GEOLOGY OF THE ANA RIVER SECTION
SUMMER LAKE, OREGON

by

CLARENCE FREDERICK CONRAD

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1953

APPROVED:

[redacted]

Professor Department of Geology

In Charge of Major

[redacted]

Head of Department of Geology

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

Date thesis is presented September 10, 1952

Typed by Roberta Matthews

ACKNOWLEDGMENTS

The writer wishes to express sincerest appreciation to his major professor, Dr. I. S. Allison, for guidance and constructive criticism during the preparation of this paper.

Thanks also are due Dr. L. F. Hintze for helpful suggestions on stratigraphic problems and Mr. H. A. Boyd for interest and advice on paleontologic problems.

The writer is also indebted to Mr. D. L. Minar for his identification of the ostracods and to Mr. H. J. Trumpour for conducting spectrographic and differential thermal analyses.

TABLE OF CONTENTS

Page

ILLUSTRATIONS

List of Plates and Charts

List of Figures

GEOLOGY OF THE ANA RIVER SECTION, SUMMER LAKE, OREGON

INTRODUCTION

Location

The Ana River section of lake beds is located near the northwestern margin of the Summer Lake basin of west-central Lake county, Oregon, and in the extreme northwestern portion of the Basin-and-Range physiographic province of the western United States (plate 1). The basin that immediately surrounds Summer Lake is approximately 20 miles long and 10 miles wide and lies between latitudes 42° 45' and 42° 58' North, and longitudes 120° 40' and 120° 50' West. The section of Pleistocene and Recent lake beds exposed along Ana River is located more specifically in the NW ¼, T. 30 S., R. 17 E., Willamette Meridian.

Summer Lake post office is 106 miles south-southeast of Bend, Oregon, by way of paved highways U.S. 97 and Oregon 31. Lakeview, Oregon, is 71 miles southeastward on paved highways Oregon 31 and U.S. 395 and is the seat of Lake County. Secondary roads in the Summer Lake basin are in part graveled, and minor dirt roads leading to almost every part of the basin are usable throughout most of the normally-dry year. In addition to the post office at Summer Lake there is a store and gas station which serves the ranchers of the area.

Purpose of Investigation

The basin is of interest geologically because during Quaternary times it was occupied by two or more deep pluvial lakes. The presence of these former large undrained lakes is indicated by a

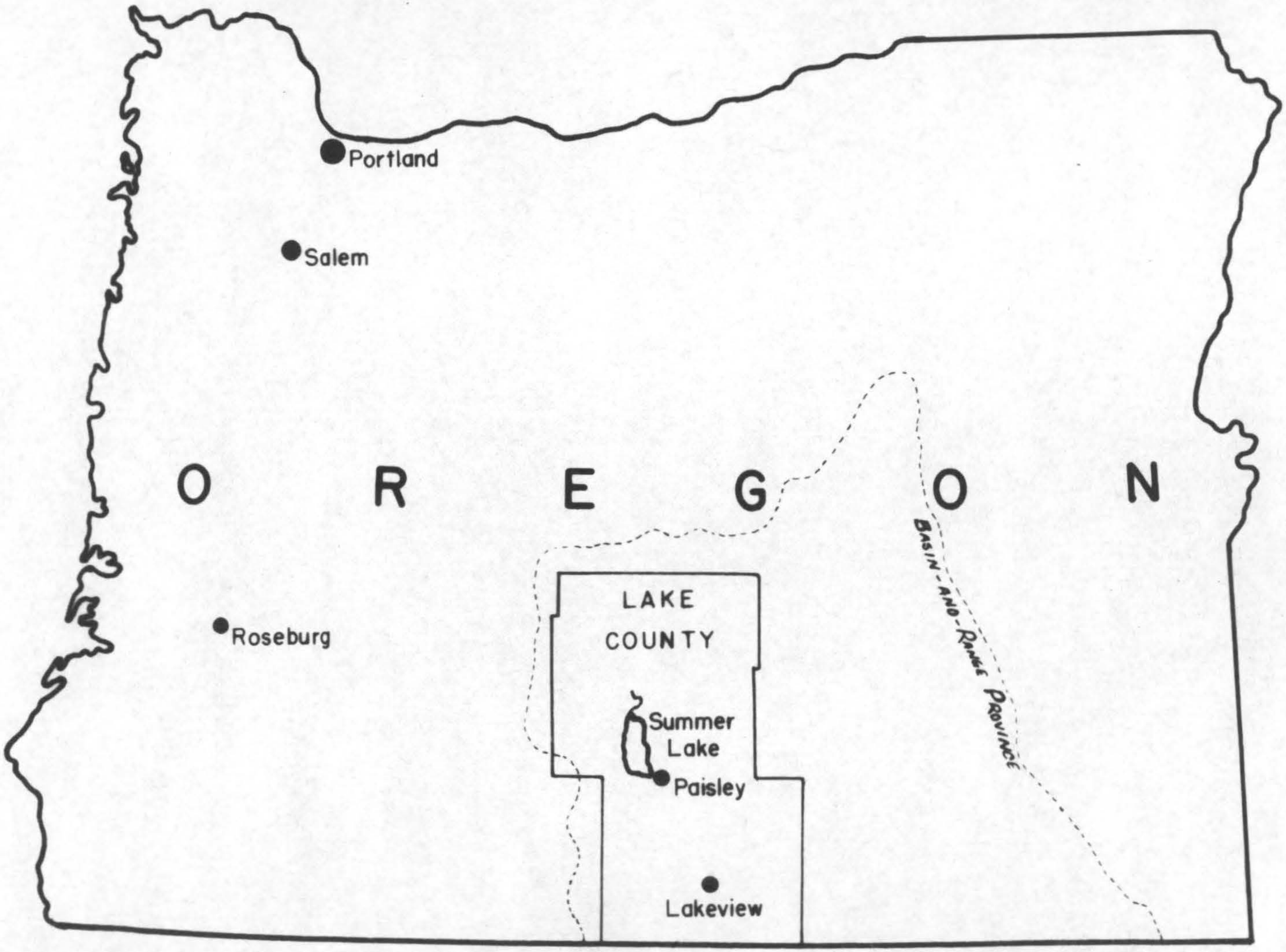


Plate I - Index map showing location of Summer Lake and Ana River multiplicity of shore line features around the margins of the basin.

Drilling within the basin has penetrated considerable thicknesses of lake sediments indicating a long, complex history, as yet only partially known. The Ana River section exposes for detailed study the uppermost 50 feet of these sediments and despite their limited extent, is valuable for reconstructing the final phases of the pluvial lake history of the basin. Several layers of pumice indicate eruptions of Mount Mazama (Crater Lake) and Newberry Crater. The pumice layers are sufficiently recent to be useful for dating and correlating throughout much of south-central Oregon, the Crater Lake pumice being especially useful for dating archaeological finds.

Fresh-water mollusks and arthropods are interspersed throughout the lake sediments and aid in reconstructing the environmental conditions present at the time they lived. A detailed study on the ostracod shells, which are abundant throughout most of the section, might serve to give definite proof of changing salinity or water temperatures at various stages of the lake and possibly relate major lake changes to corresponding facies changes in the sediments.

Since this region lies at the northwestern edge of the Basin-and-Range province it expresses a type of structure common to large areas of the western United States. Winter Ridge, bounding the western edge of the Summer Lake basin, is one of several major fault scarps in southeastern Oregon.

The primary purpose of this study is the examination and interpretation of the lake sediments exposed along the banks of Ana River to add to the increasing knowledge of the pluvial lake history of this basin.

Previous Work

The first geological study of the Summer Lake basin was conducted by I. C. Russell during a hasty reconnaissance across southeastern Oregon in the year 1882. His findings were embodied in the United States Geological Survey's 4th Annual Report published in 1884. In connection with a study of the water supply of south-central Oregon, Waring (49, pp. 21-31) made a more comprehensive study of the Summer Lake basin. His work included the first reconnaissance geologic and topographic maps of south-central Oregon. Even today this area has no topographic maps, other than Waring's, and only a few scattered areas have been geologically mapped in detail. A more recent general discussion of the geology of south-eastern Oregon was published by Smith in 1926 (43, pp. 199-256). The results of analysis of Summer Lake water have been published by Van Winkle (48, p. 119), and by Allison and Mason (3, p. 3).

Recent workers in the Summer Lake basin have been primarily concerned with the pluvial lake history, climatic successions in the late Pleistocene and Recent times, or archaeological studies. Allison (1, pp. 789-808) studied the lake history and pumice beds at Summer Lake and named the pluvial lakes formerly present in the basin. In 1946 Allison (2, pp. 63-65) published a geological background of the south-central Oregon region to which archaeological findings could be applied. Archaeological studies have been conducted at the Paisley Caves, and other sites in south-central Oregon.

The Paisley Caves are not in the Summer Lake basin proper, but their origin is due to the wave action of the pluvial lakes which extended to the south from the Summer Lake basin. Consequently the dating of the archaeological finds is dependent upon the dating of the lakes. These archaeological studies have been carried out by L. S. Cressman or under his direction. Publications by Cressman include: (12, pp. 300-306), (13, pp. 1-155), (14, 236-246). Hansen (24, pp. 164-171) has studied forest successions based on pollen profiles as a guide to postglacial climatic changes. His work includes a chronology of postglacial time. Hansen (25, p. 1252) dates the Crater Lake and Newberry Crater pumice through their relation to the climatic stages, as indicated by pollen profiles from peat sections in central Oregon.

GEOGRAPHY

Physiography

Basin-and-Range Province

The Basin-and-Range province is a physiographic feature of rather indefinite boundaries comprising approximately one-tenth of the area of the United States and continuing southward into Mexico. The province is characterized by tilted fault blocks generally trending north-south and separated by inter-montane desert basins.

To the northern half of the province, an area of interior drainage, the name "Great Basin" is applied. The name was given this area by Fremont in 1844, after crossing the region and noting that it had no water running to the sea. Despite the implication of the name, the region is not a single basin but rather is composed of more than 90 separate basins and more than 160 mountain ranges (10, p. 11). The mountains occupy about half of the total area of the Great Basin section of the Basin-and-Range province. The Great Basin extends north of the Oregon-Nevada border for about 160 miles and embraces approximately 16,000 square miles of central and southern Oregon (40, pp. 435-436). On the north and east it is bounded by the hydrographic basin of the Columbia River while on the west it is bounded by the drainage of the Klamath and Pitt Rivers.

The exact boundaries of the Great Basin in Oregon are indefinite, the edges being determined by hydrographic boundaries which are uncertain in many places. In the past the boundaries have changed, in a hydrographical sense, as at Klamath Lake which became tributary to the ocean during the Quaternary and forced the boundary of the province eastward of the Sierra Nevada-Cascade mountain crest. Other local boundary changes can occur, as at Malheur Lake, where only a low pass keeps the lake from becoming tributary to the Malheur River. A slight increase in the level of the lake would accomplish this and again alter the margin of the basin. Properly, however, the province should be considered only in a physiographic sense and thus would include such boundary areas regardless of the precipitation.

Because of the interior position and large ranges of elevations, the climate of the Great Basin is generally semi-arid, but locally it varies from arctic climates above timberline on the highest mountains to true desert conditions near sea level in the southern part. In the northern half, the Great Basin proper, water drains into enclosed basins while in the southern portion there are slopes on which water could run directly to the sea, but the region is too arid to supply a continuous flow or has no runoff at all (17, p. 326).

The first theory of origin of the individual mountain ranges in the Great Basin was published by King in 1870 (30, pp. 451-473) who considered the ranges to be a series of eroded folds. A short time later, Gilbert(18, p. 41) formulated the idea that the ranges of the Great Basin were the result of differential elevation of crustal blocks, bounded on one or both sides by profound faults showing vertical displacement, with little or no folding. The idea was adopted by Powell in his outline of the types of mountain origin under the heading "Basin Range type." King agreed to the idea of extensive faulting, but he emphasized that the faulting had been superimposed on the earlier folding.

While the general character of the mountain ranges of the Basin-and-Range province is that of the fault block or Basin Range type, the individual ranges display several fundamental types of structure. Louderback (33, pp. 354-355) reports one common type of the basin ranges to be that of a tilted block with a scarp developed on one side. One slope of the range, normally the longest, contains Tertiary formations tilted by block rotation. Another common type has scarps developed on both sides of the range. In this instance, the Tertiary formations are truncated by both scarps and may expose pre-Tertiary rocks at each base. The range scarps, then, are principally the result of progressive development by faulting. The recent phase of this faulting is seen at the base of the scarp where occasionally renewed faulting in Recent time exposed uneroded fault scarplets. While the early exposed portions of major scarps have suffered degradation, most have not been eroded enough to destroy the evidence of faulting or to cause doubt as to which side is the scarp. In several places of Recent movement along these faults there has been but slight retreat of the range scarp from the fault line.

Drainage

Because of the barrier effect of the Cascade Mountains and the resultant low precipitation beyond it, the Summer Lake hydrographic basin is characterized by an insequent, nonintegrated drainage pattern

(43, p. 56). The drainage area of Summer Lake is approximately 550 square miles, but because of the low precipitation, no streams of consequence enter the basin. At high water stages the lake occupies an area of about 70 square miles but shrinks to nearly half that size during dry years. The lake is largely independent of local run-off for its water, its principal source being Ana River which is fed by at least 5 springs that rise in the sediments at the north end of the basin. The total flow of these springs is quite constant at the rate of about 145 second feet (49, p. 32). Ana Springs is one of the largest fresh water springs in the United States. From the springs, the river follows a meandering course for about 7 miles to where it discharges into Summer Lake.

Although Ana River is the main feeder of Summer Lake, its flow is supplemented by that of smaller springs and by seepage. Waring (49, p. 42) reports the flow of Ana River to increase from 155 second feet near the springs to 179 second feet near the mouth. Numerous other springs tributary to Summer Lake rise along the western side of the basin but the total discharge of 16 springs measured by Waring amounted to only 4 per cent of that of Ana River.

The temperature of the water of Ana Springs is 66° F. At the southeastern end of the Summer Lake basin one spring, the Woodward hot spring, is reported by Waring (49, pp. 54-55) to have a temperature of 123° F.

At present Summer Lake is one of the largest lakes of the northern Great Basin. Its waters contain sufficient dissolved salts to render it uninhabitable to fish life, but it swarms with crustaceans of the genus Artemis, or "brine shrimp" as they are more commonly called.

Since the early settlers moved into southeastern Oregon small changes have been noticed in the levels of the nearby lakes. Because of the shallowness of these lakes, the water level can change but little without destroying them. While some of the lakes have enlarged and even overflowed, a few, as Silver Lake in the years 1888-1889, and again in the 1940's, have temporarily dried up (49, pp. 37-38). No notable changes in the level of Summer Lake, however, have been recorded. Although Summer Lake has a constant source of water supply, several arid seasons likewise could reduce its area to a fraction of that existing today by the unbalancing of the rate of evaporation to that of inflow.

Climate

The Summer Lake basin is characterized by a semi-arid climate with cold winters, hot summers, and wide diurnal temperature changes. The seasonal precipitation occurs chiefly between the months of October and March with a secondary maximum during May and June, followed by a relatively dry summer. The prevailing wind is southerly in winter months but changes to the northwest in the summer.

The only United States Weather Bureau station near Summer Lake is located 29 miles to the southeast at Paisley, Oregon, at approximately the same elevation. From data recorded for more than 25 years, the mean annual rainfall is 8.9 inches while the mean annual temperature (15 years record) is 48.4° F.

In accordance with Köppen's quantitative classification of climates, as modified by Trewartha (47, pp. 357-361), the climate would be classified as Steppe (BSks). This emperically devised classification is based primarily upon annual and monthly means of temperature and precipitation. The letter designation BS refers this climate to that of a semi-arid, Steppe climate; k indicates the coldest monthly temperature to be less than 32° F.; and the letter s corresponds to the rainfall which is distributed such that it gives the area a dry season in the summer.

Vegetation

The harsh climatic conditions prevalent in the Summer Lake basin and adjacent region is reflected by the scanty flora. The basin is situated in the upper Sonoran vegetation province (one of the 5 life zones of the northern Great Basin) near the northern border of this typically more southern zone.

The flora is separted into 2 main groups depending on the alkalinity of the soil. The halophytic flora includes several varieties of saltbush, the most common being *Atriplex confertifolia*. Greasewood (*Sarcobatus vermiculatus*) and salt grass (*Distichlis spicata*) are also locally present.

The most ubiquitous plant of the basin is sagebrush, the predominating variety being *Artemisia tridentata*, while rabbit brush or golden sage (principally of the genus *Chrysothamnus* or *Tetradymia*) is less abundant.

The Canadian life zone covers the higher part of the mountains of this region, including Winter Ridge. The upper half of Winter

Ridge contains a notable stand of predominantly ponderosa pine timber. (42, pp. 99-109).

PLEISTOCENE AND RECENT HISTORY OF THE SUMMER LAKE BASIN

Pluvial Lakes and Their Origin

Throughout the Great Basin evidence of an extensive series of Pleistocene pluvial lakes is apparent and well known. Evidence of their former existence is seen in well preserved shore line features and characteristic deposits. Such is the case in the Summer Lake basin where wave-cut cliffs and terraces and lacustrine deposits record a similar, contemporaneous history.

The early workers in the Great Basin, as Russell (1884) and Gilbert (1890), first recognized the relationship of expanding lakes in the Southwest to the glacial stages in the north. The existence of such lakes was thought to have required a much cooler and moister climate than that existing today. More recent workers in the region as Antevs (1925;1938;1941), Blackwelder (1931;1948), Meinzer (1922) and others have accepted and expanded these relationships.

Antevs (5, pp. 51-114) has shown the chief events of the Pleistocene lake history to have paralleled the larger events in the northern part of the continent. While in the north at least 4 glacial stages with warm interglacial stages have been recognized, in the Great Basin glaciation and pluvial lakes alternated with periods of aridity. The maximum mountain glaciation and highest levels of the lakes were contemporaneous with, or slightly later than, the climax of glaciation and early stages of ice retreat. The stages of aridity corresponded to interglacial stages.

The lakes of the Great Basin, then, were caused by the combined effects of decreased evaporation because of low summer temperatures and relatively heavy precipitation connected with climatic changes association with glaciation elsewhere. These humid and semi-humid stages are referred to as pluvial stages. The lakes held fresh water during the cooler epochs, but these lakes probably dwindled to playas or salinas in the intervening dry times.

Antevs (7, pp. 63-76) has further shown the climatic conditions of the Southwest to have been influenced most by the state of glaciation in western Canada. As the last continental ice cap advanced and neared its maximum the glacial anticyclone became strong enough to force the storm paths southward into the region of the Great Basin. The heaviest precipitation then occurred well to the south of the ice border. The increased precipitation in the region of the Great Basin, as the result of this dislocation, produced the great pluvial lakes and mountain glaciers. The forcing of the storm paths to the south led to the undernourishment of the ice and, as the western ice-sheet began to shrink, the anticyclone weakened and the polar front moved northward so as to diminish precipitation in the Southwest.

The difference in humidity between the northern and southern parts of the province apparently was greater in the Pleistocene than at the present. The existing southward increase in the rate of evaporation and decrease in precipitation apparently was accentuated during this time.

Meinzer (35, pp. 541-552) has compiled a series of maps showing the distribution of Pleistocene lakes of the Great Basin which further substantiates Antevs' findings. These maps clearly show the important relationship of latitude to the size and abundance of the lakes. The Pleistocene lakes were crowded in the northern part of the province and generally were large, while those to the south were smaller and less abundant. Other southern basins probably held water but never of sufficient permanence to leave recognizable shore lines.

Jones (29, p. 47) after studying the Lahontan basin advocates the extreme recency of Lake Lahontan and consequently other contemporaneous lakes of the Great Basin. He estimates the lake to have had its beginning between 2,000 and 4,000 years ago, and to have reached its maximum depth extent about 1,000 years ago. Jones's dating (29, p. 28) is based on the fact that if the present lakes are remnants of Lake Lahontan the age of the lake can be calculated from the amount of salt in the present lakes in the Lahontan basin and the rate at which streams are carrying salts into these lakes. For further substantiating evidence he refers to Huntington (28, pp. 1-255) who studied sequoias as a guide to climates. Huntington's rainfall curve (28, p. 172) shows wet periods at about the time of Christ, 1,000 A.D., and 1,350 A.D. From this dating Jones believes the lake to have had its beginning during the first wet period about 2,000 years ago and to have reached its maximum during the second about 1,000 A.D. Jones further refers to the fact that many animals, the remains of which are found in the basin, no longer exist and concludes such extinctions could take place in a short time, referring as evidence to the many extinctions of animals in historic time.

The dating advocated by Jones has been refuted by Antevs (8, p. 211), Hay (26, p. 147), and others. Hay does not accept this dating on the basis that it would require the rapid extinction of camels, native horses, and other animals existing in the region 1,000 years ago.

Blackwelder (10, p. 12) has recently pointed out that the lakes could have existed even without the presence of increased precipitation. He suggests that during the coldest ages the temperature was probably 8-12° F below long term averages and consequently the region would have been less arid, even without increased precipitation. The surplus winter snow could then form in ice fields at the heads of mountain canyons and at the same time lakes could have formed in nearly all basins as the result of the balance between inflow and evaporation changing in favor of inflow.

Because of the close relationship of glaciation to pluvial lake stages, the dating of various lake stages can be made from a knowledge of the glacial stages. Coincident with the pluvial lakes, alpine glaciers formed on all higher mountains in the Great Basin, and especially on the major ranges to the east and west. The known mountain glaciers in the Great Basin, however, were small and their deposits comparatively insignificant.

On the east slope of the Sierra Nevada, Blackwelder (9, p. 870) has recognized 4 stages of glaciation. To these glacial epochs he assigned the names Tioga, Tahoe, Sherwin, and McGee and correlated them with the late Wisconsin, Iowan, Kansan, and Nebraskan glacial stages of the eastern United States.

While there has been no continental glaciation in Oregon, Thayer (45, p. 30) has recognized 3 alpine glacial stages in the North Santiam

River valley of the Cascade Mountains and to these he has assigned the names Tunnel Creek, Detroit, and Mill City. He tentatively correlated these with the Tioga, Tahoe, and Sherwin glacial stages of the Sierra Nevada, respectively.

Lake Stages Recognized in the Summer Lake Basin

Throughout the Great Basin the last two glacial ages are fairly well known, but the rest of the epoch is poorly recorded. Blackwelder (10, p. 11) states that judging from the limited record available, the second glacial age was more extensive than the third, and the third greater than the last. A long interglacial epoch separated the second and third while the third and fourth had a shorter interval between them. Although the last two glacial stages have left a fairly clear record in the Great Basin by shore line features and lacustrine sediments, the history of early Pleistocene is lacking or preserved only in the sedimentary deposits now buried beneath the floors of the basins.

In the Summer Lake basin no direct evidence of lakes earlier than middle Pleistocene have been found. Allison (1, p. 793), however, reports the penetration of 960 and 1286 feet of soft, blue lake muds in the Summer Lake basin during unsuccessful attempts to obtain artesian water. The presence of quantities of lake sediments of this magnitude would seem to imply a history much longer than that recorded by the existing shore line features.

Several distinct lake stages are recorded in the Summer Lake basin. The highest lake stage is marked by shore line features approximately 355 feet above the present level of Summer Lake. Other shore line features, one being especially well pronounced at a level 215 feet above Summer Lake, indicates intermediate stages. To the former deep-water lake, Allison (1, p. 793) gave the name "pluvial Lake Chewaucan" and to the later pluvial lake recorded at an intermediate level he gave the name "Winter Lake."

At the time of its maximum development, Lake Chewaucan extended to the southeast to a depth of 200 to 250 feet over the Upper and Lower Chewaucan marshes and Abert Lake. The Summer Lake-Chewaucan Marsh portion of this lake extended southeasterly for 45 miles to the Abert Lake basin where it branched to the north for an additional 15 miles or more (1, p. 792).

Hubbs and Miller (27, p. 22) advocate the use of the name of Recent lakes for the pluvial lakes of the same basin and refer to Lake Bonneville and Lake Lahontan as classical examples. In view of the priority of publication and the continue reusage of the names "pluvial Lake Chewaucan" and "pluvial Winter Lake," the use of these names will be continued in this paper.

Relationships to Other Pluvial Lakes of the Great Basin

Despite the small drainage area of the Summer Lake basin (550 square miles) as compared to the major drainage basins of Lake Bonneville (19,750 square miles) and Lake Lahontan (8,422 square miles) a contemporaneous lake history in these basins is to be expected. Those conditions necessary for the formation of lakes in one basin similarly affected adjacent basins at the same approximate latitude. While there is a difference of 2° 45' in latitude between Summer Lake and the area occupied by Lake Lahontan they are within 100 miles of being equal distances inland and have similar barrier effects as a result of the westward-lying mountains.

Early studies of the pluvial lake history of the Great Basin were conducted in the Bonneville and Lahontan basins. Since that time considerable effort has been expended in the correlation of equivalent lake stages and corresponding shore lines between the two basins. With the succession of lake stages established in the large basins, correltions can be made from smaller nearby basins.

Two high water lake stages have been recognized at Lake Bonneville and Lake Lahontan. In the Summer Lake basin two lake stages have similarly been recognized. There are four principal terraces recognized in the Lahontan basin, while at Summer Lake the highest shore line and one shore line at an intermediate level are the most prominent. Other less easily classified shore lines do exist, however, at both intermediate and lower levels. They are yet to be resolved.

Summer Lake never overflowed during any of its high water stages, nor did Lake Lahontan. Hubbs and Miller (27, p. 39) working with ichthyological evidence believe Lake Lahontan to have had an outlet, although they admit none is readily apparent after studying the lowest passes along its periphery. Lake Bonneville, while without outlet during the first high water stage overflowed during the second, discharging its water into the Snake River.

Postpluvial Climates and Dating of Postpluvial Time

Antevs (7, pp. 73-76) divided postpluvial time into three main climatic ages. He considers postpluvial time to have started after the last pluvial climax, at the time the climate had become about that of today. The postpluvial apparently started somewhat earlier than did the postglacial of the northern United States and comprises the last 10,000 years. On the basis of summer temperatures, Antevs has further subdivided the postpluvial into early, middle and late postpluvials. The first, from 10,000 to 8,000 years ago was more moist than today. The second or middle postpluvial was distinctly warmer and drier than that of today and by correlation with the warmer middle postglacial of the glaciated regions, has been dated at 8,000 to 4,000 years ago. The last postpluvial saw the change from a dry to a moist climate about 4,000 years ago which has continued, with minor variation, up to today.

Pollen analysis has been employed in the interpretation of climatic trends of postglacial times. From the analysis of 70 postglacial sedimentary sections of the Northwest, Hansen (24, p. 165) has divided postglacial time into four climatic phases. The first was cool and moist and prevailed from the time of the glacial maximum to about 15,000 years ago (10,000 years, Antevs). The second phase was marked by increasing warmth and dryness and prevailed from 15,000 to about 8,000 years ago. The third phase existed from 8,000 to about 4,000 years ago and was the time of maximum warmth and dryness. The fourth and final phase saw the return of a colder and moister climate which has persisted to the present.

However, recent developments from radiocarbon dating would reduce postglacial time to about 11,000 years and telescope postpluvial time to even less than 11,000 years. Somewhat pluvial conditions still prevailed in Summer Lake basin when Mt. Mazama erupted 6450 years ago.

During the dry phase previously dated from 8,000 to 4,000 years ago the earlier lakes are thought to have dried up and their precipitated salts buried or blown away by deflation (40, p. 462). The lakes, then, could have begun relatively fresh after complete desiccation during this dry period. This interpretation is largely the result of the moderate salinity of Summer and other undrained lakes of the Great Basin. Since the lakes did not overflow, the salinity is too low for them to be the direct descendents of the former large pluvial lakes. Van Winkle (48, p. 123) has assigned a conservative age of 4,000 years to the present lakes, basing his calculations on the concentration and area of the present lake water, the composition of the influent waters, and the rate of evaporation. Such values, however, are subject to many variables that are not readily determined. A paleoecologic study of the ostracods, gastropods, and fish (where present) might serve further to validate this dating. The return to moister conditions in the late postpluvial occurred about 2,000 B.C., a date that is in complete agreement with the value assigned by Van Winkle.

In the Summer Lake basin, the return to a wetter climate after the xerothermic climatic phase seems to be indicated by an abandoned sandy beach standing 10 to 20 feet above the present high water stage of the lake. Allison (1, p. 794) reports this beach appears to have truncated a series of north-south dune ridges which he refers to the dry stage of the previous few thousand years. Since the formation of the beach, drier conditions have reduced the lake to its present size.

GEOLOGY

Lithology

Two major lithologic types are concerned in the study of the Summer Lake basin, the volcanic rocks surrounding the lake basin proper and the lake silts, sands and gravels within the basin and along its margins.

In the earliest study of these lithologic units, Waring (49, pp. 21-25) divided the rocks into three divisions: (1) "older acid effusives," (2) "older basaltic effusives," and (3) "Recent eruptive rocks." To the first group he assigned the andesites, rhyolites, and related obsidian of Coyote Hills, Rabbit Hills, Gray Butte, Big Juniper Mountain, and others and assigned the age of early Tertiary or pre-Tertiary. The second group comprises the extensive series of basalt that cover most of Lake County along with related tuff deposits. Waring considered the basalt equivalent to the Columbia River basalt of northeastern Oregon. The third group represents local flows and small volcanic cones principally in northern Lake County of probable Pleistocene age. These flows and associated tuffs overlie the older basalts with a decided unconformity.

If the basalts are correlated with the Columbia River basalt, the age of middle Miocene may be assigned them. Recent stratigraphic work by Lowry and Baldwin (34, p. 3) has shown the Columbia River basalt to be interbedded with the marine Astoria formation of middle Miocene age, in the lower part of the Columbia River Valley. Units older than the Columbia River basalt, other than "older acid effusives," are not exposed in the vicinity of Summer Lake, since the basalt covered the pre-existing topography to such a depth that despite later uplifting, gentle folding, and large scale faulting, the pre-basalt lithologies are not exposed.

A much younger age for the basalt is indicated on the United States Geological Survey's Geological Map of the United States (1932) which indicates the entire region of southeastern Oregon to be covered by "basaltic lavas younger than Cascade Andesite." The Cascade Andesite is upper Pliocene in age.

Within the basin, the fine-grained lake sediments serve as the valley floor. These lake sediments have a thickness of more than 1,000 feet but only the uppermost 50 feet are exposed for study. Other Pleistocene (and Recent) deposits include the gravels around the margin of the basin. Some of these gravels, as along the east side of Summer Lake, have been cemented by calcium carbonate to form a conglomerate.

Deposits of alluvium form local lithologic units in the Summer Lake basin. At the south end of the basin, the Chewaucan River during one of the lake stages built a delta deposit which now serves to separate the Summer Lake basin from the Chewaucan marshes.

One other minor unit of Recent origin is the loose sand that has blown up along the east side of Summer Lake. Smith (43, p. 57) describes this as "surficially like sands of the sea coast but having the nature of eolian desert material."

Structure

Origin of Summer Lake Basin

The Summer Lake basin is bounded on the west by a major fault line scarp (Winter Ridge) and on the east by a scarp of much lower slope, so the resultant structure of the basin is that of a graben. The north end of the basin is separated from the Christmas Lake valley by the slopes of an east-west trending anticline (49, p. 53). To the south, delta deposits serve as a hydrographic boundary between Summer Lake and the Chewaucan marshes but the structural relations continue.

The Winter Ridge fault runs in an approximate north-south direction for approximately 20 miles (plate 2). Near the north end of the basin, the fault divides into many smaller branches. Russell (40, pp. 448-449) reports a continuation of the fault, or a branch of it, again to appear and continue along the shore of Silver Lake.

Winter Ridge rises more than 2,000 feet in the distance of a few miles and has a gentle (3°) dip toward the west. The displacement has been estimated by Russell (40, p. 448) to be not less than 2,500 to 3,000 feet. This figure is quite fitting since, in addition to the height of the fault line scarp, it is now known from recent drilling within the basin that the down-faulted block lies more than 1,200 feet below the surface of the valley floor.

Winter Ridge is characteristic of the fault line scarps of the northern Great Basin in that it has, as yet, suffered rather slightly from the effects of erosion, has quite small accumulations of talus

Figure 1. Panoramic view of Winter Ridge near the north end of Summer Lake basin. West is one-fourth the distance from the right margin.

at its base, and is still in the youth of its first erosional cycle. Also characteristic is the fact that the throw of the fault, while sizeable, has not exposed any structure other than that of a great tilted block of lava. The faults bounding Summer Lake are similar to other major faults of the Great Basin in that they run in a general north-south direction.

Age of Faulting

The age of the faulting responsible for the formation of the Summer Lake basin has not been determined in the immediate vicinity and probably can not be. In view of the lack of detailed geologic mapping in the area the age and relations of the rocks concerned are poorly known. Until such work is done the units will of necessity continue to be classed in a general way as Miocene, Pliocene or

Figure 2. Panoramic view of the north end of Summer Lake basin. Winter Ridge is at the extreme left. Tilted fault blocks are prominently seen near the left edge of the picture. North is just left of center. Note typical vegetation and minor irregularities of the basin floor.

"undifferentiated Tertiary volcanics." As a result, the faulting can be dated only as being later than one of these epochs. Under these conditions, the assumption must be made that those processes responsible for the faults in the Great Basin, which are structurally similar and apparently orogenically related as to origin, took place at a similar time and the dating carried in from such regions where the time relations are more clearly seen.

Because of the immensity of the Basin-and-Range province the time of faulting probably varied somewhat from one area to another and the many workers of the region have accordingly assigned different dates. Louderback (33, p. 38) refers to block faulting in the western part of the Great Basin as having started in late Pliocene and post-Pliocene time, but having been completed before late Pleistocene. He further states that while movement has taken place at intervals up to within a few years, the Recent displacement represents but a small fraction of the total.

In general agreement with Louderback is Nolan (38, pp. 183-184) who has summed up the literature concerning faulting in the Basin-and-Range province and states that "the best conclusion that may be reached from present information is that block faulting as a process probably began in early Oligocene time and has been more or less continuous ever since. Topographically expressed faults, however, probably date back only to the late Pliocene or early Pleistocene time, though there may have been still earlier movement along such faults. There are two possible qualifications to the conclusion of intermittently continuous faulting. One of these results from the apparently widespread distribution of upper Miocene sedimentary beds, many of which were deposited in closed basins, for this suggests that block faulting with concomitant formation of such basins was especially widespread before or during late Miocene time. ... The second qualification is the apparent greater age of the faulting in the southern portion of the province, chiefly southeastern California and southwestern Arizona."

Stratigraphy of the Lake Sediments

Source of Samples and Methods of Sampling

The best exposures of the lacustrine sediments of the Summer Lake basin are found along the banks of Ana River. The thickest sections occur near Ana Reservoir, the thickness somewhat diminishing farther downstream. Two sites were selected for sampling to obtain a complete stratigraphic section.

Site A was excavated along the bank of Ana River approximately 200 yards downstream from Ana Reservoir (plate 2). This southern

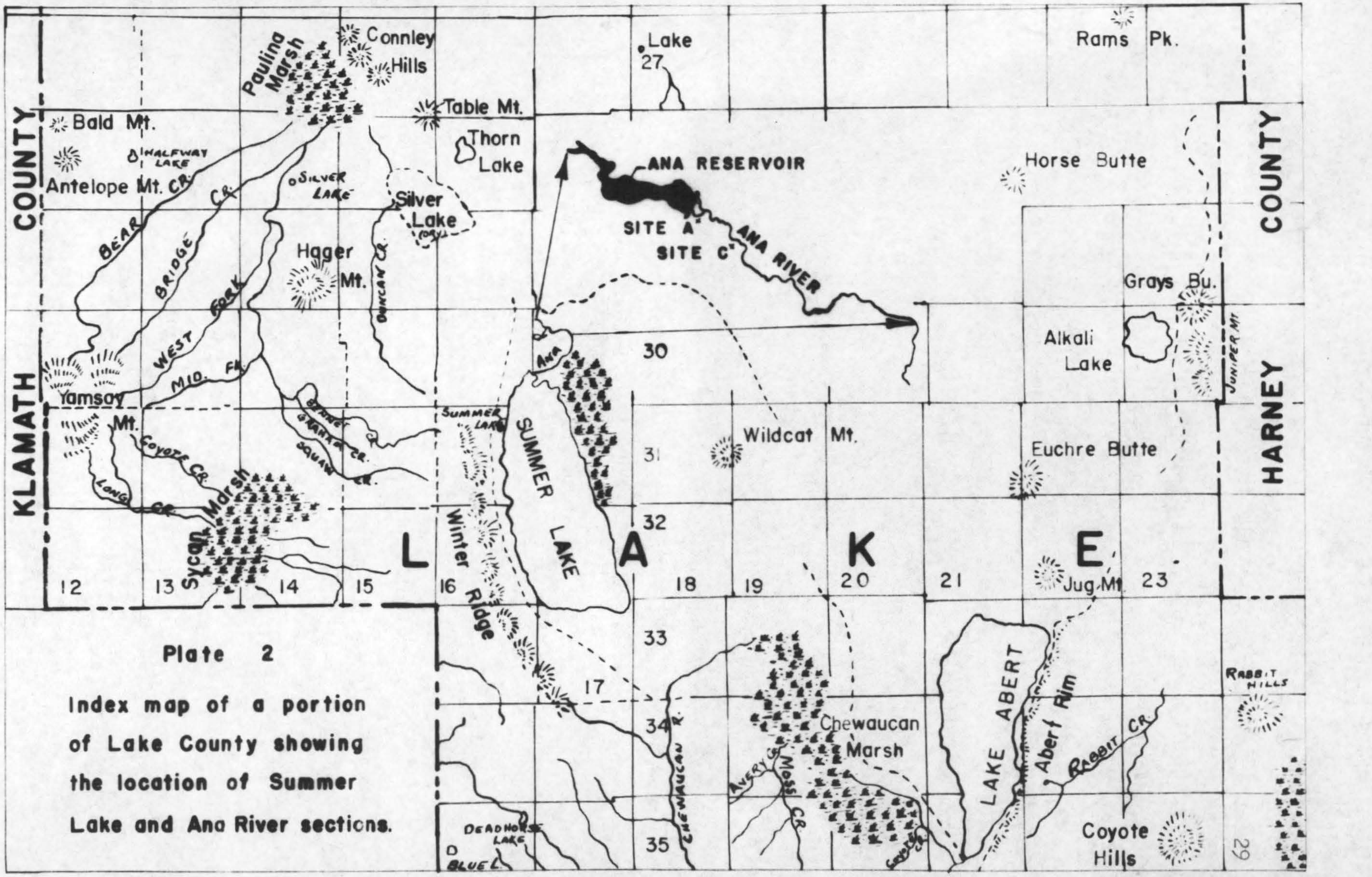


Plate 2

Index map of a portion of Lake County showing the location of Summer Lake and Ana River sections.

bank exposes for study 48 feet of sediments. The lowest one third of this exposure is very wet and physically difficult to work because of the clayey nature of the sediments. The next 15 feet stand as a talus-free face (fig. 3). The low rainfall in this area and the consequent lack of sidewash greatly reduce the gullying of the banks, but some slumping, especially in the lower half of the bank, has occurred (fig. 4). A total of 86 samples was collected at this site.

In sampling this and site C, the hard, dry surficial materials were removed with a shovel and the slope benched for convenience in working. Inasmuch as the beds generally could be subdivided into units of 2 feet or less, they were measured directly with a steel tape. The layers sampled were divided into the smallest possible units to obtain a sample as nearly homogeneous as possible. After exposing the beds, the surface was scraped clean and a representative sample taken from all parts along the face of the layer. The samples were collected in pint waxed paper containers with moisture-tight covers. The containers were numbered immediately upon collection, the numbers corresponding to numbers used in the description of each unit. Every effort possible was made to prevent contamination from overlying and underlying units. Since the sediments are moist, the unit overlying that being sampled rarely tended to break away and contaminate the sample, but in the many thin ash layers slight contamination may have occurred. For these units, the ash was carefully scraped into a container with a knife blade, the sample collected constituting only the center portion of each ash layer. These samples, however, are not truly representative because of the graded

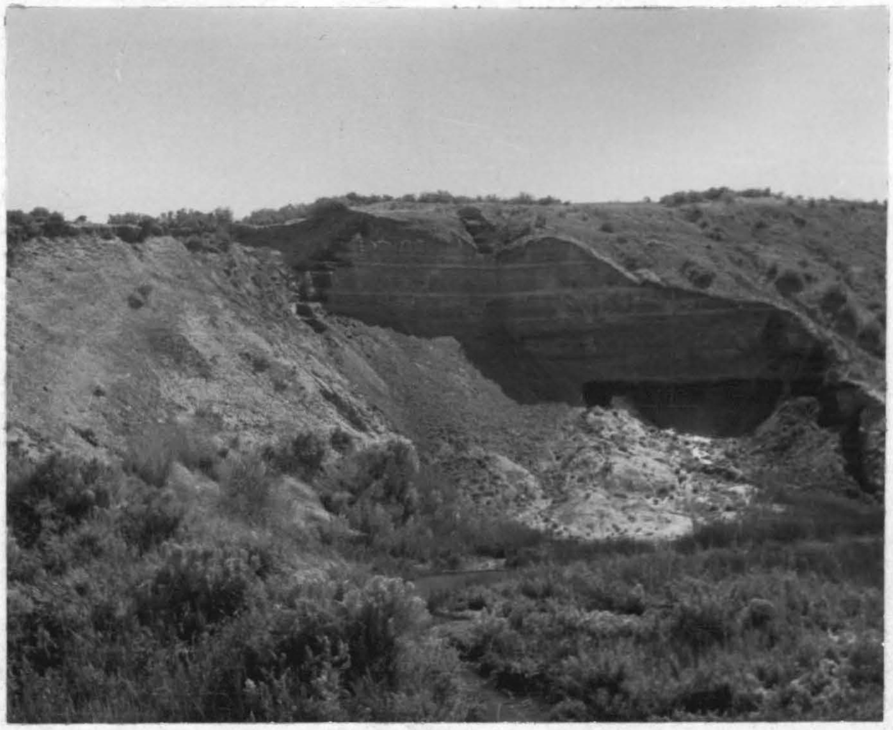


Figure 3. Ana River section, site A.

bedding of the ash.

Site C is located on the south river bank about 1/2 mile downstream from Ana Reservoir and constitutes the uppermost portion of the Ana River section studied. A total section of 8 feet was measured and 27 samples collected.

The bottom of the section at Site A is determined by the water level of Ana River. The sediments immediately below the level of Ana River were sampled but found to represent a downward continuation of the layer at water level and therefore were not saved. No effort was made to use an auger or other device to collect samples below this level.

Site A is the same collection locality used by Allison

3

Figure 4. Ana River section, site C.

(1, pp. 794-795).

In the following description of the Ana River section, a notation of the color of each unit has been included. The colors were twice recorded, once when the sample was wet and once when dry, since the samples were wet at the time of collection and their color changed markedly upon drying. The color chart used was the "Rock Color Chart" (1948) as prepared by the rock-color chart committee of the National Research Council.

By using the rock color chart, a definite color is assigned each layer that can be accurately referred to at any time and is free from the ambiguities common in general descriptions of color. A few samples contained such a variety of colored constituents that no color

ANA RIVER SECTION

NW 1/4, SEC.6, T.30S., R.17E.

LAKE COUNTY, OREGON

Plate 3

Composite columnar section of lake sediments at Ana River.

seemed dominant or characteristic, in which case no value was assigned. In the description of the section the color name and number are recorded the first time it appeared, thereafter only the number was recorded.

Detailed Description of Ana River Section

Number	Description	Thickness in inches.	Cumulative thickness in feet.
	---Surface of basin---		
1.	(C-1;1,2) Silt, with intermixed clay, fine sand, and volcanic ash. Uppermost 3 inches rather coarse because of much-included sand and subrounded basalt granules. Color: Wet, dusky yellowish brown 10 YR 2/2; Dry, pale yellowish brown 10 YR 6/2.	15.5	1.3
2.	(C-2;3,4,5) Reworked volcanic ash. Several 1/16 inch, nearly silt-free, ash layers in this 2 1/4 inch thick layer. Pumice, fine grained, nearly crystal-free, ascribed to Newberry Crater. Layer 1 inch thick. Color: Wet, Light olive gray 5 Y 6/1; Dry, very light gray N 8. Pumice, coarse-grained, crystal rich; basal portion of Newberry Crater pumice. Color: Wet, 5 Y 6/1; Dry, N 8.	4.0	1.6
3.	(C-3) Lake silt with clay forming faint, poorly-defined laminations. Ill-defined layer of white ash occurs at level 1 1/2 inch below top of this unit. Color: Wet, 10 YR 2/2; Dry, 10 YR 6/2.	11.1	2.5
4.	(C-4) Caliche. Top, case-hardened, weathers dark. Underside, soft, light-colored, predominantly ash. Color: (top) Dry, 10 YR 6/2; Bottom, yellowish gray 5 YR 8/1.	0.3	
5.	(C-5) Very fine sand. Basal 1/2 inch contains abundant intermixed oolites. Thickness of layer variable because of		

Number	Description	Thickness in inches.	Cumulative thickness in feet.
	undulating surface of underlying bed. Color: Wet, grayish brown 5 YR 3/2; Dry, 10 YR 6/2.	2.5	2.8
6.	(C-6;9,10,11) Volcanic ash, cemented with 1/8 inch calcareous deposit on top and bottom to form a "sandwich" 7/8 inch thick. This unit discontinuous and gives way laterally to a 1-inch layer of fine grained volcanic ash with oolites at the base. The oolites and ash (1/4 inch thick) underlie the "sandwich" where present. Silt, with intermixed sand. 3/8 inch thick. Cemented ash, 1/2 inch thick. Color: Wet, 10 YR 6/2; Dry, N 8.	2.0	2.9
7.	(C-7;12,13) Silty, very fine sand, upper 2 inches contains one thin layer of gray ash. Basal 7 inches of layer contains numerous basalt pebbles. Color: Wet, 5 YR 3/2; Dry, 10 YR 6/2.	13.0	4.0
8.	(C-8) Caliche. Top 1/8 inch especially well cemented; bottom side, predominantly ash, soft, and crumbles easily. Color: (bottom side) Wet, 10 YR 6/2; Dry, light olive gray 5 Y 4/1.	0.4	
9.	(C-9;15,16) Sandy silt (top 4 1/2 inch). Two traces of buff-colored ash 3 3/4 and 4 1/8 inch below top of layer. Clayey silt (basal 3 inches). Marked by pronounced, closely spaced, desiccation shrinkage cracks. Lowermost 1/4 inch predominantly sand. Color: Wet, medium gray N 5; Dry, 10 YR 6/2.	7.5	4.75
10.	(C-10;17,18) Pumice, upper 2/3 of layer fine-grained, slightly compacted. One 1/4 inch layer, almost at top, darker colored from included silt. Pumice, crystal rich, containing abundant flakes of biotite (1 1/4 inch thick). Color: Wet, Medium gray N 5; Dry, medium light gray N 6.	4.0	5.0
11.	(C-11;19,20,21,22) Sand and calcareous oolites. This 1/4 inch thick layer contains abundant ostracod shells and subrounded basalt		

Number	Description	Thickness in inches.	Cumulative thickness in feet.
	pebbles ranging up to 25 mm in length. Silt (1.1 inch thick). Three caliche layers, 1/4 inch thick, top, middle, and bottom of layer. Numerous brown calcareous oolites included, and many included ostracod shells have a thin calcareous coating. Subrounded basalt granules and pebbles, measuring up to 1 1/4 by 1 3/4 inch, present. Silt, with intermixed sand, oolites, calcareous-coated ostracod shells, and basalt pebbles. Top 3/4 inch of silt marked by prominent shrinkage cracks. Silt (14 1/2 inch layer). Lowermost 1/2 inch contains 4 or 5 paper-thin layers of ash. Basal half of layer has closely spaced shrinkage cracks. One pebbly layer noted at level 5 1/2 inch below top of unit. Pebbles predominantly basalt but includes jasper, and andesite (?). Average size of pebbles, 3/4 by 1/2 inch.	18.1	6.5
12.	(C-12) Caliche. Layer has included sand, calcareous coated ostracod shells, and occasional rock granules, especially in the basal half.	0.2	
13.	(C-13) Silty clay, displays pronounced shrinkage cracks throughout layer. Top 1/2 inch of layer contains abundant intermixed ash.	7.0	7.0
14.	(C-14;25) Silty ash (reworked). Ash contains diatom tests.	3.3	7.3
15.	(A-2) Pumice, crystal rich; top half of Crater Lake pumice. Color: Dry, light gray N 7.	2.6	7.6
	(A-3) Pumice, basal half of Crater Lake pumice. Slight color gradation within this unit; basal 0.6 inch dark grays from numerous included dark minerals; overlying 0.75 inch ligher gray, and top darker gray-black.	1.4	7.7
16.	(A-4) Lake silt. Color: Wet, grayish brown 5 YR 3/2; Dry, yellowish gray 5 Y 8/1.	0.5	
	(A-5) Pumice, uppermost 3/4 of layer finer grained than the basal 1/4. Ascribed to Mt. Mazama.	0.25	

Number	Description	Thickness in inches.	Cumulative thickness in feet.
	(A-6) Silt, with interspersed fine sand. Color: Wet, 5 YR 4/1; Dry, yellowish gray 5 Y 7/2.	0.25	
	(A-7) Volcanic ash. Upper half of layer shows slight intermixing of silt. Ash contains a few diatoms. Ascribed to Mt. Mazama. Color: Wet, 10 YR 6/2; Dry 5 Y 8/1.	0.25	
17.	(A-8) Sandy silt. A few ostracod shells and occasional basalt pebbles ranging in size up to 0.3 inch included in layer. One calcareous-cemented sand, granule, and ostracod shell layer (1/8 inch thick) in lower third of unit. Color: Wet, dark yellowish brown 10 YR 4/2; Dry, 5 Y 7/2.	5.12	8.2
18.	(A-9) Volcanic ash. Upper half contains minor quantities of intermixed silt. Color: Wet, 5 Y 7/2; Dry, 5 Y 8/1.	1.5	8.3
19.	(A-10) Fine sand. Occasional small basalt pebbles and ostracod shells intermixed in layer. Caliche (1/8 inch thick) occurs at levels, 4, 6, and 10 inches above base of unit. Color: Wet, 10 YR 4/2; Dry, 10 YR 4/2.	11.25	9.2
20.	(A-11) Calcareous cemented layers of sand, small pebbles, occasional ostracod shells, and slight traces of white ash. These layers are multiple, hard, and average 1/4 inch in thickness. Color: Wet, 5 Y 7/2; Dry, 5 Y 8/1.	1.75	9.3
21.	(A-12) Clayey silt. Included layers of clay gives lower 14 inches of unit a varved-like appearance. Widely spaced (1 inch or more apart) shrinkage cracks evident in this portion of the layer. Next 4 inches exhibit closely spaced (less than 1/2 inch) shrinkage cracks. Occasional ostracod shells intermixed throughout layer and one thin gray ash layer occurs in upper third of layer. Color: Wet, 10 YR 4/2; Dry, 10 YR 6/2.	22.0	11.2
22.	(A-13) Caliche. Top coated with 1/8 inch layer of nearly pure $CaCO_3$ and has		

Number	Description	Thickness in inches.	Cumulative thickness in feet.
	irregular furrowed surface. Underside of layer less cemented and contains intermixed sand, ostracod shells, and small pebbles of basalt. A thin sand-oolite layer underlies caliche. Top surface level, but lower surface irregular up to 1/2 inch. Color: Wet, 5 Y 7/2; Dry, 5 Y 8/1.	1.0	
23.	(A-14) Silt, with varved-like appearance from included clay. Top 3 inches darker colored due to included fine sand. Occasional ostracod shells throughout layer. Color: Wet, 10 YR 4/2; Dry, 10 YR 6/2.	15.75	
	(A-15) Volcanic ash. Color: Wet, 5 Y 6/1; Dry, N 8.	0.05	
	(A-16) Silt, with thin layers of included fine sand giving varved-like appearance. Two faintly seen ash layers 3.5 and 6 inches above base. Basal 5/8 inch of layer composed of oolite-sand. Well defined shrinkage cracks throughout unit. Occasional ostracod shells. Color: Wet, 10 YR 4/2; Dry, 10 YR 6/2.	9.75	13.4
24.	(A-17) Calcareous cemented sand, oolites, volcanic ash, and ostracod shells comprise top 0.25 inch of layer. Fragmental fish bones abundant at bottom of this hard layer. Unconsolidated fine sand, oolites, and ostracod shells comprise the remaining lower portion of the unit. Compacted ash, 0.2 inches thick marks the base. Color: Wet, olive gray 5 Y 4/1; Dry, light olive gray 5 Y 5/2.	2.5	13.6
25.	(A-18) Lake silt, with intermixed ostracod shells, fine sand, and occasional large oolites. Upper half of layer exhibits poorly-defined shrinkage cracks. Color: Wet, 5 Y 5/2; Dry, 5 Y 5/2.	7.0	14.1
26.	(A-19) Sand, ostracod, oolite layer. (Oolites limited). Many small subrounded basalt pebbles intermixed. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	2.75	14.3

Number	Description	Thickness in inches.	Cumulative thickness in feet.
27.	(A-20) Sandy silt, with many included ostracod shells, less abundant oolites, and small angular basalt pebbles. Layer grades from coarsest, at basal 2 inches, to slightly contaminated silt near top. Ostracod shells most abundant near base. Color: Wet, 5 Y 7/2; Dry 10 YR 4/2.	11.25	15.3
28.	(A-21) Oolites, with many well-rounded to sub-rounded rock fragments. The largest pebble measured was 1 by 0.9 by 0.3 inches. A few ostracod shells included in layer, but minor. Lower contact extends downward as finger-like extensions of oolites which fill holes in the underlying layer. Color: Wet, dusky yellow 5 Y 6/4; Dry, 5 Y 7/2.	1.4	15.4
29.	(A-22) Silt, showing faintly-discernible laminations from included sand. Top of layer marked by 1/4 inch thick pitted caliche layer. The holes are 1/16 to 1/8 inch in diameter and average about 10 to the square inch. A 1/2 inch thick oolite layer occurs at a level 10 1/2 inches above base of unit. The basal 3 inches contain fragments of a thin, previously compacted, and now broken ostracod shell layer. Color (silt): Wet, 10 YR 4/2; Dry, 5 Y 5/2.	12.5	16.4
30.	(A-23) Volcanic ash, dark mineral-rich. Color: Wet, N 5; Dry, light bluish gray 5 B 7/1.	0.12	
31.	(A-24) Sandy silt. One 2 inch thick layer, 3 1/3 inches above base, nearly black because of abundant dark sand. A few ostracod shells occur in a 1-inch layer immediately below the black sand. Color: Wet, 5 Y 5/2; Dry, 5 Y 7/2.	8.5	17.2
32.	(A-25) Fine sand, faintly bedded and banded. The basal 1/2 inch composed principally of oolites and calcareous-coated ostracod shells. Color (sand): Wet, 5 Y 4/1; Dry, N 6.	2.25	17.4
33.	(A-26) Oolites, overlain with many scaly sheets of caliche. The sheets average		

Number	Description	Thick-ness in inches.	Cumulative thickness in feet.
	about 3/16 inch thick and serve to separate oolites from 5/8 inch layer of sand, ostracod shells, oolites, and subrounded rock pebbles at top of layer.	2.25	17.7
34.	(A-27) Sandy silt, containing ostracod shells. Top 1 inch darker colored from included black sand. Upper surface undulating; irregular about 1 inch. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	1.5	17.8
35.	(A-28) Pumice, with many intermixed ostracod shells, minor quantities of oolite, and very fine sand. Occasional granules of basalt included. Unit discontinuous over short lateral distances.	0.25	
36.	(A-29) Silt, containing a few ostracod shells, abundant gastropod shells, and less abundant tiny pelecypod shells. Color: Wet, olive gray 5 Y 3/2; Dry, 10 YR 4/2.	12.0	
	(A-30) Volcanic ash, fine-grained and mineral rich. Contains a few ostracod shells and numerous diatom skeletons. Color: Wet, 5 Y 7/2; Dry, 5 Y 5/2.	0.4	
	(A-31) Silt, containing a few ostracod shells and occasional angular basalt pebbles. Color: Wet, 10 YR 2/2; Dry, 5 Y 7/2.	2.0	18.8
37.	(A-32) Pumice, mineral-rich. Top 3/8 inch fine-grained while basal 5/8 inch coarsely crystalline. Color: Wet, 5 Y 4/1; Dry, 5 Y 6/1.	1.0	18.9
38.	(A-33) Silty volcanic ash, numerous included ostracod shells and many diatoms. Lower limit of layer undulating causing unit to vary in thickness from 1 to 2 inches. Color: Wet, 10 YR 4/2; Dry, 5 Y 5/2.	1.0	
	(A-34) Pumice, coarse, crystal rich. Color: Wet, 5 Y 5/2; Dry, 5 Y 7/2.	0.4	19.1
39.	(A-35) Lake silt. Color: Wet, 10 YR 2/2; Dry, 5 Y 5/2.	2.12	19.2
40.	(A-36) Pumice sand. Color: Wet, 10		

Number	Description	Thickness in inches	Cumulative thickness in feet.
	YR 2/2; Dry, 5 Y 5/2.	0.25	
41.	(A-37) Silt, faintly banded from included fine sand. Sand especially prominent at levels 2 and 5 inches above base. Top of unit undulating; irregular about 2 inches. Numerous ostracod shells throughout layer. Color: Wet, 10 YR 2/2; Dry, 10 YR 4/2.	19.5	20.9
42.	(A-38) Fine sand, with abundant included ostracod shells and basalt pebbles ranging in size up to 1.3 by 0.8 inches. One thin (1/4 inch) layer of sand and pebbles slightly cemented by calcareous cement. Color: Wet, 5 Y 3/2; Dry, 5 Y 5/2.	1.60	21.0
43.	(A-39) Lake silt. Lower half of layer clayey, slightly darker colored. Calcareous cemented silt layer, 2 inches thick, occurs 2 inches above base. Thin layer of brown sand with intermixed ostracod shells underlies the cemented layer. Color (silt): Wet, 5 Y 3/2; Dry, 5 Y 7/2.	3.75	21.3
44.	(A-40) Caliche (top 1/2 inch). Underlain by 1.5 inch layer of silt with intermixed sand. Basal 1 inch composed of fine sand containing numerous ostracod shells. Color (sand): Wet, 5 Y 4/1; Dry, 5 Y 5/2.	3.0	21.6
45.	(A-41) Silt, with two 1/4 inch layers of fine sand near top. A few ostracod shells noted throughout unit. Top of layer even but bottom undulating. Color: Wet, 5 YR 3/2; Dry, 10 YR 6/2.	3.25	
	(A-42) Volcanic ash. Conforms to undulating surface of underlying layer. Color: Wet, N 6; Dry, 5 Y 7/2.	0.25	
	(A-43) Silt, containing intermixed ostracod shells. Top of layer undulating; irregular approximately 3 inches. Color: Wet, 5 Y 3/2; Dry, 5 Y 7/2.	17.25	23.3
46.	(A-44) Caliche, contains numerous ostracod shells and minor quantities of ash. Color: Wet, 5 Y 5/2; Dry, 5 Y 8/1.	0.25	

Number	Description	Thickness in inches.	Cumulative thickness in feet.
47.	(A-45) Silt, shows faint banding as the result of included clay and occasional seams of fine sand. Layer of nearly pure ostracod shells occurs at level 22 1/4 to 22 1/2 inches above base. White ash (1/8 inch thick) occurs at level 19 1/4 inches above base. Occasional small basalt pebbles occur throughout layer. Color: Wet, 10 YR 4/2; Dry, 10 YR 6/2.	24.5	
	(A-46) Caliche, contains included ostracod shells, granules and occasionally small pebbles of basalt, and about 5% volcanic ash. Color: Wet, 5 Y 5/2; Dry, N 8.	0.5	
	(A-47) Clayey silt. Ostracod shells numerous in the upper 5 1/8 inch of layer. Next 2 inches alternating fine sand and silt. Basal 4.6 inches clay with occasional ostracod shells. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	11.1	26.4
48.	(A-48) Caliche, with included ostracod shells and subangular basalt pebbles ranging in size up to 1.3 by 1 inches. Broken edge of caliche tends to alter to a reddish-brown color.	3.0	26.7
49.	(A-49) Coarse silt, contains about 15% included volcanic ash and occasional ostracod shells. Color: Wet, 10 YR 2/2; Dry 5 Y 7/2.	9.25	
	(A-50) Fine sand, containing abundant ostracod shells. Color: Wet, 10 YR 2/2; Dry, 10 YR 6/2.	0.75	
	(A-51) Silt, with distinct thin sand-ostracod layers near middle of layer. Color: Wet, 5 Y 4/1; Dry, 5 Y 4/1.	3.0	27.7
50.	(A-52) Volcanic ash, top 3 inches fine-grained and somewhat contaminated by silt. Basal 1/2 inch coarser grained, silt free. Color: Wet, 10 YR 4/2; Dry, 5 Y 6/1.	3.5	
	(A-53) Pumice sand (top 3/16 inch). Basal 5/8 inch silt. Color (silt): Wet, 10 YR 4/2; Dry, 5 Y 7/2.	0.7	28.1
51.	(A-54) Fine sand, with intermixed ash and ostracod shells. Ostracod shells especially abundant in upper 2/3 of layer.	1.5	28.2

Number	Description	Thick- ness in inches.	Cumulative thickness in feet.
52.	(A-55) Clayey silt, (top 3 3/8 inch). Basal 3.75 inches alternating clay and ostracod shell layers with intermixed fine sand. A total of five clearly defined ostracod layers counted. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	7.1	
	(A-56) Silt, with some included black sand (top 4 3/4 inches) underlain by distinct 1/8 inch layer of black sand. Basal 1-inch fine sand with a few basalt pebbles ranging in size up to 1/2 inch. Ostracod shells occasionally present throughout layer. Color: Wet, 10 YR 4/2; Dry, 5 Y 6/1.	5.8	29.2
53.	(A-57) Caliche, shows occasional streaks of limonite stain. Dark minerals form a thin band near the base. Color: Wet, 5 Y 7/2; Dry, yellowish gray 5 Y 8/1.	0.5	
54.	(A-58) Silt, with thin sand layer approximately 3 inches above base. Color: Wet, dusky brown 5 YR 2/2; Dry, 5 Y 7/2.	9.25	
	(A-59) Volcanic ash, fine grained, and ripple marked. Crests marked by bands of limonite stain. Ripple marks run in S 88° E direction, have an amplitude of about 1/16 inch, and are 1/2 inch from crest to crest. Color: Wet, 5 Y 5/2; Dry, 5 Y 7/2.	0.25	
	(A-60) Silt, exhibits banding due to alternation of silt and lighter colored clay. Color: Wet, grayish brown 5 YR 3/2; Dry, 5 Y 7/2.	0.9	
	(A-61) Volcanic ash, fine grained and containing occasional ostracod shells. Color: Wet, 10 YR 4/2; Dry, N 7.	0.1	
	(A-62) Silt. Upper half exhibits faintly seen, irregular banding. Thin (1/8 inch) ash layer occurs 3/4 inch above base of unit. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	7.6	30.8
55.	(A-63;32,33,34) Silty ash, two equal layers (1 1/8 inch thick) separated by 1/4 inch layer of blue-gray ash. Color: Wet, N 5; Dry, grayish black N 2. Pumice, mineral-rich. Basal 1/4 inch brown, upper 1 1/8 inch gray. Pumice. Upper 7/8 inch coarse. Color: Wet, 5 Y 4/1; Dry, 5 Y 6/1.	4.9	31.2

Number	Description	Thickness in inches.	Cumulative thickness in feet.
56.	(A-64) Silt. Upper 1 1/2 inch irregularly banded because of included fine sand layers. Indefinite white ash layer occurs at level 2 inches below top of unit. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	6.5	
	(A-65) Volcanic ash, with dark minerals concentrated in lower third of unit. Several dark ridges mark top of layer. Ridges have S 10° E direction but apparently caused by cracking of this slightly compacted layer with subsequent refilling of fracture cracks. The ash contains diatoms. Color: Wet, medium gray N 5; Dry, N 7.	0.4	
	(A-66) Silt, with slight included sand near top. Color: Wet, 5 YR 3/2; Dry, 10 YR 6/2.	36.25	34.7
	(A-67) Pumice sand, coarsest light-colored shards and mineral grains comprise basal 3/4 of layer. Upper 1/4 fine grained, slightly consolidated ash. Color (ash): Wet, N 4; Dry, N 7.	0.4	
	(A-68) Lake silt, with abundant ostracod shells in basal half of unit, decreasing in number toward the top. Faint trace of fine sand at base of layer. Color: Wet, 10 YR 6/2; Dry, 5 Y 6/1.	5.0	
	(A-69) Lake silt. One 2-inch thick layer exhibits poorly defined laminations at a level 7 inches above base. This is overlain by a 3 1/4 inch layer of oolites, the oolites becoming more coarse toward the top. Some ostracod shells distributed throughout the layer. Color: Wet, 10 YR 4/2; Dry, 10 YR 6/2.	23.25	36.2
	(A-70) Silty sand, composed predominantly of dark mineral and rock fragments with numerous intermixed ostracod shells. Color; Wet, N 2; Dry, N 5.	0.25	
	(A-71) Lake silt, with abundance of included ostracod shells. One 1/2 inch thick layer of calcareous oolites occurs 4 inches down from the top of the unit and is underlain by a thin layer of ash. Basal 1/4 inch composed of clayey silt. Color: Wet, 5 Y 4/1; Dry, 5 Y 7/2.	24.0	39.3
57.	(A-72) Caliche, upper surface irregular, case hardened. Underside soft with occasional included ostracod shells.	0.25	

Number	Description	Thickness in inches.	Cumulative thickness in feet.
58.	(A-73) Lake silt, abundant intermixed ostracod-sand at top. Fine black sand gives banded appearance to unit at level 4 inches above the base. Two light gray ash layers occur at levels 1 and 9 inches above base. A small gastropod shell was found in a 1/4 inch sandy layer, 2 1/4 inches above the base. Color: Wet, 10 YR 4/2; Dry, 5 Y 5/2.	17.0	
	(A-74) Silt, with abundant intermixed octracod shells and slight included volcanic ash, containing diatoms. (Upper and lower limits indefinite, could be included with overlying or underlying layer).	10.0	
	(A-75) Clayey silt, with occasional intermixed fine sand layers, forming poorly-defined banding. A few ostracod shells intermixed. Color: Wet, 10 YR 4/2; Dry, 10 YR 6/2.	28.5	43.9
59.	(A-76) Caliche. Top, typical irregular precipitate surface. A few ostracod shells and volcanic ash included in soft basal half. Color: Wet, 10 YR 6/a; Dry, 5 Y 7/2.	0.25	
60.	(A-77) Clayey silt, contains many ostracod shells and a fine sand layer at the base. A few basalt pebbles included, the largest measured 1 by 0.6 inches. Color: Wet, 5 Y 5/2.	6.25	44.4
61.	(A-78) Ostracod-sand layer. Color: Wet, 10 YR 4/2; Dry, 5 Y 7/2.	5.25	44.9
62.	(A-79) Clayey silt, basal 1.5 inches contain abundant intermixed ostracod shells. Poorly consolidated ash "pebbles" ranging up to 1 inch in diameter included in the silt. Color: Wet, 10 YR 4/2.	25.5	47.1
63.	(A-80) Calcareous cemented ash, silt. Abundant ostracod shells, a few oolites, and many basalt fragments ranging from granules to pebbles 3/8 inch in diameter underlie hardened layer. Pebbles predominantly sub-rounded. Color: Wet, 10 YR 4/2; Dry, N 8.	0.25	

Number	Description	Thick-ness in inches.	Cumulative thickness in feet.
64.	(A-81) Clayey silt, hard and exhibiting varved-like appearance. Thin limonite-stained ash layers occur at levels 4, 5 1/2 inches above base and 8 inches below top of unit. Basal 5 inches banded from included sand. Color: Wet, 10 YR 4/2.	31.0	49.8
65.	(A-82) Caliche, limonite-stained and containing a few basalt pebbles, measuring up to 1 by 0.7 inches. Color: Wet, 10 YR 6/2; Dry, 5 Y 8/1.	0.5	
66.	(A-83) Silt, with irregular thin clay partings. Top 1 inch sandy and possesses a varve-like appearance because of the thin, discontinuous layers of sand. Many sub-rounded basalt pebbles included with sand. Color: Wet, 10 YR 2/2.	31.5	52.3
67.	(A-84) Pumice sand, crystal-rich. Upper contact irregular; approximately 1 inch, and lower contact almost equally uneven. Color: Wet, 10 YR 4/2; Dry, 5 Y 6/1.	4.0	52.7
68.	(A-85) Clayey silt, hard and containing a few thin layers of sand and occasional ostracod shells. Color: Wet, 5 YR 3/2; Dry, 5 Y 6/1.	8.00	53.5

Interpretation of Sediments

The sediments of the Ana River secion contain a suite of allogenic minerals characteristic of basic rocks. This however is supplemented by volcanic glass and minerals similar in composition and size to those of the interbedded pumice and ash layers. The presence of volcanic glass in quantities averaging about 15% of most samples emphasizes the importance of volcanic eruptions to the formation of sediments in the lake basin. Forty-two layers of pumice and ash were measured in the Ana River section while many others exist as traces or quantities too small to sample. The ash and pumice layers have a random distribution in the section although the layers of greatest quantity are concentrated near the top. This distribution indicates the persistency of volcanism throughout the time of accumulation of the lake sediments.

Considering the Ana River section as a whole, the greatest percentage of its constituent materials are silt-sized, all containing some intermixed fine sand and less abundant clay-sized particles. Although the fine-grained nature of the sediments is characteristic, included oolites, granules and pebbles of basalt and calcareous cemented layers represent changes in the conditions of sedimentation from time to time. The constituent minerals are comparatively angular, the slightly abraded fragments showing highly irregular edges as would be expected of weathered rock fragments transported a short distance from their place of origin.

The mineralogical composition of the sediments indicates the assemblage to be an unstable one. The presence of minor quantities of olivine, an unstable mineral as compared to the moderately stable plagioclase feldspars, hypersthene and augite suggests these allogenic minerals have not been subjected to extensive weathering and therefore recently sedimented. Minor alterations of the minerals have occurred; many plagioclase crystals contain dusty coatings of kaolinite and the surfaces of most of the particles of volcanic glass are coated with clay minerals apparently of the bentonite group. These changes are not of sufficient importance to cause difficulty in the identification of the original mineral.

The place of origin of the materials comprising the lake sediments seems to be the volcanic rocks surrounding the basin, while the air borne volcanic ash and pumice was carried in from areas probably to the west and northwest. The presence of detrital magnetite, plagioclase feldspar (andesine and labradorite), basaltic hornblende, and minor quantities of hypersthere, augite, and olivine can leave little doubt that the basalt which comprises nearly all of the rocks in the Summer Lake drainage is the main source and the ash the second source. The place of origin of the constituent ash and pumice is less apparent. The known occurrence in the Ana River section of several pumice layers from Mt. Mazama and Newberry Crater immediately suggests these well known vents as possible sources of the remainder of them. Crater Lake is 65 air line miles nearly due west of Summer Lake while Newberry Crater lies about 55 air line miles away in a north-northwest direction. Both Mount Mazama and Newberry Crater are known sources of at least part of the pumice of central Oregon. The distance of these vents from the Summer Lake basin, however, would cause a limitation of the quantity of pumice that might be deposited. Also, the prevailing direction of the wind throughout more than half of the year is southerly which would tend to carry the finer materials, that ordinarily might be deposited in fringe areas such as this, to the north and hence away from the Summer Lake basin.

Although the drainage area of Summer Lake is comparatively small, the transportation to the lake of even half of the ash deposited in this 550 square mile area would represent a sizeable addition to the detrital basalt minerals carried downward by streams. Because the time of deposition of most of the sediments is referred to the pluvial stages the precipitation would have been adequate to transport the ash and mineral fragments, even from the outer edges of the hydrographic basin.

The predominantly fine-grained character of the sediments indicate the lake to have been deep enough for the settling of silt-size particles during the formation of most of the Ana River section. Ripplemarks on the surface of one layer (A-59) indicate the shore line, at least at that time, to have been almost due north. The nearest prominence north of the section is a small tilted fault block. This block is about a mile distant and represents the closest feature exposed to the limited wave action during the lower water stages. The more distant sloping surface marking the north end of the basin was the shore line during deeper water stages. The distance from the Ana River section to the shore lines on the gently sloping north margin would have varied greatly with small changes in the depth of the lake.

Many of the silt layers contain intermixed clay and sand. The included clay often gives a varve-like appearance to the layers and probably is the result of annual or irregularly spaced changes of precipitation, the result of which would be a variation in the ability of surface water to transport different sizes and quantities of detritus to the lake. Fluctuations of the lake level could account for the greater percentage of clay, but the alternation of thin layers of clay and silt would require many major changes of the lake level to accomplish this, and so are not to be expected.

The sand intermixed with the silt is most probably the result of minor, possibly seasonal, fluctuations at a time when the lake was at its lower levels. The oolites, not uncommonly associated in minor quantities with some layers of silt, are more certain evidence of fluctuations of the lake level, as they represent times of low water and high concentrations of calcium carbonate. The intermixed oolites, sand, and basalt pebbles represent times when the lake was shoaling and the shore line was at or near the general area now represented by the Ana River section. A thin section was cut of oolites from sample A-21. The requisite concentric deposition bands are present, but poorly shown, while the radial fibrous crystal structure is well displayed (figures 5 and 6). It is not known whether the oolites are composed of aragonite or calcite since a good interference figure could not be obtained. Considering the time since the formation of the oolites and their exposure to moist conditions throughout most of the ensuing time, the oolites probably are composed of calcite. The photomicrographs show the tendency for the growth of secondary deposits on the side of the early-formed oolites. This is probably the result of a renewal of condition favorable for their growth some time after the center portion had been formed.

Other indications of low water and temporary exposure of the lake bottom are the numerous thin caliche layers. These cemented layers often have included sand and pebbles indicating a low level of the lake prior to cementation. The formation of the caliche might also be referred to more recent effects of circulating ground waters, the layers cemented being determined by their permeability.

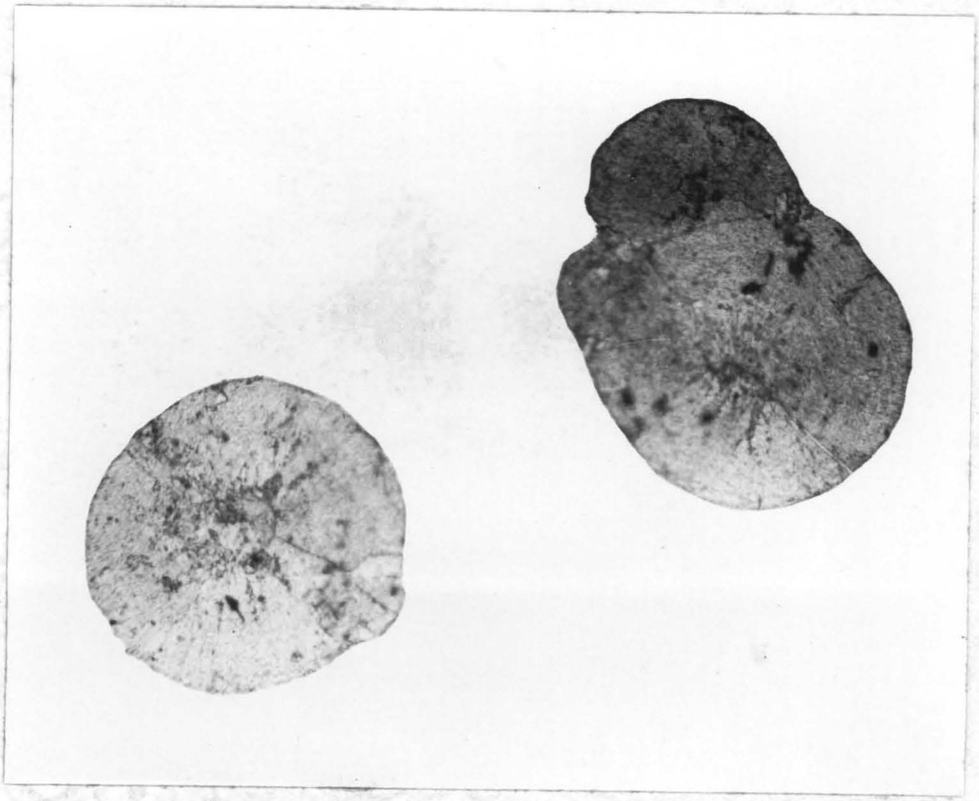


Figure 5. Photomicrograph of oolites showing poorly-defined deposition bands. Note secondary deposition on edges of early-formed oolite. Ordinary light, 30X.

However, inasmuch as nearly all of these layers are firmly cemented on the top, often with a 1/16 to 1/8 inch coating of pure calcium carbonate on the upper surface, and the bottom half of the layer is poorly cemented and crumbles readily, their cementation during low water stages seems to have been the dominant cause of their origin.

A few silt layers, especially in the upper half of the section, exhibit desiccation shrinkage cracks. The formation of these cracks is referred to recent drying of the layers, since the cracks are not filled as they would be had they formed during temporary exposures of the lake bottom.

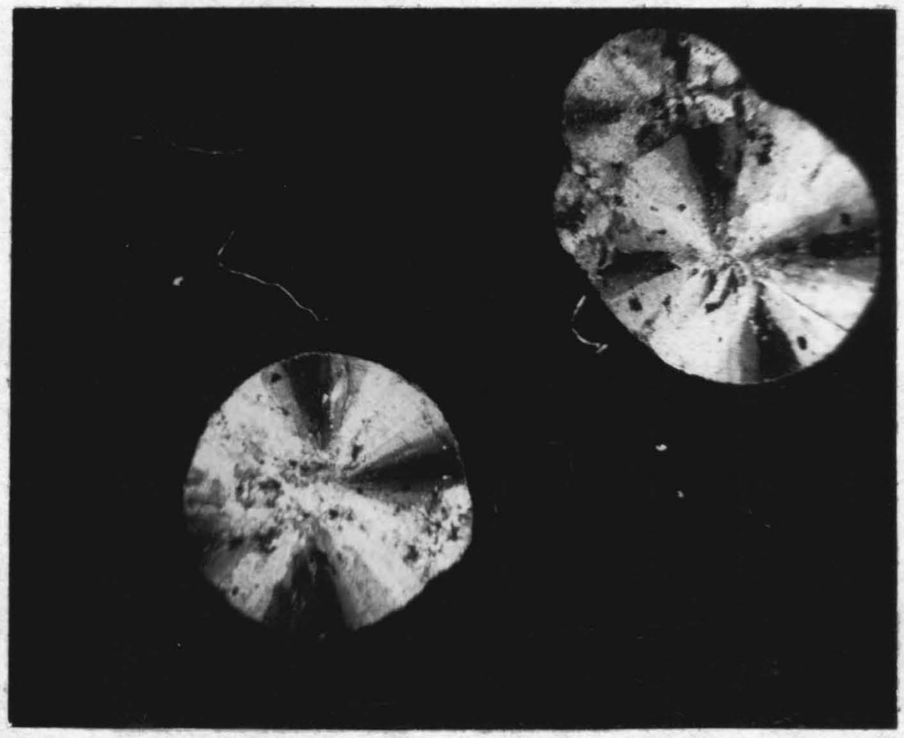


Figure 6. Photomicrograph of oolites showing pseudouniaxial interference cross. Crossed nicols, 30X.

Fossils

One layer (A-29) contains abundant remains of one gastropod species and one tiny species of pelecypod. A possible new species of gastropod is also found in this layer. Several other layers contain occasional mollusk shells, but the total containing shells constitutes a very minor percentage of the Ana River section.

Phylum MOLLUSCA
Class GASTROPODA
Family PLANORBIDAE
Genus *Parapholyx* Hanna

Parapholyx packardi Hanna (plate 4, fig. 1 a,b,c). Hanna, G. Dallas, *Fresh water mollusks from Oregon*, Univ. Ore. Publ., vol. 1, no. 12, p. 6, 1922.

Shells small, composed of $3\frac{1}{2}$ whorls which increase rapidly; sutures deeply impressed around the last whorl. Spire is elevated but apex flattened and smooth. Whorls are marked by fine, even ribbing. Specimens measured showed an average height of 6.6 mm and an average diameter of 7.9 mm and are considerably smaller than the type specimen reported by Hanna which have a height of 15.4 mm and a diameter of 13.2 mm.

Parapholyx n. sp. cf. *Parapholyx packardi* Hanna. (plate 4, fig. 2 a,b,c).

Class PELECYPODA
Family SPHAERIIDAE
Genus *Pisidium* C. Pfeiffer

Pisidium variabile Prime. (plate 4, fig. 3 a,b,c). Prime, Temple, *New Species of Pisidium*. Boston Society of Natural History Proceedings, vol. 4, p. 163, 1851.

Shell small, stout, very oblique; striations rather heavy for so small a shell.

Three specimens of the gastropod illustrated in plate 4 (fig. 2 a,b,c) were collected that seem to be the same as *Parapholyx packardi* Hanna except that they are marked by more prominent growth line ornamentations. The shells apparently belong to the species genus *Parapholyx*, possibly representing a new variety of *P. packardi*.

These shells were submitted to a fresh water gastropod specialist for confirming identification, but since this identification has not been completed at the time of this writing, no new varietal names will be advanced.

PLATE 4

1 a, b, c. Parapholyx packardi Hanna. Side, bottom, top view. Page 53. 5X.

2 a, b, c. Parapholyx n. sp. cf. Parapholyx packardi Hanna. Side, bottom, top view. Page 53. 5X.

3 a, b. Pisidium variabile Prime. Exterior, interior view. Page 53. 12X.

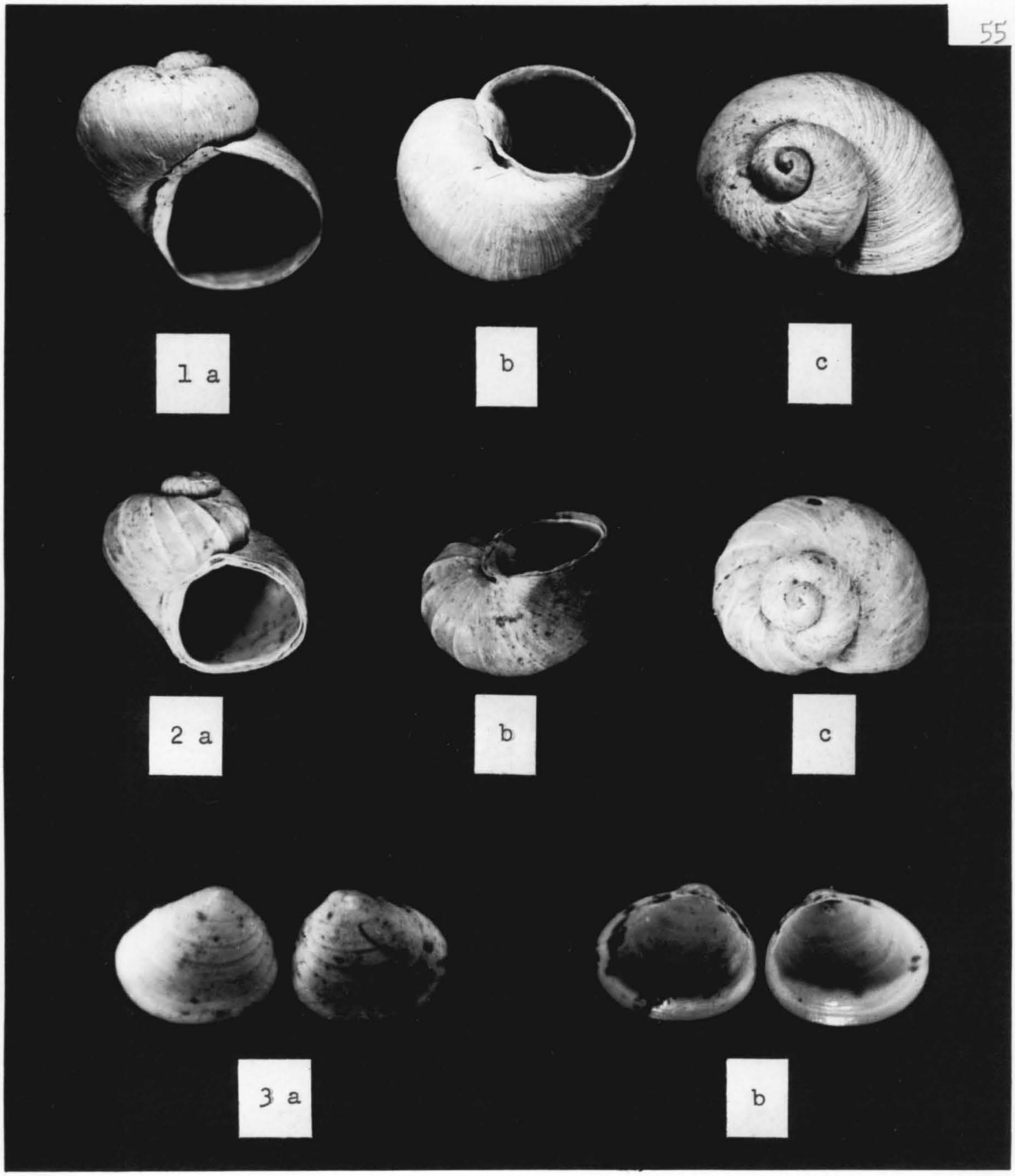


Plate 4

Gastropod and pelecypod genera represented in the Ana River section.

One of the most notable occurrences in the lake sediments was the abundant ostracod shells. These shells were found in nearly all layers from the bottom to the top of the section. The ostracod shells are less common in the silt layers but are abundant in the sandy layers where the shells comprise one-third to one-half of the volume of some of these layers.

A detailed study on the ostracod shells was undertaken by Mr. Donald L. Minar, graduate student at Oregon State College, during the winter term of 1952. The identifications and findings here reported are the result of his efforts.

All the forms identified were bottom dwellers, crawling over the lake bottom or burrowing in the mud. This portion of the lake could have changed from deep water to swampy or marshy conditions with corresponding changes in the salinity of the water without affecting most of the forms present. Ostracods are tolerant of many types of water and often thrive in waters too foul for most invertebrate animals to live. Only a few ostracods are found in clear cold spring or well water.

The samples studied were taken at irregular intervals throughout the section and represent different periods of time when the respective layers were being deposited. Since the brackishness of the water is closely related to the seasonal precipitation, the ostracods serve to record such changes in the climate at the time they lived.

Of the 7 samples studied the following climatic conditions prevailed at the time of their deposition: A-28 conditions were wet; A-38, medium wet; A-48, dry; A-50, wet; A-73, very dry; A-74, medium;

and A-78, very wet.

Phylum ARTHROPODA
Class CRUSTACEA
Subclass OSTRACODA

Family CYTHERIDAE

1. *Limnicythere* cf. *reticulata* Sharpe. Ward, H.S., Whipple, G.C., Fresh-water Biology, John Wiley and Sons, p. 806, fig. 1250, 1918.

A bottom dwelling form, burrowing in and creeping over a muddy bottom; often found in brackish waters.

Family CYPRIDIDAE

Candona

A creeping or burrowing form. Some species live in brackish waters.

2. *Candona* cf. *balatonica* Duday. Dobbins, C.N., Fresh-water ostracods from Washington and other western states, Univ. Wash., publ. in Biology, vol. 4, no. 3, pl. 3, fig. 8, 1941.

3. *Candona* cf. *candida* (O. F. Muller). Dobbins, C. N., Fresh-water ostracods from Washington and other western states, Univ. Wash., publ. in Biology, vol. 4, p. 242, pl. 4, fig. 10, 1941.

4. *Candona* cf. *candata* Kaufman var. *occidentales* n. var. Dobbins. Dobbins, C.N., Fresh-water ostracods from Washington and other western states, Univ. Wash., publ. in Biology, vol. 4, p. 245, pl. 4, fig. 2, 1941.

5. Candona cf. decora n. sp. Furtosa. Furtosa, M.C., The ostracods of Ohio, Ohio Biological Survey, Bull. 29, vol. 6, p. 477, pl. 8, fig. 4, 1933.

ABUNDANCE CHART

	A-28	A-38	A-48	A-50	A-73	A-74	A-78
1. Limnicythere cf. reticulata Sharpe	●	■	■	■	■	■	■
2. Candona cf. balitonica Duday	■	●	○	■	○	●	■
3. Candona cf. candida (O. F. Miller)	○	○	○	○	☒	☒	●
4. Candona cf. caudata Kaufman var. occidentales n. var. Dobbin✓	☒		○	○	☒	☒	○
5. Candona cf. decora n. sp. Furtosa	○		☒	●			●
Conditions of moisture	W	M	D	W	VD	M	VW

Key: 1- 5 = ☒

6-10 = ○

11-50 = ●

Over 50 = ■

VD = very dry

D = dry

M = moist

W = wet

VW = very wet

Occasional diatom tests were noted at irregularly spaced intervals in the Ana River section. The diatom tests occur in layers of silt—most of which contain abundant altered volcanic glass—and are even more abundant in layers of volcanic ash. This occurrence agrees with the observed world-wide association of diatoms and related siliceous sediments with volcanic products, especially volcanic ash.

Murray and Irvine (37, pp. 232-233) report the silica used by the diatoms is made available in the form of hydrous aluminum silicates and silicic acid. Since the hydrous aluminum silicates are more soluble than silicic acid they probably furnish most of the silica required for the formation of the diatom tests. The formation of the hydrous silicates requires the alteration of volcanic products. The alteration to hydrous silicates apparently takes place prior to deposition; in the volcanic vent, or very close to it, or by gasses and solutions emanating from the volcano. Likewise, any silicic acid liberated by the reaction of less stable volcanic ash with water, or introduced in any other way, is available for utilization by the diatom.

In the Tertiary of California, Taliaferro (44, p. 36) reports that altered volcanic ash is believed to have been the chief source of supply for the rapid and continued growth of the diatoms. The growth of such unusually large numbers of siliceous organisms apparently was contingent upon the presence of equally large amounts of hydrous silicates and silicic acid.

Inasmuch as volcanic ash is abundant in the Ana River section it is puzzling why more diatoms are not found. At no place in the section was a layer found where diatom tests were abundant—much less in quantities necessary for the formation of diatomite. The relative freshness or salinity of the lake water at the time these forms lived should not have been a hindrance to their growth since diatoms have been found to live in fresh, brackish, or marine waters. They live only in the upper layers of water affected by sunlight, but again this would not have been a limiting factor. The principal reason for their limited numbers, then, may be the lack of alteration of the ash or the lack of phosphates and nitrates that are known to be necessary for their growth.

A number of different genera of diatoms appear to be represented throughout the section, but no effort was made to identify them. Instead, a photomicrograph (figure 5) of one of the most abundant species is included in this report.

One sample (A-17) yielded fragmental remains of fish life. The remains are principally broken pieces of bone and a few whole ribs. Unfortunately the bones occur in a cemented silt and volcanic ash layer which hinders efforts to remove them without breakage. Inasmuch as the number of fragments is limited and their identification improbable, no special effort was made to remove the bones.

Vertebrate fossils previously have been collected in the Summer Lake basin. Hay (26, p. 101; p. 245) reports the discovery, in 1882, of the remains of a camel. One of the bones is believed to belong to Camelops huerfanensis and the remaining bones belong possibly to C. kansanus. Other bones collected were identified as a species of Equus, a peccary of some species of Platygonus, and a piece of the breast bone of a swan, Olor. Another collection of vertebrate fossils was made in 1883 and included 3 bones of a very large camel, Camelus maximus. Both of these collections are now housed at the United States National Museum.

Since that time, bison teeth are reported (26, p. 245) to have been found at Summer Lake and Paisley, Oregon.

No vertebrates other than fish are known from the Ana River lake beds.

Statistical Analysis of Sediments

Undisturbed Settling Velocity Tests

Inasmuch as the Ana River section is composed of predominantly

Figure 7. Photomicrograph of one species of diatom from sample A-34. 150X.

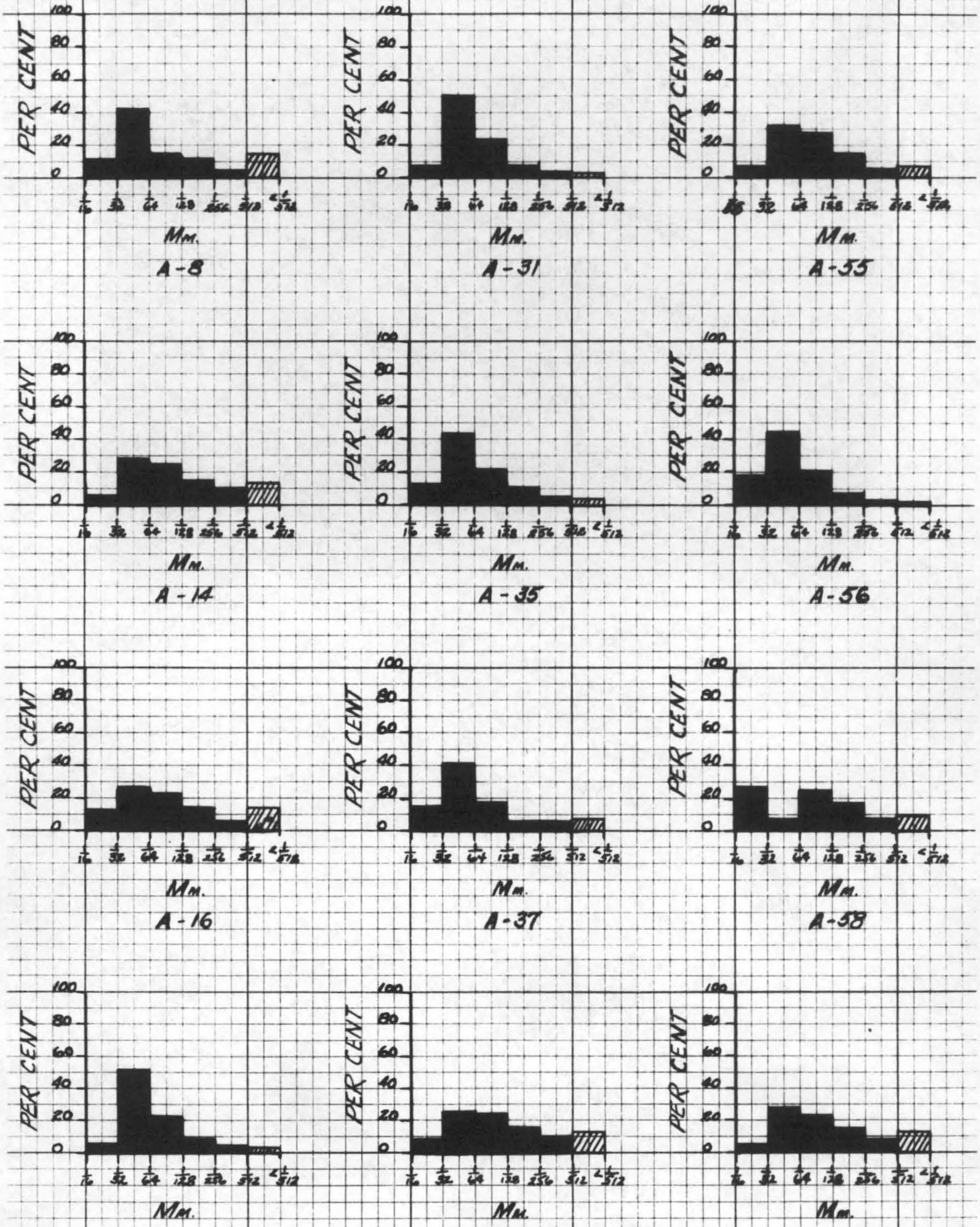
fine-grained sediments a series of undisturbed settling Velocity tests was initiated to determine the relative quantities of clay and silt-sized particles. Eleven samples were tested using a modification of the settling velocity method described by Tickell (46, pp. 12-17). In accordance with the procedure outlined in this article, individual twelve-inch test tubes were used, but the liquid and unsettled particles near the top was decanted with a pipette for measurement instead of computing the percent of sediments settled and collected in a brass cup at the bottom of the test tubes.

As a further test, the method of analysis was changed to the pipette method, using a one-liter graduate to hold the suspension, in accordance with the procedure outlined by Krumbein and Pettijohn (31, pp. 166-170). The samples tested were first dried and sieved, the material passing through a 200 mesh screen being used for the settling tests. The samples were then weighed with accuracy to the third decimal place and dispersed with N/100 sodium oxalate. After thorough agitation, twenty cubic centimeter volumes of the suspension were withdrawn at time intervals of 58 seconds, 1 minute 56 seconds, 7 minutes 44 seconds, 31 minutes, and 2 hours and 3 minutes to give size values, corresponding to the Wentworth grade scale, ranging from 1/16 mm. downward to the 1/256-1/512 mm. size. A total of 18 samples was tested using this method.

The results of the settling velocity tests were graphically plotted in the hope they could be more easily read and compared, one unit against another, than could a list of numbers.

Of the 18 samples tested by the pipette method, the results were plotted as histograms (plates 5 and 6) which readily portray the silty nature of these minus 1/16th mm. sediments. Histograms of fourteen of the 18 samples settled show the maximum quantity of any one size range to be the 1/32-1/64 mm. size. Of the remaining four samples, three show the 1/64-1/128 mm. size to be most abundant while one sample shows the 1/16-1/32 mm. size dominant. In all instances more than 77% of each sample settled as various grades of silt and the clay-sized particles made up the comparatively minor remaining percentages. One sample contained 93% silt-sized particles.

One third of these samples showed about 20% of their constituent particles to be less than 1/256 mm. in size, but the distribution of these layers in the section is random and does not suggest any greater



A-8 A-31 A-55

A-14 A-35 A-56

A-16 A-37 A-58

A-27 A-53 A-62

Plate 5

Histograms of size distribution of lake sediments based on settling velocity tests.

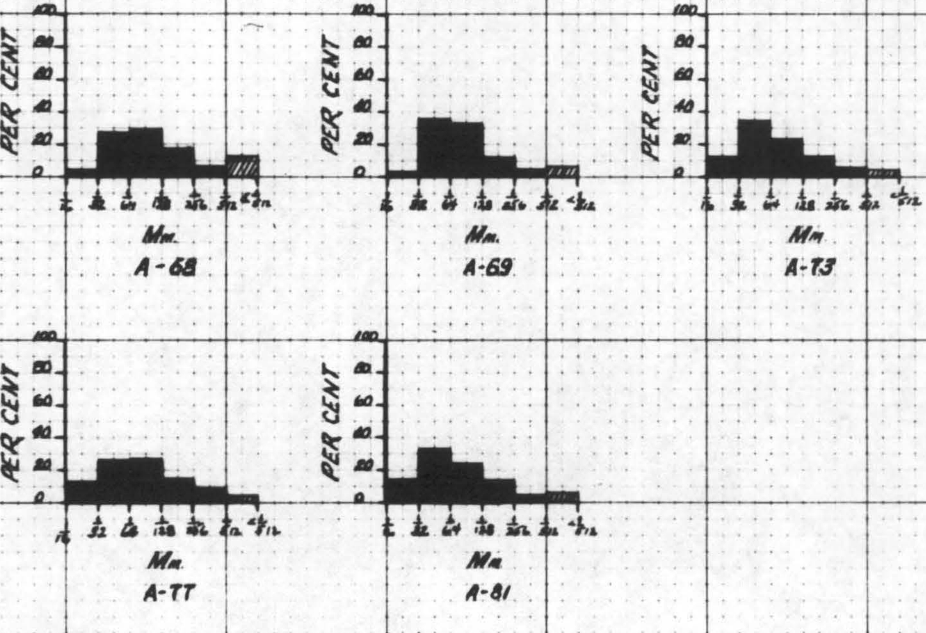


Plate 6

Histograms of size distribution of lake sediments

BASED ON SETTLING VELOCITY TESTS.

abundance of clay-sized particles in sediments at the base of the section than those near the top.

Differential thermal analyses indicated the particles of less than 1/256 mm size to be almost devoid of clay minerals or, if present, to be in quantities of less than 10% of the total. Samples A-35 and A-58 contain a total of 11.8% and 18.8% of the material less than 1/256 mm, respectively, but upon being tested gave no indication of a differential thermal curve for clay. Samples A-12, A-43 and A-66 similarly showed no differential thermal curve.

Of the 11 samples tested using the test tube method, all show predominantly silty character as do the samples tested by the pipette method. Settling velocity curves were drawn for the samples and in each instance they show a rapid settling of the particles during the first 1 minute 56 seconds, with the curve starting to flatten, because of the reduced settling rate, by the end of 7 minutes 44 second. At the end of 31 minutes the greater percentage of the material had settled and from this point the curve shows a slow, continuous rise indicating the less abundant fine materials were settling steadily.

Three settling curves were plotted for inclusion in this report (plate 7) to show the general characteristics of all eleven samples. The curves are clustered in one small area on the graph, as the settling velocities they portray are very similar for all the samples. Two of the curves, representing the extremes of settling rates for the group, were plotted along with a curve representing an average of all samples tested. Even the opposite extremes of the rate of settling velocity show a curve similar to that representing the average and the group does not exhibit a very great spread along either the ordinate or the abscissa.

The samples portrayed by these curves occur at various intervals throughout a stratigraphic section of about 45 feet thickness. The similarity in the size grade of the respective units is notable since other sediments of the Ana River section indicate great changes of the lake took place during the intervening time between the sedimentation of these various fine-grained layers.

Dry Sieving

A number of samples were dry sieved for separation into size grades. The samples were dried, split into approximately 50-gram samples using a Jones Sample Splitter, and sieved for a period of 10 minutes in a Cenco-Meinzer sieve shaker. A total of 33 samples was tested. Tyler Standard sieves having mesh sizes of 9 (1.981 mm), 16 (0.991 mm), 32 (0.495 mm), 60 (0.246 mm), 150 (0.124 mm) and 200 (0.074 mm) were used for these tests.

Twenty other samples were dry sieved using a Tyler Ro-Tap machine. For these tests, 10-gram samples were weighed and sieved for a period of 10 minutes. Because of the fine-grained nature of the samples, the use of the 9-mesh screen was discontinued for these tests. The fine-grained nature of the sediments and ash was responsible for some losses from dusting during sieving. The sieve losses of samples tested with the Cenco-Meinzer sieve shaker ranged from 0.03 to 3 per cent. Of the 10-gram samples sieved with the Ro-Tap, sieve losses ranged from 0.1 to 4 per cent. The highest percentage

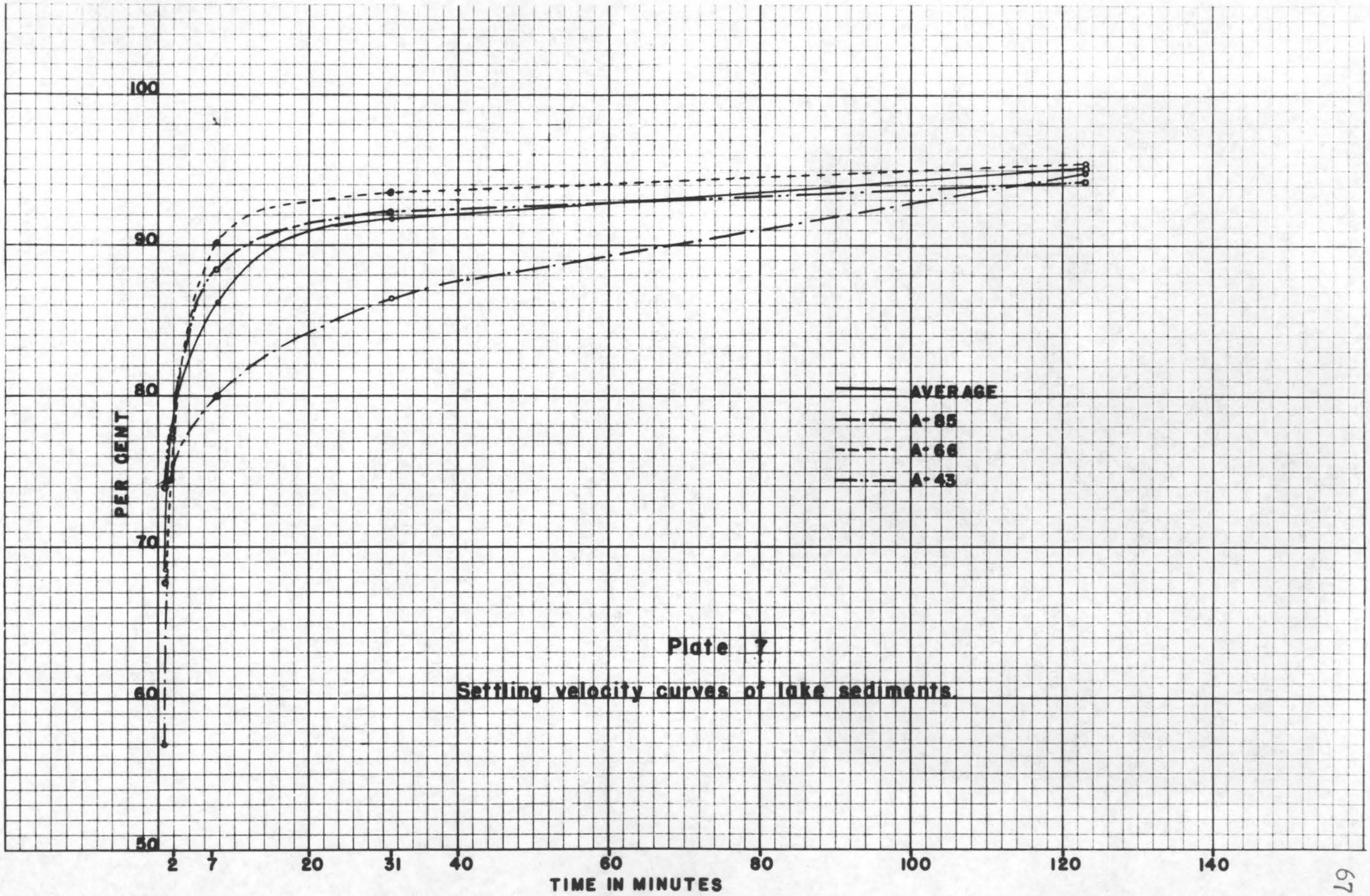


Plate 7

Settling velocity curves of lake sediments.

loss from dusting occurred during tests with the Ro-Tap machine.

To better describe and understand the character of the sediments and pumice of the Ana River section, several cumulative frequency and frequency curves have been drawn (plates 8 and 9). From data derived from the curves, a statistical description of the samples is possible in concrete terms that may be used for the comparison of various samples, especially those exhibiting slight or no apparent variation to the observer.

It is known (31, p. 223) that by arranging the frequency distribution in the order of magnitude of the particles, the smallest particles at one end and the largest particles at the other end, certain particles representing significant values can be chosen. The median is the size of the middle most particle and represents an average of the group. The medians of samples C-5 and C-7 (plate 8) are 0.12 mm and 0.115 mm, respectively, indicating the two samples to be nearly alike in grain size. The spread of the distribution around the median is indicated by the first quartile (Q_1), just larger than one-fourth of the distribution, and the third quartile (Q_3), just larger than three-fourths of the distribution. As indicated by plate 8, sample C-5 has much less distributive spread than C-7.

Quartile derivatives are a measure of the average spread, which is usually used with the median. QDa is the arithmetic quartile derivative, a measure of half the spread between the two quartiles. QDg is a geometric quartile derivative based on the ratio between the quartiles. "So" indicates the sorting coefficient of the sample. Krumbein and Pettijohn (31, p. 232) report a value of So less than

PLATE 8 - CUMULATIVE FREQUENCY AND FREQUENCY CURVES OF VERY FINE SAND.

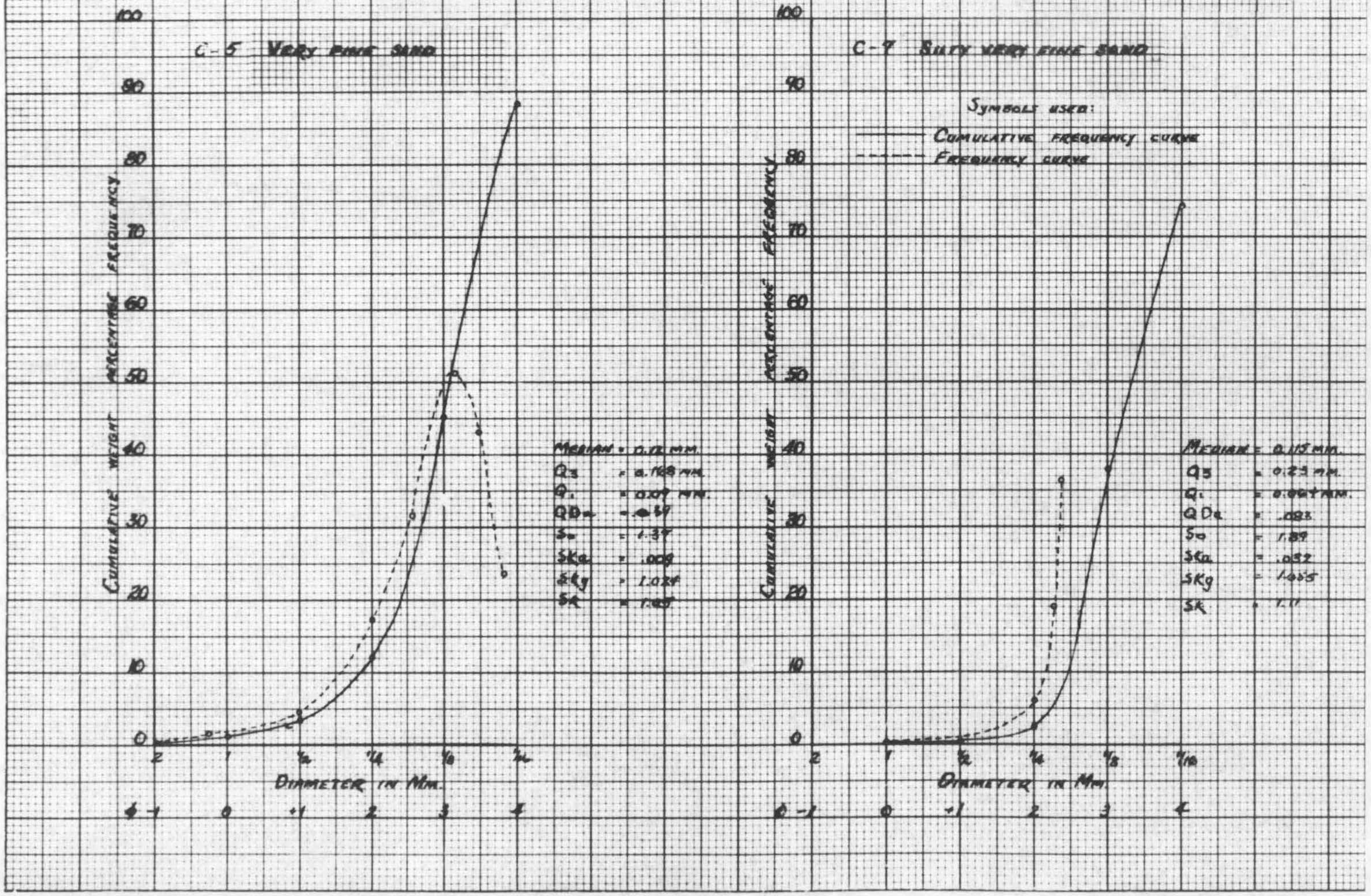
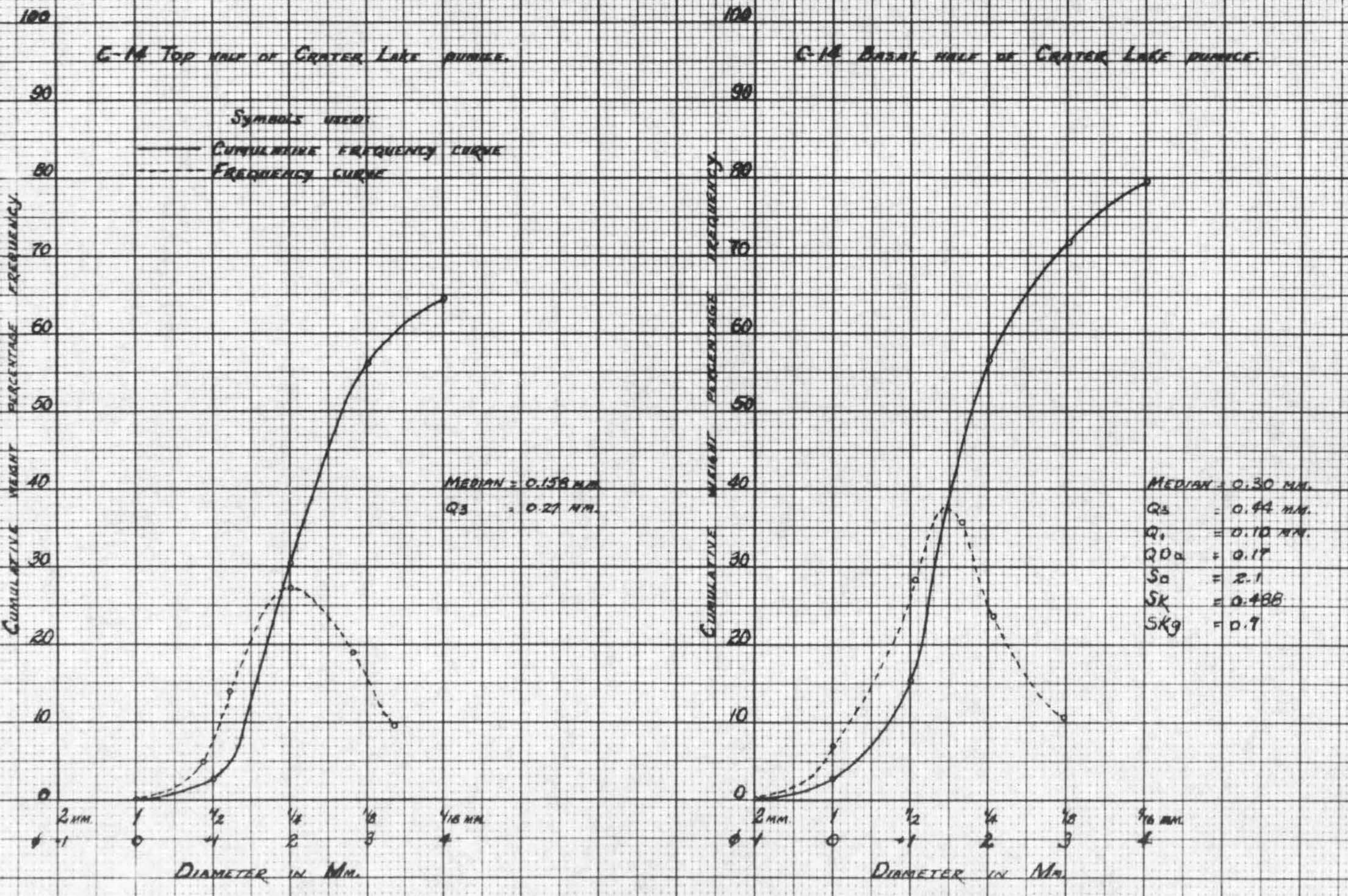


PLATE 9 - CUMULATIVE FREQUENCY AND FREQUENCY CURVES OF CRATER LAKE PUMICE



2.5 to indicate a well sorted sediment, with a value of about 3.0 a normally sorted sediment. Samples C-5 and C-7, accordingly, are very well sorted with So values of 1.37 and 1.89 respectively.

Samples C-5 and C-7 are classed as very fine sand, and silty very fine sand, respectively. The curves (plate 8) indicate this by the fact that the great bulk of both samples is of the 1/4-1/16 mm, fine to very fine sand, size. Sample C-7 possesses the smaller median number, however. The curve correspondingly indicates the finer character of C-7 by the fact that over 25% of the total is finer than 1/16 mm. The greater quantity of fine sand, 1/4-1/8 mm, size and the smaller amount of silt, cause sample A-5 to be classed as very fine sand.

The median and quartile values are of greatest value for describing the Crater Lake pumice (plate 9). The top half of the pumice is nearly twice as fine as the basal half as indicated by the respective medians. The basal half median occurs between 1/2 mm and 1/4 mm while the top half median occurs between the 1/4 mm and 1/8 mm size. Inasmuch as the curve for the top half of the pumice had not yet crossed the 75% line, Q_1 could not be computed. Other methods of size determination for this material, less than 1/16 mm, would have to be employed to derive this value.

Size distribution chart for volcanic ash and pumice from samples collected at Site A. Samples sieved for a ten minute period in a Tyler Ro-Tap shaker. Numbers indicate weight percentages:

Sample Number	Sieve Mesh Sizes 16	32	60	115	200	200	Sieve Losses
(Volcanic Ash)							
A-7	0.0	0.0	1.6	3.8	14.6	78.5	0.27
A-17	1.2	9.3	28.5	22.7	19.8	18.6	0.10
A-23	0.0	2.1	24.7	26.4	8.5	38.3	0.13
A-30	0.0	1.9	18.5	34.2	5.6	39.8	0.12
A-32	1.8	18.0	24.3	14.9	7.7	33.3	0.20
A-34	0.0	2.1	17.2	21.7	13.5	44.3	0.20
A-36	1.3	47.7	26.8	5.9	6.5	11.8	0.10
A-42	0.0	6.7	10.9	3.9	7.2	71.3	0.22
A-52	0.0	1.9	0.8	3.1	13.0	81.2	0.10
A-54	0.9	4.2	11.0	14.4	26.3	43.2	0.10
A-59	0.0	3.4	1.7	7.6	13.4	73.8	0.07
A-61	0.0	2.3	2.0	5.6	13.9	76.2	0.30
A-63	0.0	16.8	49.6	12.0	4.4	17.2	0.35
A-63	0.0	9.2	39.9	16.9	3.1	30.9	0.18
A-65	0.0	1.0	6.9	9.7	13.6	68.7	0.17
A-78	0.0	6.4	24.6	22.3	24.9	21.8	0.20
A-84	7.0	25.5	46.9	6.4	3.0	10.9	0.40

Size distribution chart for sediments from samples collected at Site A. Samples sieved for a ten minute period in a Tyler Ro-Tap shaker. Numbers indicate weight percentages:

Sample Number	Sieve Mesh Sizes 16	32	60	115	200	200	Sieve Losses
(Other Sediments)							
A-19	4.3	5.3	41.5	11.7	17.0	20.2	0.10
A-50	0.0	11.7	6.7	25.0	45.0	11.5	0.01
A-74	1.1	3.8	27.4	24.7	20.4	21.5	0.20

Size distribution chart for volcanic ash, pumice, and other sediments from samples collected at Site A. Samples sieved for a ten-minute period in a Cenco-Meinzer sieve shaker. Numbers indicate weight percentages.

Sample	Sieve Mesh Sizes							Sieve
Number	9	16	32	60	115	200	200	Losses
(Volcanic Ash)								
A-7	0.0	0.1	0.1	4.0	4.4	14.2	76.5	0.85
A-9	0.0	0.0	0.8	5.2	10.2	14.9	68.5	0.60
A-23	0.0	0.3	2.3	25.4	25.8	7.9	38.3	0.07
A-30	0.2	0.1	10.6	21.3	33.2	10.0	34.4	0.65
A-32	0.0	0.1	18.3	22.3	16.6	8.0	33.1	0.73
A-34	0.6	0.2	2.0	19.3	21.8	12.3	43.7	0.25
A-36	0.0	0.6	50.8	24.2	5.1	6.7	12.0	0.95
(Other Sediments)								
A-21	0.0	2.5	16.9	67.8	4.5	4.9	3.3	0.25
A-25	0.6	0.7	13.9	25.7	11.5	26.0	21.1	0.95

Size distribution chart for volcanic ash, pumice, and other sediments from samples collected at Site C. Samples sieved for a ten-minute period in a Cenco-Meizer sieve shaker. Numbers indicate weight percentages.

Sample	Sieve Mesh Sizes							Sieve
Number	9	16	32	60	115	200	200	Losses
(Volcanic Ash)								
C-2	0.0	0.0	0.4	5.4	50.0	15.8	28.3	0.03
C-2	0.0	0.0	0.0	3.6	3.0	3.4	89.9	0.02
C-2	0.0	0.0	2.6	6.5	4.5	10.8	75.3	0.42
C-6	0.0	0.3	2.8	23.2	15.9	39.0	18.8	0.70
C-10	0.0	0.0	0.2	2.2	36.6	35.3	25.4	0.28
C-10	0.0	0.0	0.0	7.6	5.0	56.0	31.2	0.24
C-14	0.0	0.0	1.0	3.9	3.9	6.4	84.9	1.04
C-14	0.0	0.0	2.6	27.6	26.0	8.6	35.1	0.90
C-14	0.0	2.9	12.5	41.1	15.3	7.8	20.1	0.35
C-16	0.0	0.5	8.4	12.4	9.2	7.1	62.1	0.42
(Other Sediments)								
C-1	0.8	0.0	2.6	10.5	16.4	53.1	16.6	0.70
C-1	0.2	0.3	6.0	9.6	11.8	47.0	25.2	1.50
C-3	0.2	1.4	5.4	12.9	10.8	30.5	38.8	1.10
C-5	0.4	0.8	2.0	8.8	33.2	43.1	11.0	1.48
C-7	0.0	1.2	6.1	16.3	15.8	39.3	20.5	0.97
C-7	0.0	2.4	11.9	13.9	11.6	19.0	41.1	0.15
C-9	0.0	2.2	8.5	11.0	9.2	22.6	45.8	0.93
C-9	0.0	0.9	1.8	8.9	11.0	21.7	54.9	0.91
C-11	0.0	2.2	16.5	46.4	14.1	10.8	9.9	0.07

Sample Number	Sieve Mesh Sizes							Sieve Losses
	9	16	32	60	112	200	200	
C-11	0.0	5.4	24.1	27.4	14.5	17.0	11.4	0.58
C-11	0.2	2.6	12.7	20.2	15.3	14.7	34.1	0.55
C-11	0.8	1.8	5.1	11.1	12.4	25.1	43.7	0.06
C-13	0.0	0.6	0.3	4.9	11.5	18.9	64.3	0.92
C-15	0.5	0.1	0.8	6.2	6.1	16.4	69.4	0.25

Organic Carbon Determination

In view of the light, fluffy gyttja-like character of many of the sediments upon being dried, it was thought they might contain above average quantities of organic carbon. Eleven samples were tested using Walkley and Black's rapid titration method (39, pp. 223-227).

The Walkley and Black method is based upon the digestion of the soil by chromic and sulphuric acids, making use of the heat of dilution of the sulphuric acid. The excess chromic acid, not reduced by the organic matter of the sample, is determined by titration with standard ferrous sulphate. It has been found that the percentage recovery by this method varies from 60 per cent to 90 per cent with the mean recovery between 70 and 80 per cent. The values obtained from these tests are "single value" determinations and will be designated as "Organic Carbon, Walkley and Black values."

A-10	0.000%	Organic	carbon, Walkley and Black values.
A-29	0.098%	"	"
A-37	0.119%	"	"
A-49	0.128%	"	"
A-58	0.244%	"	"
A-63	0.000%	"	"
A-64	0.199%	"	"
A-75	0.247%	"	"
A-77	0.180%	"	"
A-81	0.157%	"	"
A-85	0.237%	"	"

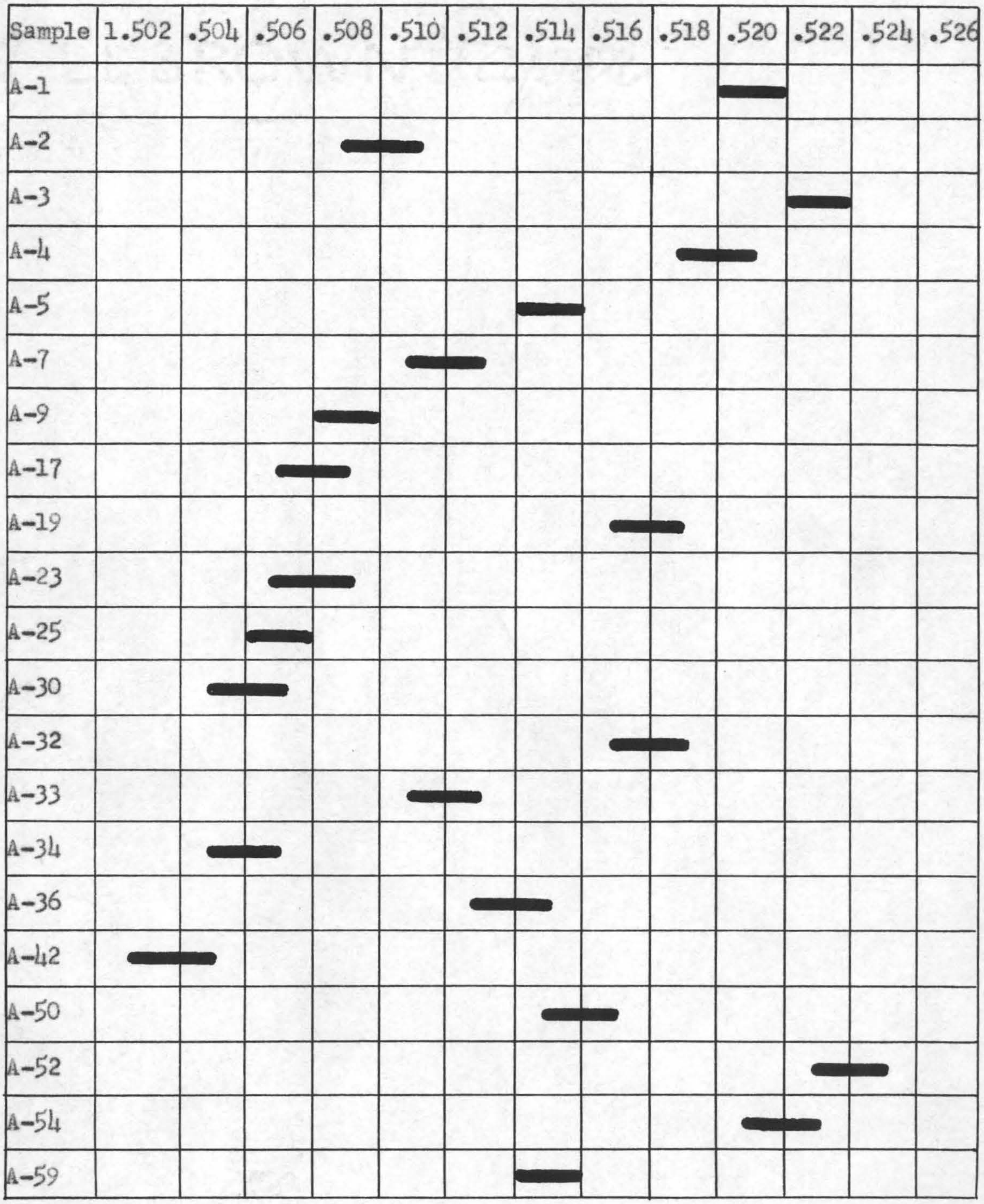
As shown by the table none of the samples tested showed the presence of any significant quantity of organic carbon.

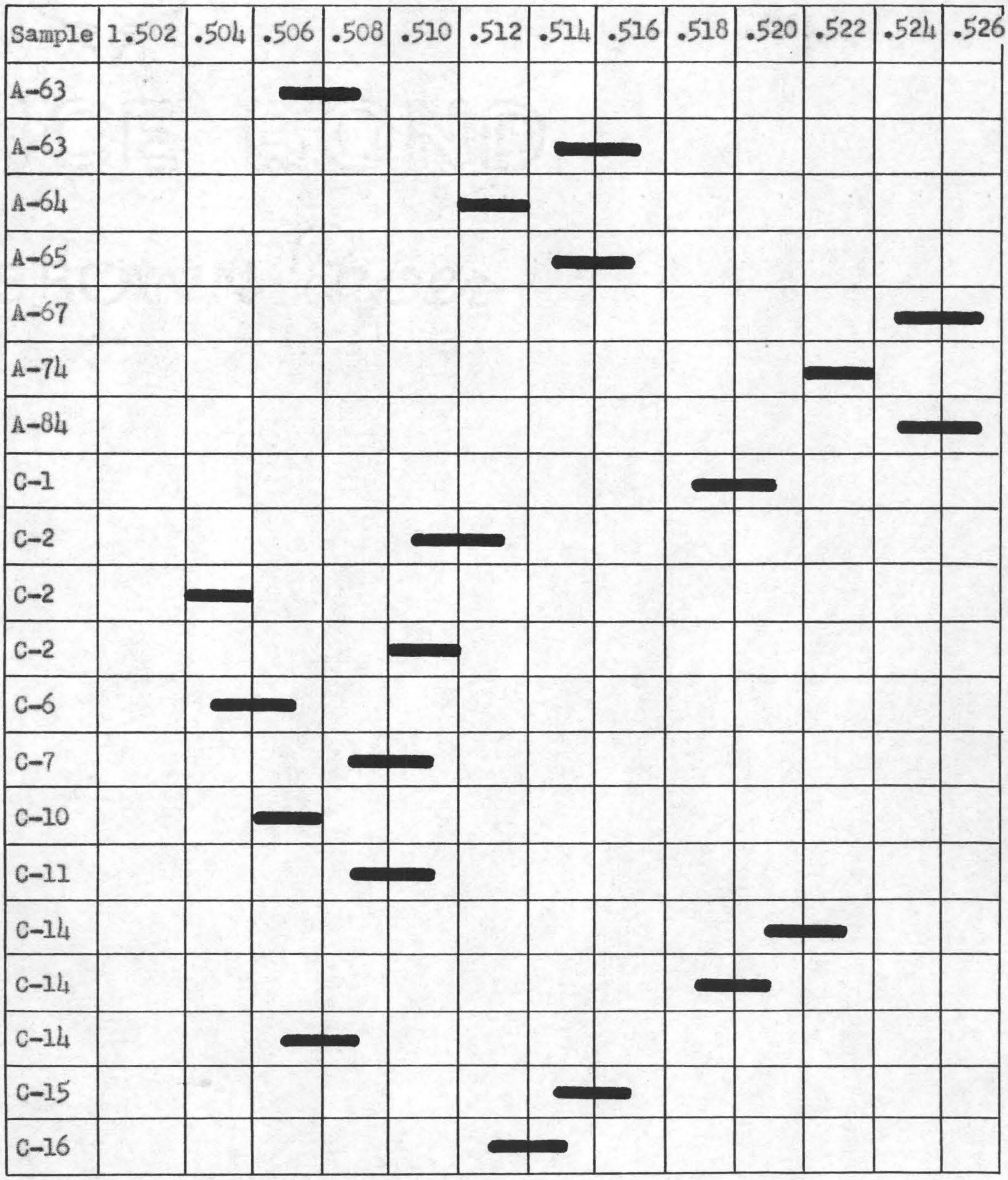
Indices of Refraction of Volcanic Glass

A study of the index of refraction of the glass found in the many included volcanic ash and pumice layers indicates about half of the samples of glass to have an index of refraction ranging from 1.502 to 1.512. The index of refraction of the remaining half ranged from 1.512 to 1.526. According to the average indices of refraction of natural glass reported by Grout (21, p. 114) the great bulk of the glass has a medium refractive index and hence a moderately silicic composition. The refractive indices of glass have wide ranges and some of the samples may represent extremes of a basic or acid parent magma instead of an intermediate dacitic, trachytic, or andesitic origin.

A tabulation of the refraction indices of the volcanic glass is presented in Chart 1.

CHART 1





Correlation and Age of Ana River Section

Correlation by Shore Lines

Antevs (7, pp. 74-75) correlated the highest stages of Lake Bonneville and Lake Lahontan, attained during the Bonneville pluvial, with the Tahoe (Iowan or early Wisconsin) glacial stage. To the Provo shore line in the Bonneville basin and the Dendritic Terrace in the Lahontan basin he correlated the Tioga (Mankato or late Wisconsin) glacial stage of the Sierra Nevada.

In the Summer Lake basin, the highest levels of Lake Chewaucan were thought by Allison (1, p. 793) to have been attained during or shortly after the Tahoe glacial stage and some of the lowest beaches during or shortly after the Tioga glacial stage of the Sierra Nevada. Within the past few years, radiocarbon dating and continued study have shown the previous dating within the Great Basin to be at least partially in error and in need of revision. As the result of these findings, the high level stage of pluvial Lake Chewaucan is now considered by Allison (4) to have been attained during the Sherwin (Kansan) glacial stage. The most prominent shore line features at an intermediate level 210 feet above Summer Lake are correlated with the Tahoe (early Wisconsin) glacial stage and the lower lines with the Tioga (late Wisconsin) stage.

The correlation of shore line features with corresponding sediments of the Ana River section seems improbable. Many sandy layers, intermixed pebbles and evaporation products represent low water stages, but their relation to the abundant layers of silts and clays deposited during times of deeper water is unknown.

Mount Mazama and Newberry Crater Pumice

The age of at least the uppermost 7 feet of the sediments of the Ana River section can be closely estimated because of the presence of Crater Lake and Newberry Crater pumice. The Crater Lake pumice is recognized over much of central Oregon and facilitates the dating and correlation of localities and the conditions present at these different localities at the time of the eruption.

Pluvial Winter Lake, at the time of the climatic outburst of Mt. Mazama, is reported by Allison (2, p. 63) to have been about 85 feet deep. The level of the lake indicates the pumice fall took place during late pluvial times, but since the lake had previously been 210 feet deep it must represent the final portion of the last pluvial stage.

The dating of this pumice fall, then, can be based on the estimated time of the climax of the last glacial stage and pluvial and postpluvial time. Based on the estimated age of the climax of the last glacial stage and the amount of time required for the reduction of Winter Lake to the level it had at the time of the Crater Lake eruption, Allison (1, pp. 801-802) assigned a value of about 13,500 years as the age of the main Crater Lake pumice and an age of about 10,500 years for the Newberry Crater pumice. Hansen (23, p. 533), basing his evidence on the thickness of peat deposits overlying the Crater Lake pumice, estimates the pumice to have been erupted between 5,000 and 7,500 years ago. Williams (50, pp. 113-114) estimates the time of the cataclysmic eruption of Mt. Mazama to have been 5,000 years ago, with 4,000 years the minimum and 7,000 years the maximum estimated time.

Very recent adjustments of the dating of the final glacial stage and of postpluvial time to 11,000 years cause any age assignment of the

Crater Lake pumice previously made on the basis of the duration of post-glacial time to be changed correspondingly. The most recent and apparently accurate dating using radiocarbon methods would assign an age of 6,450 years ago as the time of the main Crater Lake eruption. Hence the top layers in the Ana River section may be only about 6,000 years old instead of 10,000 to 14,000.

Correlation by Fossils

The correlation and determination of the age of beds containing fossil remains is often possible on the basis of "guide fossil" or the overlapping ranges of certain restricted genera. While the Ana River section contains gastropod, pelecypod, and ostracod shells, the shells seem to be of no value for age determination but are useful for the most general sort of correlation. The gastropod and pelecypod shells represent genera that range to the present and the ostracod shells, while not studied in detail, most probably do too. The comparative recency and short time interval represented by the Ana River section makes improbable any major change in the invertebrate forms since the time they lived.

Near Fossil Lake in northern Lake County, Dole (16, p. 61) reports several localities where the ground is nearly white as the result of pelecypod and gastropod shells weathering out of the sediments. Abundant ostracod shells are reportedly intermixed with these larger, more conspicuous, mollusk shells. Four genera and 9 different species of gastropods are reported by Dole (16, pp. 62-65) from this locality. Of these, only one genus Parapholyx packardi Hanna is present in the

Ana River section and occurs principally at a level 34 feet above the river. *P. packardi*, however, is very abundant in the gravel deposits 3.2 miles north and 0.3 mile east of Summer Lake post office.

Similar occurrences of *P. packardi* are reported by Hanna (22, p. 6) from the vicinity of Warner Lake, where the species was named. To the assemblage of fossils at this locality, Hanna (22, p. 6) assigned the age of Pliocene, but the geology was little known then and the species were new.

Inasmuch as all three of the previously mentioned areas represent sites of contemporaneous pluvial lakes, the presence of the same species of at least one genera of gastropods suggest that similar conditions favorable for their growth existed in the separate basins at the same time. The position of the shells in the section however does not suggest that they represent any one unit or period of time that can be compared to an equivalent layer or time unit in the adjacent basins. The greatest percentage of the specimens collected did come from one layer (A-29) but a few specimens were found at a level below this and further excavation probably will reveal other gastropod-bearing layers.

A few tiny bivalved shells representing one genus of pelecypods was collected at Summer Lake in the same layer as that containing the most abundant gastropods. These specimens are thought to be *Pisidium variabile* Prime. Dole (16, p. 65) reports the presence of *Pisidium variabile* Prime cf. *magnum* Sterki near Fossil Lake. *P. variabile* Prime cf. *magnum* Sterki is the same as *P. variabile* except for its great size.

Erratic Boulders

Throughout at least part of the Summer Lake basin, occasional erratic boulders are seen. These boulders seem to be distributed in equal quantities on the playa deposits and the slightly irregular basin floor around the playa margins. No time was devoted to looking for these boulders outside a radius of several miles of the Ana River section, but their presence throughout the rest of the basin is strongly suspected.

The erratic boulders are composed primarily of basalt, much of which is vesicular basalt, with some less common red scoriaceous basalt also present. Most boulders noted had an average diameter of about 14 to 18 inches. Angular boulders predominate although all show slight rounding of previously sharp edges. Figure 8 shows a typical erratic boulder, the base of which is less than 2 inches below the playa surface. Other erratic boulders can be seen in the background of this picture.

The type of rock of which the erratics are composed leaves little doubt that the place of their origin was the margins of the basin. The transportation and random distribution of these erratics in the basin seems to have been accomplished by the action of ice. The time of formation of this ice would seemingly be referred to the last pluvial stage. Ice formed along the shore line could attach itself to the boulders, and be broken up later by the action of winds roiling the lake, if the ice did not cover the entire lake surface, or by spring thawing that would allow the ice and entombed boulders to float out

Figure 8. Ice-rafted erratic boulder.

into the lake, only to have the ice melt and the boulders dropped to the lake bottom.

Although some of the boulders are nearly buried, many lie on the surface with their base buried no more than inches. Their exposure in part may be the result of the wind removing the surficial sand, silt, and ash that completely or partially covered the rocks previously.

Mineral Efflorescences and Analysis of Summer Lake Water

While the salinity of Summer Lake is moderate as compared to that of other lakes of the Great Basin the utilization of its contained alkalies has been considered but seems questionably feasible. Along the playa immediately adjacent to the lake, salt incrustations occur in quantities of equally doubtful economic value. Other major occurrences of alkali deposits in Lake County are known from Abert and Alkali Lakes, with Alkali Lake the most promising. Abert and Summer Lakes contain nearly equal quantities of dissolved salts and surface incrustations, but are of doubtful value primarily because of the low prospective tonnage, seasonal exposure of surface salts, distance from market, and the lack of local fuel.

From time to time numerous analyses have been made of Summer Lake water in connection with plans for soda recovery. One of the first references to such an analysis was published by Chatard in 1890 (12, p. 51). This article served to draw attention to the Oregon lakes and in 1901, 1902, and 1911 analyses were run for various investors. Van Winkle (48, p. 119) also analyzed the water in 1912 and compiled all the previous analyses. The most recent analysis is that of Allison and Mason (3, p. 2) which is embodied in the latest report on the sodium salts of Summer Lake. Much of the material embodied in this report has been taken liberally from their account. As a result of their study, it was found that the lake water would be an unlikely source of soda because of its low salinity. Of the surface salts exposed on the Summer Lake playa, sodium carbonate predominates, but in quantities of doubtful economic value.

Allison and Mason (3, p. 3) report the following analysis of Summer Lake efflorescence salts:

Analysis of Salts from Summer Lake Playa

(in percentages by weight)

	1	2
Na_2CO_3	70.80	35.54
$NaHCO_3$	9.45	5.01
NaCl	12.12	6.43
Na_2SO_4	7.83	4.15
K_2SO_4	1.64	.87
Water of crystallization	-----	46.00a/
Total	101.84	100.00

a/ By difference.

1. Composite of 3 samples averaging 54 per cent soluble salts (in anhydrous state), taken September 1944. Analysis by L. L. Hoagland, State of Oregon Dept. of Geology and Mineral Industries.

2. Same, recalculated to percentages of original composite sample.

Of the subsurface samples studied, Allison and Mason (3, p. 4) report all the lake muds to carry at least 1% (hydrous) soluble salts with the content ranging from 7% (anhydrous state) in the upper 6 inches downward to 2% or less at a depth of 7 feet.

Allison and Mason (3, p. 2) list 4 separate analyses of water of the lake. Of the analyses, numbers 1, 2, and 3 represent recalculated values from analyses of Summer Lake water previously published by Van Winkle (48, pp. 119-120), while the fourth was analyzed by the Oregon State Department of Geology and Mineral Industries in 1944. Their chart is as follows:

Analyses of Summer Lake Waters

(grams per kilogram)

	1	2	3	4
Na_2CO_3	23.48[a]	14.67	8.01	12.43
$NaHCO_3$		6.77[b]	3.81[b]	5.03[b]
NaCl	9.27	8.33	4.58	8.84
Na_2SO_4	2.15	1.82	1.03	1.69
KCl	1.38	1.07	.51	.68[c]
NO_3	n.d.	n.d.	trace	n.d.
SiO_2	.27	.29	.10	.23
Ca, Mg, Fe			trace	n.d.
Al			.02	n.d.
Total dissolved solids	36.55	32.95	18.06	28.90

[a] Total carbonates as Na_2CO_3

[b] By difference

[c] K_2SO_4 instead of KCl

CONCLUSIONS

The Summer Lake basin is a well defined fault block depression bounded on the west by the fault line scarp, Winter Ridge. The fault bounding the east side of the basin is lower and less pronounced.

At least two distinct pluvial lakes occupied the Summer Lake basin. These former deep water lakes were named "Lake Chewaucan" and "Winter Lake" by Allison (1, p. 793). The correlation of shore line features formed by these lakes with corresponding sediments of the Ana River section seems improbable.

The Ana River section exposes for study 54 feet of lake sediments. The sediments are predominantly silt-sized, with the 1/32 mm to 1/64 mm size dominant. Intercalated sand, pebbles, oolites, and caliche record changing levels of the lake. Pumice and ash layers occur throughout the section, the layers near the top being the thickest. Several eruptions of Mount Mazama and Newberry Crater are recorded by these pumice layers.

The sediments of the Ana River section contain about 15% included ash, but the main source of the detritus was the weathering of the basalt which comprises most of the rocks of the drainage basin. The mineral variety is not great and represents an unstable assemblage.

Ostracod, pelecypod, and gastropod shells were found in the section. The ostracod shells are the most abundant and occur in nearly every layer from the top to the bottom of the section. The ostracod shells are more abundant in the sandy layers than in the silty layers. The shells are of no use for dating the Ana River section. A few diatom tests are found in the volcanic ash and fine-grained sediments of the Ana River section.

The top of the section is about 6,000 years old.

BIBLIOGRAPHY

1. Allison, Ira S. Pumice beds at Summer Lake, Oregon. Bulletin of the geological society of America 56:789-808. 1945.

2. ______ Early man in Oregon; pluvial lakes and pumice. Scientific monthly 62:63-65. 1946.

3. ______ and Ralph S. Mason. Sodium salts of Lake County, Oregon. State of Oregon department of geology and mineral industries short paper no. 17, 1-12. 1947.

4. ______ Personal communication.

5. Antevs, Ernst. On the pleistocene history of the Great Basin. Carnegie institution of Washington publication 352:51-114. 1925.

6. ______ Postpluvial climatic variations in the Southwest. Bulletin of the American meteorological society 19:190-193. 1938.

7. ______ Climatic variations in the Southwest during the past 75,000 years (abstract). Pan American geologist 75:73-76. 1941.

8. ______ Regarding J. C. Jones' rate for Lake Lahontan. American Antiquity 10:p. 211. 1944.

9. Blackwelder, Eliot. Pleistocene lakes of the Basin Range Province (abstract). Bulletin of the geological society of America 42:313. 1931.

10. ______ The Great Basin with emphasis on glacial and postglacial times; the geological background. University of Utah biological series 10:no. 7:1-16. 1948.

11. ______ Pleistocene glaciation in the Sierra Nevada and Basin ranges. Bulletin of the geological society of America 42:865-922. 1931.

12. Chatard, Thomas M. Natural soda, its occurrences and utilization. United States geological survey bulletin 60:27-101. 1890.

13. Cressman, Luther S. Studies on early man in the northern Great Basin. Carnegie institution of Washington yearbook 39:300-306. 1940.

14. ______ Archaeological researches in the northern great Basin. Carnegie institution of Washington publication 538:1-155. 1942.

15. Cressman, Luther S. Results of recent archaeological research in the northern Great Basin region of south central Oregon. Proceedings of the American philosophical society 86:no. 2:236-246. 1943.

16. Dole, Hollis M. Petrography of the Quaternary lake sediments of northern Lake County, Oregon. Oregon State College, master's thesis. 1942. 98 p.

17. Fenneman, Nevin M. Physiography of western United States. New York, McGraw-Hill, 1931. 534 p.

18. Gilbert, Grove K. Report upon the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872; the Basin Range system. United States geographical and geological surveys west of the one hundredth meridian 3:21-42. 1875.

19. ______ Contributions to the history of Lake Bonneville. United States geological survey second annual report 2:169-200. 1881.

20. ______ Lake Bonneville. United States geological survey monograph 1. 1890. 438 p.

21. Grout, Frank F. Petrography and petrology. New York, McGraw-Hill, 1932. 522 p.

22. Hanna, G. Dallas, Fresh water mollusks from Oregon. University of Oregon publication 1:no. 12:1-15. 1922.

23. Hansen, Henry P. Post-Mount Mazama forest succession on the east slope of the central Cascades of Oregon. American midland naturalist 27:523-534. 1942.

24. ______ Postglacial vegetation in the northern Great Basin. American journal of botany 34:no. 3:164-171. 1947.

25. ______ Chronology of postglacial volcanic activity in Oregon and Washington (abstract). Bulletin of the geological society of America 58:no. 12:1252. 1947.

26. Hay, Oliver P. The Pleistocene of the western region of North America and its vertebrated animals. Carnegie institution of Washington publication 322-B:1-267. 1927.

27. Hubbs, Carl L. and Robert R. Miller. The Great Basin with emphasis on glacial and postglacial times; the zoological evidence. University of Utah biological series 10:no. 7:21-156. 1948.

28. Huntington, Ellsworth. The climatic factor as illustrated in arid America. Carnegie institution of Washington publication 192:1-341. 1914.

29. Jones, J. Claude. The geologic history of Lake Lahontan. Carnegie institution of Washington publication 352:3-49. 1925.

30. King, Clarence. United States geological exploration of the 40th parallel 3:451-473. 1870.

31. Krumbein, W. C. and F. J. Pettijohn. Manual of sedimentary petrography. New York, Appleton-Century, 1938. 549.p.

32. Louderback, George D. Basin range structure in the Great Basin. University of California publications in geological sciences, 14:no. 10:329-376. 1923.

33. ——— Period of scarp production in the Great Basin. University of California publication in geological sciences 15:1-40. 1924.

34. Lowry, W. D. and E. M. Baldwin. Late cenozoic geology of the lower Columbia River valley, Oregon and Washington. Bulletin of the geologic society of America 63:541-522. 1922.

35. Meinzer, Oscar E. Map of Pleistocene lakes of the Basin-and-Range province and its significance. Bulletin of the geological society of America 33:541-552. 1922.

36. Moore, Bernard N. Deposits of possible Nuée ardente origin. Journal of geology 42:358-375. 1934.

37. Murray, John and Robert Irvine. On silica and the siliceous remains of organisms in modern seas. Proclamation of the royal society of Edinburg 18:229-251. 1891.

38. Nolan, Thomas B. The Basin-and-Range province in Utah, Nevada, and California. United States geological survey professional paper 197-D:151-196. 1943.

39. Piper, Clarence S. Soil and plant analysis. New York, Interscience publishers, 1944. 368 p.

40. Russell, Isreal C. A geological reconnaissance in southern Oregon. United States geological survey, 4th annual report 431-464. 1884.

41. ——— Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada. United States geological survey monograph 11. 1885. 288 p.

42. Sipe, F. P. Physical and economic geography of Oregon; flora of Oregon. Salem, Oregon state board of higher education, 1940. 319 p.

43. Smith, Warren D. Physical and economic geography of Oregon; the southeastern lake province. Salem, Oregon state board of higher education, 1940. 319 p.

44. Taliaferro, Nicholas L. The relation of volcanism to diatomaceous and associated siliceous sediments. University of California publications department of geological sciences, bulletin 23:no. 1:1-56. 1936.

45. Thayer, Thomas P. Geology of the Salem Hills and the north Santiam river basin, Oregon. State of Oregon department of geology and mineral industries bulletin 15:20-26. 1939.

46. Tickell, Frederick G. The examination of fragmental rocks. Stanford, California, Stanford University press, 1931. 154 p.

47. Trewartha, Glenn T. An introduction to weather and climate. New York, McGraw-Hill, 1943. 545 p.

48. Van Winkle, Walton. Quality of the surface waters of Oregon. United States geological survey water supply paper 363:7-133. 1914.

49. Waring, Gerald A. Geology and water resources of a portion of south central Oregon. United States geological survey water supply paper 220:1-86. 1908.

50. Williams Howel. The geology of Crater Lake national park; with a reconnaissance of the Cascade range southward to mount Shasta. Carnegie institution of Washington publication 540: 1-159. 1942.