# ENVIRONMENTAL SIGNIFICANCE OF LATE QUATERNARY NONMARINE MOLLUSKS FROM FORMER LAKE BRETZ, LOWER GRAND COULEE, WASHINGTON

By

JAMES JERRY LANDYE

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

WASHINGTON STATE UNIVERSITY
Department of Anthropology

1973

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of JAMES JERRY LANDYE find it satisfactory and recommend that it be accepted.

Roald Fryxell

Chai

Henry T. Irwin

Carl E. Gustafson

## ACKNOWLEDGMENTS

I wish to thank members of my thesis committee, Carl E. Gustafson and Henry T. Irwin, for their assistance and Roald Fryxell, my chairman, for his help, encouragement, and for making available unpublished notes and ideas about the Quaternary history of eastern Washington. Additional encouragement and assistance were freely given by Allan Smith, Charles W. McNeil, and James Goss. Completion of this work was made possible through the Quaternary Studies Option in Anthropology, supported by the National Science Foundation through grant NSF GZ-1353.

Invaluable aid in the knowledge and identification of the nonmarine mollusks was given by Dwight W. Taylor, San Diego Natural History Museum, who also made available his extensive library and molluscan collections and arranged access to Pleistocene nonmarine molluscan collections of the U.S. Geological Survey. Without his help, this and my other investigations of freshwater mollusks would have become hopelessly mired in the Pleistocene of malacology.

Myra Keen, Stanford University, D. W. Savage and James R. Firby, University of California at Berkeley, the late G Dallas Hanna, the late Leo G. Hertlein, California Academy of Sciences, and the staff at the Thomas Burke Memorial Museum at Seattle, Washington are acknowledged with appreciation for making collections of Pleistocene nonmarine mollusks at their respective

institutions available for examination. Denis Delorme, Calgary, Alberta and W. I. Follett, California Academy of Sciences, identified ostracod and fish remains, respectively.

The Washington State University, Department of Anthropology Graduate Fund and my mother, Mrs. James T. Landye provided essential financial assistance for radiocarbon dates, supplies, travel, and field expenses. Technical assistance in the sorting of mollusks was obtained from Caren Ross and Derek Valley. Mrs. Karen Schubert typed the manuscript. Finally I wish to thank my wife, Sandra, for her encouragement, sorting, typing, critical editing, and financial support of this paper.

ENVIRONMENTAL SIGNIFICANCE OF LATE QUATERNARY NONMARINE MOLLUSKS FROM FORMER LAKE BRETZ, LOWER GRAND COULEE, WASHINGTON

ABSTRACT

by James Jerry Landye, M.A.
Washington State University, 1973

Chairman: Roald Fryxell

Nonmarine mollusks comprising a total sample population of more than 85,000 individuals were collected from a barrow pit near Soap Lake, Washington at the east wall of Lower Grand Coulee. Other samples of mollusks were obtained from deposits located elsewhere throughout the Lower Grand Coulee in 1965-1969. Sediments from which this molluscan assemblage was obtained consist of silt and coarse volcanic ash of Glacier Peak origin, and place its age and that of the associated shells at about 12,000 years old. Shells were separated from sediments by washing, drying, screening, and sorting. Ostracod, fish, bird, amphibian, and plant remains also were recovered. At least 19 species of nonmarine mollusks, representing 12 genera, were found in the 3 m section sample. Two genera of pelecypods *(Anodonta* and *Pisidium)* were represented along with seven genera of aquatic gastropods *(Valvata, Lymnaea, Gyraulus, Armiger, Vorticifex, Planorbella,* and *Physa).* An additional species of pelecypod, *Musculium lacustre,* was found in two samples of Lake Bretz deposits.

Numbers of individuals increased generally from the lower to upper lacustrine sediments.

Three species of terrestrial gastropods found at the primary locality were represented by only 11 individuals, which probably washed by chance into the perennial lake from adjacent terrestrial habitats. Their presence suggests that vegetation such as sedges and perhaps a few trees grew near the lake margin. In lacustrine sediments near Sun Lakes State Park, remains of *Anodonta californiensis*, *Lymnaea* cf. *L. binneyi,* and *Vorticifex effusus* were larger, had greater shell thickness, and were more numerous than at the primary locality to the south. These differences suggest more current and oxygenation in this area than at L65-1.

Lake Bretz was formed by geologic events related t glaciation; regional climatic conditions cooler than present were inferred independantly from the nonmarine molluscan assemblage found in Lake Bretz sediment. Both faunal and geological evidence are interpreted as recording a cool freshwater lake fed through underground aquifers from the Upper Grand Coulee and the Columbia River. A slow current was maintained throughout the lake system, but embayments were also present. The glacially dammed Columbia River to the north gradually resumed its preglacial course, causing flow in the aquifers to be less. This, in turn, caused the Lower Grand Coulee to become an internal drainage basin resulting in a modern salinity gradient from north to south. Thus salts became highly concentrated in the modern Soap and Lenore lakes.

If present during the few hundred years that Lake Bretz existed, Early Man would have taken advantage of the many natural resources of the lake. Campsites would have been above the highest stable lake level of 1,159±1 ft. (352.6 m) along the 72 km length of shoreline.

Review of previous archaeological work at Early Man sites in eastern Washington and of previous studies in malacology (summarized here), shows Early Man to have been near Lower Grand Coulee by at least 10,000 years ago and to have had abundant molluscan food resources available in the region. Lake Bretz and its shoreline environments would have provided a variety of abundant food resources for man at an earlier time.

TABLE OF CONTENTS

Page

## LIST OF TABLES

# LIST OF ILLUSTRATIONS

# 1. INTRODUCTION

In November 1965 a nonmarine molluscan assemblage of Late Quaternary age was sampled from a lacustrine deposit exposed at many localities in the Lower Grand Coulee, Washington. The main locality, L65-1, is situated three miles north of the town of Soap Lake at the base of the east coulee wall (Fryxell and Neff 1965), 2,000 ft. N. and 2,400 ft. E. from the SW corner of sec. 36, T.22N, R.26E. These deposits extend from Soap Lake north to Dry Falls State Park and represent the Late Pleistocene lake, Lake Bretz (Landye 1969). This lake was named for J Harlen Bretz whose pioneering work on the channeled scablands of eastern Washington spanned 40 years (Bretz 1923a, 1969). Lake Bretz was about 20 miles long and 1 mile wide (Fig. 1.1), and reached a maximum elevation just under 1,160 feet above sea level, recorded clearly by sediments exposed in a Bureau of Reclamation canal constructed in 1969, southeast of the town of Soap Lake.

Sediments collected and examined from Lake Bretz contain large amounts of coarse volcanic ash from Glacier Peak in the northern Cascade Range and numerous freshwater molluscan shells embedded in silts and cemented by carbonates. The Glacier Peak ash identified from this locality (Fryxell 1965) places the deposits at approximately 12,000 years in age. Presence of ash from the Glacier Peak eruption in all sample localities thus

Fig. 1.1.--Map of Lower Grand Coulee, Washington showing location of Glacial Lake Bretz and molluscan localities. Positions of modern lakes are represented by shaded areas. Locality descriptions are given in Appendix B. Terminal moraine of the Okanogan ice lobe is depicted at upper left by symbol gravel.

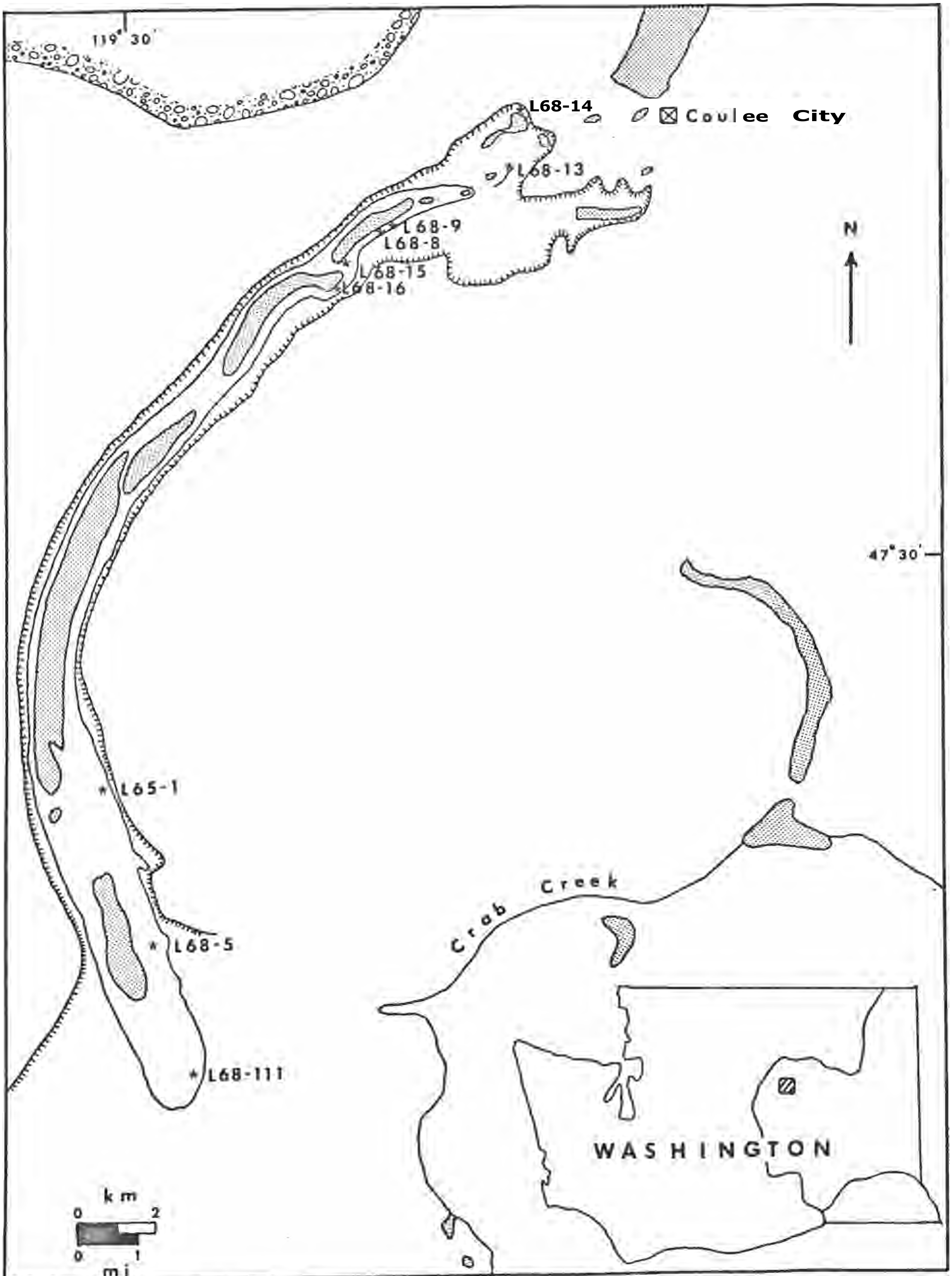
119° 30'
L68-14
Coulee City
L68-13
L68-9
L68-8
L68-15
L68-16
N
47° 30'
L65-1
Crab Creek
L68-5
L68-111
WASHINGTON
km
0
2
0
1
mi

Fig. 1.1

provides a consistent time stratigraphic marker horizon demonstrating their common age.

Lacustrine sediments from the major collecting locality, L65-1 (Fig. 1.2), were subdivided into nine stratigraphic units, each consisting of approximately the same volume, 0.06 $m^3$, of material. This matrix was washed and screened, after which the mollusks were separated from it, identified, and counted. In total, shells of more than 85,000 individual mollusks were recovered. Sediments exposed at other localities of the same Pleistocene stratigraphic unit also were located and sampled to provide evidence from more than one kind of habitat in Lake Bretz. From this information, evaluations were made regarding past environments at a time when Early Man may have been entering eastern Washington, time of deposition, relative magnitude of a protein resource available to man, and the development of a classic limnological feature now known as Soap Lake (Edmondson 1963).

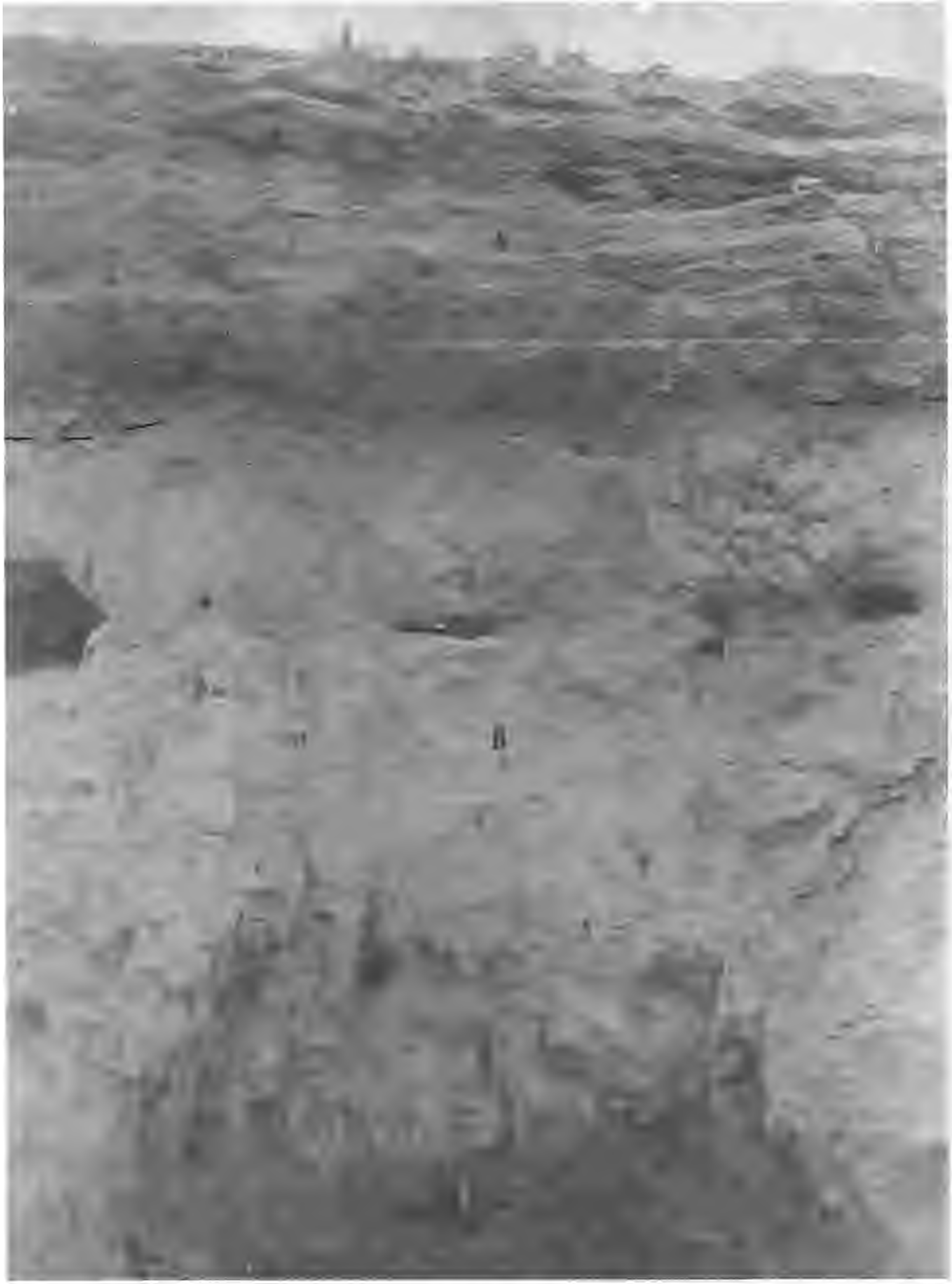

Fig. 1.2

## 2. NATURE AND SCOPE OF INVESTIGATION

The primary objective of this investigation was to bring together scattered knowledge regarding nonmarine mollusks and to assess the extent to which it may be possible to apply such information for paleoenvironmental research in the Columbia Basin. This objective was attained through a review of published information, examination of existing collections, and field investigations of fossil and living nonmarine molluscan assemblages.

### Goals of This Research

Detailed analyses of Pleistocene nonmarine molluscan assemblages in the Pacific Northwest had not been conducted prior to initiation of this study. Basic background information consequently had to be gathered before field information could be evaluated. Goals of the present paper are:

1. To provide an historical review of published information dealing with nonmarine mollusks of Pleistocene and Recent age in the Pacific Northwest, and especially of papers related to the Lower Grand Coulee, Washington.

2. To prepare a nonmarine molluscan collection for the Laboratory of Anthropology at Washington State University, to aid in the preliminary identification of mollusks from archaeological and related investigations.

3. To assess the potential value of information available directly from field investigations at archaeological sites and from previous published data, regarding their theoretical paleoenvironmental implications, particularly hydrological and terrestrial natural resources.

4. To illustrate the potential value and problems of interpretation of nonmarine molluscan assemblages by using a

specific Late Quaternary deposit of known age, with an abundance of molluscan material undisturbed by man.

## Premises and Precedents for This Study

Overall evaluation of a molluscan fauna such as that of Lake Bretz relies on the widely accepted concept that most individual species of the Late Pleistocene molluscan faunas must have lived in about the same type of environment in which they occur today. A thorough understanding of the systematics and ecology of modern nonmarine mollusks should, therefore, make possible environmental interpretation of paleomolluscan faunal assemblages. Combining this faunal information with Pleistocene geological data, one can, in the case of aquatic species, generally pin down the size, velocity, salinity, alkalinity, water purity, and temperature of the water body. For example, the existence of large streams and lakes, slow or fast moving streams, spring seepage areas, stagnant or perennial ponds could be inferred from molluscan remains.

Terrestrial molluscan forms may indicate much about natural vegetation, topography, and available moisture; such settings as dense forests, open grasslands, or marshes may be inferred through comparison of modern and fossil mollusks and their distribution. Thus some botanical resources available to man may be inferred even if no pollen record is available for study, such as those used for reed and grass baskets, dugout canoes, or food. The apparent absence of such resources may be equally useful to indicate limiting factors which would have been imposed on man by the environment in which he lived.

Nonmarine mollusks of Pleistocene and Recent ages have been studied in both geological and archaeological contexts during the past ninety years in the western U.S.A. (Call 1884). Ecological inferences based on comparison of Pleistocene and modern environments using fossil and modern nonmarine mollusks contain, however, many assumptions which could be pitfalls. Before attempting paleoecologic interpretation, perhaps one should read the essay of G. H. Scott (1963). Scott suggests that Lyell's principle of ecological uniformity is not the only condition to be met for paleoecological reconstruction. Differential preservation, either due to the material preserved or the type of matrix in which the specimens lie, and differential death rates among individual mollusks are both factors for an imperfect fossil record. Abundance of fossils within the unit sampled is another factor to be dealt with before reconstructions of past environments are made. If the particular Pleistocene assemblage of nonmarine mollusks contains extant species, interpretation of past conditions is more reliable than if extinct species are present. Deposition of animal remains at the site of original habitat have fewer inherent problems than if remains are redeposited. For example, investigations would be hampered if a snail died and was transported and redeposited in a nontypical habitat area.

One thus must make a series of assumptions regarding the presence or absence of molluscan species and their reactions to environmental change. This poses a problem with theoretical and practical implications as to what the biological species actually represents, for the genetic make up of populations may change through time. Some changes have no morphologic expression; others do. Not every phenotypic change, moreover, will alter the animal's ability to cope with the environment of its ecological niche. With only the shell remaining in fossil deposits, phenotypic changes in the soft parts of the animals will not show and systematics with its nomenclature based on hard parts alone may be erroneous and may lead to other errors of interpretation. In order to maintain more stability and utility within the nomenclature of nonmarine mollusks and to obtain more ecological information, it thus may be argued that it would be best to refer to most Late Pleistocene fossils as their modern molluscan descendants, rather than to assign them names as distinct species (Taylor 1965). In the present study, for example, there are no indications that any of the Lake Bretz species are extinct.

During the period of about 1920-1940 the problem of variation within groups of nonmarine mollusks was the subject of continuing debate. The two main adversaries were Frank C. Baker and Bohumeil Shimek. Baker, using quantitative data, came to the conclusion that a great many more varieties and species are extinct than was indicated by collections that were available at that time (Baker 1920, 1921, 1936, 1937). Shimek,dealing with the same materials, suggested only a wide variation within the same species (Shimek 1913, 1930, 1935, 1936). The latter view is accepted by most workers today.

Interpretation of the fossil assemblage of nonmarine mollusks usually is based on three factors: biogeographic history, habitat preference, and geologic time (Taylor 1965).

The first study in the western U.S.A. to consider salinity, temperature, elevation, geologic time, and biogeography was on lakes Lahontan and Bonneville (Call 1884). In addition, numerous investigations stressing the limnological aspects of Pleistocene water bodies besides being the habitats of the freshwater mollusks have been conducted by members of a team under Aurèle La Rocque at Ohio State University (La Rocque 1963a, 1964; Roy 1964). Other studies in North America have focussed on the climatic inferences of the Pleistocene nonmarine mollusks (Hibbard and Taylor 1960; Taylor 1960b). An approach using soils, stratigraphy, and paleontology has been employed successfully by Vojen Lolek (1964, 1965) and others in Czechoslovakia. Unfortunately this broad, thorough approach has not been used in any detailed study in the U.S.A. The status of these investigations in Europe and North America has been reviewed by Lo2ek (1965) and Taylor (1965).

As is evident from the bibliography of Taylor (1970), archaeological site reports from western North America frequently contain references to Pleistocene and Recent nonmarine mollusks, but most are lists of names with few, if any interpretative statements. The use of fossil nonmarine mollusks in American archaeological investigations was suggested effectively by Loren Eisley (1931). Archaeologists have been deterred by complex systematics of nonmarine mollusks from utilizing this source of relevant information. Only recently has it been recognized that when mollusks are involved, aid of a specialist knowledgeable in nonmarine systematics and Quaternary geology is necessary in the interpretation of archaeological sites.

Environmental interpretation of molluscan remains from an archaeological site is difficult because of man's disturbance of the environment. Therefore, areas undisturbed or little disturbed by man are more suitable to study for environmental and climatological information.

One of the earliest collections of nonmarine mollusks in connection with archaeological research in the western U.S.A. was that of E. B. Howard (1935) at the Clovis site. Pilsbry (1935) and Richards (1936) interpreted the fauna as representing a cooler climate than that of today. Drake (1963, 1964) published reports on several sites in the western U.S.A. Some unfortunately were lacking in detail and apparent correlation. However, Drake's study on the Llano Estacado, containing a more thorough analysis than his earlier work, remains unpublished (oral communication, 1968, Robert Drake, Vancouver, British Columbia). Taylor's (1967, 1968) interpretations of the molluscan fauna from archaeological sites were hampered by lack of information regarding the distribution of living species especially on the Mexican Plateau. The data still were sufficient to show a cooler climate on the southern Mexican Plateau from 20,000 to 9,000 years ago (Taylor 1968).

Ernest Roscoe made a detailed investigation of *Margaritifera falcata* (Gould) in his report on the freshwater mollusks of the Round Butte archaeological sites on the Deschutes River, Oregon. The report contains an extensive review of the literature regarding the biology and the use of *M. falcata* by Indians in the Pacific Northwest (Roscoe 1967).

Another molluscan study conducted in conjunction with an archaeological site was at Lind Coulee, Washington (Enbysk 1956). No paleoenvironmental or ecological interpretations were suggested in the report. Second-hand inference based on these specimens is limited for the exact stratigraphic positions of the molluscan assemblages were not made clear.

Methodology obviously cannot be overlooked in handling fossil nonmarine mollusks; poor techniques will lose valuable data. First, the stratigraphic position of collections is extremely important. Second, samples should be large enough to be representative of the total molluscan assemblage because hand-picking a sample from the deposit may bias results. Perhaps the best method is to wash bulk samples through a fine nylon screen, as suggested in this investigation.

## 3. METHODS AND MATERIALS

Laboratory and field methods used in the collection and processing of materials from the primary locality, L65-1, included subdivision in the field of the Late Quaternary deposit into stratigraphic units, sampling, and processing the material following modified procedures of Hibbard (1949). Exposures at L65-1 resulted from a barrow pit abandoned several years previously. A section of sediment at the southern wall of the barrow pit was selected for sampling, and was subdivided on the basis of stratigraphy into nine units. The first two, "A" and "B," were characterized by evidence of reworking such as color change, lack of cementing, and lack of the lacustrine characteristics of the other units. Units sampled and their respective depths from the present surface are as follows:

A = 0.01 - 0.30 m
B = 0.30 - 0.75 m
C = 0.75 - 1.20 m
D = 1.20 - 1.54 m
E = 1.54 - 2.00 m
F = 2.00 - 2.28 m
G = 2.28 - 2.55 m
H = 2.44 - 2.775 m
I = 2.775 - 3.005 m

From each of these units a sample of approximately the same volume, $0.06\ m^3$, was taken. Each sample was put into individual 100 pound flour sacks and transported to the laboratory, where they were air dried before processing. Subsequently, for all sample units, modifications were made in Hibbard's suggested procedure. Samples "A" and "B," for example, were processed differently than samples from units "C" through "I" because lack of cementing permitted "A" and "B" to be dry screened. Unit "A" was shaken through a series of Tyler Standard Sieves (5, 9, and 16 squares per inch). Shells were then picked out of the residue, a procedure which was found to be too time consuming. As an alternative, sample "B" was shaken through a commercial nylon screen with 21 squares per inch. Faunal remains then were picked out under a magnifying glass by use of forceps, identified, and counted. Since very few shells were present--only 243 in sample "A" and 1,167 in sample "B"--picking by hand was not prohibitively slow. After preliminary examination of samples "C" through "I," however, it was noted that a change in procedures again was in order; the matrix was slightly cemented with carbonates and required soaking in water to extract the mollusks. Secondly, since these samples contained a great many more individual mollusks, it was more efficient to concentrate the samples before dry separation, identification, and counting took place.

Modifying Hibbard's method, each matrix sample from "C" to "I" was soaked for 24-48 hours. During this time the larger genera of *Anodonta, Lymnaea,* and *Planorbella* were picked out to prevent damage to them during further processing. Both volcanic ash and gastropods floated during the soaking. The ash, however, became waterlogged within 24 hours and settled out, leaving the gastropods floating, and at the end of the soaking period they were collected with a small tea strainer. These and larger genera of mollusks were dried before identification and counting. The residue was placed in commercial nylon screen again and washed to flush from the sample silt and small fractions of the volcanic ash, and, accidently, some specimens of *Armiger crista* (Linnaeus).

Material left from washing finally was dried, sorted, identified, and counted. Drying was accomplished by putting the nylon screen over a window screen mounted above a large hot plate. This residue was placed under a magnifying glass with fluorescent lights mounted around the glass. Specimens were separated with a small brush and tissue forceps. Each specimen then was identified, tabulated, and computations were made.

Localities sampled in this study are designated with the use of U. S. Geological Survey topographic maps in a system described by Taylor (1966b). The first set of numbers and letters assigned to each locality refers to a specific map, using the index system designating individual sheets of the U. S. Geological Survey and Army Map Service map series at 1:250,000 scale. The final set of letters and numbers refers to a specific quadrangle map at 1:62,500 or 1:24,000 scale (Fig. 3.1). For example, NL11-1 refers to the Ritzville 1:250,000 quadrangle, and C-6D refers to the Coulee City 1:24,000 scale quadrangle within the Ritzville area. Further description makes use of the section, township, and range system of surveying. Field numbers appear at the end of each locality description.

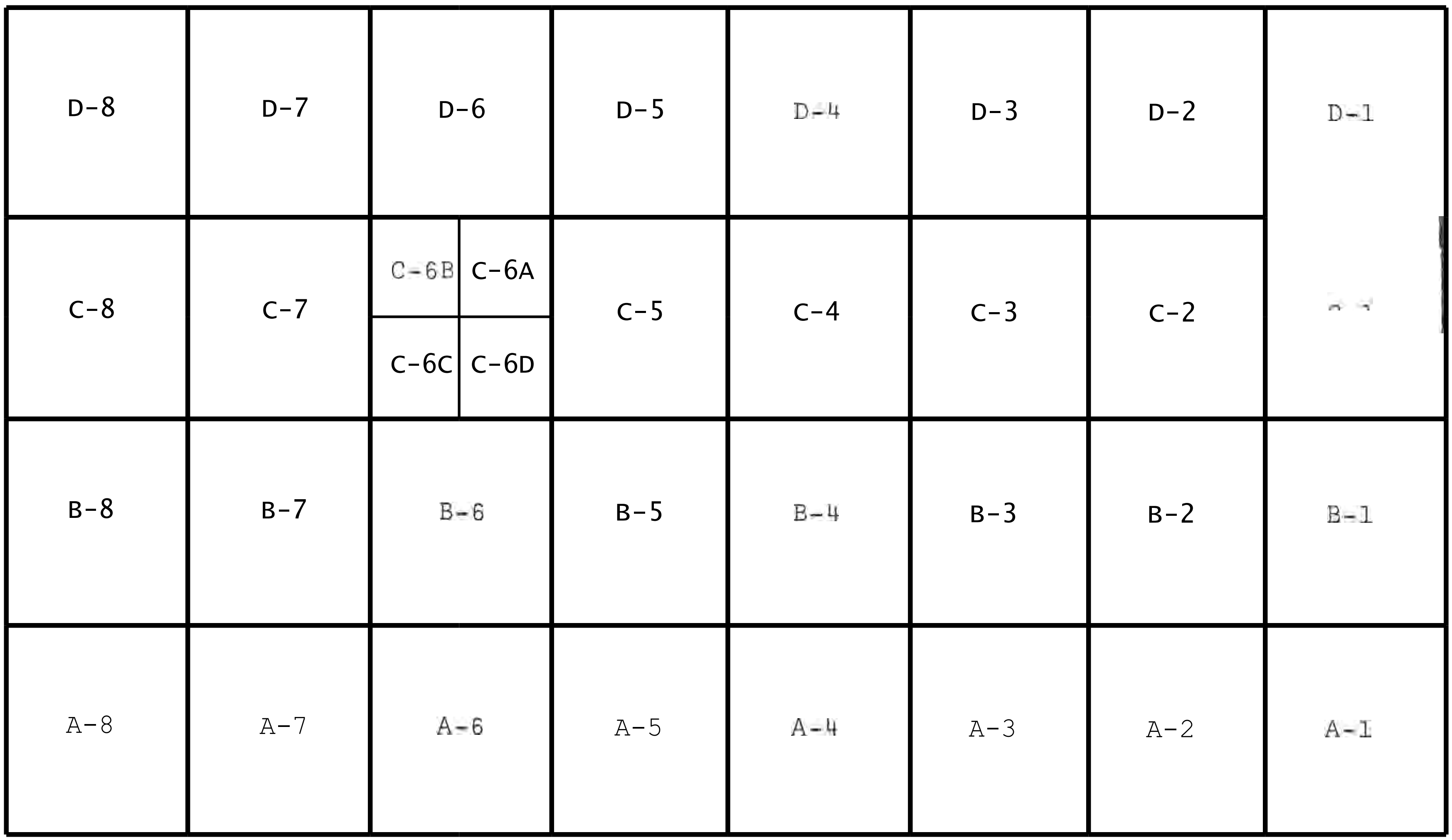


Fig. 3.1.--Universal designation system for 1:62,500 scale topographic map quadrangles for any area within U.S. Geological Survey 1:250,000 scale maps following Taylor's (1966b) presentation. Quadrangle maps of 1:24,000 scale are coded as shown in the C-6 1:62,500 scale quadrangle.

# 4. EARLY NONMARINE MOLLUSCAN AND BIOLOGICAL INVESTIGATIONS

During the past 100 years many collections and studies of nonmarine mollusks have been made along the Lower Grand Coulee of Washington and from the Pacific Northwest in general. Most early work prior to 1920 was based on limited collections or brief descriptions of phenomena seen in the area. No convenient summary of these studies exists. The following review of early investigations and collections has been prepared to make these references, many of which first appeared in journals not now well known, more easily available for general use.

## Molluscan Studies in the Pacific Northwest

Thomas Nuttall, an English botanist, collected the first recorded scientific specimens of living nonmarine mollusks from the Pacific Northwest in 1835 (Carpenter 1857), while he traveled from San Diego, California to Oregon in conjunction with the U.S. War Department Pacific Railroad survey (Conrad 1857). Also attached to this survey party, under the command of Lt. R. D. Williamson, was Dr. John S. Newberry, M.D. Newberry collected nonmarine mollusks and sent them for identification to Isaac Lea of Philadelphia. Lea reported Newberry's collections of *Juga* from the upper Deschutes in Oregon (Lea 1860) and later described an occurrence of *Planorbis newberri* (Lea 1864a).

Other early biological investigations in the Pacific Northwest were carried out in the 1840's by the U.S.A. Exploring Expedition under the command of Charles Wilkes (1844). In May 1840 Wilkes arrived aboard the U.S.S. Vincennes in Puget Sound, Washington. Attached to Wilkes' command, Joseph Drayton, artist, gathered more biological material in the Northwest than any other member of the expedition. Besides sketching people and scenery, Drayton collected samples of the modern fauna and flora on his trips with Wilkes to Fort George (Astoria), Fort Vancouver, and the Willamette Valley. Drayton later was detached with a small party of men to travel up the Columbia River to Walla Walla. During this trip Drayton collected a number of fish and mollusks (Gould 1847a, 1847b, 1847c, 1849, 1850, 1860). Another small party under the command of Lt. Robert E. Johnson was sent to Yakima and Fort Colville, and eventually reached and described the Grand Coulee. Lakes in the coulee were reported to be teeming with wildlife, birds, and fish. From evidence found in the Lower Grand Coulee, Johnson thought that it had been created by a river, noting that granitic rocks from exposures many miles to the north were found in the alluvium of the canyon floor (Wilkes 1844). The Wilkes party encountered Sir George Simpson and Dr. Robert M'Laughlin of the Hudson's Bay Company, possibly prompting Simpson to send molluscan specimens to Isaac Lea at a later date (Lea 1864).

Almost two decades later, the British-American Boundary Commission, 1858-1860, collected living nonmarine mollusks from what now is the border between the U.S.A. and Canada (Baird 1863).

J. K. Lord, naturalist for the commission, collected *Physa lordi* Baird from Lake Osoyoos on the international border.

During the same period of time, Lea described the snail, *Juga,* which Joseph Drayton had given to him from the Fort George and Walla Walla area (Lea 1862). It was in this same report that material labeled as "Oregon" from Dr. Wesley Newcomb was described. Around the turn of the century Joseph F. Whiteaves received material from the International Boundary Commission from the headwaters of the Columbia River (Whiteaves 1905). Contained in this collection were a few shells of *Juga,* thus extending the known range of this genus east, to southeastern British Columbia.

From 1900 to the present day a considerable number of collections of nonmarine mollusks have been made by amateur shell collectors. Mr. Erval J. Newcomer of Yakima, Washington collected nonmarine mollusks from a late Pleistocene-Recent lacustrine deposit near Northport, Washington in 1929 (NM11-11, D-81) (Berry 1948). Berry reported the following mollusks:

*Pisidium* cf. *concinnulum* Sterki
*Pisidium roperi* Sterki
*Pisidium roseum* Sholtz
*Pisidium rotundatum* Prime
*Musculium* cf. *secure* (Prime)
*Lymnaea (Stagnicola) proxima* Lea
*Lymnaea (Fossaria) dalli* F. C. Baker
*Helisoma subcrenatum* (Carpenter)
*Gyraulus altissimus* (F. C. Baker)
*Armiger crista* (Linne)
*Menetus exacuous megas* (Dall)
*Physa* sp.
*Aplexa hyporum* (Linne)

*Valvata humeralis californica* Pilsbry
*Allogona ptycophora* (W. D. Brown)
*Euconulus fulvus*
*Zonitoides arboreus (Say)*
*Discus (Gonyodiscus) cronkhitei* (Newcomb)
*Vertigo ovata* (Say)
*Gastrocopta pentodon* (Say)
*Succinea* cf. *S. hawkinsii* Baird

During the past 50 years Walter Eyerdam from Seattle, Washington has traveled throughout the Pacific Northwest collecting both living and fossil mollusks, including material from the Soap Lake and Yakima areas (Eyerdam 1934). Many of his other collections are from western Washington (Eyerdam 1942, 1967). In 1911 Harold Hannibal, a student at Stanford University, also made collections of nonmarine mollusks in western Washington (Hannibal 1912).

Most recently, molluscan material has been obtained from archaeological sites. The Lind Coulee site excavated by Richard Daugherty (1956) provided material closest in proximity to the Lake Bretz locality of Lower Grand Coulee. Near the main site, Betty Enbysk obtained molluscan specimens of Pleistocene and Recent age from several localities along Lind Coulee (Enbysk 1956). Mollusks from all of the localities reported include:

*Sphaerium dentatum* Haldeman
*Sphaerium* sp.
*Pisidium* cf. *P. contortum* Prime
*Anodonta* cf. *A. californiensis* **Led**
*Valvata humeralis californica* Pilsbry
*Stagnicola (Galba) palustris* (MUller)
*Stagnicola (Galba) palustris,* narrow form

*Helisoma trivolvis trivolvis* (Say)
*Helisoma* cf. *H. antrosus antrosus* (Conrad)
*Gyraulus* cf. *G. vermicularis* (Gould)
*Menetus* sp.
*Physa* sp.
*Succinea haydeni* Binney
*Succinea avara* Say
*Vallonia* cf. *V. alba* Sterki
*Pupa* cf. *P. muscorum* Linnaeus

Archaeological sites also have provided other samples of Recent nonmarine mollusks in north-central Oregon. University of Oregon archaeologists have excavated material at The Dalles, Oregon, which was described by Baker (1942b). The same group of investigators collected specimens from the middle Deschutes River, Oregon. This material was made available to Ernest Roscoe (1963, 1967), who discussed the relationships of early Indians to the area to their nonmarine molluscan resources.

Malacologists have conducted few investigations on the Pacific Northwest living fauna. Several studies have been made on snails in their relationships as intermediate hosts for parasites (Pauley and Becker 1968; Macy 1952, 1956, 1960). At Washington State University a program of research was carried out on winter survival of certain pulmonate gastropods (McNeil 1959, 1960, 1961, 1963a, 1963b, 1965; McNeil and Walter 1956, 1957, 1958; Beeson 1964). During this same period *Physa* and *Lymnaea* were used in experiments on various water velocities and substrates and their effect on the distribution of snails (Moore 1964).

<u>Molluscan and Related Studies in the Lower Grand Coulee</u>

The earliest malacological work recorded from the Lower Grand Coulee was done in 1902 by R. E. Snodgrass (Pilsbry 1903), who sent specimens from Blue Lake to H. A. Pilsbry for identification and which were later deposited at Washington Agricultural College (Washington State University) and the Academy of Natural Sciences of Philadelphia. Pilsbry reported the following mollusks:

*Pyramidula strigosa* Gould
*Agriolimax campestris* Binney
*Succinea nuttalliana* Lea
*Succinea gabbi* Tryon
*Limnaea nuttalliana* Lea
*Limnaea adelinae* Tryon
*Limnaea* nr. *L. sumassi* Baird
*Planorbis trivolvis* var. *horni* Tryon
*Planorbis parvus* Say
*Physa triticea* Lea
*Pisidium compressum* Prime
*Pisidium* sp. undetermined

Extensive living and fossil molluscan collections were made in the Pacific Northwest in the 1920's by Junius Henderson (1927a, 1927b, 1928a, 1928c, 1928d, 1928e, 1929a, 1929b, 1929c, 1935, 1936b; Craig 1927). In the 1927 expedition Henderson and Eugene H. Nanney collected material from an area near Soap Lake in the Lower Grand Coulee, Washington (Henderson 1928b). Non-marine mollusks collected from the coulee floor included:

*Pisidium compressum* Prime
*Valvata humeralis californicus* Pilsbry
*Valvata utahensis* Call

*Lymnaea* nr. *L. traskii* Tryon
*Planorbis vermicularis* Gould
*Pompholyx effusa* Lea

According to the description of the locality, it was close to the primary locality of this study, L65-1 (see Appendix B). Mollusks listed above are in synonymy with those collected during this study except for *Valvata utahensis* Call, of which Henderson stated only one shell was found.[1] Henderson (1929b) also reported nonmarine molluscan material from the east side of Park Lake. These specimens were probably found very close to or at the same place as L68-8 (Fig. 1.1). These mollusks included:

*Pisidium compressum* Prime
*Pisidium* sp.
*Valvata humeralis californica* Pilsbry
*Stagnicola coulensis* Baker
*Planorbis vermicularis* Gould
*Planorbis antrosus* Conrad
*Planorbis trivolvis* Say
*Paraphyolyx effusa effusa* (Lea)
*Physa* related to P. *humerosa* Šould

All of the mollusks were observed from samples taken from L68-8 adjacent to Park Lake except *Planorbis antrosus*. He also found *Anodonta californiensis* a few hundred yards north which may correspond to the upper portion of my locality, L68-9 (Fig. 1.1). Subsequently, after having read Bretz's ideas on the origin of Grand Coulee Henderson concluded:

---

[1] Observations made on many *Valvata humeralis* (over 38,000 individuals) from deposits of Lake Bretz at L65-1, suggest that V. "*utahensis*" was only a variation of V. *humeralis*. This supports Taylor's (1966b) opinion that the shell was misidentified.

> I am not sure whether the fossils from Soap Lake District represent mollusks that lived there while the river flowed through the Coulee, or lived in a large lake after the abandonment of the Coulee by the river, but before the lakes had shrunken to their present dimensions. Certainly Soap Lake was once larger and deeper than now" (Henderson 1929b:119).

Walter Eyerdam (1943), a long time natural historian from Seattle, Washington, also made collections in the area and reported them to the Conchological Club of Southern California. Included in these fossils were:

*Anodonta californiensis* Lea
*Pisidium* sp. one valve
*Valvata humeralis californica* Pilsbry
*Stagnicola coulensis* F. C. Baker
*Lymnaea (Stagnicola) traskii* Tryon
*Planorbis (Gyraulus) vermicularis vermicularis* Gould
*Planorbis trivolvis occidentalis* Cooper
*Parapholyx effusa effusa* Lea
*Physa diaphana* Tryon

Samples of these were found in the private collection of the late Lew Livingson of Des Moines, Washington. These specimens did not have exact locality information, but were referred to Soap Lake, Grant Co., Washington.

During the past two decades several investigators have collected molluscan material from the Pleistocene deposits of Lake Bretz. Beginning in 1959, Roald Fryxell noted the occurrence of mollusks with coarse volcanic ash at Nat Cave (Sprague 1960) and subsequently collected molluscan fossils from 12 localities in Lower Grand Coulee, including L65-1, just north of Soap Lake. Some of this material was used in his report on the Glacier Peak and Mazama ash falls (Fryxell 1965). The remainder of the mollusks were made available to Larry French, geology student at Washington State University, for identification. French (unpublished manuscript, 1964, Washington State University, Pullman, Washington) identified eight species of nonmarine mollusks. The report was brief, but illustrates well the problems produced by the confusing systematic literature of freshwater mollusks.

J. W. Bingham and M. J. Grolier collected fossil mollusks from Lake Bretz deposits in 1960 within the city limits of Soap Lake. This U.S. Geological Survey collection, USGS 23222, added *Musculium lacustre* to the Lake Bretz fauna list. These two workers collected Pleistocene mollusks from several localities in eastern Washington (Appendix A).

During the Fall, 1965, two collections of nonmarine mollusks and other fossils from Lake Bretz were made; one was by Jean Mead, a student at Central Washington State College at Ellensburg and a second by myself. Mead recovered most of the same type of material as I did, but found more fish bones and a single amphibian bone. This information has not been published and was placed at Central Washington State College (oral communication, April 1968, Jean Mead, Central Washington State College, Ellensburg, Washington).

Hanna (1966) published another account of "Soap Lake" material. After my investigation of this Pleistocene-Recent collection at the California Academy of Sciences at San Francisco, the locality designation was found to be erroneous. The *Heliosoma anceps* and other mollusks collected by Olaf Jenkins did not contain any locality information. Jenkins had actually been working an area north of Riverside, Washington (letter dated March 14, 1967 from G D. Hanna, California Academy of Sciences, San Francisco, California; Jenkins 1918). Upon visiting this latter area, the locality, L67-5, at Booher Lake (NM11-10, C-8), was found to contain material similar to Jenkins' collection (see Appendix B).

Additional field work was conducted for my own studies in the Lower Grand Coulee from 1966 to 1969. During this time Lake Bretz was mapped with the aid of aerial photographs, aerial reconnaissance, and U.S. Geological Survey topographic maps, and additional mollusks from the Lake Bretz deposits were collected.

Other forms of biological studies have taken place in the Lower Grand Coulee, most of them in either Soap or Lenore Lakes. During the late 1950's investigations were conducted by W. T. Edmondson and students from the University of Washington on the modern limnology, algae, diatoms, crustaceans (Edmondson 1963).

Phytoplankton-zooplankton relationships were the subject of the earliest paper from this group (Anderson, Comita, and Engstran-Heg 1955). Anderson (1958) pursued this line of investigation and studied the diatoms of Lenore and Soap lakes. Bottom fauna of both modern lakes were found to be devoid of mollusks during a 1957 sampling (Lauer 1959). Periphytic algae including diatoms were described by Castenholz (1960a). Further work by this group included estimating the reproductive rates of the copepods from Lake Lenore. The limnology of the modern Lower Grand Coulee was reviewed in light of the above research and the dilution of the lakes caused by increasing irrigation and seepage from natural aquifers from Lake Roosevelt (Edmondson 1963).

# 5. ARCHAEOLOGICAL RESEARCH ON EARLY MAN IN EASTERN WASHINGTON

Archaeological investigations of Early Man in eastern Washington have been conducted mainly along the Snake and Columbia rivers. Cultural materials 10,000 years or more old have been found at five sites, including the Lind Coulee site only 65 km from the shore of the former Lake Bretz. Data from sites such as Lind Coulee, Marmes Rockshelter, Windust Caves, and Granite Point show that man was in eastern Washington shortly after the time of Lake Bretz and may have been present to camp at its shore. In the Lower Grand Coulee several archaeological investigations have been conducted, but no well-documented Early Man material was recovered.

## Archaeological Investigations in Lower Grand Coulee

Until 1958 most archaeological collecting in Lower Grand Coulee was done by amateurs. At this time, through the work and early reconnaissance by State Senator Nat Washington of Ephrata, money was made available by the Washington State Department of Mines for investigation of archaeological resources in the Lower Grand Coulee. Studies were conducted by Washington State University archaeological teams during the summers of 1957-1961 (Gallager 1959; Osborne 1959, 1967; Sprague 1960; Clinehans 1961; Mallory 1962). During their excavations no convincing evidence of Early Man was discovered, and most of the cultural material clearly was only a few thousand years old (Mallory 1962). Sprague (1960) described Nat Cave, located just north of Soap Lake, which contained the longest cultural sequence in the area, but included only artifacts from stratigraphic positions well above Lake Bretz sediments.

Observations made during the present study showed that many caves and rockshelters occur above the level of Lake Bretz and could have been used at the time the lake existed in the coulee. Most of these possible human habitation sites are in closely jointed basalt which has shed large amounts of rockfall due to frost wedging. Thus, in these possible Early Man sites the provenience of artifacts may be difficult to ascertain and the removal of large amounts of basaltic overburden will make excavation difficult. Additional zones of human occupation would have been available along the extensive shoreline created by Lake Bretz.

## Early Man Studies in Eastern Washington

Lind Coulee (45GR97).--Lind Coulee archaeological site near Warden, Washington is located 65 km from the southern limit of Lake Bretz, and was the first locality to yield evidence demonstrating that paleo-Indian hunters inhabited the area at least 8,700 years ago (Daugherty 1956). This site was of great importance to Early Man studies in eastern Washington for several reasons. First, it established that there were paleo-Indian sites in the area. Second, it was one of the first archaeological sites dated using the radiocarbon method (Libby 1954). Third, the interdisciplinary approach used by Daugherty at this site established a precedent for future archaeological work in the area. This approach has provided knowledge of Late Pleistocene environments and topography essential to the discovery and interpretation of other early sites in eastern Washington. Of importance in the present study are the nonmarine mollusks collected by Enbysk (1956) and geological investigations which indicated that slackwater was present in Lind Coulee before and possibly during the time of human occupation.

Excavations during 1972 and comparisons with the Marmes Rockshelter cultural sequence have provided stratigraphic evidence that this site was considerably older than 8,700 years and may predate materials found elsewhere in eastern Washington (oral communication, July 27, 1972, Roald Fryxell, Washington State University, Pullman, Washington). The first radiocarbon dates measured on material from this site were obtained using the solid carbon method (Libby 1954) and may have been less accurate than dates obtained from charcoal with newer techniques now in use. Further, the site is more complex than the single component reported by Daugherty (1956). Cultural material from at least five different surfaces of occupation have been found with numerous bones of elk, bison, and other vertebrates. In addition, bones of muskrat, beaver, and duck (Daugherty 1956) record moister conditions than existed just prior to the initiation of the Columbia Basin Irrigation Project.

<u>Marmes Rockshelter</u> (45FR50).--Marmes Rockshelter, located near the confluence of the Snake and Palouse rivers, produced a long history of occupation (Fryxell et al. 1968a; D. G. Rice 1972). The earliest cultural materials in the rockshelter and in the overbank silt of the adjacent floodplain belong to the Windust Phase of Leonhardy and D. G. Rice (1970) or the Early Phase of Daugherty (1962). Artifacts discovered included bone needles, bone points, stemmed and lanceolate projectile points, and bola stones (Fryxell et al. 1968b; D. G. Rice 1972).

In addition to the cultural information, the site provided knowledge concerning the faunal history of the area. Gustafson (1972) investigated faunal. remains from the site and found bones including those of Arctic fox, large elk, pronghorn antelope, deer, bison, rodents, and salmonid fish. These vertebrates belonged mainly to an early postglacial steppe fauna. My own study demonstrated the presence of the clams, *Anodonta californiensis, Margaritifera falcata,* and *Gonidea angulata* whose significance is discussed below.

From a geological standpoint, a chronology of the floodplain sediments adjacent to the site was developed by Marshall (1971), who considers precipitation and stream run-off to have been greater than now prior to 7,500 years ago. Frost polygons were found in the overbank silt deposits in which the early Marmes cultural material was discovered, but do not form in the area at present. Rockfall frequencies also showed that a cool moist climate was present during the time of occupation which produced the early cultural component in the site (Fryxell et al.

1968b). Thus peoples of the Windust Phase lived in a cooler and moister environment than that present today in the Marmes Rockshelter region. Lacustrine sediments were found underlying the cultural material and were related to the period of Glacier Peak eruption wince volcanic ash of similar properties was found in these sediments. Thus a maximum age of about 12,000 years was possible for human occupation of the site.

Windust Caves (45FR46).--Excavations at Windust Caves downstream on the Snake River near Windust, Washington also produced a long sequence of occupation (H. S. Rice 1965). The earliest material was thought to be 9,000 to 10,000 years old, but lack of charcoal from the site prevented accurate radiocarbon dating. Later this cultural material was found to be similar to the early components of Marmes Rockshelter and Granite Point discussed below, and later was named the Windust Phase (Leonhardy and D. G. Rice 1970).

Granite Point (45WT41).--Located on the Lower Snake River, Granite Point archaeological site produced an early cultural component thought to be 9,000 to 10,000 years old (Leonhardy 1970). Close similarities exist among cultural materials from Component 1 at Granite Point, the early artifacts of the Windust Caves and Marmes Rockshelter. Some resemblance also exists between the Granite Point early material and the Lind Coulee artifacts, although Leonhardy regards the latter to be distinct and perhaps represent an earlier period. Most cultural material from Leonhardy's Component 1 is made of stone with both stemmed and lanceolate projectile points being present. Although few faunal remains were found associated with this early cultural component, the presence of elk, beaver, and the clam, *Margaritifera falcata* suggests a diverse economy.

Early sites in adjacent regions.--Early cultural material also has been found in the Lenore site near Lenore, Idaho. D. G. Rice (1972) relates this material to the Windust Phase and other sites having the Windust type artifacts on the Snake River. Both stemmed and lanceolate projectile points, which resemble closely material from Granite Point, Marmes Rockshelter, and Windust Caves, were found. South and west of the Lower Snake River, artifacts of similar manifestations, which may be culturally related, were found at the Wildcat Canyon site in Oregon (oral communication, August 1, 1972, Frank C. Leonhardy, Washington State University, Pullman, Washington).

Mollusks and cultural sequences.--Clams and snails are good sources of material for radiocarbon dating in Early Man sites, especially if no charcoal is present in the stratum to be dated. Some problems may be encountered when using shell material, especially if the mollusks have utilized older carbon from terrestrial rather than atmospheric sources in their water or food (Rubin and Taylor 1963; Rubin et al. 1963). Exotic shells in archaeological materials may indicate early trade routes or places of origin for Early Man, as in the case of *Olivella* at Marmes Rockshelter in sediments beneath the Mazama volcanic ash layer (Fryxell and Daugherty 1962). Changes in protein sources can be demonstrated by the pelecypod remains found in Marmes Rockshelter. Cultural units below the Mazama volcanic ash layer (6,700 years ago) (Fryxell 1965) have a high incidence of *Gonidea angulata,* but post-Mazama units produced a higher number of *Margaritifera falcata.* This may have been due to changes in Early Man's food preferences, local availability of clams, or populations of another protein resource, fish. Population numbers of *Salmo* sp. which serve as an intermediate host for the glochidia of *M. falcata* or the unknown fish host of the young of *G. angulata,* may have fluctuated due to environmental stress. Whichever occurred, the result was a change in dietfor Early Man at Marmes Rockshelter.

<u>Summary of Early Man sites in Eastern Washington.--Of</u> all these sites, only Marmes Rockshelter has been extensively dated by numerous radiocarbon meesurements on shell and charcoal. The early components at Marmes yielded determinations of essentially 10,000 $^{14}C$ years B.P. (report to the U.S. Army Corps of Engineers dated 1969 from R. Fryxell and B. C. Keel, Washington State University, Pullman, Washington). Present dating of Windust Phase materials from other sites thus rests on geological estimates, a few radiocarbon dates, and comparisons of the cultural materials with those of the Marmes Rockshelter sequence. In each case, estimates of age indicate occupation about 2,200 years younger than the age of Lake Bretz.

Even though artifacts have not yet been found in Late Pleistocene sediments adjacent to the former Lake Bretz, it is possible that man was present in eastern Washington at that time. Since the lake level is now known, efforts to discover Early Man sites in the Lower Grand Coulee that are approximately 12,000 years old should be concentrated along and above 72 km of the former shoreline. Much of this shoreline can be eliminated from investigation since it lies on abrupt coulee walls. Since other Late Pleistocene lakes are known to have existed in the Columbia Basin, their sediments also should be investigated to provide meaningful data for the location of Early Man sites in this region.

# 6. PALEOENVIRONMENT, MODERN ENVIRONMENT, AND EARLY MAN NEAR THE LOWER GRAND COULEE

## Modern Situation of Lower Grand Coulee

Several lakes are found within the confines of the modern Lower Grand Coulee. Park, Blue, Alkali, Lenore, and Soap lakes are remnants of the Late Quaternary Lake Bretz. These lakes possess a salinity gradient from north to south, with Soap and Lenore being the most saline (Edmondson 1963). Sodium bicarbonate is the major dissolved constituent of lake waters at the northern end of the Lower Grand Coulee, with a progressive increase of sulfates southward until, in Soap Lake, most of the dissolved salts are sodium sulfate.

Since the construction of the Grand Coulee Dam, this area has undergone dramatic changes. Despite less than eight inches (0.20 m) annual precipitation, new springs have formed and existing lakes such as the meromictic Soap Lake have increased in size. Water from newly charged aquifers, which emanate particularly from Banks Lake, have caused not only a 27% dilution of Soap Lake from 1946 to 1955, but also would have flooded the town of Soap Lake if pumps had not been put into operation (Edmondson 1963). Lake levels in Blue and Park lakes are about 1,095 ft. (333.8 m) above sea level at the present time. Lenore and Soap lakes have a level of about 1,074 ft. (327.4 m), reflecting the gradient of subsurface drainage as modified by discharge since development of the Columbia Basin Irrigation Project.

Riparian vegetation around modern lakes is limited mainly to trees planted by man with most of these in Sun Lakes State Park and Park Lake. Lenore and Soap lakes are largely devoid of any riparian habitats. Park and Blue lakes support large stands of sedges whereas Soap and Lenore lakes do not.

Sedge habitats at these lakes support many forms of wildlife, the most obvious are waterfowl. Many types of ducks are present with Canadian geese common in the Park and Blue lake areas. Molluscan populations also are present, but the diversity of species is very small compared to that of the Lake Bretz fauna (see Appendix B). In 1968, only a few dead mollusks were found in Alkali Lake, a segment of Lake Lenore which was cut off by construction of state highway 17. These fresh shells represented *Lymnaea* gr. L. *"palustris"* and *Planorbella subcrenata* and may have been recent introductions that have not survived. Soap and Lenore lakes were sampled several times from 1966 to 1968 but no living mollusks were found. This substantiates the report by Lauer (1959) that both lakes have a very limited macrofauna. Because mollusks are absent from these three lakes, limnological conditions obviously have changes since the time of Lake Bretz when mollusks were abundant there.

*Vorticifex effusus,* a gastropod generally characteristic of highly oxygenated waters of large lakes and rivers, was found living in Delany Spring, which once would have fed directly into Lake Bretz at its northern end. Today this species appears nowhere else in the Lower Grand Coulee. Because *V. effusus* was found in deposits representing many habitats in Lake Bretz, the population in Delany Spring must be relict, representing only a remnant which existed in the coulee when an extensive perennial lake or river was present. The isolated population has persisted because the spring duplicated the limnological conditions necessary for its survival. Thus *V. effusus* provides a clear indication of the great environmental change which has followed since its initial appearance in the Lower Grand Coulee.

## Geological History of Lower Grand Coulee

As uplift of the Cascade Range progressed during Plio-Pleistocene time, climate of the Columbia Basin changed because the rain shadow effect developed gradually resulting in decreased precipitation to the east (Smiley 1963). Deformation of the basalt flows in the Columbia Basin occurred simultaneously producing the Saddle Mountains, Frenchman Hills, and the Coulee Monocline (Bretz 1932).

The geological event that eventually led to formation of the Lower Grand Coulee was growth of the Pleistocene Cordilleran ice sheet (Flint 1937). Portions of this ice sheet blocked the Columbia River (Richmond et al. 1965). The Pend Oreille lobe dammed the Clark Fork of the Columbia River in Montana and impounded Glacial Lake Missoula. Because the Okanogan lobe of the same ice sheet advanced across the Columbia at the present site of Grand Coulee Dam, the Columbia River was diverted southwest through the area of the Coulee Monocline (Bretz 1932). The new channel did not gain its present size until a series of three to five catastrophic floods occurred as the Pend Oreille ice dam collapsed repeatedly. These deflected floods quickly eroded the Coulee Monocline, a structurally weak point in the Columbia River basalts. One of these floods might have been as early as pre-Bull Lake glaciation, but the largest and last catastrophic flood is estimated to have occurred about 18,000 to 20,000 years ago (Richmond et al. 1965). The cumulative result of these floods and glacial meltwaters diverted into the area north of Soap Lake was a recessional cataract gorge, the Grand Coulee (Bretz 1932).

After the last catastrophic flood the Lower Grand Coulee may have been filled by the still-diverted Columbia River. If so, there was sufficient water to keep its bedload in motion and to remove parts of the talus from the coulee walls. In slackwater areas of the river, some fauna and flora could have repopulated the coulee after the last flood. Once the Okanogan lobe of the glacier had retreated north of the Columbia Canyon, the river resumed its original course along the border of the Columbia River basalt (Bretz 1932; Flint 1937; Richmond et al. 1965). With the lack of inflow from the Columbia River the Lower Grand Coulee became first a single large lake and later a series of smaller lakes. Silt deposited as the discharge through the coulee decreased may have helped to seal gravel bars at the southern margins of the Lower Grand Coulee. Static ponding probably occurred in other parts of the Columbia Basin because lacustrine sediments, including two or more bands of volcanic ash containing the mineral cummingtonite, have been found at Vantage and other adjacent areas (Fryxell 1972a), sometimes in association with nonmarine molluscan shells.

By 12,000 years ago, the Cordilleran ice masses had retreated to the Canadian border in eastern Washington (Fryxell 1965). Aquifers in the basalt evidently still supplied a considerable volume of water to Grand Coulee. This water was able to maintain a large lake in the Lower Grand Coulee until the depth of the Columbia River was lowered enough to reduce the number of aquifers available. This lake, Lake Bretz, supported large populations of ostracods, fish, and mollusks.

Deposits of the former shoreline sediments of Lake Bretz were exposed by a newly constructed Bureau of Reclamation canal southeast of Soap Lake (SE 1/4 Sec. 30, T.22N, R.27E) (Fig. 6.1). Lacustrine sediments with nonmarine mollusks occur at elevations up to 1,159±1 ft. (353.3 m). At 353.3 m to 353.6 m these sediments grade into beach sands which contain a few mollusk shells in *situ.* At its southern end, Lake Bretz drained through Rocky Ford Coulee into a precursor to Moses Lake (Bretz et al. 1956). When most springs ceased to function, the size of Lake Bretz was reduced and it became an internal drainage basin because less than 0.20 m annual precipitation could not maintain the lake level at an elevation as high as 353.3 m. Thus the lakes in Lower Grand Coulee evolved, and today are maintained by small natural springs and limited precipitation. Because the coulee became an internal drainage system, dissolved salts accumulated at the lower end of the basin until Soap and Lenore lakes became highly saline.

<u>Faunal Analysis of Lake Bretz Sediments</u>

Interpretation of the Lake Bretz fossil nonmarine mollusks from L65-1 was based on both qualitative and quantitative data (Table 6.1). This was possible due to the large numbers of articulated pelecypod and complete gastropod shells in the stratigraphic section below Unit "B." Former environments may be reconstructed with confidence using the total assemblage rather than employing one or two species. Habitat and distributional statements are based on field work done by either Dwight W. Taylor or myself in western North America. Many ideas regarding distribution and habitat have come from unpublished data and conversations with Taylor. Statements concerning the Sphaeriidae are based on Herrington's (1962) investigations. Accurate quantitative data was obtained to give each species a proper perspective relative to the total assemblage. Nonmarine mollusks identified from the collections made at L65-1 are:

*Anodonta californiensis* Lea 1852
*Pisidium casertanum (Pon* 1791)
*Pisidium compressum* Prime 1852
*Pisidium idahoense* Roper 1890
*Pisidium lilljeborgi* Clessin 1886
*Pisidium nitidium* Jenyns 1832
*Pisidium variabile* Prime 1852
*Valvata humeralis* Say 1829
*Lymnaea stagnalis appressa* Say 1818
*Lymnaea* cf. *L. binneyi* Tryon 1865
*Lymnaea* gr. *L. "palustris"*
*Gyraulus parvus* (Say 1816)
*Armiger crista* (Linnaeus 1758)

TABLE 6.1.--Number [illegible] stratigraphic [illegible]

| T[illegible] | Stratigraphic U[illegible] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | TOTAL |
| **F[illegible] S[illegible]** | | | | | | | | | | |
| *Anodonta californiensis* L[illegible] | ... | ... | 8 | 12 | 7 | 4 | 4 | 7 | 8 | 50 |
| *Pisidium* spp. | 57 | 492 | 5,380 | 7,247 | 4,997 | 3,949 | 3,585 | 3,902 | 1,973 | 31,582 |
| *Valvata humeralis* Say | 149 | 498 | 3,798 | 7,090 | 6,102 | 5,438 | 3,884 | 3,817 | 1,058 | 31,834 |
| *Lymnaea stagnalis appressa* Say | ... | ... | 25 | 106 | 75 | 52 | 11 | 26 | 3 | 298 |
| *Lymnaea* [illegible]. *L. binneyi* T[illegible] | ... | ... | 3 | 5 | 4 | 4 | 2 | 2 | 1 | 21 |
| *Lymnaea "palustris"* | 6 | 13 | 208 | 556 | 409 | 458 | 123 | 194 | 45 | 2,012 |
| *Gyraulus parvus* (S[illegible]) | 30 | 161 | 2,408 | 4,428 | 3,686 | 2,980 | 1,360 | 1,813 | 385 | 17,251 |
| *Armiger crista* (L[illegible]) | ... | ... | 29 | 529 | 615 | 465 | 53 | 89 | 1 | 1,781 |
| *Vorticifex effusa* (L[illegible]) | 1 | 2 | 39 | 33 | 12 | 8 | 12 | 4 | 4 | 115 |
| *Planorbella subcrenata* C[illegible]) | ... | 1 | 20 | 67 | 77 | 29 | 2 | ... | ... | 196 |
| *Physa gyrina* S[illegible] | ... | ... | 16 | 34 | 21 | 13 | 15 | 13 | 3 | 115 |
| **T[illegible] S[illegible]** | | | | | | | | | | |
| *Zonitoides arboreus* (Say) | ... | ... | ... | ... | 1 | ... | ... | ... | ... | 1 |
| *Discus cronkhitei* (N[illegible]) | ... | ... | ... | ... | ... | ... | ... | 1 | ... | 1 |
| cf. *Succinea* | ... | ... | .. | 2 | ... | ... | ... | 2 | 5 | 9 |
| TOTAL | 243 | 1,167 | 11,934 | 20,109 | 16,006 | 13,400 | 9,051 | 9,870 | 3,486 | 85,266 |

*Vorticifex effusus* (Lea 1856)
*Planorbella subcrenata* (Carpenter 1842)
*Physa gyrina* Say 1821
*Zonitoides arboreus* (Say 1816)
*Discus cronkhitei* (Newcomb 1865)
cf. *Succinea*

Of primary interest are three genera: *Pisidium, Valvata,* and *Gyraulus,* which make up over 90% of the total sample of each unit at L65-1 (Table 6.2). *Pisidium* is represented by six species; not all of the over 62,000 valves were identified individually. *Pisidium castertanum* and *P. compressum* are adapted to a variety of habitats, so are not very useful in the total reconstruction. Generally, a perennial lake or river is indicated by *P. variabile* and *P. nitidium,* but more specifically, the shallow areas of these waters. *Pisidium lilljeborgi* has a preference for fine sand bottoms in perennial lakes with small submergent vegetation. Most revealing is *P. idahoense,* which is characteristic of cool water habitats in large lakes.

The next most abundant genus is *Valvata,* which makes up over 30% of the mollusks from each unit. Living *V. humeralis* has been found most commonly in slower velocity areas of clear water lakes and streams, at the base of aquatic vegetation. *Gyraulus parvus* also has been found most often on submergent vegetation in lakes or slackwater areas of streams. This latter gastropod made up from 11% to 23% of each sample. *Armiger crista,* found most often on submergent aquatic vegetation in lakes and ponds with quiet water, was present in lesser numbers, possibly due to their small size and loss of individuals during separation from the

TABLE 6.2.--Relative [illegible] stratigraphic [illegible]

| U[illegible] | Stratigraphic U[illegible] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | | | | | | | | |
| **F[illegible] S[illegible]** | | | | | | | | | |
| *Anodonta californiensis* L[illegible] | | ... | 0.07 | 0.06 | 0.04 | 0.03 | 0.04 | 0.08 | 0.23 |
| *Pisidium* spp. | 23.46 | 42.16 | 45.08 | 36.04 | 31.22 | 29.48 | 39.60 | 39.53 | 56.59 |
| *Valvata humeralis* Say | 61.31 | 42.67 | 31.83 | 35.26 | 38.12 | 40.58 | 42.91 | 38.67 | 30.34 |
| *Lymnaea stagnalis appressa* S[illegible] | | ... | 0.21 | 0.53 | 0.47 | 0.39 | 0.12 | 0.26 | 0.09 |
| *Lymnaea* [illegible]. *L. binneyi* T[illegible] | | ... | 0.04 | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 | 0.03 |
| *Lymnaea* "*palustris*" | 2.47 | 1.11 | 1.77 | 2.79 | 2.58 | 3.45 | 1.38 | 1.99 | 1.32 |
| *Gyraulus parvus* (S[illegible]) | 12.35 | 13.80 | 20.17 | 22.02 | 23.03 | 22.24 | 15.02 | 18.36 | 11.04 |
| *Armiger crista* (L[illegible]) | | ... | 0.24 | 2.63 | 3.84 | 3.47 | 5.86 | 0.90 | 0.03 |
| *Vorticifex effusa* (L[illegible]) | 0.41 | 0.17 | 0.33 | 0.16 | 0.07 | 0.06 | 0.13 | <0.00 | 0.11 |
| *Planorbella subcrenata* (C[illegible]) | | 0.09 | 0.17 | 0.33 | 0.48 | 0.22 | 0.02 | ... | |
| *Physa gyrina* S[illegible] | ... | | 0.13 | 0.17 | 0.13 | 0.10 | 0.16 | 0.13 | 0.09 |
| **T[illegible] S[illegible]** | | | | | | | | | |
| *Zonitoides arboreus* (Say) | ... | ... | ... | ... | 0.01 | ... | ... | ... | ... |
| *Discus cronkhitei* (N[illegible]) | ... | ... | ... | ... | ... | ... | ... | <0.00 | |
| cf. *Succinea* | ... | ... | ... | 0.01 | ... | ... | ... | 0.02 | 0.14 |
| TOTAL | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

matrix. *Lymnaea* gr. *L. "palustris,"* which is characteristic of ponds and backwater areas of streams, comprised 1% to 3% of each sample. Mollusks which make up a total of less than 1% of each sample are important for the total reconstruction of the environment of Lake Bretz. They include the freshwater species: *Anodonta californiensis, Lymnaea stagnalis appressa, Lymnaea* cf. *L. binneyi, Vorticifex effusus, Planorbella subcrenata,* and *Physa gyrina.* The terrestrial snails, *Discus cronkhitei, Zonitoides arboreus,* and cf. *Succinea* also were present. The land species indicate that a terrestrial environment was near the primary locality. The same five species were found at two other localities, L68-8 and L68-9. In addition, *Musculium lacustre* (Müller 1774) was found in sediments of Lake Bretz at locality L68-16 at Blue Lake and at U.S. Geological Survey locality 23222 just north of the town of Soap Lake. Samples suitable for quantitative analysis were not removed from L68-8 or L68-9, but *A. californiensis, L.* cf. *binneyi,* and *V. effusus* were judged to be relatively abundant compared to the L65-1 populations. Additionally, individuals were larger and had thicker shells than mollusks at the primary locality. These three species are more indicative of open water with some current as in the deeper portions of a large perennial lake or river. Topographically, these two localities adjacent to Park Lake represent the middle of Lake Bretz. Articulated *A. californiensis* valves were found in large numbers on a basalt knob at locality L68-9. This concentration might have been due to spawning of their glochidial host, *Gila* sp. or another fish host (D'Eliscu 1972) in this area.

Alternatively, natural eddying of the water behind the basalt knob may have provided a sedimentation point for the glochidia.

Stratigraphic variation from one sample to another at the primary locality shows slight changes in percentage of species present (Table 6.2). All species of freshwater mollusks were represented at each unreworked level except *Planorbella subcrenata* which did not occur in units "H" and "I." This snail was not found in large quantities in any units (Table 6.1), so its absence probably does not reflect environmental change. Sampling bias or delayed dispersal into the lake fauna might account for its absence in the lower sediments. Quantitative differences in molluscan assemblages were apparent in the stratigraphic sequence. Layer "A" and "B" were not considered since they represented reworked materials. The presence of articulated clam shells below layer "B" was considered to indicate unreworked deposits of fossils. The lowest unit sampled (unit "I") contained 3,486 individual mollusks. Units deposited subsequently show an over-all increase in freshwater molluscan populations as the lake matured until unit "D." The overlying sample from unit "C" shows an overall decrease in the percentages of mollusks in relation to those present in "D" (Table 6.3).

As inferred from these mollusks, Lake Bretz offered several types of freshwater habitats. The primary locality represented a perennial slackwater littoral area with little or no current. This was partially due to the gravel bar which surrounds the locality, creating what would have been a small, protected embayment in a larger lake. Submergent vegetation was

TABLE 6.3.--Relative [illegible] stratigraphic [illegible]

| T[illegible] | Stratigraphic U[illegible] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | TOTAL |
| **F[illegible] S[illegible]** | | | | | | | | | | |
| *Anodonta californiensis* L[illegible] | .. | .. | 16.00 | 24.00 | 14.00 | 8.00 | 8.00 | 14.00 | 16.00 | 100.00 |
| *Pisidium* spp. | 0.18 | 1.56 | 17.04 | 22.95 | 15.82 | 12.50 | 11.35 | 12.36 | 6.25 | 100.00 |
| *Valvata humeralis* S[illegible] | 0.47 | 1.56 | 11.93 | 22.27 | 19.17 | 17.08 | 12.20 | 11.99 | 3.32 | 100.00 |
| *Lymnaea stagnalis appressa* Say | .. | | 8.39 | 35.56 | 25.17 | 17.45 | 3.69 | 8.72 | 1.01 | 100.00 |
| *Lymnaea* [illegible]. *L. binneyi* T[illegible] | .. | | 14.31 | 23.80 | 19.10 | 19.10 | 9.54 | 9.54 | 4.76 | 100.00 |
| *Lymnaea "palustris"* | 0.30 | 0.64 | 10.38 | 27.59 | 20.31 | 22.73 | 6.15 | 9.64 | 2.26 | 100.00 |
| *Gyraulus parvus* (Say) | 0.17 | 0.93 | 13.96 | 25.67 | 21.37 | 17.27 | 7.88 | 10.51 | 2.23 | 100.00 |
| *Armiger crista* (L[illegible]) | .. | .. | 1.63 | 29.70 | 34.53 | 26.11 | 2.98 | 5.00 | 0.06 | 100.00 |
| *Vorticifex effusa* (L[illegible]) | 0.87 | 1.74 | 33.91 | 28.70 | 10.43 | 6.96 | 10.43 | 3.48 | 3.48 | 100.00 |
| *Planorbella subcrenata* (C[illegible]) | .. | 0.51 | 10.20 | 34.18 | 39.29 | 14.80 | 1.02 | .. | .. | 100.00 |
| *Physa gyrina* Say | .. | .. | 13.91 | 29.57 | 18.26 | 11.30 | 13.04 | 11.30 | 2.61 | 100.00 |
| **T[illegible] S[illegible]** | | | | | | | | | | |
| *Zonitoides arboreus* (Say) | .. | .. | .. | .. | 100.00 | .. | .. | .. | .. | 100.00 |
| *Discus cronkhitei* (N[illegible]) | .. | .. | .. | .. | .. | .. | .. | 100.00 | •. | 100.00 |
| [illegible]. *Succinea* | .. | .. | .. | 22.22 | •. | .. | .. | 22.22 | 55.55 | 100.00 |

present in two major portions of the water. Abundant remains of the pond weed, *Chara* sp., were found in the Lake Bretz sediments at L65-1 during this study.

Not all of Lake Bretz was made up of these backwater zones. Mollusks from other localities, L68-8 and L68-9 at the margins of Park Lake, represent habitats of open water with some flow. This same situation was repeated at L68-111 at the outflow of Lake Bretz south of Soap Lake. *Pisidium idahoense* and the snail fauna found here imply cool perennial water and fairly good circulation.

Water flowed into the Lower Grand Coulee from springs situated along its course. Outflow was into Rocky Ford Coulee and south to a precursor of Moses Lake. Additional circulation in the lake was provided by strong southwesterly winds blowing across and up the Lower Grand Coulee, probably accounting for the greater shell concentration at the east rather than west wall of the coulee. Freshwater mollusks probably were transported into the Lower Grand Coulee when the Columbia River was diverted by glacial ice. Additional introductions could have been made by birds and fish. As Lake Bretz matured, molluscan populations increased in size. When the sources of the water were cut off, many habitats ceased to be available and molluscan populations became extinct locally as the lake receded. In addition, many local faunas may have been eliminated directly through the immediate physiological effects of large quantities of volcanic ash. Lack of water circulation also decreased the number of suitable habitats for mollusks. Water from remnant lakes such as

Soap and Lenore became highly saline, eliminating the remainder of the fauna. A few species such as *Gyraulus parvus* were able to maintain populations in the less brackish lakes.

Lake. Bretz, at the elevation of about 353.3 m, existed more than 33 years, but less than a few hundred years according to estimates based on the populations and size of the mollusks at the primary locality L65-1, particularly *Anodonta californiensis.* Individuals of this particular pelecypod were found to be 3 to 5 years old in units "C" through "I." Thus with seven units, each containing five year old individuals, the minimum age of the lake would be 35 years. Below the units sampled lie about three meters more of the material. Assuming similar rates of deposition for these lower sediments, a minimum age of about 100 years is inferred. The primary locality may, however, have provided a misleading impression of lake age due to variation in the sedimentary history of the area. For example, the lower portion of the section was not sampled and little is known of its characteristics, and an undetermined thickness has been removed from the top by erosion. Deposition of sediments high in the section may have occurred rapidly because Glacier Peak volcanic ash was contained within all units. Samples of Glacier Peak volcanic ash from this locality were able to float on the surface of water for 24-48 hours before becoming waterlogged, as shown by use of this property in separation of faunal samples. Thus during initial fallout and times when it may have been washed from the coulee walls, quantities of ash probably were wind driven into the embayment and deposited rapidly. Even with allowance for all variables, Lake Bretz was a short term phenomenon in geological time.

Water quality of Lake Bretz must have been considerably different than that of the modern Soap and Lenore lakes to permit growth of the molluscan populations recorded by fossil shells. Molluscan populations of this type usually inhabit natural waters with low concentrations of sodium or calcium bicarbonate. Sodium sulfate brines like those found in Soap or Lenore lakes usually do not support molluscan populations, except for an occasional euryhaline species. Water temperatures appear to have been a few degrees cooler than they are in the modern lakes. Because most of the inflow into Lake Bretz was from springs between basalt layers, the annual temperatures of these feeder springs probably was fairly constant. There is no evidence that the local basalt flows were being heated from geothermal sources or that glaciers were contributing cold water directly to the lake. Rock temperatures therefore would have been maintained by the prevailing regional climate. Thus lower water temperatures inferred from fossil assemblages probably resulted from a climate cooler than present.

Fossil fish bones found in Lake Bretz deposits represented members of the Cottidae and Cyprinidae (oral communication, 1966, W. J. Follett, California Academy of Sciences, San Francisco, California). Further work is needed to complete the list of fish fauna. Fossilized bones of a duck also were found in deposits adjacent to Park Lake, at locality L68-8. Anurans were present in Lake Bretz too, as evidenced by the fossil found by Jean Mead at the primary locality.

Delorme identified some of the ostracods found in the Lake Bretz sediment (letter dated April 14, 1967 from L. D. Delorme, Department of Energy, Mines, and Resources, Calgary, Alberta). Two species found, *Candona acuminata* (Fischer 1851) and *Cypria opthalmica* (Jurine 1820) represented a relatively cold water environment. The total assemblage of ostracods was interpreted as reflecting a littoral area of a calcium bicarbonate lake. From unit "I" Delorme identified two additional species, *Ilyopyris bradi* Sars 1890 and *I. gibba* (Ranidohr 1808) which represented a fluvial element, perhaps suggesting that in the early history of the backwater area at L65-1 there was greater current. Later, as sediments built up, especially from the Glacier Peak ashfall, currents in the area may have been restricted.

In summary Lake Bretz resulted from geologic events related to conditions of glaciation, without which, it could not have existed. Therefore presence of the lake basically is related to the Pleistocene climate. In addition, it provided an important environmental resource which is no longer available in the area in that form or magnitude. If Lake Bretz had existed over a long period of time, it might have included episodes of fluctuation in the water level, thus providing a greater variety of habitats for more species of both freshwater and terrestrial mollusks. All evidence, however, suggests that the lake existed only for a short period of geologic time.

Cultural Implications of Lake Bretz Aquatic Resources

Sediments of Lake Bretz offer several lines of evidence useful to prehistorians as indications of conditions in central Washington 12,000 years ago. Since the Lower Grand Coulee was scoured by floods 18,000 to 20,000 years ago, archaeological material found in the coulee must be younger than these floods. Older cultural material, if present in the area, would have been scattered or destroyed by the floods unless located above the flood level. Cultural materials that are approximately 12,000 years old would be found at or above the shorelines of Lake Bretz. Man, if present, could not have established camps with long continuous occupation on the shores of Lake Bretz because the lake may have existed only a few hundred years. Thus early cultural material should not be expected to have extensive range in time. This may have been true also of other lakes in the Columbia Basin during late glacial time. Additional work is needed to map these Late Quaternary lakes and to correlate them using associated volcanic ash layers and other information (Fryxell 1972a).

Even though these large lakes may have been short term events in geological time, they surely would have influenced Early Man if he was present in eastern Washington. For example, these lakes, including Lake Bretz, would have provided many advantages to the early inhabitants of the area for water would have been more available than at present. With more water, man may have been able to exploit a larger portion of his surrounding environment. Sedges growing at the margins of Lake Bretz would have provided raw materials useful for mats and baskets. Trees growing on the shoreline also could have been used as a natural resource.

Lake Bretz additionally provided habitats for fauna, which included both fish and freshwater pelecypods. Even though no identifiable *Gila* sp. remains were found the presence of *Anodonta californiensis* indicated that this chub probably was present. In other inland areas, river mussels were widely used as part of the aboriginal diet, but other than *A. californiensis*, Lake Bretz apparently lacked this resource.

Game animals certainly used this lake for water and nearby vegetation as a food resource. Birds, such as the fossil duck found at L68-8, inhabited the area at least seasonally. Man could have exploited these protein sources for meat, bone, hides, and eggs.

## Summary of the Late Quaternary of Lower Grand Coulee

The Lower Grand Coulee has had a long history reflecting geologic and climatic events in the region. Analysis of fauna, comprised primarily of mollusks found in sediments of Lake Bretz, has provided information on the Late Quaternary environment of the Lower Grand Coulee. This information leads to the following conclusions:

1. Lake Bretz existed about 12,000 years ago, with a shoreline elevation at about 353.3 m in the Lower Grand Coulee, Washington.

2. The lake supported abundant populations of mollusks and fish. Aquatic vegetation, birds, and anurans also were present.

3. Faunal remains from sediments of the lake indicate that the necessary aquatic habitats were available in Lake Bretz during this time.

4. The Lake Bretz fauna probably evolved from animals already present in the Columbia River drainage during late glacial time, and were introduced into the Lower Grand Coulee when the Columbia was diverted into Grand Coulee by glacial ice.

5. Man, if present during the period of Lake Bretz, could have used a variety of natural resources related to the lake for maintaining his existence.

6. Search for evidence of Early Man in the area should include careful examination of the potential occupation sites, including both rockshelters and open sites along and above the shoreline.

7 Lake Bretz reduced in size when the majority of the natural basalt aquifers were cut off as the glacial ice disappeared. Increasing salinity in remnant lakes of the Lower Grand Coulee caused most of the macrofauna from Lake Bretz to die, and gradually the salinity gradient which marks the chain of modern relict lakes developed.

8 Based on geological, biological, and limnological evidence, Lake Bretz lasted at least 35 years and as many as a few hundred years, but was a short lived phenomenon in the geologic history of the Columbia Basin.

# REFERENCES

Abbott, R. Tucker. 1962. Historical notes on the American Journal of Conchology. Sterkiana. 6:1-4.

Allen, Don and E. P. Cheatum. 1961a. A Pleistocene molluscan fauna near Byers, Clay County, Texas. J. Grad. Res. Center. 29(3):137-169.

Allen, Don and E. P. Cheatum. 1961b. Ecological implications of freshwater and land gastropoda in Texas archaeological studies. Bull. Texas Archeol. Soc. 31:291-316.

Allison, Ira S. 1952. Dating of pluvial lakes in the Great Basin. Amer. J. Sci. 25:907-909.

Anderson, G. C. 1958. Seasonal characteristics of two saline lakes in Washington. Limno. Oceanogr. 3:51-68.

Anderson, G. C., G. W. Comita, and Verna Engstran-Heg. 1955. A note on the plytoplankton-zooplankton relationship in two lakes in Washington. Ecology. 36:757-759.

Antevs, Ernst. 1962. Late Quaternary climates in Arizona. Amer. Antiquity. 28:193-198.

Aschmann, Homar. 1958. Great basin climates in relation to human occupance. Rep. Univ. Calif. Archeol. Surv. 42:23-40.

Baird, W. 1863. Description of some new species of shells, collected at Vancouver, Island and British Columbia by J. K. Lord, Esq., naturalist to the British-American Boundary Commission in the years 1858-1862. Proc. Zool. Soc. London. 1863:66-71.

Baker, F. C. 1911. The Lymnaeidae of North and Middle America, recent and fossil. Chicago Acad. Sci. Spec. Pub. 3, 539 pp.

Baker, F. C. 1913. *Galba ferruginea* in Oregon. Nautilus. 27:24.

Baker, F. C. 1914. Northern Idaho shells. Nautilus. 27:104-106.

Baker, F. C. 1920. The life of the Pleistocene or Glacial period as recorded in the deposits laid down by the great ice sheets. Univ. Ill. Bull. 17(41):1-476.

Baker, F. C. 1921. The importance of ecology in the interpretation of fossil faunas. Ecology. 2:277-280.

Baker, F. C. 1927. Description of a new species of *Lymnaea* from British Columbia. Nautilus. 41:23-24.

Baker, F. C. 1928a. The fresh water Mollusca of Wisconsin, Gastropoda. Wisc. Geol. Natur. Hist. Surv. 70(1):1-507.

Baker, F. C. 1928b. The fresh water Mollusca of Wisconsin, Pelecypoda. Wisc. Geol. Natur. Hist. Surv. 70(2):1-495.

Baker, F. C. 1930a. A review of our present knowledge concerning the character and distribution of the Pleistocene aquatic molluscan life of Illinois. Trans. III. State Acad. Sci. 22:411-434.

Baker, F. C. 1930b. Influence of the glacial period in changing the character of the molluscan fauna of North America. Ecology. 11:469-480.

Baker, F. C. 1930c. The variations of molluscan life during Pleistocene and Recent times. Nautilus. 44:21-24.

Baker, F. C. 1936. Quantitative examination of molluscan fossils in two sections of Pleistocene loess in Illinois. J. Paleontol. 10:72-76.

Baker, F. C. 1937. Pleistocene land and fresh water Mollusca as indicators of time and ecological conditions. Pages 67-75 in George Grant MacCurdy, ed. Early man. J. P. Lippincott Co. Philadelphia.

Baker, F. C. 1941. New race of *Parapholyx effusa.* Nautilus. 55:16-17.

Baker, F. C. 1942a. A new *Gyraulus* from the Pleistocene of California and a new *Parapholyx* from a supposed Pliocene deposit in Oregon. Nautilus. 55:130-132.

Baker, F. C. 1942b. Mollusca contained in the test pit deposits. Pages 117-119 in L. S. Cressman, Archaeological Researches in the Northern Great Basin. Carnegie Inst. Wash. 538.

Baker, F. C. 1945. The Mollusca family Planordidae; Univ. Ill. Press. Urbana, Ill. 530pp.

Baker, F. C. and Junius Henderson. 1933. A new *Stagnicola* from Montana. Nautilus. 47:30-32.

Baker, Victor R. 1971. Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington. Ph.D. Thesis. University of Colorado (Libr. Cong. Card No. Mic. 71-25,803). 245pp. University Microfilms, Ann Arbor, Mich. (Diss. Abstr. 32:2228-2229.)

Baker, Victor R. 1973. Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington. Geol. Soc. Amer. Spec. Paper. 144. in press.

Beeson, Roberta J. 1964. Some effects of light and temperature upon *Physa propinqua* Tryon, 1865. M.S. Thesis. Washington State University. 47 pp.

Berry, S. Stillman. 1947. A new *Pyrgulopsis* from Oregon. Nautilus. 60:76-78.

Berry, S. Stillman. 1948. A noteworthy molluscan faunule from northeastern Washington. Amer. Midland Naturalist. 39:721-727.

Binney, W. G. 1859. Checklist of the shells of North America, terrestrial and fluviatile. Smithsonian Misc. Coll., 2nd edition. 128. 2(7):1-13.

Binney, W. G. 1885. A manual of American land shells. Bull. U. S. Nat. Mus. 28. 528 pp.

Bradley, W. H. 1963. Paleolimnology. Pages 621-652 in David G. Frey, ed. Limnology of North America. Univ. Wisc. Press. Madison, Wisc.

Bretz, J Harlen. 1923a. Glacial drainage on the Columbia Plateau. Geol. Soc. Amer. Bull. 34:573-608.

Bretz, J Harlen. 1923b. The channeled scablands of the Columbia Plateau. J. Geol. 31:617-649.

Bretz, J Harlen. 1925. The Spokane flood beyond the channeled scabland. J. Geol. 33:86-115, 236-259.

Bretz, J Harlen, 1928a. Bars of channeled scabland. Geol. Soc. Amer. Bull. 39:643-702.

Bretz, J Harlen. 1928b. Channeled scabland of eastern Washington. Geol. Rev. 18:446-477.

Bretz, J Harlen. 1928c. Alternative hypothesis for channeled scabland. J. Geol. 36:193-223, 312-341.

Bretz, J Harlen. 1932. The Grand Coulee. Amer. Geograph. Soc. Spec. Pub. 15. 89 pp.

Bretz, J Harlen. 1959. Washington's channeled scabland. State Wash., Div. Mines Geol. Bull. 45. 55pp.

Bretz, J Harlen. 1969. The Lake Missoula floods and the channeled scabland. J. Geol. 77:505-543.

Bretz, J Harlen, H. T. U. Smith, and G. D Neff. 1956. Channeled scabland of Washington; new data and interpretations. Geol. Soc. Amer. Bull 67:957-1047.

Bright, Robert C. 1963. Pleistocene lakes Thatcher and Bonneville, southeastern Idaho. Ph.D. Thesis. University of Minnesota (Libr. Cong. Card No. Mic. 63-7,912). 363 pp. University Microfilms, Ann Arbor, Mich. (Diss. Abstr. 25:2440)

Brown, Randall E. 1970. Some suggested rates of deformation of the basalts in the Pasco Basin, and their implications. Pages 179-187 in Ernest H. Gilmour and Dale Stradling, eds. Proc. Second Columbia Basalt Symposium, Eastern Washington State College Press. Cheney, Wash.

Bryan, Alan Lyle and Ruth Gruhn. 1964. Problems relating to the neothermal climatic sequence. Amer. Antiquity. 29:307-315.

Butler, B. Robert. 1958. Ash Cave (45-WW-61), A preliminary report. Wash. Archaeologist. 2(12):3-10.

Byers, H. G. 1902. The water resources of Washington potable and mineral. Wash. Geol. Survey Ann. Reports. 1905(5):1-11.

Caldwell, Warren W. and Oscar L. Mallory. 1967. Hells Canyon archeology. Smithsonian Institution River Basin Surveys Publications in Salvage Archeology. 6:1-153.

Call, R. Ellsworth. 1884. On the Quaternary and Recent Mollusca of the Great Basin with descriptions of new forms. U. S. Geol. Surv. Bull. 11:13-66.

Carpenter, Philip Pearsall. 1857. Monograph of the shells collected by T. Nuttall, Esq., on the Californian coast, in the years 1834-5. Proc. Zool. Soc. London. 24:209-229.

Castenholz, R. W. 1960a. Seasonal changes in the attached algae of fresh and saline lakes in the Lower Grand Coulee, Washington. Limnol. Oceanogr. 5:1-28.

Castenholz, R. W. 1960b. The algae of saline and freshwater lakes in the Lower Grand Coulee, Washington. Res. Studies Wash. State Univ. 28:125-155.

Chatters, Roy M. 1968. Washington State natural radiocarbon measurements 1. Radiocarbon. 10:479-498.

Cheatum, E. P. and Don Allen. 1964. Limitations in paleo-ecological reconstruction utilizing date from fossil non-marine molluscs. Pages 31-33 in James J. Hester and James Schoenwetter, eds. The reconstruction of past environments. Fort Burgwin Res. Center. 3.

Cheatum, E. P. and Don Allen. 1966. Ecological significance of the fossil freshwater and land shells from the Domebo mammoth kill site. Pages 36-43 in Frank C. Leonhardy, ed. Domebo, a paleo-Indian mammoth kill in the praire-plains. Contrib. Mus. Great Plains. 1.

Clarke, Arthur H., Jr. 1968. Zoogeographic and evolutionary patterns in northern Lymnaeidae and Planorbidae. Ann. Rep. Amer. Malacol. Union. 34:21-22 (Abstr.).

Clarke, G. R., III. 1968. Mollusk shell: Daily growth lines. Science. 161:800-802.

Clarke, William T., Jr. 1938. The occurrence of flints and extinct animals in pluvial deposits near Clovis, New Mexico. Part VII,--Pleistocene mollusks from Clovis gravel pit and vicinity. Proc. Acad. Natur. Sci. Philadel. 90:111-121.

Clench, William James. 1940. *Pyrgulopsis nevadensis* Stearns in Oregon. Nautilus. 39:71.

Clinehens, S. S. 1961. Further archaeological excavations in the Lower Grand Coulee of central Washington. Wash. State Univ., Lab. Archaeol. Geochronol. Rep. Invest. 7, 73 pp.

Conrad, Timothy Abbott. 1857. Descriptions of the fossil shells. U. S. War Dept. Pacific Railroad Surveys. 5(2):317-329.

Craig, Elberta L. 1927. Some mollusks and other invertebrates from the Northwest. Univ. Colo. Studies. 16:63-74.

Dall, W. H. 1905. Land and fresh water mollusks. Harriman Alaska Expedition. 13, 171 pp.

Daugherty, Richard D. 1952. Archaeological investigations of O'Sullivan Reservoir Grant County, Washington. Amer. Antiquity. 17:352-359.

Daugherty, Richard D. 1956. Lind Coulee Proc. Amer. Phil. Soc. 100:223-278.

Daugherty, Richard D. 1962. The intermontane western tradition. Amer. Antiquity. 28:144-150.

D'Eliscu, Peter N. 1972. Observations cf the glochidium, metamorphosis, and juvenile of *Anodonta californiensis* Lea, 1857. Veliger. 15:57-58.

Delorme, L. Denis. 1967a. New freshwater Ostracoda from Saskatchewan, Canada. Can. J. Zool. 45:357-363.

Delorme, L. Denis. 1967a. Freshwater Ostracoda synonyms. Paleontol. 41:792-794.

Drake, Robert J. 1963. Molluscs from Pacific Northwest archaeological sites, Idaho: Camas Prairie and Birch Creek region. Tebiwa. 6(1):34-37.

Drake, Robert J. 1964. The possibilities of paleoecological reconstructions-biological, Mollusca. Pages 32-36 in James J. Hester and James Schoenwetter, eds. The reconstruction of past environments. Fort Burgwin Res. Center. 3.

Edmondson, W. T. 1963. Pacific coast and Great Basin. Pages 371-393 in David Frey, ed. Limnology of North America. Univ. Wisc. Press. Madison.

Edmondson, W. T., G. E. Comita, and G. C. Anderson. 1962. Reporduction rate of copepods in nature and its relation to phytoplankton population. Ecology. 43:625-634.

Eggleton, Frank E. 1931. A limnological study of the profundal bottom fauna of certain freshwater lakes. Ecol. Monographs. 1:231-331.

Eisley, Loren C. 1931. Archaeology and Mollusca. Pages 77-93 in D. S. Davidson, ed. Twenty-fifth anniversary studies. Pub. Philadel. Anthropol. Soc. 1.

Eisenberg, Robert M. 1966. The regulation of density in a natural population of the pond snail, *Lymnaea alodes.* Ecology. 47:889-906.

Enbysk, Betty. 1956. Vertebrate and Molluscs from Lind Coulee, Washington. Pages 270-278 in Richard D. Daugherty, Lind Coulee. Proc. Amer. Phil. Soc. 100:223-278.

Eyerdam, Walter. 1925. Station of *Ferrissia oregonensis* (Clessin). Nautilus. 39:71.

Eyerdam, Walter. 1934. Land and freshwater shells from the vicinity of Yakima, Washington. Nautilus. 48:46-48.

Eyerdam, Walter. 1942. *Lymnaea auricular linnaeus* in western Washington. Nautilus. 55:18-19.

Eyerdam, Walter. 1943. Note on fossil fresh-water shells from Soap Lake, Washington. Min. Conchol. Club Southern Calif. 27:12.

Eyerdam, Walter. 1967. Freshwater mollusks eaten by trout and other fish. Pacific Northwest Shell News. 7:45.

Fenenga, Franklin. 1952. The archaeology of the Slick Rock Village, Tulare County, California. Amer. Antiquity. 17:339-347.

Firby, James R. .963. A new genus of Planorbid gastropods from the "Esmeralda Formation" of Nevada. J. Paleontol. 37:1120-1122.

Firby, James R. 1966. New non-marine Mollusca from the Esmeralda formation, Nevada. Proc. Calif. Acad. Sci. 33:453-480.

Firby, James R. 1967. Pliocene non-marine mollusks from Contra Costa County, California. Proc. Calif. Acad. Sci. 34:511-524.

Flint, R. F. 1935. Glacial features of the southern Okanagon region. Geol. Soc. Amer. Bull. 46:169-194.

Flint, R. F. 1936. Stratitide drift and deglaciation in eastern Washington. Geol. Soc. Amer. Bull. 47:1849-1884.

Flint, R. F. 1937. Pleistocene drift border of eastern Washington. Geol. Soc. Amer. Bull. 48:203-232.

Flint, R. F. 1938. Origin of the Cheney-Palouse scabland tract, Washington. Geol. Soc. Amer. Bull. 49:461-524.

Flint, R. F. 1971. Glacial and Quaternary geology. John Wiley and Sons Inc. New York, 892 pp.

Flint, R. F. and W. H. Irwin. 1939. Glacial geology of Grand Coulee Dam, Washington. Geol. Soc. Amer. Bull. 50:661-680.

Fretter, Vera and Alastair Graham. 1962. British Prosobranch Mollusca, their functional anatomy and ecology. Ray. Soc. London, 755 pp.

Frey, David G., ed. 1966. Limnology in North America. Univ. Wisc. Press. Madison, Wisc. 734 pp.

Fryxell, Roald. 1960. Detailed stratigraphic description; Park Lake housepit 45GR-90. Pages 43-45 in Roderick Sprague, Archaeology in the Sun Lakes area of central Washington. Wash. State Univ. Lab. Anthrol. Rep. Invest. 6, 48 pp.

Fryxell, Roald. 1961. Geological field examination of the Park Lake housepit site (45-GR-90) Lower Grand Coulee, Washington. Wash. State Univ. Lab. Archeol. Geochronol. Rep. Invest. 9, 8 pp.

Fryxell, Roald. 1962. A radiocarbon limiting date for scabland flooding. Northwest Sci. 36:113-119.

Fryxell, Roald. 1963. Through a mirror, darkly; A geologist's interpretation of man's changing environment. The Record, Wash. State Univ., Pullman, Wash. 18 pp.

Fryxell, Roald. 1965. Mazama and Glacier peak volcanic ash layers: Relative ages. Science. 147:1288-1290.

Fryxell, Roald. 1972a. Relationship of Late Quaternary volcanic ash layers to geomorphic history of the Columbia Basin, Washington. Geol. Soc. Amer. Cordilleran Sec. 4:159. (Abstr.)

Fryxell, Roald. 1972b. The contribution of interdisciplinary research to geologic investigation of prehistory, eastern Washington. Ph.D. Thesis. University of Idaho (Libr. Cong. Card No. Mic. 72-2082). 691 pp. University Microfilms, Ann Arbor, Mich. (Diss. Abstr. 32:7111)

Fryxell, Roald, Tadeusz Bielicki, Richard D. Daugherty, Carl E. Gustafson, Henry T. Irwin, and Bennie C. Keel. 1968a. A human skeleton from sediments of Mid-Pinedale age in southeastern Washington. Amer. Antiquity. 33:511-514.

Fryxell, Roald, Tadeusz Bielicki, Richard D. Daugherty, Carl E. Gustafson, Henry T. Irwin, Bennie C. Keel, and Grover S. Krantz. 1968b. Human skeletal material and artifacts from sediments of Pinedale (Wisconsin) age in southeastern Washington. United States. Proc. VIII Cong. Anthropol. Ethnol. Sic. 3:176-181.

Fryxell, Roald and Earl F. Cook. 1964a. A field guide to the loess deposits and channeled scablands of the Palouse area, Eastern Washington. Wash. State Univ. Lab. Anthropol. Rep. Invest. 29, 32 pp.

Fryxell, Roald in cooperation with Richard D. Daugherty. 1962. Interim report: Archaeological salvage in the Lower Monumental Reservoir, Washington. Wash. State Univ. Lab. Archeol. Geochronol. Rep. Invest. 21, 39 pp.

Fryxell, Roald, Richard D. Daugherty, and James Baenen. 1962. The discovery of early human skeletal remains near Lyons Ferry, Washington. Northwest Sci. 36:127. (Abstr.)

Fryxell, Roald and Richard D. Daugherty. 1963. Development of a late glacial and postglacial geological and archaeological chronology for the Columbia plateau, Washington: An interim report to the National Science Foundation. Wash. State Univ. Lab. Anthropol. Rep. Invest. 23, 22 pp.

Fryxell, Roald and Richard D. Daugherty. 1964b. Demonstration of technique for preserving archaeological stratigraphy: A report to the Wenner-Gren Foundation. Wash. State Univ. Lab. Anthropol. Rep. Invest. 31, 19 pp.

Fryxell, Roald and George E. Neff. 1965. The origin of Grand Coulee. Pages 77-79 in C. Bertrand Schultz and H. T. U. Smith, eds. Guidebook for field conference E., northern and middle Rocky Mountains. 7th Congress of the International Association for Quaternary Research. Neb. Acad. Sci. Lincoln, Neb.

Frye, John C. and A. Byron Leonard. 1967. Buried soils, fossil mollusks, and late Cenozoic paleoenvironments. Pages 390-L128 in Curt Teichert and Ellis L. Yochelson, eds. Essays in paleontology and stratigraphy. Dept. Geol. Spec. Pub. 2. Univ. Kansas Press. Lawrence, Kan.

Gallagher, Patrick. 1959. South cave: A site in the Lower Grand Coulee of Central Washington. Wash. Archaeol. 5(5):3-26.

Gardner, E. W. 1932. Some lacustrine Mollusca from the Faiyum depression: A study in variation. Mem. Inst. Egypt. 18:1-223.

Garner, H. F. 1967. Rivers in the making. Sci. Amer. 216(4):84-94.

Gebhard, Paul Henry. 1949. An archaeological survey of the blowouts of Yuma County, Colorado. Amer. Antiquity. 15:132-143.

Germain, Louis. 1923. Les climate des temp quaternaire d'apres les molluscan terrestres et fluviatiles. Anthropologie. 33:301-322.

Goodrich, Calvin. 1932. The Mollusca of Michigan. Univ. Mich Mus. Hanbook Series. 5, 120 pp.

Gould, Augustus Addison. 1847a. Descriptions of species of Limniadae from collection of the Exploring Expedition. Proc. Boston Soc. Natur. Hist. 2:210-212.

Gould, Augustus Addison. 1847b. Descriptions of species of *Physa* from collection of the Exploring Expedition. Proc. Boston Soc. Natur. Hist. 2:214-215.

Gould, Augustus Addison. 1847c. Descriptions of species of *Melania* from collection of the Exploring Expedition. Proc. Boston Soc. Natur. Hist. 2:222-225.

Gould, Augustus Addison. 1849. Descriptions of new species of shells, brought home by the U. S. Exploring Expedition. Proc. Boston Soc. Natur. Hist. 3:118-121.

Gould, Augustus Addison. 1850. Descriptions of new shells. Proc. Boston Soc. Natur. Hist . 3:292-296.

Gould, Augustus Addison. 1860. Mollusca and shells. U. S. Exploring Expedition. 12:1-510.

Grass, Al L. 1967. *Menetus opercularis planatus.* Pacific Northwest Shell News. 7:53-54.

Grass, Al L. 1968. Planorbidae of British Columbia. Pacific Northwest Shell News. 8:5-6.

Grolier, Maurice J. and James W. Bingham. 1971. Geological map and sections of parts of Grant, Adams, and Franklin counties, Washington. U. S. Geol. Survey Misc. Geol. Invest Map 1-589.

Grolier, Maurice J. and B. L. Foxworthy. 1961. Geology of the Moses Lake North quandrangle, Washington. U. S. Geol. Survey Misc. Geol. Invest. Map 1-330.

Gustafson, Carl Eugene. 1972. Faunal remains from the Marmes Rockshelter and related archaeological sites in the Columbia basin. Ph.D. Thesis. Washington State University. 183 pp.

Hanna, G Dallas. 1922. Fresh water mollusks of Oregon. Univ. Oregon Publ. 1(12):1-22.

Hanna, G Dallas. 1930. *Pyrgulopsis nevadensis* (Stearns) in Oregon. Nautilus. 43:103-104.

Hanna, G Dallas. 1965. Some Pleistocene and Pliocene fresh water Mollusca from California and Oregon. Calif. Acad. Sci. Occasional Papers. 43, 20 pp.

Hanna, G Dallas. 1966. Introduced Mollusks of Western North America. Calif. Acad. Sci. Occasional Papers. 48, 108 pp.

Hannibal, Harold. 1912. A synopsis of the recent and Tertiary freshwater Mollusca of the Californian Province. Proc. Malacol. Soc. 10:112-211.

Hansen, Henry P. 1941. A pollen study of post-Pleistocene lake sediments in the upper Sonoran life zone of Washington. Amer. J. Sci. 239:503-522.

Hansen, Henry P. 1947a. Chronology of post-glacial volcanic activity in Oregon and Washington. Geol. Soc. Amer. 58:1252. (Abstr.)

Hansen, Henry P. 1947b. Postglacial forest succession, climate, and chronology in the Pacific Northwest. Trans. Amer. Phil. Soc. 37:1-130.

Harrington, Mark Raymond and Ruth DeEtte Simpson. 1961. Tule Springs, Nevada with other evidence of Pleistocene man in North America. Southwest Mus. Pap. 18:1-146.

Heard, William H. 1962. Distribution of Sphaeriidae (Pelecypoda) in Michigan, U.S.A. Malacologia. 1:139-160.

Heard, William H. 1965. Comparative life histories of North American pill clams (Sphaeriidae: *Pisidium).* Malacologia 2:381-411.

Heard, William H. and Richard H. Guckert. 1970. A re-evaluation of the Recent Unionacea (Pelecypoda) of North America. Malacologia. 10:333-355.

Henderson, Junius. 1907a. The Mollusca of Colorado, Part I. Univ. Colo. Studies. 4:77-96.

Henderson, Junius. 1907b. The Mollusca of Colorado, Part II. Univ. Colo. Studies. 4:167-185.

Henderson, Junius. 1910. Mollusca collected in northwestern Colorado in 1909. Univ. Colo. Studies. 7:125-126.

Henderson, Junius. 1912. The Mollusca of Colorado, Part III. Univ. Colo. Studies. 9:53-63.

Henderson, Junius. 1924. Mollusca of Colorado, Utah, Montana, Idaho, and Wyoming. Univ. Colo. Studies. 13:65-223.

Henderson, Junius. 1927a. A Pleistocene fossil locality on Big Hope Island, Puget Sound. Univ. Colo. Studies. 16:1-3.

Henderson, Junius. 1927b. Mollusks from the Northwest. Nautilus. 41:75-78.

Henderson, Junius. 1928a. A collecting trip to the Northwest. Nautilus. 41:73-77.

Henderson, Junius. 1928b. Molluscan provinces in the western United States. Nautilus. 41:85-91.

Henderson, Junius. 1928c. Mollusca in their relation to the geological history of Soap Lake, Washington. Nautilus. 41:118-120.

Henderson, Junius. 1928d. Interesting additions to the fresh-water molluscan fauna of Oregon and Washington. Nautilus. 41:141.

Henderson, Junius. 1928e. Collecting in Washington. Nautilus. 42:64-65.

Henderson, Junius. 1929a. Some new forms of non-marine Mollusca from Oregon and Washington. Nautilus. 42:80-82.

Henderson, Junius. 1929b. Some fossil fresh-water Mollusca from Washington and Oregon. Nautilus. 42:119-123.

Henderson, Junius. 1929c. Non-marine Mollusca of Oregon and Washington. Univ. Colo. Studies. 17:47-190.

Henderson, Junius. 1931. Molluscan provinces of the United States. Univ. Colo. Studies. 18:177-186.

Henderson, Junius. 1935. Fossil non-marine Mollusca of North America. Geol. Soc. Amer. Spec. Paper:. 3, 313 pp.

Henderson, Junius. 1936a. Mollusca of Colorado, Utah, Montana, Idaho, and Wyoming-Supplement. Univ. Colo. Studies. 23:81-145.

Henderson, Junius. 1936b. The non-marine Mollusca of Oregon and Washington-Supplement. Univ. Colo. Studies. 23:251-280.

Herrington, H. B. 1954. *Pisidium* species and synonyms, North American, north of Mexico. Nautilus. 67:97-104, 131-138.

Herrington, H. B. 1962. A revision of the Sphaeriidae of North America, (Mollusca: Pelecypoda). Mich. Univ. Zool. Misc. Publ. 118:1-74.

Herrington, H. B. and Dwight W. Taylor. 1958. Pliocene and Pleistocene Sphaeriidae (Pelecypoda) from the central United States. Mich. Univ. Zool. Occasional Papers. 596:1-28.

Hester, James J. 1970. Ecology of the North American paleo-indian. Bioscience. 20:213-217.

Heusser, Calvin J. 1965. A Pleistocene phytogeographical sketch of the Pacific Northwest. Pages 469-483 in H. E. Wright and D. G. Frey, eds. The Quaternary of the United States. Princeton University Press. Princeton, New Jersey.

Hibbard, C. W. 1949. Techniques of collecting microvertebrate fossils. Mich. Univ. Mus. Paleontol. Contrib. 8:7-19.

Hibbard, C. W. and Dwight W. Taylor. 1960. Two Late Pleistocene faunas from southwestern Kansas. Mich. Univ. Mus. Paleontol. Contrib. 16:1-223.

Howard, Edgar. 1935. The occurrence of flints and extinct animals in pluvial deposits near Clovis, New Mexico. Part 1--Introduction. Proc. Acad. Natur. Sci. Philadel. 87:299-303.

Hubbs, Carl L. 1967. A discussion of the geochronology and archeology of the California Islands. Pages 337-341 in Ralph N. Philbrick, ed. Proc. Symposium Biol. Calif. islands. Santa Barbara Garden Inc. Santa Barbara, Calif.

Ingersoll, Ernest. 1876. Report on the Mollusca. Hayden's U. S. Geological Survey of the Territories, 8th Annual Report for 1874:389-410.

Ingram, William Marcus. 1949. The larger freshwater clams of California, Oregon, and Washington. J. Entomol. Zool. 40(4):72-92.

Ingram, William Marcus and Carol Lotz. 1949. Land mollusks of the San Francisco Bay Counties. J. Entomol. Zool. 41(2):3-22, 41(3):39-48, 42(1):5-27, 42(2):20-39.

Ives, Patricia C., Betsy Levin, Charles L. Oman, and Meyer Rubin. 1967. U. S. Geological Survey Radiocarbon Dates IX. Radiocarbon. 9:505-529.

Jenkins, Olaf P. 1918. Spotted lakes of epsomite in Washington and British Columbia. Amer. J. Sci. 196:638-644.

Jennings, Jesse David. 1957. Danger Cave. Mem. Soc. Amer. Archaeol. 14:1-328.

Kirk, Ruth. 1970. The oldest man in America, an adventure in archaeology. Harcourt Brace Jovanovich, Inc. New York. 96 pp.

Lambert, R. J., Jr. 1960. Review of the literature of ethno-conchology pertinent to archeology. Sterkiana. 2:1-8.

Landye, James Jerry. 1968. Nonmarine mollusks of Late Quaternary age from Lower Grand Coulee, Washington. North-west Sci. 42:37. (Abstr.)

Landye, James Jerry. 1969. Late Pleistocene nonmarine mollusks from Lake Bretz, Lower Grand Coulee, Washington. Ann. Rep. Amer. Malacol. Union. 36:33-34. (Abstr.)

La Rocque, Aurèle. 1956. Variation of carinae in V[illegible] [illegible]. Nautilus. 70:13-14.

La Rocque, Aurèle. 1963a. Late Cenozoic non-marine molluscan associations in eastern North America. Sterkiana. 11:1-50, 12:15-60.

La Rocque, Aurèle. 1963b. Current literature in non-marine Ostracodes. Sterkiana. 12:1-7.

La Rocque, Aurele. 1964. Late Cenozoic non-marine molluscan associations in eastern North America. Sterkiana. 13:23-53, 14:19-38.

Lauer, Gerald Joseph. 1959. The bottom fauna of two saline lakes in Washington. M. S. Thesis No. 10389. University of Washington. 147 pp.

Lea, Isaac. 1838. Description of new freshwater and land shells. Trans. Amer. Phil. Soc. 6:1-111.

Lea, Isaac. 1852. Descriptions of new species of the family Unionidae. Trans. Amer. Phil. Soc. 10:253-294.

Lea, Isaac. 1860. Descriptions of four new species of Melanidae of the United STates. Proc. Acad. Natur. Sci. Philadel. 12:93.

Lea, Isaac. 1862. Description of a new genus (Goniobasis) of the family Melanidae and eighty-two new species. Proc. Acad. Natur. Sci. Philadel. 14:262-272.

Lea, Isaac. 1864a. Description of and remarks on *Planorbis Newberryi.* Proc. Acad. Natur. Sci. Philadel. 16:5.

Lea, Isaac. 1864b. Descriptions of twenty-four new species of *Physa* of the United States and Canada. Proc. Acad. Natur. Sci. Philadel. 16:114-116.

Lefebvre, R. H. 1969. Columbia River basalts of the Grand Coulee area. Pages 1-38 in Ernest H. Gilmour and Dale Stradling, eds. Proc. Second Columbia Basalt Symposium. Eastern Washington State College Press. Cheney, Wash.

Leonard, Arthur Byron. 1963. Mollusca fauna in Wisconsin loess at Cleveland, Ohio. Amer. J. Sci. 251:369-376.

Leonard, A. B. and J. C. Frye. 1960. Wisconsin molluscan faunas of the Illinois valley region. III. State Geol. Surv. Circ. 304, 32 pp.

Leonhardy, Frank C. 1970. Artifact assemblages and archaeological units at Granite Point locality I (45WT41), southeastern Washington. Ph.D. Thesis. Washington State University (Libr. Cong. Card No. Mic. 70-16,876). 263 pp. University Microfilms, Ann Arbor, Mich. (Diss. Abstr.31:1030.)

Leonhardy, Frank C. and David G. Rice. 1970. A proposed culture typology for the Lower Snake River region, southeastern Washington. Northwest Anthropol. Res. Notes. 4:1-29.

Libby, Willard F. 1954. Chicago radiocarbon dates V. Science. 120:733-742.

Livingston, Vaughn E., Jr. 1959. Fossils in Washington. State Wash. Div. Mines Geol. Information Cir. 33, 35 pp.

Longinelli, A. and H. Craig. 1967. Oxygen-18 variations in sulfate ions in sea water and saline lakes. Science. 156:56-59.

Loud, Llewellyn L. and Mark R. Harrington. 1929. Lovelock cave. Univ. Calif. Public. Amer. Archaeol. Ethnol. 25:236-243.

Lo2ek, Vojen. 1964. Quärtarmollusken der Tschechoslowake. Rozpravy Ustředního ústavu geologickeho. 31, 374 pp.

Lolek, Vojen. 1965. Problems of analysis of the Quaternary non-marine molluscan fauna in Europe. Pages 201-208 in H. E. Wright and David G. Frey, eds. International Studies on the Quaternary. Geol. Soc. Amer. Spec. Paper 84.

McCulloch, D. S., Dwight W. Taylor, and Meyer Rubin. 1965. Stratigraphy, non-marine mollusks, and radiometric dates from Quaternary deposits in the Kotzebue Sound area, western Alaska. J. Geol. 73:442-453.

McMacken, Joseph G. 1927. Lake Lewis and flood-waters of Okanogan ice sheets. Pan-Amer. Geol. 48:101-108,

McMacken, Joseph G. 1937. Vicissitudes of Spokane River in late geological time. Pan-Amer. Geol. 68:111-132.

McMacken, Joseph G. 1950. The Grand Coulee of Washington and Dry Falls in picture and story. Times Publishing Co. Davenport, Wash. 31 pp.

McNeil, Charles Winslow. 1959. Winter survival and competition of *Stagnicola palustris nuttalliana* (Lea) and *Physa propinqua* Tryon. Bull. Ecol. Soc. Amer. 40:69. (Abstr.)

McNeil, Charles Winslow. 1960. Winter survival of snails on culvert walls. Bull. Ecol. Soc. Amer. 41:71. (Abstr.)

McNeil, Charles Winslow. 1961. Winter survival of snails in experimental cultures. Bull. Ecol. Soc. Amer. 42:83. (Abstr.)

McNeil, Charles Winslow. 1963a. Winter survival of *Stagnicola palustris nuttalliana* and *Physa propinque.* Ecology. 44:187-191.

McNeil, Charles Winslow. 1963b. Some temperature and light effects upon snails. Bull. Ecol. Soc. Amer. 44:88. (Abstr.)

McNeil, Charles Winslow. 1965. Comparison of snail survival during two winters. Trans. Amer. Microscop. Soc. 84:159. (Abstr.)

McNeil, Charles Winslow and Waldemar Melchert Walter. 1956. Surface-wintering of aquatic snails in central Washington. J. Parasitol. 42(4):33. (Abstr.)

McNeil, Charles Winslow and Waldemar Melchert Walter. 1957. Surface-wintering of aquatic snails in central Washington. J. Parasitol. 42:114-115.

McNeil, Charles Winslow and Waldemar Melchert Walter. 1958. Preliminary winter survival studies 1956-1957, 1957-1958 on *Stagnicola palustris nuttalliana* (Lea, 1841) and *Physa propinque* Tryon, 1865. J. Parasitol. 44(4):19. (Abstr.)

Macy, Ralph William. 1952. Studies on schistosome dermatitis in the Pacific Northwest. Northwest Med. 51:947-950.

Macy, Ralph William. 1956. The life cycle of *Plagiorchis parorchis,* n.sp., (Trematoda: Plagiorchiidae). J. Parasitol. 42(4):28. (Abstr.)

Macy, Ralph William. 1960. The life cycle of *Plagiorchis vespertilionis paraorchis*, n. ssp., (Trematoda: Plagiorchiidae) and observations on the effects of light on the emergence of the cercaria. J. Parasitol. 46:337-345.

Malde, Harold Edwin. 1960. Geological age of the Claypool site, northeastern Colorado. Amer. Antiquity. 26:236-243.

Malde, Harold Edwin. 1964. Environment and man in arid America. Science. 145:123-129.

Malde, Harold Edwin. 1965. Snake River Plain. Pages 255-263 in H. E. Wright Jr. and D. G. Frey, eds. The Quaternary of the United States. Princeton Univ. Press. Princeton, New Jersey.

Malde, Harold Edwin. 1968. The catastrophic late Pleistocene flood, Snake River Plain, Idaho. U. S. Geol. Survey Prof. Paper. 596:1-52.

Mallory, O. L. 1962. Continued archaeological appraisal of the Lower Grand Coulee, central Washington. Wash. State Univ. Lab. Archeol. Geochronol. Rep. Invest. 14, 20 pp.

Marshall, Alan Gould. 1971. An alluvial chronology of the lower Palouse River canyon and its relation to local archaeological sites. M.A. Thesis. Washington State University. 73 pp.

Miller, Robert Rush. 1965. Quaternary freshwater fishes of North America. Pages 569-581 in H. E. Wright and D. G. Frey, eds. The Quaternary of the United States. Princeton Univ. Press. Princeton, New Jersey.

Mills, John E. and Carolyn Osborne. 1952. Material culture of an upper Coulee rockshelter. Amer. Antiquity. 17:352-359.

Moore, Irvin J. 1964. Effects of water currents on freshwater snails *Stagnicola palustris* and *Physa propinqua.* Ecology. 45:558-564.

Morrison, Joseph Paul Eldred. 1955. Family relationship of the North American fresh water mussels. Ann. Rep. Amer. Malacol. Union. 22:16-17. (Abstr.)

Murphy, Garth. 1942. Relationships of the fresh-water mussel to trout in the Truckee River. Calif. Fish Game. 28(2): 89-102.

Oana, Shinya and Edward S. Deevey. 1960. Carbon-13 in lake water and its possible bearing in Paleolimnology. Amer. J. Sci., Bradley Vol. 258:253-272.

Osborne, Douglas. 1957. Excavations in the McNary reservoir basin near Umatilla, Oregon. Bur. Amer. Ethnol. Bull. 166(8):1-258.

Osborne, Douglas. 1959. Archaeological tests in the Lower Grand Coulee, Washington. Wash. State Univ. Lab. Archeol. Geochronol. Rep. Invest. 5, 244 pp.

Osborne, Douglas. 1967. Archaeological tests in the Lower Grand Coulee, Washington. Occasional Papers. Idaho State Mus. 20, 83 pp.

Ouellet, Marcel. 1967. A correlation of postglacial molluscan succession and radio-carbon-dated pollen sequences from Alkins Lake, Ontario. Ann. Rep. Amer. Malacol. Union. 34:18-19. (Abstr.)

Pace, Gary L. 1967. The distribution and habits of *Carinifex* and *Parapholyx*. Ann. Rep. Amer. Malacol. Union. 34:32-33. (Abstr.)

Parodiz, J. J. and A. A. Bone Ho. 1963. Pelecypoda: Unionacea and Mutealacea. Malacologia. 1:179-213.

Patterson, Charlotte M. 1971. Taxonomic studies of the land snail family Succineidae. Malacol. Review. 4:131-202.

Pauley, Gilbert B. and C. Dale Becker. 1968. *Aspidogaster cononchicola* in mollusks of the Columbia River system with comments on the host's pathological response. J. Parasitol. 54:917-920.

Pennack, Robert W. 1953. Freshwater invertebrates of the United States. Ronald Press Co., New York. 769 pp.

Pewe, Troy. 1954. The geological approach to dating archaeological sites. Amer. Antiquity. 20:51-61.

Pilsbry, Henry A. 1903. Shells of Douglas county, central Washington. Nautilus. 17:84.

Pilsbry, Henry A. 1933. Amnicolidae from Wyoming and Oregon. Nautilus. 47:9-12.

Pilsbry, Henry A. 1935. Report on the shells collected by E. B. Howard from lake bed southwest of Clovis, Roosevelt Co., New Mexico. Pages 89-90 in Edgar Howard, Evidence of early man in North America. Mus. J. (Univ. Penn. Mus.). 24.

Pilsbry, Henry A. 1939. Land Mollusca of North America. Acad. Natur. Sci. Philadel. Mono. 3. 1:1-574.

Pilsbry, Henry A. 1940. Land Mollusca of North America. Acad. Natur. Sci. Philadel. Mono. 3. 1:575-994.

Pilsbry, Nenry A. 1946. Land Mollusca of North America. Acad. Natur. Sci. Philadel. Mono. 3. 2:1-520.

Pilsbry, Henry A. 1948. Land Mollusca of North America. Acad. Natur. Sci. Philadel. Mono. 3. 2:521-1113.

Powers, Howard A. and Ray E. Wilcox. 1964. Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak. Science. 144:1334-1336.

Prime, Temple. 1865. American Corbiculadae (recent and fossil). Smithsonian Misc. Collections. 145:1-80.

Randolph, P. B. 1896. Shells of Seattle, King Co., Washington. Nautilus. 9:101-102.

Randolph, P. B. 1968. Non-marine mollusks of Seattle, Washington. Pacific Northwest Shell News. 8:7-8.

Rice, David G. 1968. Archaeological investigations in the Coulee Dam National Recreation area, Spring 1968. Wash. State Univ. Lab. Anthropol. Rep. Invest. 45:1-49.

Rice, David G. 1972. The Windust phase in Lower Snake River region prehistory. Ph.D. Thesis. Washington State University. 225 pp.

Rice, Harvey S. 1965. The cultural sequence at Windust Caves. M.A. Thesis. Washington State University. 116 pp.

Richards, Horace G. 1936. Mollusks associated with early man in the Southwest. Amer. Natural. 70:369-371.

Richmond, G. M., Roald Fryxell, George E. Neff, and Paul L. Weis. 1965. The Cordilleran ice sheet of the northern Rocky mountains, and related Quaternary history of the Columbia plateau. Pages 231-242 in H. E. Wright, Jr. and David G. Frey, eds. Quaternary of the United States. Princeton Univ. Press. Princeton, New Jersey.

Roberts, Frank Harold Hanna, Jr. 1942. Archeological and geological investigations in the San Jon district, eastern New Mexico. Smithsonian Misc. Coll. 103(4):1-30.

Roper, Edward W. 1896. Notes on the Washington *Sphaeria* and *Pisidia* with descriptions of new species. Nautilus. 9:97-99.

Roscoe, Ernest J. 1963. Some *Goniobases* in western United States. Nautilus. 77:43-47.

Roscoe, Ernest J. 1967. Ethnomalacology and paleoecology of the Round Butte archaeological sites, Deschutes River Basin, Oregon. Mus. Natur. Hist. Univ. Oregon Bull. 6. 20 pp.

Roscoe, Ernest J. and Susan Redelings. 1964. The ecology of the fresh-water mussel *Margaritifera margaritifera* (L.). Sterkiana. 16:19-32.

Roy, Edward Carl, Jr. 1962, Molluscan faunas of the Gunnison Reservoir deposit, Sanpete County, Utah. Sterkiana. 6:5-13.

Roy, Edward Carl, Jr. 1964. Pleistocene non-marine Mollusca of northeastern Wisconsin. Sterkiana. 15:5-77.

Rubin, Meyer, Robert C. Likins, and Elmer G. Berry. 1963. On the validity of radiocarbon dates from snail shells. J. Geol. 71:84-89.

Rubin, Meyer and Dwight W. Taylor. 1963. Radiocarbon activity of shells from living clams and snails. Science. 141:637.

Say, Thomas. 1821. Descriptions of univalve shells of the United States. J. Acad. Natur. Sci. Philadel. 2:149-179.

Say, Thomas. 1829. Descriptions of some terrestrial and fluviatile shells of North America. Disseminator of Useful Knowledge. 2:229-230, 244-246, 259-261, 275-277, 291-293, 308-310, 323-325, 339-341, 355-356.

Sayles, Edwin Booth and Ernst V. Antevs. 1941. Archaeology of the northern San Joaquin Valley. Univ. Calif. Pub. Amer. Archaeol. Ethnol. 25:289-413.

Schwennesen, A. T. and O. E. Meinzer. 1918. Ground water in Quincy Valley, Washington. U. S. Geol. Survey Water Supply Paper. 425:131-161.

Scott, G. H. 1963. Uniformitarianism, the uniformity of nature, and paleoecology. New Zealand J. Geol. Geophys. 6:510-527.

Shimek, Bohumeil. 1899. The distribution of loess fossils. Proc. Iowa Acad. Sci. 6:98-113.

Shimek, Bohumeil. 1913. The significance of Pleistocene mollusks. Science. 37:501-509.

Shimek, Bohumeil. 1930. Land snails as indicators of ecological conditions. Ecology. 11:673-686.

Shimek, Bohumeil. 1935. The habitats of Iowa Succineas. Nautilus. 49:10.

Shimek, Bohumeil. 1936. Comparative studies of loess and recent mollusks. Nautilus. 49:71-73.

Simpson, George Gaylord. 1933. A Nevada fauna of Pleistocene type and its probable association with man. Amer. Mus. Novitates. 667:1-10.

Smiley, Charles J. 1963. The Ellensburg flora of Washington. Univ. Calif. Pub. Geol. Sci. 35:159-276.

Smith, Allyn G. 1943. Mollusks of the Clearwater Mountains, Idaho. Proc. Calif. Acad. Sci. 23:537-544.

Smith, Allyn G. and Freddie Curtis. 1964. Snails and other invertebrates from Indian village sites, principally Contra Costa County, California. Veliger. 6:227-229.

Smith, Gerald Ray. 1966. Distribution and evolution of the North American catostomid fishes of the subgenus *Pantosteus*, genus *Catostomus*. Univ. Mich. Mus. Zool. Misc. Publications. 129. 132 pp.

Sparks, B. W. 1962. Post glacial Mollusca at Hawes Water, Lancashire, illustrating some difficulties of interpretation. J. Conchology. 25:78-82.

Sparks, B. W. 1963. Non-marine Mollusca and Quaternary Ecology. Pages 87-98 in A. MacFadyen and P. J. Newbould, eds. British Ecological Society Jubilee Symposium. J. Ecol. 52 Supplement. 244 pp.

Sprague, Roderick. 1960. Archaeological in the Sun Lakes area of central Washington. Wash. State Univ. Lab. Anthropol. Rep. Invest. 6. 48 pp.

Sprague, Roderick. 1967. A preliminary bibliography of Washington archaeology. Wash. State Univ. Lab. Anthropol. Rep. Invest. 43. 91 pp.

Steen, Virginia. 1963. A study of the chemical and physical characteristics of Pumice from Glacier Peak, Washington and Mt. Mazama (Crater Lake), Oregon. Wash. State Univ. Lab. Anthropol. Rep. Invest. 24. 8 pp.

Steen, Virginia and Roald Fryxell. 1965. Mazama and Glacier Peak pumice glass: Uniformity of refractive index after weathering. Science. 150:878-880.

Swanson, Earl Herbert. 1959. The Wiskey Dick shellmound, Washington. Amer. Antiquity. 25:122-123.

Taylor, Dwight W. 1950. Three new *PyrguZopsis* from the Colorado desert, California. Leaflets Malacol. 1(7):27-33.

Taylor, Dwight W. 1952. Notes on the freshwater mollusks of Yellowstone Park, Wyoming. Leaflets Malacol. 1(9):43-49.

Taylor, Dwight W. 1954. Nonmarine mollusks from the upper Miocene Barstow Formation, California. U. S. Geol. Surv. Prof. Paper 254-C:67-80.

Taylor, Dwight W. 1956. Pliocene mollusks from Jackson Hole, Grand Valley, and Star Valley, Wyoming and Idaho. Wyo. Geol. Assoc. 11th Ann. Field Conference, Guidebook:123-125.

Taylor, Dwight W. 1958. Geologic range and relationships of the freshwater snail *Anisus pattersoni.* J. Paleont. 32:11'49-1153.

Taylor, Dwight W. 1960a. Distribution of the freshwater clam *Pisidium ultramontanum;* a zoogeographic inquiry. Amer. J. Sci. 258-A:325-334.

Taylor, Dwight W. 1960b. Late Cenozoic molluscanfaunas from the High Plains. U. S. Geol. Surv. Prof. Paper 337. 94 pp.

Taylor, Dwight W. 1960c. Mollusca: W5-4 Road Cut. Page 75 in L. S. Cressman, Dalles, Oregon Report. Trans. Amer. Phil. Soc. 50(10).

Taylor, Dwight W. 1964. Historical analysis of distribution of west American freshwater mollusks. Amer. Zool. 4:436-437. (Abstr.)

Taylor, Dwight W. 1965. The study Pleistocene nonmarine mollusks in North America. Pages 597-611 in H. E. Wright and David G. Frey, eds. The Quaternary of the United States. Princeton Univ. Press. Princeton, New Jersey.

Taylor, Dwight W. 1966a. An eastern American freshwater mussel, *Anodonta,* introduced into Arizona. Veliger. 8:197-198.

Taylor, Dwight W. 1966b. Summary of North American Blancan nonmarine mollusks. Malacologia. 4:1-172.

Taylor, Dwight W. 1967. Late Pleistocene molluscan shells from the Tule Springs area. Nevada State Mus. Anthropol. Papers. 13:396-399.

Taylor, Dwight W. 1968. Late Pleistocene nonmarine mollusks from the state of Puebla, Mexico. Ann. Rep. Amer. Malacol. Union. 34:76-78. (Abstr.)

Taylor, Dwight W. 1970. West American freshwater Mollusca, 1: Bibliography of Pleistocene and Recent species. San Diego Soc. Natur. Hist. Mem. 4:1-73.

Taylor, Dwight W. and N. F. Sohl. 1962. An outline of gastropod classification. Malacologia. 1(1):7-32.

Taylor, Dwight W., H. J. Walter, and J. B. Burch. 1963. Freshwater snails of the subgenus *Hinkleyia* (Lymnaeidae: *Stagnicola)* from the western United States. Malacologia. 1:237-281.

Taylor, Dwight W. and Teruya Uyeno. 1966. Evolution of host specificity of freshwater salmonid fishes and mussels in the North Pacific region [in Japanese, English summary]. Venus 24:199-209.

Taylor, George W. 1893. Land and fresh water shells in the Rocky Mountains. Nautilus. 7:85-86.

Thomas, Grace Jean.. 1963. Study of a population of Sphaeriid clams in a temporary pond. Nautilus. 77:37-43.

Trimble, Donald D. and Wilfred J. Carr. 1961. Late Quaternary at American Falls, Idaho. Geol., Soc. Amer. Bull. 72:1739-1748.

Tryon, George W. 1865. Review of the *Goniobasis* of Oregon and California. Amer. J. Conchol. 1:236-246.

Tuthill, Samuel J. and Wilson M. Laird. 1963. Molluscan fauna of some alkaline lakes and sloughs in southern central North Dakota. Nautilus. 77:47-55, 81-89.

Waitt, Richard B., Jr. 1972. Revision of Missoula flood history in Columbia Valley between Grand Coulee Dam and Wenatchee, Washington. Geol. Soc. Amer. Cordilleran Sec. 4:255-256. (Abstr.)

Walter, Waldemar Melchert and Charles Winslow McNeil. 1959. Chemical composition of natural and irrigation waters in central Washington. Northwest Sci. 33:19-42.

Warren, Claude Nelsen and John James DeCosta. 1964. Dating Lake Mohave artifacts and beaches. Amer. Antiquity. 30:206-209.

Washington, Nat W. 1958. Caves of the Lower Grand Coulee. Wash. Archeologist. 3:12.

Waters, Aaron C. 1933. Terraces and coulees along the Columbia River near Lake Chelan, Washington. Bull. Geol. Soc. Amer. 44:783-820.

Waters, Aaron C. 1939. Resurrected erosion surface in central Washington. Bull. Geol. Soc. Amer. 50:635-660.

Wayne, William J. 1959. Stratigraphic distribution of Pleistocene land snails in Indiana. Sterkiana. 1:9-18.

Wedel, Waldo Rudolph. 1941. Archeological investigations at Buena Vista Lake, Kern County, California. Bur. Amer. Ethnol. Bull. 130:1-194.

Wendorf, Fred. 1961. Paleoecology of the Llano Estacado. Ft. Burgwin Res. Cent. Publication. 1:1-144.

Wenz, Wilhelm. 1923. Gastropoda extramarina tertiaria II. Pulmonata II: Fossilium Catalogus, I Animalia. 20-22: 885-1734.

Wenz, Wilhelm. 1938-1944. Gastropoda. Allgemeiner Teil und Prosobranchia. Pages 1-1639 in O. H. Scindenwolf, ed. Hardbuch der Paleozoologie 6(1). Borntraeger, Berlin. 1639 pp.

Whiteaves, Joseph Frederick. 1905. Description of a new species of *Goniobasis,* from British Columbia. Nautilus. 19:61-62.

Whiteaves, Joseph Frederick. 1906. Notes on some fresh water shells from British Columbia. Ottawa Nat. 20:115-116.

Wilkes, Charles. 1844. Narrative of the United States Exploring Expedition during the years 1838, 1839, 1840, 1841, 1842. C. Sherman. Philadelphia. 6 vols.

Wilson, C. B. 1916. Copepod parasites of fresh-water fishes and their economic relations to mussel glochidia. U.S. Bur. Fish. Bull. 34:331-374.

Yen, Teng-chien. 1951. Fossil fresh water mollusks and ecological interpretation. Geol. Soc. Amer. Bull. 62:1375-1380.

Zhadin, V. I. 1965. Mollusks of fresh and brackish waters of U.S.S.R. Israel program for Sci. Translation. Jerusalem. 368 pp.

Zeuner, W. H. 1945. The Pleistocene period, its climate, chronology, and-faunal successions. Bernard Quaritech. Ltd. London.

Zilch, Adolf. 1959-1960. Gastropoda, Euthyneura. Pages 1-834 in O. H. Schindenwolf, ed. Handbuch der Paläozoologie 6(2). Borntraeger, Berlin.

# APPENDIX A

## CHECKLIST OF U.S. GEOLOGICAL SURVEY QUATERNARY MOLLUSCAN LOCALITIES AND COLLECTIONS FROM EASTERN WASHINGTON

# CHECKLIST OF U.S. GEOLOGICAL SURVEY QUATERNARY MOLLUSCAN LOCALITIES AND COLLECTIONS FROM EASTERN WASHINGTON

Collections .of Quaternary nonmarine mollusks have been made during the last 60 years in Washington by personnel of the U.S. Geological Survey. Most of this material remains unreported except for unpublished manuscripts, but the collections were made available for consideration in this study through the courtesy of Dwight W. Taylor. Most of the collections examined are from eastern Washington, and many of these were made by M. J. Grolier and J. W. Bingham in 1960 (Grolier and Foxworthy 1961; Grolier and Bingham 1971). All localities except 16 and possibly 15 range in age from Early Pleistocene to Recent.

Localities represented by the U.S. Geological Survey collections are listed below, following the system of Taylor (1966b). Table A.1 compares the geographic distribution of fresh-water and terrestrial species identified in those collections. Species present at any given locality are denoted by an "F." When only fragments of shell were found, but thought to represent a particular species, a "?" was used. Localities are placed on a map of eastern Washington (Fig. A.1) to show spatial relation-ships.

# Quaternary Fossil Localities, Eastern Washington, from the U.S. Geological Survey Collections[1]

1. NL11-1 B-6B, Grant County, Washington, SE 1/4, NW 1/4 Sec. 19, T.22N, R.27E, elev. 1,100 ft., near mouth of Grand Coulee, behind Royal View Motel at north end of the town of Soap Lake, M. J. Grolier and J. W. Bingham, 1960 (USGS 23222).

2. NL11-1 B-6C, Grant County, Washington, SE 1/4, NW 1/4 Sec. 8, T.21N, R.27E, about 1,150 ft. elev., head of Rocky Ford Coulee, in Soap Lake soil and peat, M. J. Grolier and J. W. Bingham, 1960 (USGS 23221).

3. NL11-1 A-8, Grant County, Washington, SW 1/4, SW 1/4 or 500 ft. E., 50 ft. N. from the SW corner Sec. 4, T.20N, R.23E, Crater Draw about 1,240 ft. elev. contact marl and basalt, M. J. Grolier and J. W. Bingham, 1960 (USGS 23217).

4. Same as 3 except 1.2 ft. above contact. (USGS 23218).

5. Same as 3 except 2.0 ft. above contact. (USGS 23219).

6. Same as 3 except 3.0 ft. above contact. (USGS 23220).

7. NL11-1 A-5, Grant County, Washington, SW 1/4 Sec. 35, T.18N, R.29E, 200 ft. E., 200 ft. N. of SW corner, about 1,105 ft. elev., M. J. Grolier and J. W. Bingham, 1960 (USGS 23216).

8. NL11-1 A-7, Grant County, Washington, SW 1/4 Sec. 22, T.18, R.25E, Bailey Post Office, Quincy Valley, Schwennessen, 1916 (USGS 7897).

9. NL11-1 A-6, Grant County, Washington, Sec. 23, T.19N, R.28E, Moses Lake, in tan brown sand and silt, 120 ft. SE from Kiefer Drive and Olive Avenue, M. J. Grolier, 1958 (USGS 23205).

10. Same as 9 except about 170 ft. south and 20 ft. west from Kiefer Drive and Olive Avenue and about 25 ft. stratigraphically lower than 9, M. J. Grolier, 1958 (USGS 23206).

11. NL11-1 A-4, Adams County, Washington, NW 1/4, NW 1/4 Sec. 36, T.19N, R.31E, Farrier Coulee, about 1240 ft. elev., M. J. Grolier and J. W. Bingham, 1960 (USGS 23215).

---

[1] Collector, collection date, and USGS locality number follow site description.

12. NL11-4 D-7, Grant County, Washington, SW 1/4 Sec. 11, T.17N, R.25E, clay zone in sands about 20 ft. below surface at the North Portal of the Bureau of Reclamation Frenchman Hills Tunnel, Quincy Lake beds, M. J. Grolier, 1958 (USGS 23210).

13. Same as 12, M. M. Mundorf, 1952 (USGS 20348).

14. NL11-4 D-6, Adams County, Washington, NW 1/4 Sec. 16, T.16N, R.28E in east bank of Crab Creek, M. J. Grolier, 1958 (USGS 23208).

15. NL11-4 C-6, Grant County, Washington, very near center of Sec. 16, T.14N, R.27E, White Bluffs, within 50 ft. of the top of bluffs, mollusks associated with vertebrates and seeds, M. J. Grolier, 1958 (USGS 23207).

16. NL11-4 B-6, Franklin County, Washington, SW 1/4, SW 1/4 Sec. 25, T.11N, R.28E, about 600 ft. elev., White Bluffs, first caliche layer above conglomerate, member of the Ringold Formation (Pliocene), M. J. Grolier and J. W. Bingham, 1960 (USGS 23214).

17. NL11-4 Connell 1916, 1:125,000, Franklin County, Washington, SW 1/4, NW 1/4 Sec. 22, T.15N, R.34E, about 1,400 ft. elev., 10 ft. below the top of a south facing bluff, McChesney Spring, M. J. Grolier and J. W. Bingham, 1960 (USGS 23213).

18. NL11-4 B-3, Franklin County, Washington, SW 1/4, NE 1/4 Sec. 29, T.12N, R.33E, about 1,060 ft. elev., M. J. Grolier and J. W. Bingham, 1960 (USGS23212).

19. NL11-4 B-4B, Franklin County, Washington, NE 1/4, NW 1/4 Sec. 4, T.11N, R.31E, Smith Canyon, about 710 ft. elev., M. J. Grolier and J. W. Bingham, 1960 (USGS 23211).

20. NL11-4 Connell 1916, 1:125,000, Franklin County, Washington, SE 1/4, NE 1/4 Sec. 33, T.14N, R.34E, 1.15 miles north of Kahlotus, Washington, first outcrop south of Bahm road on west side, M. J. Grolier, 1958 (USGS 23209).

21. NL11-4 D-1, Whitman County, Washington, 1,000 ft. N. and 1,300 ft. W. of SW corner Sec. 22, T.15N, R.38E, McLaughlin, 1949 (USGS 20853).

22. NL11-5 D-8, Whitman County, Washington, 600 ft. E. and 1,200 ft. S. of NW corner Sec. 25, T.15N, R.38E, McLaughlin 1949 (USGS 20852).

TABLE A.1--Continued

| Locality | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | | | | | | | x | x | | | | | x | | |
| | | | | | | | | | | | | x | x | x | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | x | | |
| x | x | x | x | | x | x | | | | | | | x | | |
| | | | | | | | x | x | | x | x | x | | | |
| | | | | x | | | | | | | | | | | |
| | x | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | x | | | | | | |
| | | | | ? | | | | | x | | | | | | |
| | | | | | x | | | | | | | | | | |
| | | | x | x | x | | | | | | | | | | |
| x | | x | x | | x | x | | | | | | | | | |
| | | | | x | | ? | | | | | | | | | |
| ? | | ? | | | x | ? | x | | ? | | | | | | |
| | | | | | | | | | | | | | x | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | x | | | | | | x | x | | x | | |
| | | | | | | | | | | | | | | | x |
| | | | | x | | | | | | | | | | | |
| | | | | | | | | | | x | x | x | | | |
| | | | | | | | | | | | | | x | | |
| | | | | | | | | x | | | | | | | |
| | | | | | | | x | x | | | | | | | |
| | | | | | | | x | | | | | | | | |
| | | | | x | | | x | | | | | | | | |
| | | | | x | | | x | x | | x | x | x | x | | x |

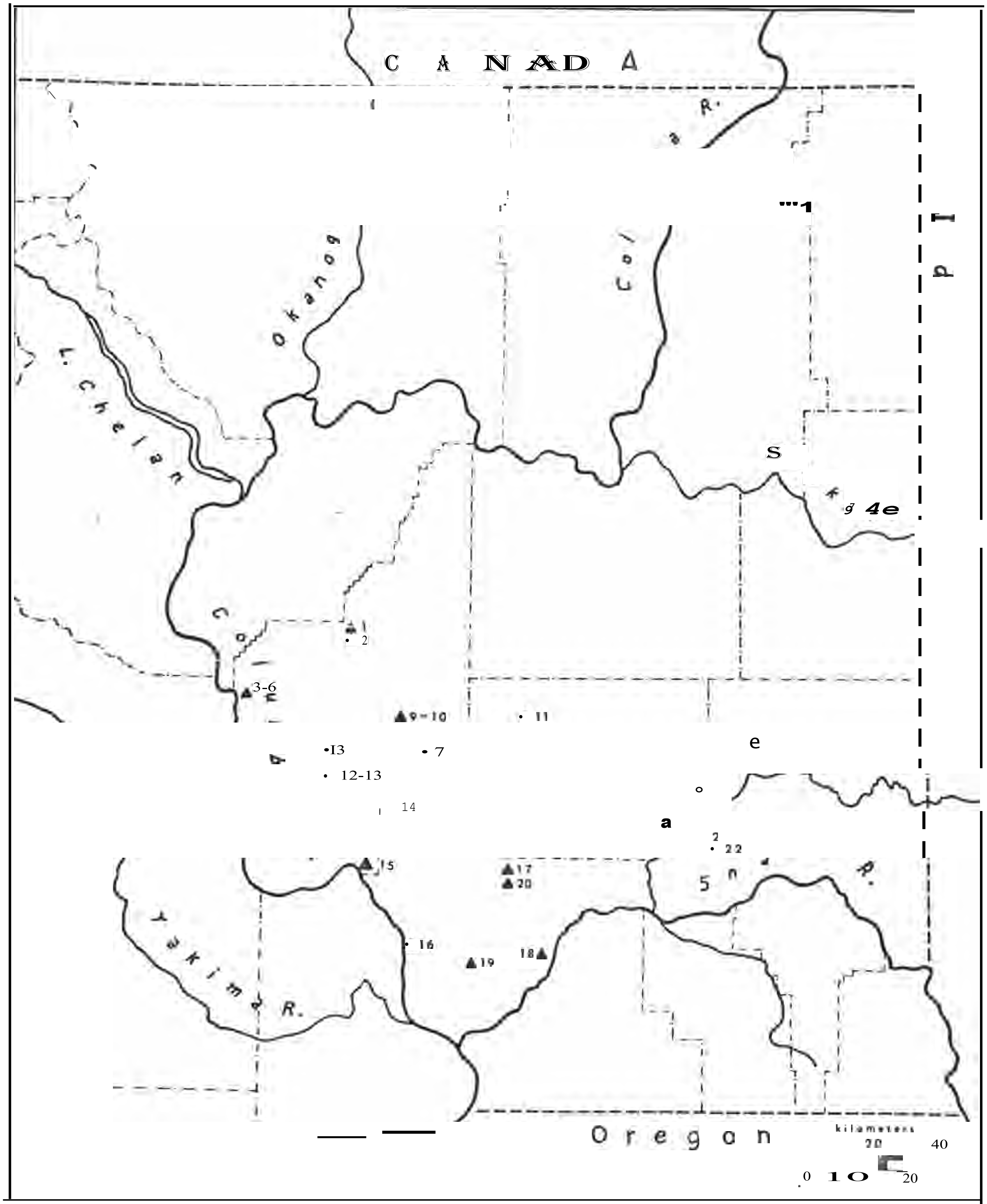
CANADA
L. Chelan
Okanog
Col
3-6
2
9-10
11
7
I3
12-13
14
15
16
17
20
19
18
22
Yakima R.
R.
Oregon
kilometers
0 10 20 40

Fig. A.1

# APPENDIX B

## ANNOTATED CHECKLIST OF RECENT AND QUATERNARY NONMARINE MOLLUSCAN LOCALITIES EXAMINED AND SPECIES COLLECTED FROM EASTERN WASHINGTON IN THIS STUDY

# ANNOTATED CHECKLIST OF RECENT AND QUATERNARY NONMARINE MOLLUSCAN LOCALITIES EXAMINED AND SPECIES COLLECTED FROM EASTERN WASHINGTON IN THIS STUDY

Populations containing both living and fossil nonmarine mollusks from eastern Washington were sampled during the present study; most localities represent either Pleistocene Lake Bretz or modern lakes of the Lower Grand Coulee, but several localities considered are several hundred miles away.

The primary locality representing Lake Bretz in the lower Grand Coulee is at the margin of a large barrow pit near the eastern coulee wall (Fryxell 1965). Henderson's Park Lake fossil locality could have been L68-8 and L68-9 of this study (Henderson 1929b). Samples of living freshwater mollusks were obtained from Park, Dry Falls, and Blue lakes and from Delany Spring which still supports a relict population of V[illegible] near the base of Dry Falls.

Booher Lake locality to the northwest, near the Okanogan River, contains molluscan material 10,195±410 years old (WSU-530), and probably represents one previously visited by Olaf Jenkins, which he called Soap Lake material (Jenkins 1918; Hanna 1966; letter dated March 14, 1967 from G D. Hanna, California Academy of Sciences, San Francisco, California). Material from the Lind Coulee locality, L68-28, is from Ringold Formation sediments of

Pliocene age (oral communication, July 27, 1972, R. Fryxell, Washington State University, Pullman, Washington). Granite Point (L69-6) and Marmes Rockshelter L68-26 represent material from archaeological sites that are less than 11,000 years old (Fryxell et al. 1968a; Leonhardy 1970). Four Mile Canyon locality (L69-2) north of Umatilla, Oregon is below what is believed to be a layer of volcanic ash from the Mt. Mazama eruption. Molluscan locality (L72-30) at Crater Draw west of Quincy, Washington is the same as U.S. Geological Survey localities 23217-23219 (see Appendix A). These mollusks occur in a marl-like deposit, which lie beneath non-lacustrine sediments containing coarse volcanic ash. This ash, not yet examined petrographically, may be Glacier Peak in origin as suggested by its stratigraphic position and texture.

All localities studied by the writer are listed below according to the system of Taylor (1966b). Table B.1 shows the geographic distribution of those species identified. Presence of a fossil species is denoted by an "F"; modern faunal species are represented by an "M"; a "B" means that both fossil and modern specimens were found at that locality. Each of those localities is shown on a map of eastern Washington (Fig. B.1) to illustrate spatial relationships. Localities from the Lower Grand Coulee are located in greater detail in Fig. 1.1.

Localities of Quaternary Nonmarine Mollusks
Collected from Eastern ashington
in this Study

1. NL11-1 B-7A, Grant County, Washington, 2,000 ft. N. and 2,400 ft. E. of the SW corner Sec. 36, T.22N, R.27E, three miles north of the town of Soap Lake at the base of the east wall of the Lower Grand Coulee, J. J. Landye and R. Fryxell, 1965 (L65-1).

2. NL11-1 C-6C, Grant County, Washington, 800 ft. S. and 1,800 ft. W. of the NE corner Sec. 15, T.24N, R.27E, on basalt knob on SE shoe of Park Lake, J. J. Landye, 1968 (L68-8).

3. NL11-1 C-6C, Grant County, Washington, 200 ft. S. and 1,500 ft. W. of the NE corner Sec. 15, T.24N, R.26E, on basalt knob NE of 2, J. J. Landye, 1968 (L68-9).

4. NL11-1 B-6B, Grant County, Washington, 1,600 ft. S. and 0000 ft. W. of the NE corner Sec. 13, T.22N, R.27E, adjacent to Soap Lake, J. J. Landye 1968 (L68-5).

5. NL11-1 B-6C, Grant County, Washington, 0000 ft. S. and 2,000 ft. W. from the NE corner Sec. 31, T.22N, R.27E, south of Soap Lake, J. J. Landye, 1968 (L68-111).

6. NL11-1 C-6C, Grant County, Washington, 1,000 ft. N. and 1,000 ft. E. from the SW corner Sec. 15, T.24N, R.27E, Blue Lake, modern and fossil, J. J. Landye, 1968 (L68-16).

7. NL11-1 C-6C, Grant County, Washington, 1,600 ft. N. and 400 ft. E. from the SW corner Sec. 15, T.24N, R.27E, Park Lake, modern and fossil, J. J. Landye, 1968 (L68-15).

8. NL11-1 C-6D, Grant County, Washington, 2,000 ft. N. and 1,500 ft. W. from the SE corner Sec. 6, T.24N, R.28E, Dry Falls Lake, modern and fossil, J. J. Landye, 1968 (L68-14).

9. NL11-1 C-6D, Grant County, Washington, 1,225 ft. S. and 1,400 ft. E. from the NW corner Sec. 7, T.25N, R.28E, Delany Spring, modern, J. J. Landye, 1968 (L68-13).

10. NM11-10 C-8, Okanogan County, Washington, 1,500 ft. N. and 2,700 ft. W. from the SE corner Sec. 3, T.35N, R.26E, Booher Lake, J. J. Landye and R. Fryxell, 1967 (L67-5).

11. NL11-1 A-5C, Grant County, Washington, 600 ft. S. and 850 ft. W. from the NE corner Sec. 35, T.18N, R.29E, Lind Coulee, Pliocene, J. J. Landye, 1968 (L68-28).

---

Collector, collection date, and field locality number follow site description.

12. NL11-4 C-1, Franklin County, Washington, 1,250 ft. S. and 2,530 ft. W. from the NE corner Sec. 17, T.13N, R.37E, Marmes Rockshelter, J. J. Landye et al., 1968 (L68-26).

13. NL11-5 C-6D, Whitman County, Washington, 2,000 ft. S. and 2,400 ft. E. from the NW corner Sec. 24, T.13N, R.43E, Granite Point, F. Leonhardy et al., 1968 (L69-6).

14. NL11-7 D-6A, Benton County, Washington, 600 ft. N. and 50 ft. E. of the SW corner Sec. 21, T.6N, R.28E, Four Mile Canyon north of Umatilla, Oregon, J. J. Landye, 1969 (L69-2).

15. NL11-1 A-8B, Grant County, Washington, 50 ft. N. and 500 ft. E. of the SW corner Sec. 4, T.20N, R.23E, Crater Draw about 1,240 ft. elev., contact basalt and marl to 0.8 m above contact, (see USGS 23217-23219)), J. J. Landye, R. Fryxell, Ula Moody, 1972 (L72-30).

TABLE B.1.--Nonmarine [illegible] Q[illegible]
[illegible] R[illegible] W[illegible]

| | T[illegible] | L[illegible] 8 9 10 11 12 13 14 15 |
|---|---|---|
| Freshwater Species | *Margartifera falcata* (G[illegible]) | F [illegible] F |
| | *Gonidea angulata* (L[illegible]) | F [illegible] F |
| | *Andonta californiensis* L[illegible] | F F F [illegible] F [illegible] F F |
| | *Musculium lacustre* (M[illegible]) | |
| | *Musculium securis* P[illegible] | |
| | *Pisidium compressum* P[illegible] | F F |
| | *Pisidium casertanum* (Poll) | |
| | *Pisidium idahoense* R[illegible] | |
| | *Pisidium variabile* P[illegible] | |
| | *Pisidium nitidium* J[illegible] | |
| | *Pisidium lilljeborgi* C[illegible] | |
| | *Pisidium* spp. | F F F F B B [illegible] F [illegible] F |
| | *Valvata humeralis* S[illegible] | F F F F F F F F F F [illegible] F |
| | *Juga* cf. *J. draytonii* (L[illegible]) | F |
| | *Lithoglyphus* cf. *L. hindsi* B[illegible] | |
| | *Lymnaea stagnalis appressa* Say | F F [illegible] F F B |
| | *Lymnaea* gr. *L. "palystris"* | F F [illegible] F F F B [illegible] F F |
| | *Lymnaea* cf. *L. binneyi* Tryon | F F F |
| | *Gyraulus parvus* (Say) | F F F F F B B B M F F F F |
| | *Promenetus umbilicateflus* (C[illegible]) | |
| | *Omalodiscus pattersoni* (B[illegible]) | |
| | *Armiger* [illegible] (L[illegible]) | F F F F F F |
| | *Helisoma anceps* (M[illegible]) | F F |
| | *Planorbella subcrenata* (C[illegible]) | F F |
| | *Vorticifex effusus* (L[illegible]) | F F F F |
| | *Physa gyrina* Say | F F F [illegible] F B B M |
| | *Physa sp.* | |
| Terrestrial Species | *Allogona ptychophora* (A. D. B[illegible]) | |
| | *Zonitoides arboreus* (Say) | |
| | *Helicodiscus salmonaceus* B[illegible] | |
| | D[illegible] *cronkhitei* (Newcomb) | |
| | *Succinea* cf. *S. avara* (Say) | M M |
| | *Oxyloma* cf. *O.* [illegible] (L[illegible]) | |

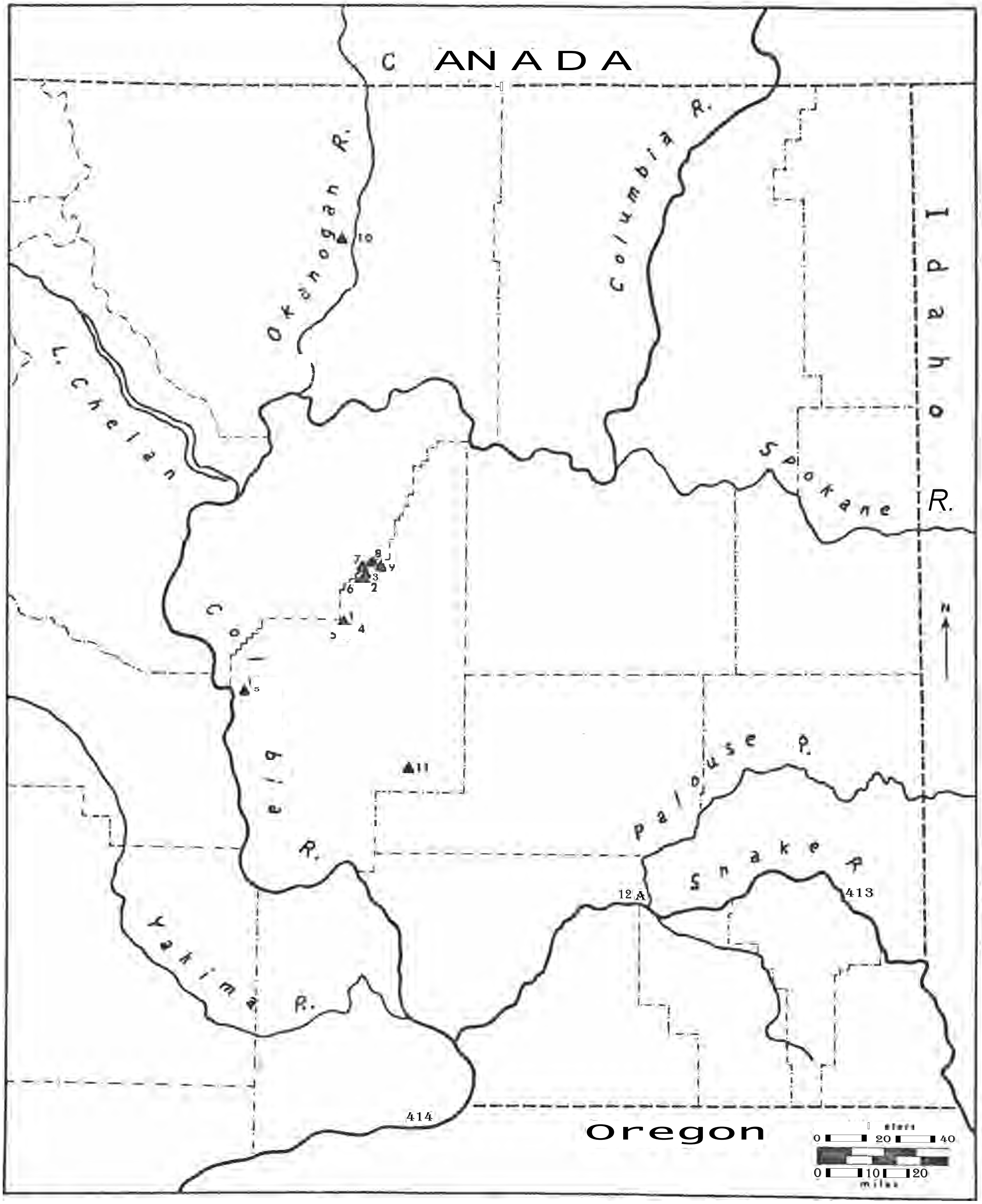
C ANADA
Okanogan R.
Columbia R.
Idaho
L. Chelan
Spokane R.
Col
10
7
8
9
3
6
2
1
4
5
11
Columbia R.
Palouse R.
Snake R.
12 A
413
Yakima R.
414
Oregon
0 20 40
0 10 20
miles

Fig. B.1

APPENDIX C

SYSTEMATIC ACCOUNT OF QUATERNARY NONMARINE

, MOLLUSCAN LOCALITIES IN LOWER

GRAND COULEE

# SYSTEMATIC ACCOUNT OF QUATERNARY NONMARINE MOLLUSCAN LOCALITIES IN LOWER GRAND COULEE

Systematic descriptions of the mollusks found in the Quaternary Lake Bretz deposits follow Taylor and Sohl (1962) and Taylor (oral communication 1969, D. W. Taylor, San Diego Natural History Museum, San Diego, California). Descriptions of terrestrial snails follow the systems presented by Pilsbry (1946) and Patterson (1971). Included in the citations are references to species of mollusks that probably will prove to be in synonymy when revisions are made. The species names used herein are taxonomically conservative, but reflect the current state of knowledge. Some species may be composite, but occupy similar ecological niches. Once the basic anatomy and ecology of living individuals is well understood, then modifications of the taxonomic position of the mollusks involved can be made.

Habitat and distribution descriptions are primarily based on field collections made by D. W. Taylor and on my own field work in western North America. In several cases this field work was undertaken as a joint venture between Taylor and myself. In addition, nonmarine molluscan collections at several West Coast museums such as The California Academy of Sciences and Stanford University have been examined. Descriptions of the Sphaeriidae closely follow the work of Herrington (1962). Pilsbry's (1946) system was employed for terrestrial molluscan material. Other sources are indicated where appropriate.

Photographs were taken from material in my personal collection from L65-1. Families were photographed separately except that a Valvatidae is present with the Planorbidae in Fig. C.2, Planorbidae and Physidae are depicted together with the Lymnaeidae in Fig. C.3, and a Sphaeriidae is shown with the terrestrial material in Fig. C.4.

Phylum Mollusca

Class Pelecypoda

Order Naidoidea

Family Unionidae

Subfamily Anodontinae

Genus *Anodonta* Lamarck, 1799

*Anodonta californiensis* Lea, 1852 (Fig. C.1, A)

*Anodonta nuttalliana idahoensis* Hemphill, 1891. Zoe. 1:321-337.

Distribution: The Columbia River drainage from southern British Columbia south through eastern Washington, eastern Oregon, northern, and southeastern Idaho is within the present range of *Anodonta californiensis*. This species also exists in the Harney Basin, Oregon, Bear River, Wyoming, Eel, Sacramento, San Margarita, and San Joaquin rivers, California, Black and lower Colorado rivers, Arizona, and the Rio Casa Grandes, Chihuahua.

This species may be a composite, but due to the inadequacies of present knowledge I have lumped specimens from these geographical areas. Relationships among the various drainages may never be known because with the development of land areas and urban sprawl, the populations of *A. californiensis* are becoming impoverished or extinct.

Habitat: This clam is found in reservoirs, rivers, streams, and small creeks in several types of substrate, but it seems to prefer muddy bottoms. Its distribution corresponds with the various species of *Gila* (Cyprinidae) which usually acts as their glochidial host, but other freshwater fish can also play this role (D'Eliscu 1972).

Family Sphaeriidae

Genus *Musculium* Link, 1907

*Musculium lacustre* (Müller, 1774)

*Sphaerium lenticula* Prime, 1862. Proc. Acad. Natur. Sci. Philadel. 14:28-37; *Sphaerium cooperianum* Prime, 1869. Amer. J. Conchol. 5:127-176; *Sphaerium raymondi* Cooper, in Raymond and Cooper, 1890. Proc. Calif. Acad. Sci. 3:61-91.

Distribution: *Musculium lacustre* is found in drainages in temperate regions of North America. Even though this small clam was not recovered at the primary locality, it was found in Lake Bretz deposits at Blue Lake. Bingham and Grolier also collected it just north of Soap Lake in Lake Bretz deposits (Appendix A).

Habitat: These small clams are found in both seasonal and perennial lakes or streams in soft sediments.

Genus *Pisidium* C. J. Pfeiffer, 1821

*Pisidium idahoense* Roper, 1890

Distribution: *Pisidium idahoense* is found over most of northern North America. In the western U.S.A. it is found as far south as central California.

Habitat: In the southern range these clams are found in lakes that formerly were large, but which still maintain a cool water regime. In the northern portion of their range they are found in small streams and lakes.

*Pisidium casertanum* (Poli,1791)

*Pisidium occidentale* Newcomb, 1861. Proc. Calif. Acad. Sci. 2:91-94; *Pisidium randolphii* Roper, 1896. Nautilus. 9:97-99; *Pisidium columbianum* Sterki, 1913. Nautilus. 26:117-119; *Pisidium furcatum* Sterki, 1913. Ibid.; *Pisidium rhombicum* Sterki, 1913. Ibid. *Pisidium modicum* Sterki, 1913. Ibid.; *Pisidium ovum* Sterki, 1916. Ann. Carnegie Mus. 10:429-477; *Pisidium eyerdami* "Sterki" Odhner, 1939. Nautilus. 52:79-84.

Distribution: *Pisidium casertanum* is found in almost every drainage in the temperate portions of the world.

Habitat: These small pelecypods are found in both seasonal and perennial freshwater habitats of all types.

*Pisidium compressum* Prime, 1852

*Pisidium curvatum* Hanna, 1923. Proc. Calif. Acad. Sci. 12:31-41; *Pisidium vegae* Pilsbry, 1926. Proc. Acad. Natur. Sci. Philadel. 77:329-334.

Distribution: *Pisidium compressum* is found in drainages of North America south to the Mexican Plateau. After *P. casertanum* this clam is the most common *Pisidium* in North America.

Habitat: Like *P. casertanum* these small clams are found in all types of freshwater with the exception that they seem to be restricted to larger streams in the Southwest.

*Pisidium lilljeborgi* Clessin, in Esmark and Hoyer, 1886

*Pisidium arcticum* Westerlund, 1883. Nachrichtsblatt der deutschen malakozoologischen Gesellschaft. 15:48-59.

Distribution: *Pisidium lilljeborgi* is found in northern North America and Eurasia. Its range in the western North America extends southward from Alaska south to Colorado, Utah, and Washington.

Habitat: These small bivalves are found most commonly in lakes with substrates of fine sands or silts supporting small submergent vegetation.

*Pisidium nitidum* Jenyns, 1932

*Pisidium prognathum* Sterki, 1922. Ann Carnegie Mus. 13:425-539.

Distribution: *Pisidium nitidum* is found in drainages or Eurasia and North America. This clam ranges from the northern to the southern borders of the western U.S.A.

Habitat: Most commonly these clams are found in the shallow areas of ponds, lakes, and streams.

*Pisidium variabZe* Prime, 1852.

*Pisidium probum* Sterki, 1923. Nautilus. 37:16-22.

Distribution: *Pisidium variabile* ranges from southern Canada south to northern California and northern Utah.

Habitat: These small pelecypods are found in the shallow areas of perennial lakes and streams.

Class Gastropoda

Order Monotocardia

Family Valvatidae

Genus Valvata Muller, 1774

*Valvata humeralis* Say, 1829 (Fig. C.2, B)

*Valvata humeralis pilsbryi* Martens, 1899. Biologia Centrali-Americana, p. 426; *Valvata humeralis patzcuarensis* Pilsbry, 1899. Proc. Acad. Natur. Sci. Philadel. 51:391-402; *Valvata humeralis californica* Pilsbry, 1908. Nautilus, 22:82.

Distribution: *Valvata humeralis* is found in Pacific drainages, the headwaters of the Rio Grande, Colorado and a few internal drainage basins from British Columbia to the Mexican Plateau. Localized populations of *V. humeralis* occur at the southern end of its range on the Mexican Plateau.

Habitat: This gastropod is found on soft mud substrate at the base of aquatic vegetation in clear freshwater lakes and slower velocity areas of streams.

Order Basommatophora

Family Lymnaeidae

Genus *Lymnaea* Lamark, 1799

*Lymnaea stagnalis appressa* Say, 1818 (Fig. C.3, E)

*Lymnaea stagnalis wasatchensis* F. C. Baker, 1911. Chicago Acad. Sci. Spec. Pub. 3:1-539; *Lymnaea lepida* Gould, 1847a. Proc. Boston Natur. Hist. 2:210-212; *Lymnaea stagnalis brunsoni* R. H. Russell, 1967. Nautilus. 80:124-126.

Distribution: *Lymnaea stagnalis appressa* is reported to live in the drainages of most of northern North America except that in the west the snail lives only north of southern Utah, southern Colorado, and central California.

Habitat: These snails are found in perennial rivers, reservoirs, lakes, or ponds on aquatic vegetation.

*Lymnaea* group of *L. emarginata*

*Lymnaea* cf. *L. binneyi* Tryon, 1965 (Fig. C.3, C)

*Stagnicola couleensis* F. C. Baker, in Henderson, 1929b. Nautilus. 42:110-123.

Distribution: *Lymnaea binneyi* is found only in the Columbia River in eastern Washington. This species as used is considered a member of the *L. emarginata* group. Not enough work has been done on the living gastropod to warrant applying a separate specific designation.

Habitat: These gastropods are found in large perennial rivers and lakes.

*Lymnaea* group of *L. "palustris"*

*Lymnaea "palustris"* (Fig. C.3, D)

Within the framework of our present knowledge of the Lymnaeidae, it is impossible to assign this snail into a strict species (Taylor 1965). Henderson (1929c) reported *L. traskii* Tryon from fossil deposits at Soap Lake which probably can be referred to the group of *L. "palustris."* With just shell characteristics, it is impossible at present to distinguish the various species within this group.

Habitat: These snails live in small ponds or streams.

Family Planorbidae

Genus *Gyraulus* Charpentier, 1837

*Gyraulus parvus* (Say, 1816) (Fig. C.2, A)

*Planorbis vermicularis* Gould, 1847a. Proc. Boston Natur. Hist. 2:210-212; *Planorbis similaris* F. C. Baker, 1919. Bull. Amer. Mus. Natur. Hist. 41:527-539; *Gyraulus* *vermicularis albolineatus* Henderson, 1933. Nautilus. 47:78-79; *Gyraulus cressmani* F. C. Baker, 1942a. Nautilus. 55:30-132.

Distribution: *Gyraulus parvus* may be a composite group of species with similar environmental requirements found living in North America south to the tropics.

Habitat: These planorbids are found on submergent vegetation in various types of freshwater habitats.

Genus *Armiger* Hartmann, 1840

*Armiger crista* (Linnaeus, 1758) (Fig. C.2, C)

*Armiger imbricatus* F. C. Baker, 1943. Carnegie Inst. Wash. Publ. 538:117-119.

Distribution: *Armiger crista* is. a Holartic species found south to central Utah and central California. This is one of the smaller freshwater pulmonates, is often overlooked when sampling a habitat.

Habitat: These minute snails are found in lakes and ponds in quiet water with a silty substrate on abundant growths of higher aquatic plants.

Genus *Vorticifex* Meek, 1870

*Vorticifex effusus* (Lea, 1856) (Fig. C.2, D)

*Pompholyx leana* var. *solida* Dall, 1870. Ann. Lycium Natur. Hist. New York. 9:333-361; *Parapholyx mailliardi* Hanna, 1924. Proc. Calif. Acad. Sci. 13:131-136; *Parapholyx effusa diagonalis* Henderson 1929a. Nautilus. 42:80-82; *Parapholyx effusa nevadensis* Henderson, 1934. Nautilus. 47:86-91; *Pompholyx solida optima* Pilsbry, 1934. Proc. Acad. Natur. Sci. Philadel. 86:29-66; *Parapholyx effusa klamathensis* F. C. Baker 1941. Nautilus. 55:16-17; *Parapholyx effusa dalli* F. C. Baker, 1945. The molluscan family Planorbidae, Univ. In. Press, Urbana. pp. 1-530; *Parapholyx klamathensis sinitsini* F. C. Baker, 1945. Ibid.; *Parapholyx pusilla* F. C. Baker 1945. Ibid.

Distribution: Today *Vorticifex effusus* lives in drainages from eastern Nevada to south central Idaho, west to northern California to eastern Washington.

Habitat: These gastropods are found in high quality water of lakes, rivers, and spring fed creeks. Usually they are found in water with a high content of dissolved oxygen.

Genus *Planorbella* Haldeman, 1842

*Planorbella subcrenata* (Carpenter, 1857) (Fig. C.3, A)

*Planorbis hornii* Tryon, 1865. Amer. J. Conchol. 1:223-232; *Planorbis oregonensis* Tryon, 1865. Ibid.; *Planorbis binneyi* Tryon, 1867. Amer. J. Conchol. 3:195-198; *Planorbis occidentalis* J. G. Cooper, 1870. Proc. Calif. Acad. Sci. 4:92-100; *Helisoma plexata* Ingersoll, 1875. Bull. U.S. Geol. Geograph. Survey Territories. a:121-142; *Planorbis subcrenatus disjectus* Cooper, in Raymond and Cooper, 1890. Proc. Calif. Acad. Sci. 3:61-91; *Helisoma trivolvis kolymense* Lindholm, 1932. Trudy Sovieta po Isucheniyu Proizvoditel'nykh Sil, Seriya Yakutskaya. 11:65-72; *Helisoma occidentale depressum* F. C. Baker, 1934. Nautilus. 47:140-142; *Helisoma columbiense* F. C. Baker, 1945. The molluscan family Planorbidae, Univ. In. Press, Urbana. pp. 1-530; *Helisoma subcrenatum perdisjunctum* F. C. Baker, 1945. Ibid.; *Helisoma binneyi randolphi* F. C. Baker, 1945. Ibid.; *Helisoma binneyi ursolacustre* Baily and Baily, 1952. Nautilus. 65:46-53.

Distribution: *Planorbella subcrenata* is found south of Alaska to northern California, northern Arizona, and northern New Mexico. At the southern limit of its range *P. subcrenata* occurs sporatically at higher elevations; perhaps Pleistocene relicts.

Habitat: These large planorbids are found on rocks and submergent vegetation in lakes, streams, and ponds.

Family Physidae

Genus *Physa* Draparnaud, 1801

Group of *Physa gyrina*

*Physa gyrina* Say, 1821 (Fig. C.3, B)

*Physa concolor* Haldeman, 1841. Proc. Acad. Natur. Sci. Philadel. 1:103; *Physa ampullacea* Lea, 1864. Ibid. 16:114-116; *Physa nuttallii* Lea, 1864. Ibid.; *Physa malleata* Tryon, 1865. Amer. J. Conchol. 1:165-173; *Physa occidentalis* Tryon, 1865.; *Physa politissima* Tryon, 1865. Ibid.; *Physa propinqua* Tryon, 1965. Ibid.; *Physa coniformis* Tryon, 1866. Ibid. 2:4-7.

Distribution: *Physa gyrina* is extremely widespread in North America north of northern Arizona and New Mexico. The snail is found on the Mexican Plateau, where populations are sporadic. This group of mollusks consists of grouping many of the previously described species of *Physa.*

Habitat: These snails are found in all types of situations including lakes, reservoirs, streams, small creeks, and ponds. Water can be either permanent or temporary with clean or polluted conditions.

Order Stylommatophora

Family Succineidae

Genus *Succinea* Draparnaud, 1801

cf. *Succinea* (Fig. C.4, C)

Distribution: *Succinea* are found throughout the world and are often confused with other genera of the Succineidae, particularly *Catinella* (Patterson 1971). It is virtually impossible to identify members of this group from shell material only.

Habitat: These terrestrial gastropods are usually found in extremely moist situations, both on soil and plants (usually sedges) adjacent to water.

Family Zonitidae

Genus *Zonitoides* Lehmann, 1862

*Zonitoides arboreus* (Say, 1816) (Fig. C.4, B)

Distribution: *Zonitoides arboreus* is widespread in North America in protected habitats.

Habitat: These gastropods occupy moist terrestrial habitats that are protected from the sun.

Family Endodontidae Pilsbry

Genus *Discus* Fitzinger, 1833

*Discus cronkhitei* (Newcomb, 1965) (Fig. C.4, A)

Distribution: *Discus cronkhitei* is found from Maine to California in favorable terrestrial habitats.

Habitat: These snails are found on leaves and grass in extremely humid situations.

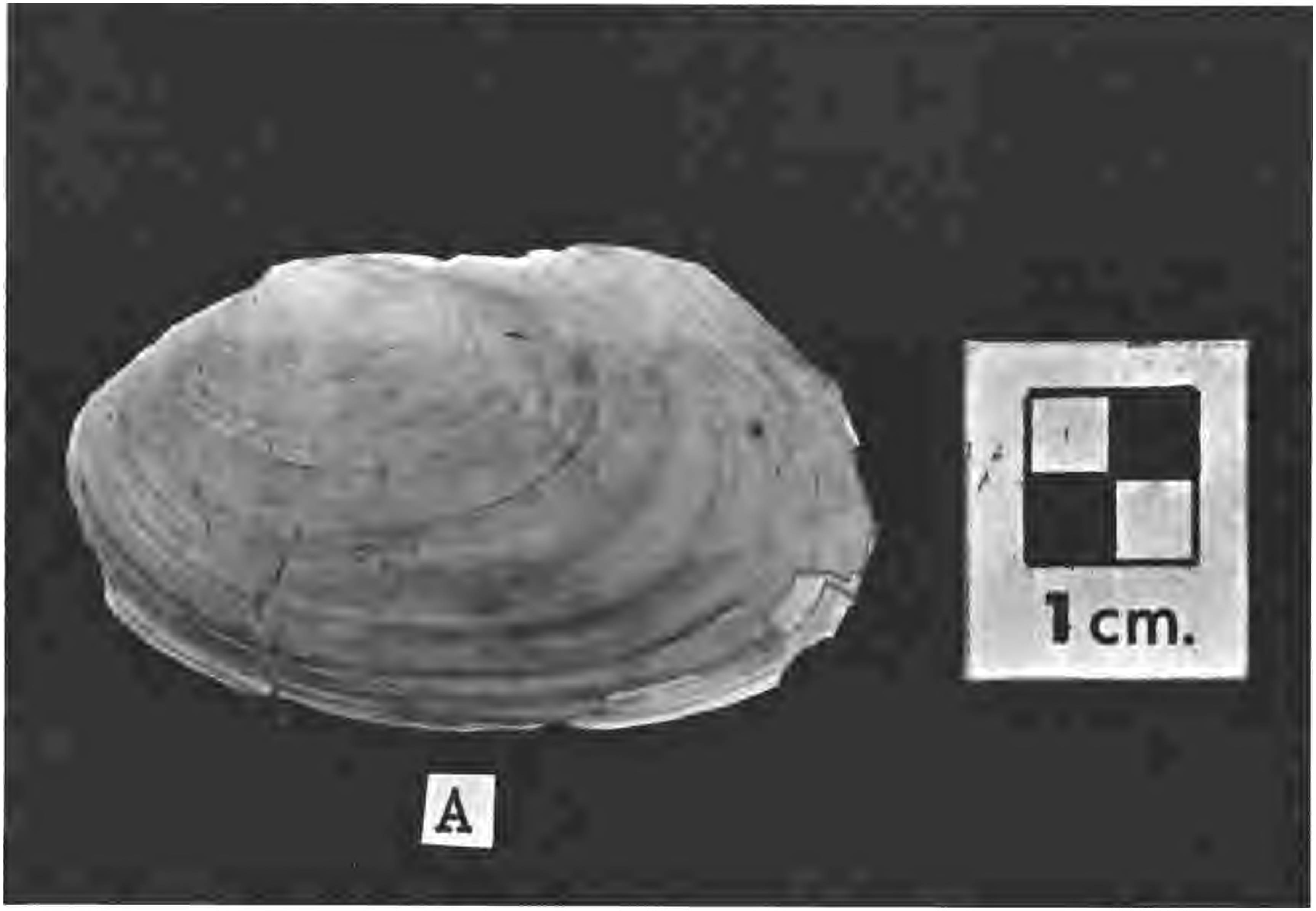


Fig. C.1

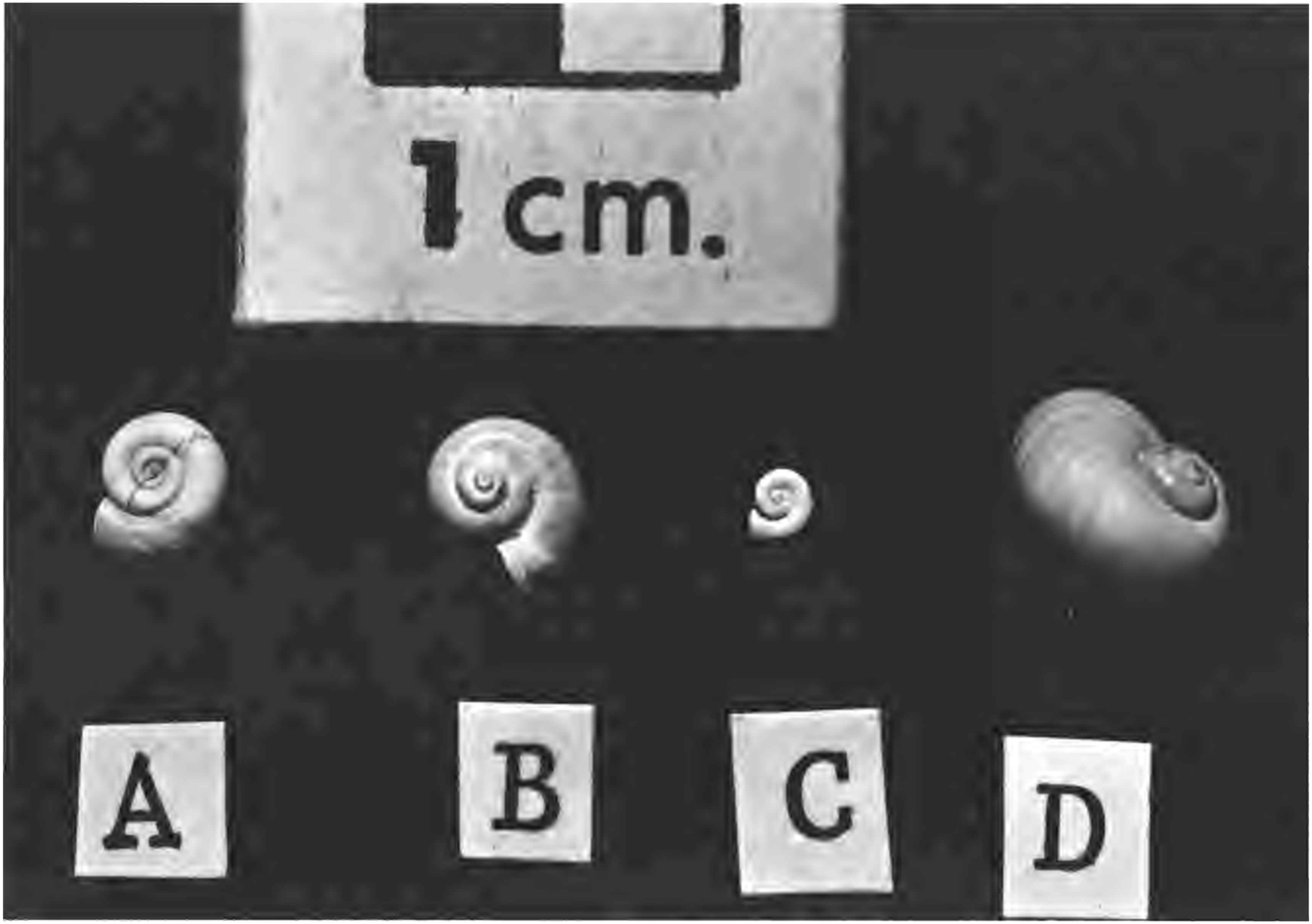


Fig. C.2

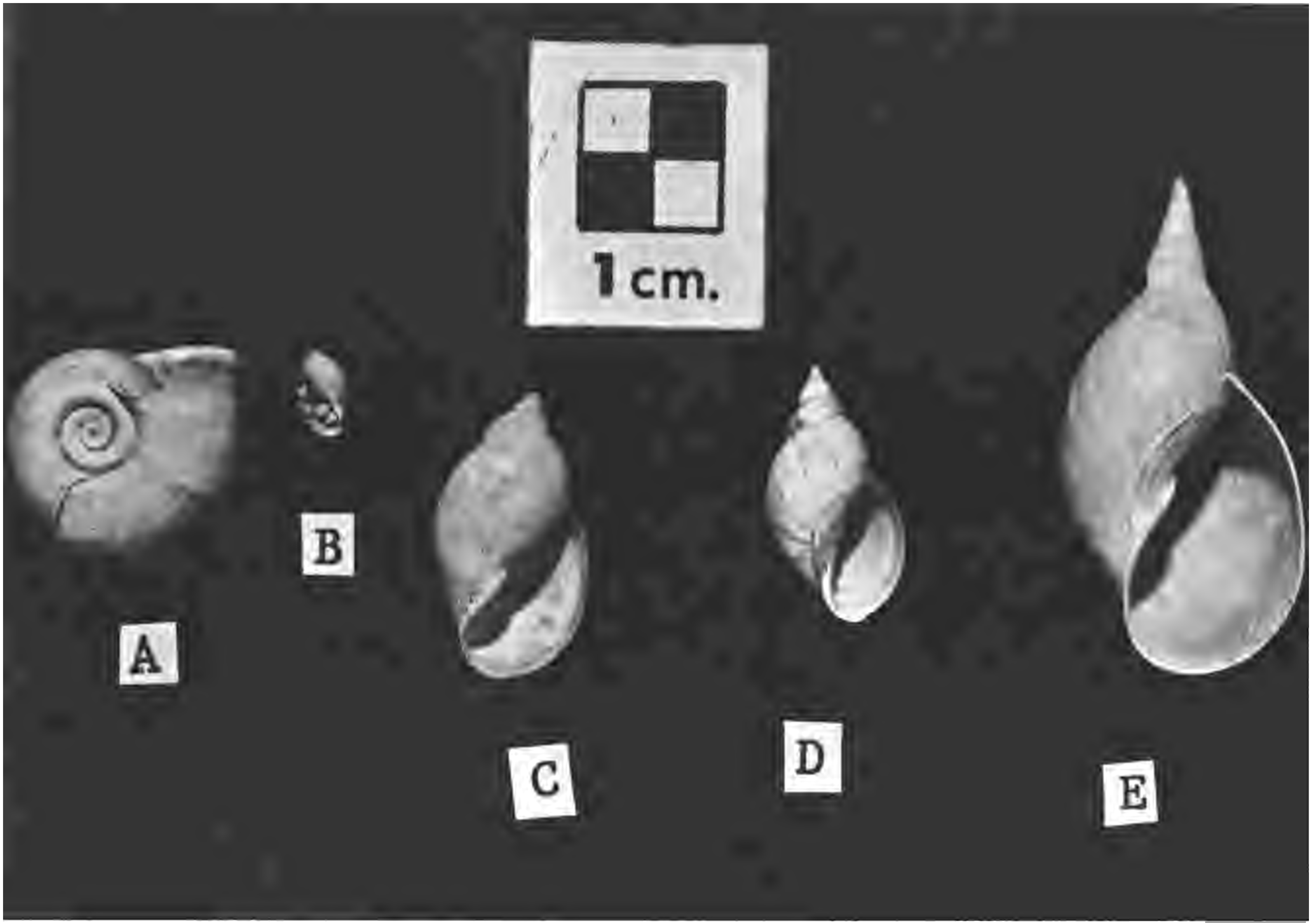


Fig. C.3

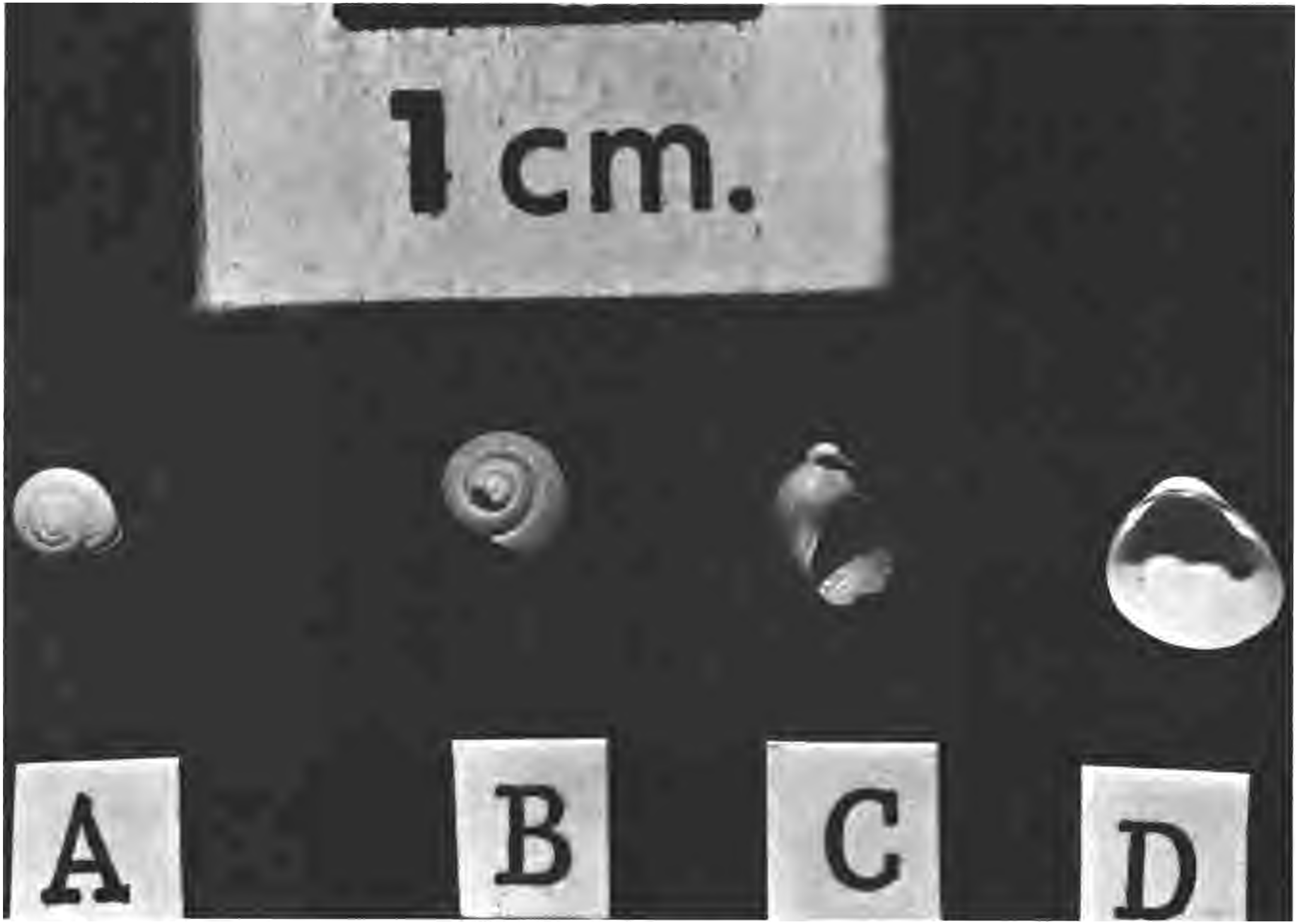


Fig.