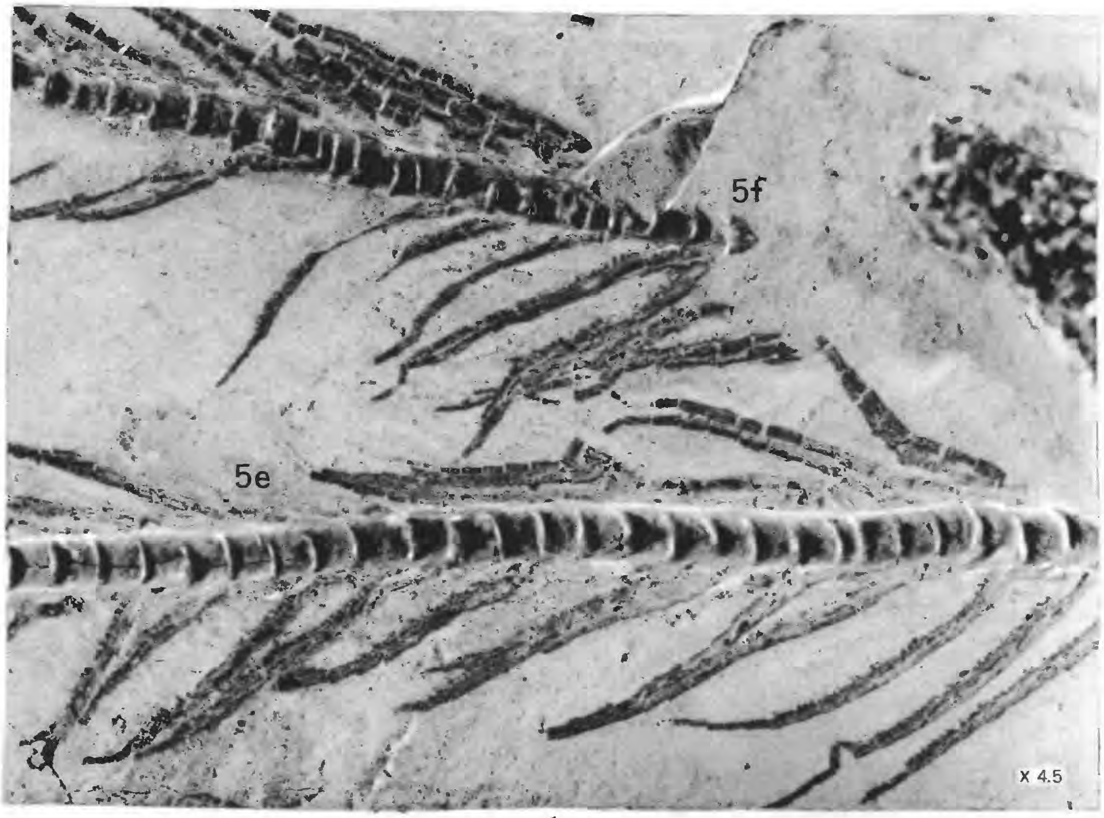
Isocrinus oregonensis Moore and Vokes, n. sp. Arms and pinnules, portion of the holotype (U.S.N.M. 560790). Covering plates of the pinnules are clearly visible in several areas, $\times$ 2.6. U.S.G.S. Tertiary loc. 15318. From Keasey formation, upper Eocene and lower Oligocene, Columbia County, Oreg.



ISOCRINUS OREGONENSIS

Plate 17

Isocrinus oregonensis Moore and Vokes, n. sp. Arms and pinnules, portion of the holotype (U.S.N.M. 560790), × 4.5 1, Portion of arms 5e and 5f (see text fig. 29); 2, portion of arms 4h, 5a-c. U.S.G.S. Tertiary loc. 15318. From Keasey formation, upper Eocene and lower Oligocene, Columbia County, Oreg.



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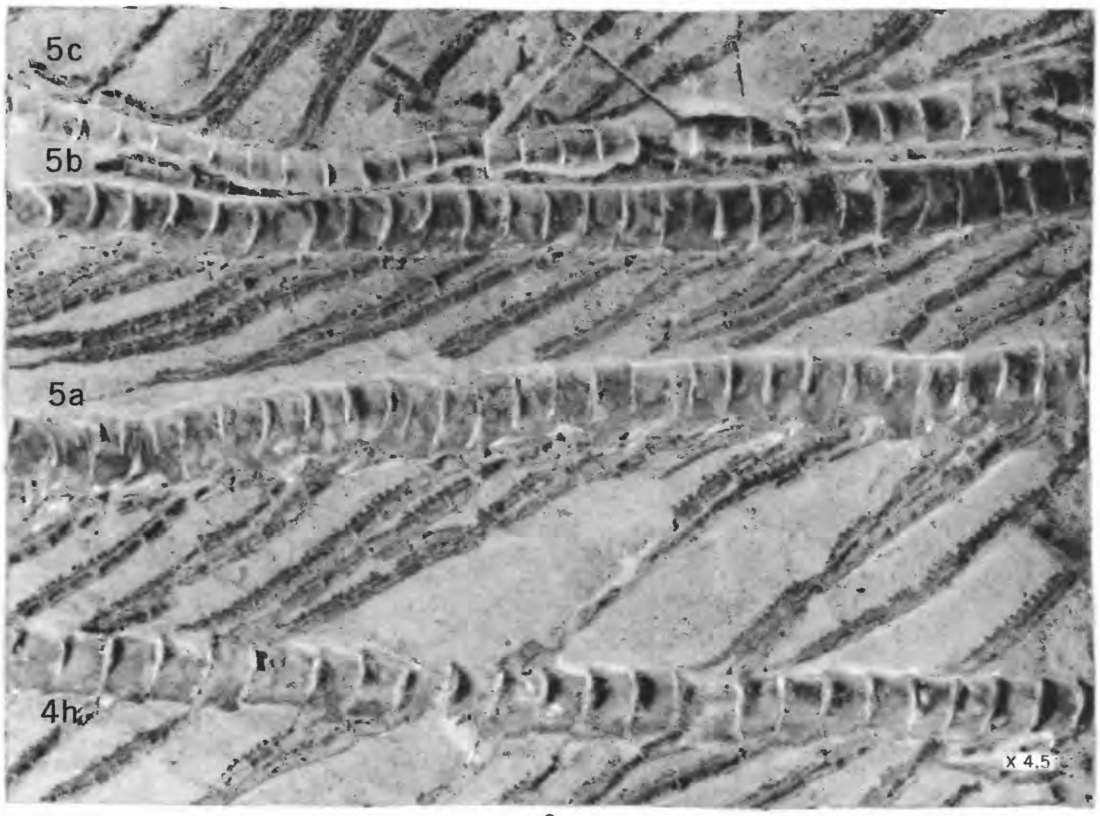
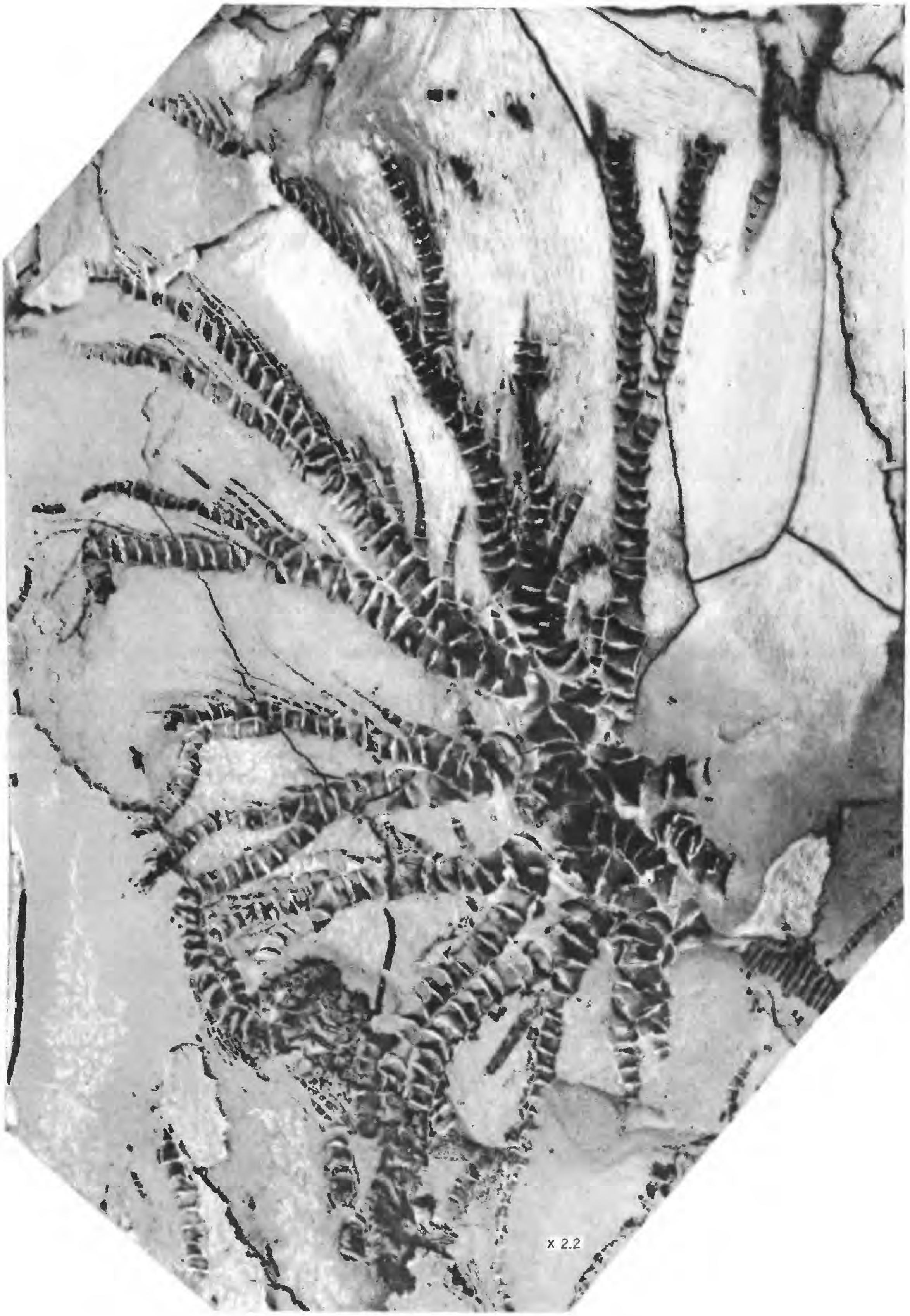


2

ISOCRINUS OREGONENSIS

Plate 18

Isocrinus oregonensis Moore and Vokes, n. sp. Paratype (U.S.N.M. 560791A), × 2.2, U.S.G.S. Tertiary loc. 15318. Compare with text fig. 31. From Keasey formation, upper Eocene and lower Oligocene, Columbia County, Oreg. This specimen is a mold prepared by removal of rotted calcite of the fossil by etching with hydrochloric acid.



ISOCRINUS OREGONENSIS

Plate 19

FIGURE 1. *Isocrinus nehalemensis* Moore and Vokes, n. sp., showing cup, proximal part of column, and lower part of arms, × 1.5, paratype C (U.S.N.M. 560793C). Compare with text fig. 37.

2–5. *Isocrinus oregonensis* Moore and Vokes, n. sp. (2) Arm fragments of paratype E (specimen lost or misplaced), × 1.5; (3) distal surface of II Br_3 of the half ray that bears arms E-H (text fig. 31) of paratype A (U.S.N.M. 560791A), showing radially disposed fine crenellae of the syzygial articulation with II Br_4, × 6.5; (4) paratype D (U.S.N.M. 560791D), showing arms and pinnules, × 1.5; (5) paratype E (specimen lost or misplaced), × 1.5. All specimens from Keasey formation, upper Eocene and lower Oligocene, Columbia County, Oreg., U.S.G.S. Tertiary loc. 15318.

ISOCRINUS OREGONENSIS AND *I. NEHALEMENSIS*

Plate 20

[Figures × 3 natural size.]

FIGURES 1, 2. *Isocrinus nehalemensis* Moore and Vokes, n. sp. (1) Intact segment of column, 52 mm in length, showing regularly spaced nodals (distinguished by their slightly greater thickness and the presence of elliptical cirrus sockets at re-entrant angles), to some of which proximal portions of cirri are attached; two groups of the internodal columnals comprise eight columnals instead of the normal number of seven; paratype I (U.S.N.M. 560793I). (2) Small incomplete crown, showing dorsal cup, attached proximal part of the stem, and lower part of the arms; paratype G (U.S.N.M. 560793G). Ray structure of this crinoid is shown in text fig. 21.

3. *Isocrinus oregonensis* Moore and Vokes, n. sp. Crown; the impression of the proximal columnal is seen at the base of the cup; ray structure of this crinoid is indicated in text fig. 33; paratype L (U.S.N.M. 560791L). All specimens from Keasey formation, upper Eocene and lower Oligocene, Columbia County, Oreg., U.S.G.S. Tertiary loc. 15318.

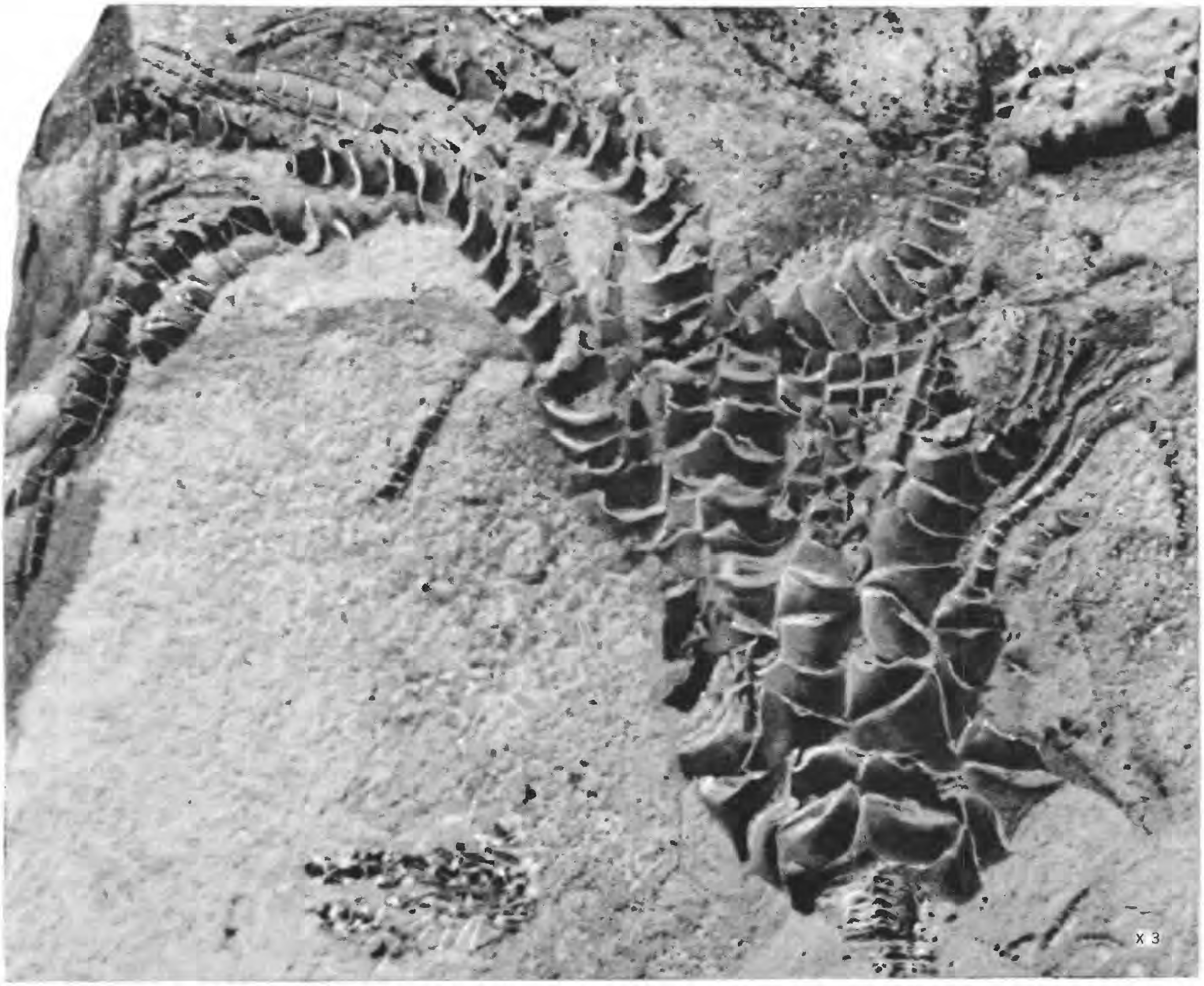
ISOCRINUS OREGONENSIS AND *I. NEHALEMENSIS*

Plate 21

FIGURE 1. Outcrop of Keasey formation on Nehalem River, ⅜ mi south of junction of Oregon State Highways 47 and 202, near Mist, Columbia County, Oreg., U.S.G.S. Tertiary loc. 15318.

2. *Isocrinus nehalemensis* Moore and Vokes, n. sp. Holotype specimen (U.S.N.M. 560792K), × 3. At right small regenerated arms belonging to one of the rays may be seen. Compare text fig. 38.

1



2

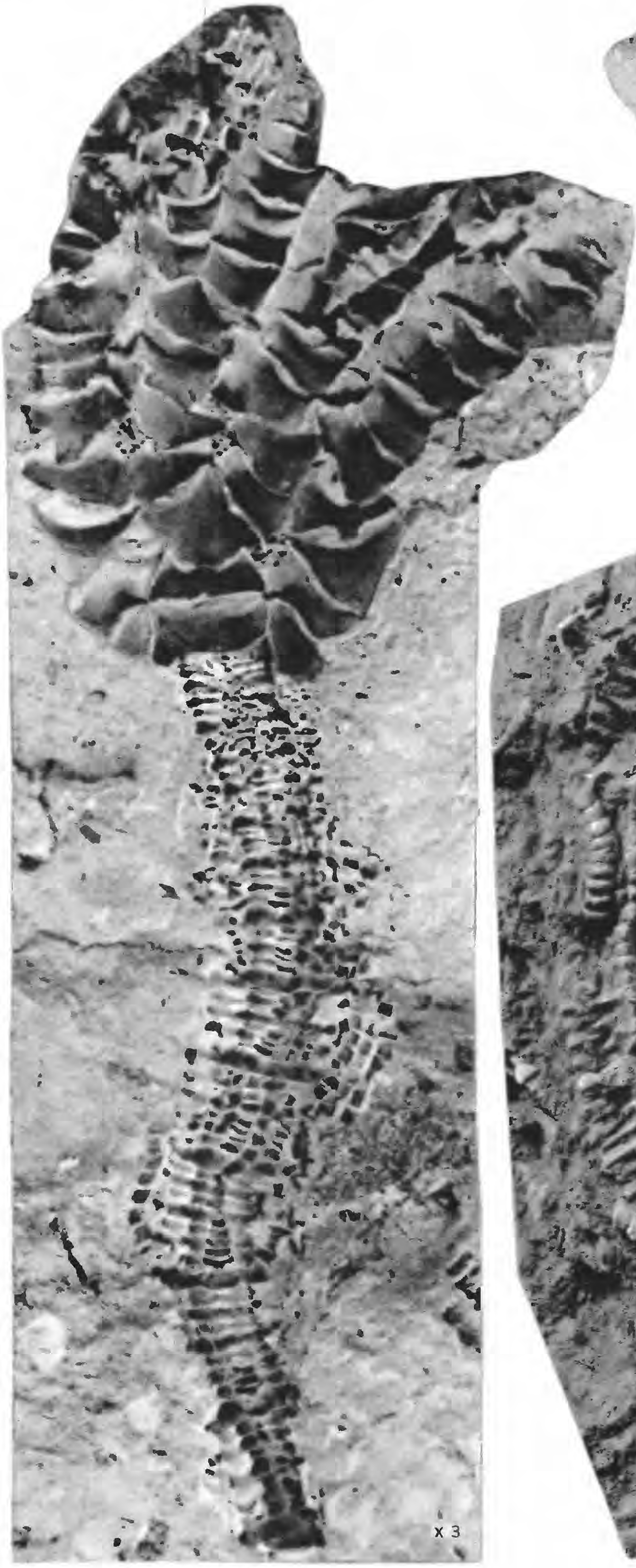
CRINOID LOCALITY NEAR MIST, OREG., AND *ISOCRINUS NEHALEMENSIS*

Plate 22

FIGURE 1. *Isocrinus nehalemensis* Moore and Vokes, n. sp. Paratype J (U.S.N.M. 560793J), which includes an unusually long attached part of the stem, × 3. Nodals are closely spaced near the dorsal cup, and whorls of short, upwardly directed cirri are very numerous. All columnals are thinner in the vicinity of cup than in middle and lower parts of stem. U.S.G.S. Tertiary loc. 15318.

2. Two carbonized leaves of plants found in association with the crinoid remains at U.S.G.S. Tertiary loc. 15318, × 1.5.

3. *Isocrinus oregonensis* Moore and Vokes, n. sp. University of California Museum of Paleontology paratype A5018C3, × 3, Keasey formation on Nehalem River near Mist, Oregon; a stem fragment consisting of many articulated columnals, each of the regularly spaced nodals bearing a whorl of five long slender cirri.



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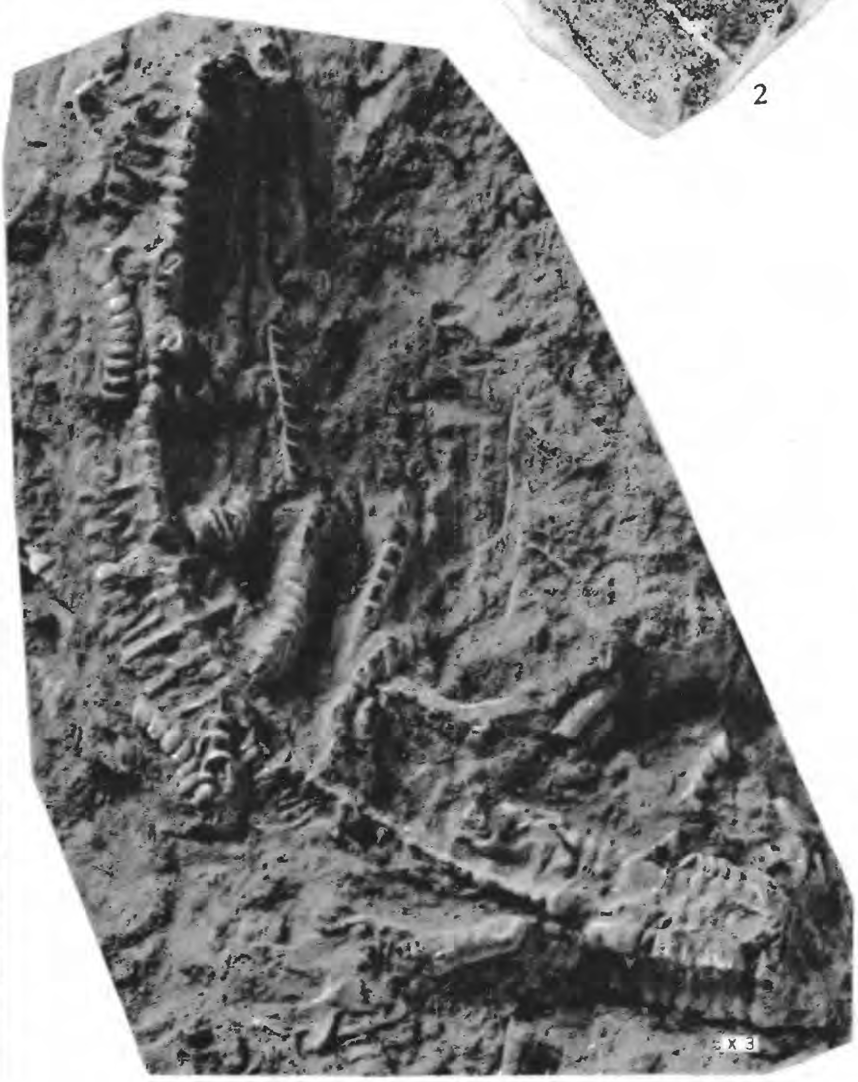
2



3

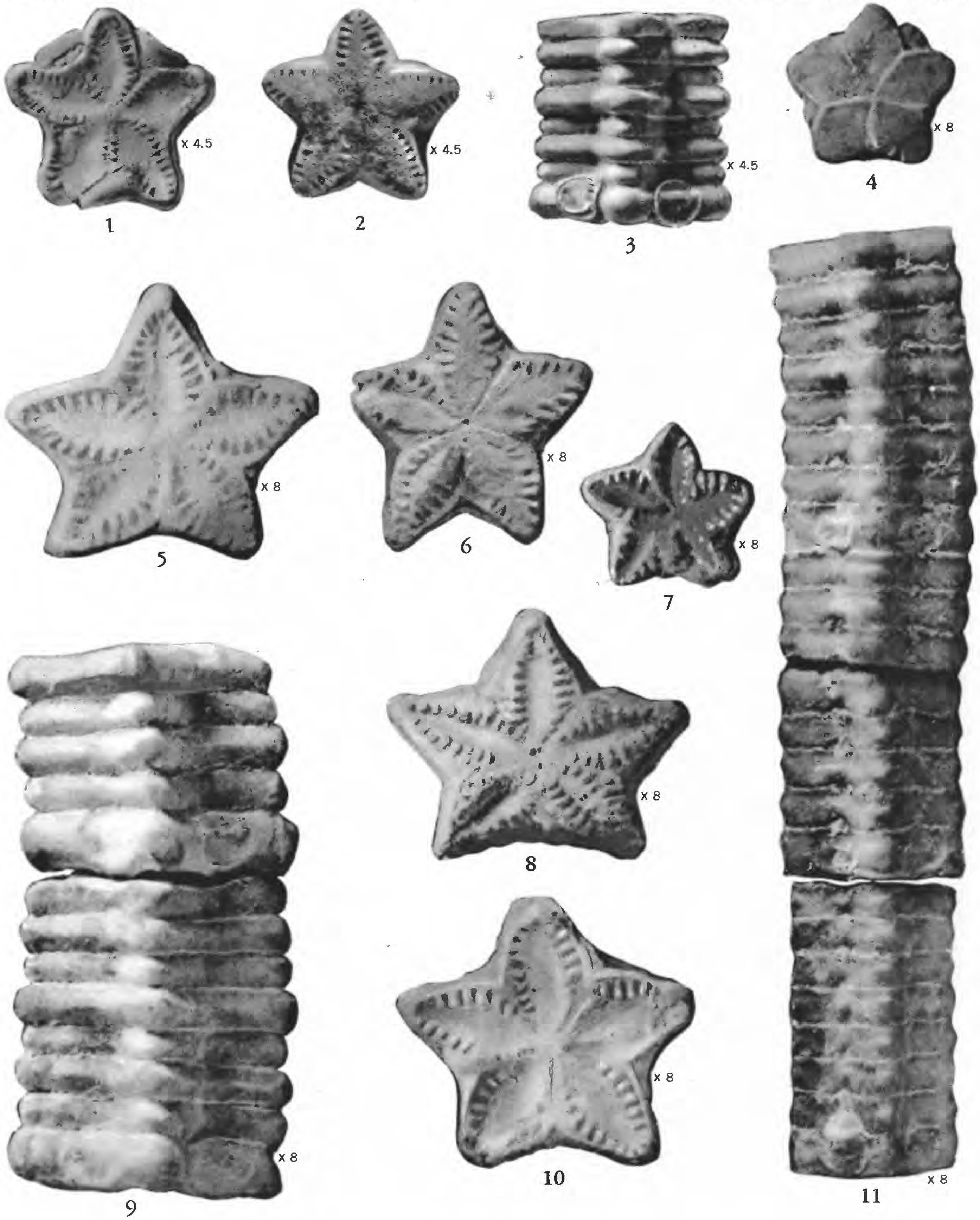
ISOCRINUS NEHALEMENSIS, I. OREGONENSIS, AND ASSOCIATED PLANT REMAINS

Plate 23

FIGURES 1–3, 5, 6, 8–10. *Isocrinus oregonensis* Moore and Vokes, n. sp. (1) Proximal face of nodal of large stem, showing short crenellae of the pentameres, the inner ones located very close to the axial lumen; proximal cirrals are attached to the nodal at three re-entrants; paratype (U.S.N.M. 560903A), × 4.5. (2) Distal face of internodal, showing type of articular surface that is in contact with the proximal face of a nodal, as illustrated in fig. 1; × 4.5. (3) Side view of relatively large stem segment consisting of a nodal (lowermost columnal) and seven internodals that are alternating small and large; the topmost internodal is a hypozygal columnal, belonging next below a nodal and characterized by a smooth articular surface proximally where it joins the nodal; the elliptical facets for attachment of two cirri are well defined on the nodal; paratype (U.S.N.M. 560903A), × 4.5, (5) Proximal face of a strongly stellate internodal; paratype (U.S.N.M. 560903B), × 8. (6) Distal face of an internodal; paratype (U.S.N.M. 560903C), × 8. (8) Proximal face of an internodal having very strongly marked crenellae; paratype (560903B) × 8. (9) Side view of portion of a medium-sized stem showing two nodals, which are distinguished by their greater thickness and cirrus sockets in re-entrants on the side, and alternating large and small internodals; the larger internodals are distinguished by the angulated nature of their outer surface, which gives them a keeled appearance; points of the star-shaped columnals tend to be produced in the form of a rounded boss; paratype (U.S.N.M. 560903C), × 8. (10) Proximal face of a nodal, showing gently concave nature of each pentamere and relatively coarse short crenellae; paratype (U.S.N.M. 560903C), × 8.

4, 7, 11. *Isocrinus nehalemensis* Moore and Vokes, n. sp. (4) Distal face of a nodal, showing nearly featureless smooth surface that adjoins the hypozygal internodal and facilitates parting of the stem at this articulation; cirrus sockets are partly visible, and at right upper is an attached cirral segment; paratype (U.S.N.M. 560904B). (7) Proximal face of an internodal, showing strong crenellae; paratype (U.S.N.M. 560904A). (11) Side view of portion of stem showing three nodals and three groups of internodals, each consisting of seven columnals of nearly uniform size; paratypes (U.S.N.M. 560904A, B). All figures × 8.

All specimens from Keasey formation, upper Eocene and lower Oligocene, of Oregon. Figs. 1–3 from U.S.G.S. Tertiary loc. 15282, Columbia County; figs. 5, 6, 8–10 from U.S.G.S. Tertiary loc. 15508, figs. 4, 7, 11 from U.S.G.S. Tertiary loc. 15268, Columbia County.



ISOCRINUS COLUMNALS

Plate 24

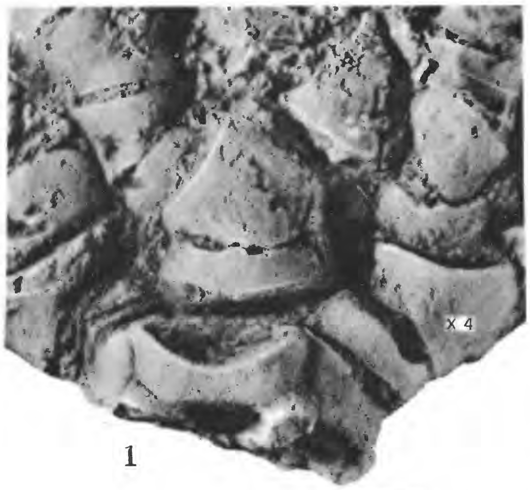
All illustrated specimens are from the Keasey formation at the locality on Nehalem River near Mist, Oregon, University of California loc. A5018 (same as U.S.G.S. Tertiary loc. 15318).

FIGURE 1. *Isocrinus oregonensis* Moore and Vokes, n. sp., University of California Museum of Paleontology, paratype no. A5018B, $\times 4$, side view of dorsal cup and proximal part of arms.

2. Same, paratype no. A5018C1, $\times 4$, side view of dorsal cup and proximal part of arms; a few columnals are attached to the cup.

3. Same, paratype no. A5018B, $\times$ 4, base of dorsal cup, showing subhorizontal proximal extension of radial plates, which occupy re-entrants between points of the strongly stellate columnals; broken distal parts of the basal plates occur at extremities of the points of the columnals.

4. Same, paratype no. A5018A, $\times$ 2, a crown consisting of a complete dorsal cup and lower parts of most of the rays.



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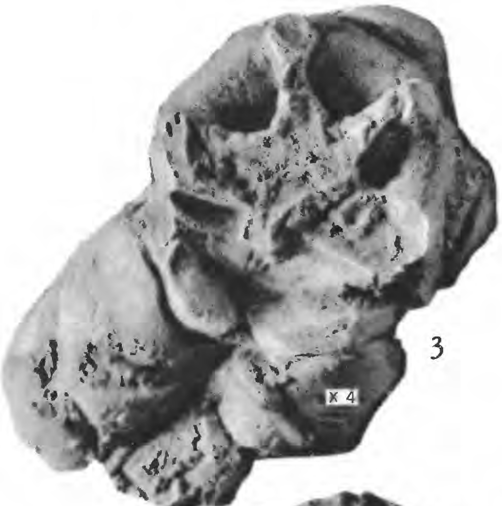

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ISOCRINUS OREGONENSIS

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[The letters in parentheses preceding the titles are those used to designate the papers for separate publication]

ILLUSTRATIONS