AN ABSTRACT OF THE THESIS OF

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Title PETROGRAPHY OF QUATERNARY LAKE SEDIMENTS OF NORTHERN LAKE COUNTY, OREGON

Abstract Approved: ____________________
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Lake sediments of Quaternary age from the Fort Rock-Christmas Lake-Fossil Lake basin of northern Lake County, Oregon obtained from trenches and pits dug in the basin floor have been subjected to petrographic analysis.

On the basis of the degree of compaction and size of particle, the sediments were divided into two classes: the lower, silty, more compa ct beds and the upper, loose, sandy beds. In general, the size medians of the lower beds are of silt size, and the size medians of the upper beds are of fine and very fine sand sizes. The size of particle of the beds indicates that the lower beds have been deposited in a comparatively deep lake, and the more sandy beds in a rather shallow lake. Well-developed beach ridges at elevations of 4470 and 4520 feet establish the lake level in which much of the lower silts were deposited as 150-200 feet above the present level of the basin floor and the small structures in the sandy beds indicate that the loose beds were deposited in water but a few feet deep.

The materials that make up the sediments are mineral grains, volcanic glass (varying from minute glass shards to pebbles of pumice 3½ inches in diameter), fossils, basalt fragments, and fragments composed of the underlying lake silts.

Plagioclase feldspars were the most common mineral grains, and there were lesser amounts of pyroxene, magnetite, and hornblende. Biotite was found in six samples.

The large amounts of glass in the sediments suggest that volcanic ash and pumice have been the principal source of the materials. From the similarity of the mineral grains of the sediments to the mineral grains of the pumice found as layers in the sediments and the similarity of the pumice of the layers to pumice from a definite Crater Lake source, it is suggested that the source of most of the pumice and

ash has been from Mt. Mazama.

The fossils found in the sediments are diatoms and bird, fish, and mammal bones, and ostracods, pelecypods, and gastropod shells. The diatoms make up large percentages of the lower beds and smaller percentages of the upper beds. The main mammal bone horizon was established as a thin zone lying near the base of the sandy beds by the finding of large bones in place, thus indicating that the lake was much reduced in size when the bones were deposited in the sediments. The ostracod and mollusk shells are found in the upper sandy beds. The pelecypod was identified as belonging to the genus of *Pisidium* and the gastropods as belonging to *Carinifex*, *Planorbis*, and *Lymnaea*.

PETROGRAPHY OF QUATERNARY LAKE SEDIMENTS OF NORTHERN LAKE COUNTY, OREGON

by

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INTRODUCTION

Geographical Relations

The sediments described in this thesis were taken from the Fort Rock-Christmas Lake-Fossil Lake-Silver Lake basin of northern Lake County, Oregon. The basin is approximately forty-five miles wide in its greatest east-west width, and twenty-seven miles long in its greatest north-south length. The area lies roughly between latitudes 43°00' and 43°30', and longitudes 121°10' and 120°20', and is in the north-western part of the Basin-and-Range Province of the western United States, and in the part of Central Oregon that is often referred to as the "low desert" country.

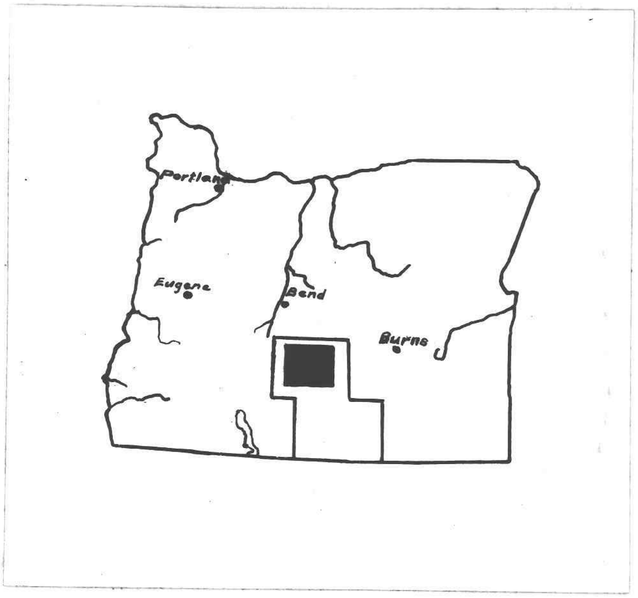


Fig. 1. Oregon - Lake County outlined. Area covered by map shown in black.

Silver Lake, (population 97, 1940 census), in the southwestern part, is the only incorporated town within the basin. Fort Rock, in the northwest, and Lake, near the south central part, are post offices serving the settlers of the region.

Fort Rock is sixty-seven miles by highway south-southwest of Bend, Oregon, and 116 miles by highway north-northwest of Lakeview, Oregon, the seat of Lake County.

PURPOSE OF STUDY

This area is of interest geologically because during the Quaternary when the climate was more humid than at present, a large inland lake occupied the basin. Evidence of this large lake is shown in beach ridges more than 200 feet above the basin floor, wave-cut benches high on the sides of the hills, wave-formed caves which were later occupied by early man, and fresh-water mollusks, arthropods, and diatoms in the sediments. The paleontologist is interested in this area because of the rich vertebrate fauna that comes from Fossil Lake.

It was only natural that the sediments of the former lake should be examined to see what information they could give as to its history. This thesis is the result of such a study.

GENERAL SETTING OF THE BASIN

Geology

Types and Ages of Rocks

The rocks that compose the hills and mountains within the basin and the area bordering the basin are all of volcanic origin. The rocks can be roughly divided into pyroclastics, basalts, and rhyolites, and they range in age from perhaps middle Tertiary to Recent.

Pyroclastics

On his approximate geologic cross-sections Waring (1) has shown pyroclastics to underlie most of the western, central, and southern parts of Christmas Lake Valley. They outcrop to form the northern part of Pine Ridge, at the eastern part of the basin, Seven Mile Ridge at the southern end of Christmas Lake Valley, and Fort Rock near the postoffice of that name. They are also found under a basalt capping in several of the buttes, most noticeable of which is the mass underlying Table Rock. The pyroclastics are a tawny, rather firmly cemented material, consisting of effusive rocks and volcanic cinders. They

1. Waring, G. A., Geology and Water Resources of a Portion of South-Central Oregon; U. S. Geological Survey Water Supply Paper #220, Diagrams G and H, p. 66, 1908.

probably belong to the same general period of eruption as the basalts which are found overlying them.

Basalts

The basalts are by far the most extensive of the materials; they occur on all sides of the basin, within the basin and at least as part of the basement rocks. They may be divided into three age groups. The oldest of these are the flows that are probably equivalent to the Columbia River Lavas of Miocene age. These rocks form most of the fault blocks surrounding the basin and the basalts of the basement rocks. The basalts of Table Rock and the older flows in the northeast also probably belong in this group. The second group comprises the basalts that are younger than the Miocene flows and older than the lake sediments. Hayes Butte and the remainder of the Connley Hills, the Black Hills, Green Mountain, and the other fairly well dissected cones to the north belong in this second group. The third group of basalts is younger than the lake sediments (or partly contemporaneous) and includes the lava flows in the northern part of Fort Rock Valley between Menkenmaier Well and Cougar Mountain, the four small volcanic cones to the east of Green Mountain, and probably Lava Mountain. The flows in the northern part of Fort Rock Valley are younger than the lake sediments because there are no lake sediments on the flows and it is reported that a well drilled several miles from the edge of these lavas struck lake silts under the basalts. As this lava is partly covered by pumice and the lavas of the small cones to the east of Green Mountain are not, it is thought the latter are probably still younger and that they represent an eruption perhaps not more than several hundred years old. All lavas of this last group show young features such as pressure ridges, blisters, blocks, ropy lava, and a very rough surface.

Rhyolites

The third class of rocks, rhyolites, is found only on the northern edge of the basin. Cougar Mountain is composed principally of rhyolite and associated obsidian flows. Rhyolites are also found in the Newberry Crater area.

Structure

The many fault blocks to the south, east, and west of the basin indicate that faulting has been a dominant factor in the orographic development of the area and perhaps in the formation of the basin itself.

In general the strike of these blocks is north-south and their dips are to the east or west. Some blocks rise hundreds of feet above the basin floor and are continuous for several miles. At their bases are fairly large slopes of talus. These fault blocks are typical of the Basin Range structure and presumably the faulting that has produced them took place at nearly the same time as the faulting in the other parts of the Great Basin. Louderback (1) in speaking of the block faulting in the western part of the Great Basin, states that "the evidence in hand points to a later Pliocene or post-Pliocene time for the beginning of the faulting. The greater part of the deformation was completed before the late Pleistocene, and while movements have taken place at intervals up to within a few years, the Recent displacements are only a small fraction of the total."

The long scarp, Pine Ridge, on the east side of Christmas Lake Valley suggests that at least the eastern side of Christmas Lake basin and perhaps the whole basin might be a down-faulted block. The scarps that border the east and west side of Silver Lake suggest that the Silver Lake portion of the basin occupies a graben. Waring (2) however, attributes most of the scarps bordering Silver Lake and to the south of Christmas Lake Valley to weathering rather than to faulting. He gives a tentative description of the

1. Louderback, G. D., Period of Scarp Production in the Great Basin; Univ. Calif. Pub. in Geol. Sci., vol. 15, p. 38, 1924.
2. Waring, G. A., Geology and Water Resources of a Portion of South-Central Oregon; U. S. Geological Survey Water Supply Paper #220, p. 27, 1908.

structure of the area in this manner: "There is a major anticline running from Silver Lake to Goose Lake...The anticline is plunging northward and forms the southern boundary of Silver Lake basin....There is a cross-anticline separating Summer Lake Basin from Christmas Lake basin." This would mean, then, that the Silver Lake and perhaps the Fort Rock parts of the basin occupy the downwarped end of a major anticline and that the central and western parts of Christmas Lake Valley and the eastern part of Fort Rock Valley occupy the downwarped sides of the cross-anticline separating Summer Lake basin from Christmas Lake basin.

It is noteworthy that the forces that produced the escarpments died out northward, for the long, narrow orographic blocks that are conspicuous on the southern, eastern, and western horizons are not as noticeable to the north.

Topography

Bordering the Basin

Fault blocks and volcanic cones are the striking features of the topography of the country surrounding the Fort Rock-Christmas Lake-Fossil Lake-Silver Lake Basin. Fault blocks dominate the southern, western, and eastern margins of the basin but are less prominent to the north where volcanic cones are the outstanding features.

Silver Lake basin is bordered on three sides by scarps. Winter Ridge, a long sloping block to the west with minor fault and erosional scarps, forms the southern boundary. The western boundary is determined by small blocks. The eastern edge is a high scarp behind which are several blocks that form the southern boundary of the Christmas Lake-Fossil Lake basin. The eastern boundary of the Fossil Lake basin is the westward facing escarpment of Pine Ridge.

Bounding the northern part of the basin are several fairly large volcanic cones and many smaller ones. Perhaps the largest of these are the Paulina Mountains which form the southwest wall of Newberry Crater and are about fifteen miles north of the basin. To the east of Newberry Crater and clearly visible on the skyline are East Butte and China Hat. Other cones of considerable size and directly bordering the basin are Cougar Mountain, Lava Mountain, and Green

Mountain. Besides these larger mountains, there are many smaller unnamed volcanic buttes. Notable among these are the four very symmetrical cones that lie in a north-north-west line just east of Green Mountain and to the north of Alkali Flat, and, at the northwest corner of the basin a crater approximately one-half mile in diameter and several hundred feet deep, named Hole-in-the-Ground. Various degrees of dissection are exhibited by these cones and they must consequently represent several different episodes of intense vulcanism.

Within the Basin

The Connley Hills, a group of hills arranged in a general north-northwest line in the southwestern part of the basin, separate Silver Lake Valley from Fort Rock and Christmas Lake Valleys. Table Rock, a prominent landmark, is a basalt capped butte at the southern end of the Connley Hills. North of Table Rock is Hayes Butte, a dissected volcano, and, forming the northern end of the Connley Hills, are a group of unnamed hills of volcanic origin. To the west of the latter are the Black Hills, the dissected remains of a volcanic cone. About six miles north of, and in direct line with, the Connley Hills is Fort Rock, a horseshoe shaped mass open to the south that rises 324 feet from the basin floor with perpendicular walls over 200 feet above its talus slopes. Notched into its open ends 100 feet above the floor of the valley is a wave-cut bench about twenty feet wide. This bench cuts across the dip of the material making up the mass, so there can be little question that it was wave-formed. In the northeast corner of the basin is another landmark called Bunch Grass Butte. Besides these buttes within the basin there are several ridges of volcanics protruding from the surrounding hills.

On the sides of these hills there are some well-developed wave-cut benches and beaches. These are especially noticeable on the Connley Hills, and as already mentioned, Fort Rock, and they are less noticeable on Bunch Grass Butte.

As can be seen from the elevations on the map, the basin floor proper as a whole is very flat. Level lines were run for miles with a change of elevation of only a few feet. On the basin floor the minor topographic features are mainly the result of the work of the winds. At the east end of Fossil Lake is a field of moving sand dunes more than six miles long and two miles wide. Their steep sides face east and their gentler sides slope to the west, indicating prevailing winds from the west. Individual dunes reach a height of more than twenty feet. The wind has caused the dunes to creep up over Pine Ridge for a distance of three miles or more. Besides this field of dunes there are many dune ridges in the basin composed mainly of pumice and soil blown off the fields when the land was cleared for cultivation.

The wind has excavated depressions to a depth of forty-five feet and up to one-half mile in length at various places in the basin floor. These are called "sinks" or "blow-holes" by the settlers of the valley. In the area near the base of the east side of Table Rock near Thorn Lake careful measurements were made in two of them. One was a hole twenty-two feet deep excavated in the lake beds, which we named Arrow Sink; the other, a hole forty-five feet deep, named Four Mile Sink. On both there was a ridge of excavated material on the leeward rim. The measurements indicated the beds had not been disturbed and in no way would it have been possible for water or other agents to have carved them.

At Fossil Lake proper, small hillocks stand above the floor of the lake eight feet and more. These are "residuals" of lake beds that have been preserved in part by their sagebrush capping. In the dune area the hillocks are more numerous and in a better state of preservation. Some of the hillocks stick through the sides of sand dunes and it is thought likely that burial by dunes has been an important factor in their preservation.

Playas are common features within the basin. They vary in size from a few square feet to several acres. Most of them have very smooth surfaces but some of them, as Alkali Flat, have a rough, hard top. This is due to the higher percentage of minerals in the water that drains into these minor basins and is subsequently precipitated to form a crust.

One of the most interesting topographic features of the basin is the set of "fossil" or ancient shore-lines and beach-ridges. At some places they are plainly visible, but at others they are picked out only with great difficulty. In the latter event aerial photographs of the area were invaluable as they reveal ridgings where the eye could scarcely detect them. These were then proved to be beaches by their waterworn pebbles and cobbles. The best developed beaches were found on the east and south sides of the basin and at mouths of certain canyons and draws. Their formation at these places can be attributed to two factors: strong wave action, and an abundant supply of detritus. As has been pointed out in describing the sand dunes, the prevailing winds are usually from the west. The east side of the basin, then, was subject to strong and steady wave-action due to the wind sweeping over the broad open space of the lake. The eastern edge of the basin is a fault scarp and the material weathered from the face furnished an adequate supply of material. The wind direction, however, is not always from the west as shown by the distribution of the pumice around Newberry Crater, which came from the northwest. The beaches to the south have been formed by waves evidently caused by northwest or northerly winds. The well-developed beaches in the canyons and draws owe their formation to the second factor (available material) more than to the first. During the spring of the year when the snows are melting the streams are swollen and carry heavy loads. Such streams contributed adequate amounts of material out of which the lake formed prominent beaches.

For exactly the same reasons, there are poorly developed beaches on the western side of the basin and on the back slopes of the fault blocks. The less strong wave-action on the west side accounts for the absence of the well-formed beach ridges so noticeable on the east side. The gentle back slopes of the fault blocks are particularly unfavorable for beach development as any slight change in the water level would cause the margin of the lake to fluctuate laterally over a long distance, thus destroying any concentration of wave energy. It would also be difficult for the waves to obtain sufficient material from these gentle slopes to work into beach ridges.

The two beaches that occur at elevations of about 4470 feet and 4520 feet are better developed and more easily recognized than the others, and they represent two periods when the lake must have stood at these levels for long periods of time. The 4520 foot beach marks the highest limit at which a beach was found and probably marks the upper limit of the lake that occupied the basin. There were many other beach ridges lower in the basin but they were not as continuous or as well developed as the first two. These lower ridgings presumably mark comparatively static stages of the lake as it was slowly receding.

The valleys of Fort Rock, Christmas Lake, Fossil Lake, and Silver Lake were occupied by the same lake at the time the high beaches were formed for the elevations of the beaches exceeded that of the barriers now separating the valleys. The Connley Hills, Fort Rock, and Bunch Grass Butte were islands within the lake. At the present time, Silver Lake is a nearly closed basin, separated from the others by the Connley Hills and the Black Hills, except in times of heavy rainfall when water from Silver Lake overflows northeastward to Thorn Lake and Christmas Lake Valley. Fort Rock Valley is separated from Christmas Lake and Fossil Lake Valleys by a low level gap approximately 3 miles wide between Seven Mile Ridge to the south and lava cliffs to the north. Fossil Lake and Christmas Lake are playas in the eastern part of the basin.

Drainage

The drainage area of the Fort Rock-Christmas Lake-Fossil Lake-Silver Lake basin is limited to the hills immediately bordering the basin. There are only three permanent streams that drain into the basin and they are all in the southwest. Water entering the basin either evaporates or sinks underground.

The three streams that drain into the basin are Buck Creek, Bridge Creek, and Silver Creek. Buck Creek and Bridge Creek have their heads at the northern and northeastern slopes of Yamsay Mountain and Silver Creek receives its water from the eastern slopes of Yamsay Mountain and from Thompson reservoir at the southwestern base of Hager Mountain. U. S. Geological Survey Water Supply records available for Silver Creek, the largest of the streams, show an average discharge per month over twenty-seven years of 26.0 second feet. These three streams discharge into Paulina Marsh which overflows into Silver Lake proper. Peter Creek and Walker Creek in the northern part of Christmas Lake Valley are the nearest approaches to living streams in this valley but even in the spring they usually flow no farther south than their "sinks". In Fort Rock Valley there are no perennial streams but as in the rest of the basin many short intermittent watercourses come down to its edge.

Recent Status of Lakes

At the present time water does not stand anywhere in the basin the year around. However, Silver Lake, Fossil Lake, Christmas Lake, and Thorn Lake have been persistent lakes several times since the early settlers first came.

The available records (1) show that in 1879 Silver Lake was only four feet deep and Thorn Lake was dry. In June of 1882 Silver Lake was ten feet deep and was confluent with Thorn Lake. In 1889 it dried up and sagebrush found on the lake bottom showed that it must have been dry sometime before the arrival of the first settlers in 1868. This period is thought by Antevs to have been during the dry period of the 1840's. The following season (1890) Silver Lake and Thorn Lake were filled, and water overflowed into Christmas Lake Valley. In the springs of 1904 and 1905 Silver Lake and Thorn Lake were again connected by water. In 1915 the greatest depth of Silver Lake was four feet and its average depth was two feet. In March of that year Thorn Lake was a small pond. From 1918 to the present time these lakes have been dry every summer and lately most of the whole year.

The records for Fossil Lake and Christmas Lake are not as complete as those of Silver Lake, but it is likely that

1. Antevs, E., Rainfall and Tree Growth; joint publ. Carnegie Institution Wash., and Amer. Geog. Soc., pp. 1-18, 1938.

the stages of these lakes corresponded somewhat to the fluctuations of Silver Lake. Both have been dry about thirty years.

THE SEDIMENTS OF THE BASIN FLOOR

Sources of Samples

The samples of the sediments which were taken for study are mainly from the Fort Rock-Christmas Lake-Fossil Lake portions of the area. Most of the samples are from the immediate vicinity of Fossil Lake proper, in the eastern part of the area, and from a locality just east of the base of Table Rock in the southwestern part of Christmas Lake Valley. The remainder of the samples were taken at scattered places, two only from Silver Lake basin. They represent the sediments primarily of the lake bottom; coarse beach gravels and other shore phases are not included as they did not appear to offer much useful data.

At Fossil Lake a total of nine pits and trenches were dug and twenty-eight samples from five pits and one sample from the modern dune sands were taken. The five pits from which the samples were taken will be referred to by name throughout the thesis, therefore their general locations will be given. From east to west they are: Dune Pit (I on map), an eight-foot pit in the lake beds in the western part of the sand dune area and about two miles east of modern Fossil Lake; Fish Bone Site Pit (II on map), a three-foot pit on the southeastern edge of the modern playa; Bird Bone Site Pit (III on map), a seven and one-half foot pit about two hundred yards north of Fish Bone Site pit, still on the edge of the playa; Elephant Site Pit (IV on map), a one-foot pit about one-half mile west of the playa; Southwest Pit (V on map), a five-foot pit on the southwest rim of the wind excavated area a little over 200 yards southwest of Elephant Site.

The deepest sections studied were at the area near the northeastern base of Table Rock, where the wind had excavated depressions to a depth that would have been impossible to reach with the hand tools available. Three "blow-outs" were carefully examined and twenty-three samples were taken from two of them. The two "blow-outs" sampled for convenience were named Arrow Sink and Four-Mile Sink. Arrow Sink (IX on map), is about one mile east of the Arrow Gap road sign post that is halfway (six miles) between the Poplars Ranch and the Fremont Highway and Four-Mile Sink (X on map), is about four miles east of the sign post.

Pits were dug in two playa lakes. One of these was in Alkali Flat (VII on map), which is located in the north end of Christmas Lake Valley and is probably part of Christmas Lake during wet seasons. The other, termed Race Track Flat (XIII on map), because of its very smooth top, is four miles southeast of Fort Rock on the Fort Rock-Poplars Ranch "short-cut" road.

The two samples taken from the Silver Lake basin were from a sand and gravel pit two and one-fourth miles northwest of the Silver Lake post office on the Silver Lake-Fort Rock road (XIV on map).

The locations of the remaining samples were not chosen for any specific reason.

In all, seventy-eight samples were taken from thirteen pits and trenches. In addition, ten other pits were dug but not sampled.

The locations of the pits are shown on the map by Roman numerals corresponding to the numbers of the pits.

Method of Sampling

Several methods were used to get good cross-sections of the beds and make them available for observation, measurement, and sampling. Perhaps the simplest method was trenching. This was used on exposed faces such as the deep wind depressions, hillocks, and the small terraces found bordering the shallow wind blown depressions. Where no faces were exposed, pits were dug so that at least one wall was vertical and the length was enough to give good exposures of the beds. After the beds had been carefully measured, studied, and photographed, samples were cut out of the smoothed sides. A soil auger was used at the bottom of several pits to see if there was any change in the lower beds, but samples from its cuttings were never kept. Three samples

(#69, #70, #71, location X and XI) were obtained from well dumps.

Detailed sections of eleven of the pits are given on the following pages.

SECTION AT DUNE PIT

(I on map)

	Ft.	In.
White lake bed capping......................		6-9
Grayish-brown sand with long cross-bedding, sample #11...................	2	5
Wavy bedded sands and silts................	1	
White ash, sample #10......................		2
Loose mixed gray and brown sands (undercuts). Pieces of basalt up to 3/4" in size, sample #9.........	2	7
--------Bottom of hillock and beginning of pit----------		
A fine lake bed breccia. Tough, resists wind, sample #8......................	1	1
Gray sand, no basalt fragments, sample #7..		5
Compact silty sand with lake bed granules sample #6..............................	1	3
Disturbed sand layers with many lake bed granules, sample #5...............		2
Lake bed breccia, sample #4................		6
Dark gray sand, sample #3..................		1½
Sandy silt.................................		6
Granule lake bed breccia, sample #2........	1	9
Compact silt, sample #1....................	1	10+
	14	6½

SECTION AT FISH BONE SITE PIT

(II on map)

	Ft.	In.
Cream to white silt cover..................		6
Dark gray to black fine sandy layer. Two layers of 3" each, upper one minutely cross-bedded. Many fish bones found here, sample #13..........		6
Sand with many grains of lake beds, sample #14............................		4
Tough buff to brown compact lake bed, sample #15............................	2	+
	3	4

SECTION AT BIRD BONE PIT

(III on map)

	Ft.	In.
White silt capping...........................		5
Thin bedded dark gray sand; bedding from light and dark colored sands. Root holes and some secondary clay, sample #16......................		9
Wavy band of clayey silt......................		½
Sand (like above)............................		2
Silty sand, yellow when moist. Nests and irregular masses of clay at top, sample #17...............		8
Yellowish compact silty sand. Forms bench, sample #18...............	1	10½
Gray sand with numerous mollusk shells; many small pebbles of lake beds, sample #19............................		8
Sand with pebbles of rock and lake beds, sample #20............................	1	
Compact silty sand; part break in flakes, part with network of mineral infiltration. Many mollusk shells....	2	3/
	7	10

SECTION AT ELEPHANT SITE PIT

(IV on map)

	Ft.	In.
Porous spongy lake bed with many mollusk shells, sample #22............		10
Yellowish-white massive-appearing lake bed, sample #23..................		4
	1	2

SECTION AT SOUTHWEST PIT

(V on map)

	Ft.	In.
Soil and sand on slope....................		9
Nearly white pumice sand, sample #24.......		2
Gray mixed sand, sample #25................		3
Mixed gray and pumice sand, partly segregated............................		6
White pumice sand, fairly even.............		2½
Alternating layers, partly crossbedded, pumice and dark sands, sample #26.....	1	3
Crossbedded mixed sands, some silt, pebbles (some well rounded). Bone fragments - fish and birds in zone 3-7 inches thick................		
------------------uneven contact----------		
Zone of disturbed beds of sands and small rounded granules of lakebeds, fishbone fragments. Fossil bone horizon, sample #27..................	1	11
Layer of pebbles, mostly lakebeds, sample #28............................		3
Coffee-brown, moist sandy silt. Penetrated 61" at bottom of trench with auger - no perceptible change in material..........................	6	2+
	11	5½

SECTION AT PIT TWO MILES NORTH OF LAKE P.O.

(VI on map)

	Ft.	In.
Loose pebbly sand, sample #34..............		3
Sand, somewhat cemented with caliche, sample #33............................	1	1
Flaky silt lake beds, sample #32...........	1	2½
Sandrock layer, sample #31.................		2½
Concretionary sandy lakebeds, sample #30...	1	10+
	4	7

SECTION AT ALKALI FLAT PIT

(VII on map)

	Ft.	In.
Irregular alkali crust, sample #35.........		1+
Mineralized silty clay, sample #36.........		6
Sandy silt with granules of lakebeds, slightly mineralized, sample #37......	1	10
Dark sand with pebbles of basalt and lakebeds, sample #38..................		6
Yellow sandy silt, top wet and sticky, sample #39...........................	1	3
Sandy silt, blue when wet, white when dry, sample #40......................		10
Hard, platy sandrock layer. Blue when moist, gray when dry, sample #41......		8
Flaky silt. Blue when moist, yellow when dry. Penetrated 15" in bottom of pit with auger. No visible change in cuttings. Water at bottom, sample #42.........................	4	+
	9	8

SECTION AT PIT WEST OF ZX (Sprague) WELL

(VIII on map)

	Ft.	In.
Loose sand................................		$1\frac{1}{2}$
Porous silty sand, spongy texture..........		$3\frac{1}{2}$
Hardpan of cemented pebbly sand, sample #42	2	3
Light gray sand with many sand size particles of lakebeds, sample #44.....	1	4
Gravel of lakebeds and dark grains, in beds about 1 inch, alternating. Very hard, sample #45.................		6+
	4	6

SECTION AT FAN ON WEST SIDE OF ARROW SINK

(IX on map)

	Ft.	In.
Sand, dust, roots, and organic matter sample #46	3	
Pebble pumice (none present 300' to southeast on edge of "sink") sample #47	2	2½
Pumice sand		½
Silt		1
Pumice sand		1
Silt		3½
Coarse pumice sand, sample #48		2¼
Silt		1½
Black volcanic cinders, sample #49		1½
Silt		3/4
Sand		¼
Silt		½
Sand		½
Laminated lakebeds		1¼
Sand		¼
Uniform lakebeds (same as top lakebed of main section at Arrow Sink)		5¼
	6	11

MAIN SECTION AT SOUTH SIDE OF ARROW SINK

(IX on map)

	Ft.	In.
Sandy zone, sample #51......................	8	
Laminated zone............................	2	2½
White colored lakebed, sample #53..........	1	9½
Sandy seam, sample #54.....................		1½
White colored lakebed......................	1	9½
Dark gray sandy seam, sample #55...........		1½
White colored lakebed, sample #56..........	3	10
Dark brown, when moist, lake bed, sample #57		4½
Yellow colored lakebed, sample #58.........	3	3½
Pebble pumice, sample #59..................	1	3½
Lakebed silicified to hard rock, sample #60		5
Top of lower bed grading into sand, sample #61............................		7
Cream colored lakebed, sample #62..........	6	3
Pebble and granule pumice and basalt sample #63............................	1	
White colored lakebed, sample #64..........		5+
	31	6

SECTION AT RACE TRACK FLAT PIT

(XIII on map)

Minutely (1" or less) sun-cracked, thin white cap, sample #73.................		1/16-1/4
Coarsely cracked (1"+) silt layer, sample #74............................		1 3/4
Tough clay with some sand and occasional pieces of rock, sample #75............	2	6
Gravel and sand, pebbles mostly less than 1", much of it "shot gravel". Pumice granules fairly abundant at 49", sample #76............................	1	8
	4	4

General Features

On the basis of the degree of compaction and size of material the sediments may be divided into two general classes: (a) the lower, generally finer, more consolidated beds and (b) the loose, sandy upper beds.

The lower beds are white to cream colored, fairly well consolidated, massive-appearing, and composed principally of silt-sized particles. Individual beds are usually several feet in thickness, but some are only a few inches thick. The beds are separated by differences in color and by seams of dark colored sand, ash, or pumice in layers 1/2 inch to 15 inches thick. They are flat-lying and show no structures within them.

The top of this series of beds is at an elevation of 4309 feet at Four-Mile Sink and at 4306 feet at Arrow Sink. At Arrow Sink the silts are overlain by a fan-shaped deposit which has prevented their erosion and preserved the original thickness.

The base of the series was not seen. Even the 30- and 50-foot wind blown depressions of Arrow Sink and Four-Mile Sink failed to reveal it. In table 1 is a list of test holes and wells taken from U. S. Geological Survey Water Supply Paper #220 and from information furnished by Mr. J. E. Upson of the U. S. Geological Survey. The latter (marked by an asterisk) is depth of "unconsolidated material."

TABLE I

LIST OF WELL AND TEST HOLES IN FORT ROCK-CHRISTMAS-LAKE-FOSSIL LAKE-SILVER LAKE BASINS

No.	Location Tsp.	Range	Sec.	Depth in feet	Material passed through
1	25	18	6	22	Lake silts
2	25	18	-	25	0-18, silts; 18-25 feet rotten basalt
3	25	18	25	12.5	Lake silts, a little rotten basalt at bottom
4	25	18	25	4	0-$1\frac{1}{2}$, silts; $1\frac{1}{2}$-4 rotten basalts
5	25	19	29	13.5	Lake silts
6	25	19	31	12	Lake silts
7	26	19	--	17	Lake silts
8	26	19	--	11.5	Lake silts; a little basalt at bottom
9	26	18	--	26	Lake silts
10	26	18	--	31	Lake silts
11	27	18	--	16	Lake silts (?) with basalt fragments
12	27	18	--	23	0-16, lake silts (?); 16-23, basalt fragments
13	27	18	7	19.5	Lake silts
14	27	17	--	27	Lake silts
15	26	17	--	19.5	0-19, sands and moist clay; 19-19.5, tuff
16	26	15	--	7.5	0-6.5, silt and sand; 6.5-7.5 tuff

No.	Location Twp.	Range	Sec.	Depth in feet	Material passed through
17	26	15	--	16	Silts, sands, and clays; 8-9, moist sand containing fresh-water shells
18	25	14	--	26	0-25, lake silts; 25-26, tuff
19	27	17	--	5	0-4, lake silts; 4-5, tuff
20	28	16	--	24	0-16, lake silts and clays; 16-24, moist clay
21	28	16	--	15	Lake silts
22	29	14	--	247	0-108, lake silts and sands; 108-223, tuff; 223-247, basalt (?)
23	28	14	--	90	Lake silts (?)
24 *	25	14	32	60	All "unconsolidated" material
25 *	26	15	4	60	All "unconsolidated" material
26 *	26	14	12	240+	All "unconsolidated" material
27 *	26	15	22	150+	Hard rock at bottom
28 *	26	15	24	60	0-20, "unconsolidated"; 20-60, hard rock
29*	26	14	21	37	Hard rock at bottom
30*	27	17	1 or 12 ?	400	Encountered hard rock at some depth between 300-400 feet
31*	27	17	22	92(?)	Encountered hard rock at 92 feet

It is not surprising the wells drilled near Bunch Grass Butte and Seven Mile Ridge (well #2, #3, and #19) went through the lake silts at such shallow depths, for Bunch Grass Butte was an island of rock in the lake (as indicated by the wave-cut benches on its sides) and Seven Mile Ridge was a rock reef.

It is very difficult to estimate the thickness of these lower beds with any degree of accuracy. However, it is safe to say there is a blanket tens of feet thick over the entire basin floor.

When these silts were examined under the microscope they were found to be composed of the same materials -- diatoms and glass making up the bulk of the material with minor amounts of mineral grains. The diatom content varied from 30 percent to almost pure diatomite. Sample #69 (from a well in the middle of the basin) and one sample from Four-Mile Sink was estimated to contain 85 percent diatoms, and three out of the seven silts from Arrow Sink were estimated to contain 60 percent. One sample, taken from a white outcrop on the northeast side of the Connley Hills (sample #72) was estimated to contain 95 percent diatoms but this sample will not be considered in the discussion as the stratigraphic position of the deposit is not certain; it appears to be associated with older rocks. The silts contain a smaller percentage of mineral grains than the upper beds, but the minerals are the same. The mineral grains differ from those found in the more sandy beds in that they are smaller, more angular and do not show well-developed crystal outlines.

The upper sandy beds vary in color from dark gray to white. They are loose, except in the few areas where percolating mineral waters have cemented them. The bulk of the sands are in fine to coarse sizes, although boulders of basalt were found on the surface and pebbles of basalt and reworked lakebeds up to 2½ inches in size and pieces of pumice as large as 3½ inches were found in some beds. The individual layers or beds vary in thickness from less than one inch to slightly over two feet and their thickness varies over short distances laterally. Within the beds are many minor structures such as crossbedding, ripple marks, and minor folds. The tops of the sections are usually uneven due to the erosional work of the wind and, because of this, their total thickness is from a little over one foot to not more than ten feet. Bedding is indicated mainly by differences in color and sizes of particles.

Diatoms make up minor amounts of the beds, most of the samples showing only a trace and 7 percent diatoms being the largest amount found. Mineral grains and glass shards are usually in about equal amounts. The mineral grains are larger than those found in the lower silts and they often show good crystal outlines.

The transition from the upper loose, sandy beds to the lower compact lake silts is usually quite abrupt. In digging the pits and trenches the change was very noticeable, due to the greater resistance that the more compact lake silts offered. This transition is locally marked by a conglomerate made up of flat pebbles composed of the underlying lake beds or a breccia made up of angular granules composed of lake beds. The flat pebbles and the angular granules when pulverized have the same appearance and composition as the compacted lake silts.

The materials that make up the sediments are fragments of rock (mostly basalt), fragments composed of the underlying lake beds, volcanic glass (varying from minute glass shards to pebbles of pumice), mineral grains, diatoms, and other fossils, and mineral salts.

Volcanic glass makes up the bulk of the material; mineral grains are always present in appreciable amounts; diatoms are a large percentage of some beds but are entirely lacking in others; rock and fragments of the underlying lake beds are sole constituents of some beds, but are scattered through the finer sediments in minor quantities; and mineral salts occur as crack fillings and efflorescence on the sediments.

Statistical Analysis of Grain Sizes

The results of a statistical analysis based on grain counts on all samples except the breccias and conglomerates and on screen analyses of 43 samples (mostly of the upper beds) are given in graphs and a chart in the appendix.

Method

The grain count was made on the loose material of -28 mesh size by traverses across the microscope field aided by a mechanical stage and on plus 14 mesh material by traverses over a glass grid with binoculars. The grain scatters used were taken from the results of the screenings. Not less than 100 grains each were counted from the -100+150, -48+100, -28+48, and -8+14 fractions of each sediment. The percentage of the different grains present was then multiplied by the weight percentage represented by the fractions figured on a 100 percent basis. The diatom content was estimated and adjustments were made so that the total would equal 100 percent. All figuring was carried to the first decimal place and then in the final figures the decimal was either dropped or changed to a whole number, depending on whether or not it was more or less than half of one percent. In the compacted lake silts the percent of minerals and diatoms was estimated by examining ten slides of each sample and using the average of the results. Each of the ten slides was taken at different times and recorded on different pages to prevent as much as possible repetition of figures due to suggestion.

Screen sizes used were 4, 8, 14, 48, 100, 150, and 200 mesh, all of the Tyler Sieve series. These were chosen as all but 150 mesh represent the lower limits of the Wentworth grade scale from pebble to very fine sand sizes. The 150 mesh screen size was used because much of the material was in the finer sizes and a greater separation was thought necessary. Fifty gram samples and a screening time of seven minutes in a Tyler Ro-Tap machine were used. The screening time was determined by running six test samples for periods varying from two to ten minutes to determine the time necessary to get the material through 200 mesh, and two test samples of lake silt and pumice granules for five to twelve minutes to determine the amount of fines produced. Screening for seven minutes obtained 97 percent of the -200 mesh material and less than 1 percent fines. Loss due to dusting varied from $2\frac{1}{2}$ percent to less than 1/2 of 1 percent, depending on the fineness of the material.

Results of the screening of the breccias and of the material containing granules of lake silts are not very accurate as that material would not break down to individual grains and therefore gave size values that were too large and other values that were misleading. Disaggregation in water and in solutions of NaOH and HCl was tried but the granules themselves would break down and other sized particles would form on drying.

Results

Perhaps the greatest contribution the grain count brought out was the large percentage of diatoms that was found in the lower lake silts as compared to the loose upper beds. In general, the count showed a greater concentration of minerals in the upper beds, the greatest concentration of lake pebbles and granules on top of the lake silts and in the lower beds of the loose material.

Of the sediments screened, 13 have size medians within the "very fine sand" range (1/16 to 1/8 mm.) of the Wentworth grade scale, 19 in the "fine sand" limit (1/8 to 1/4 mm.), 6 in the "medium sand" (1/4 to 1/2 mm), 2 in the "coarse sand" (1/2 to 1 mm), 2 in the "very coarse sand" (1 to 2 mm.), and 1 in the "granule" size (2 to 4 mm.). In the eleven sediments which are larger than fine sand size, five are breccias or conglomerates found in the Fossil Lake pits (sample #4, #14, #8, #17, and #2), five are pumice, cinder, and soils found in the Arrow Sink cuts (samples #48, #63, #49, and #46) and one is the pumice, basalt and lake silt granule bed found at the base of Race Track pit (sample #76). The one of granule size is the loose pumice layer found in the lake silts at Arrow Sink (sample #69).

If, as Trask (1) found, "a value of So less than 2.5 indicates a well sorted sediment, a value of about 3.0 a normally sorted sediment, and a value greater than 4.5 a poorly sorted sediment" then all but five of the samples screened are well sorted, and of these five, three are normally sorted, and two are poorly sorted. The two that are poorly sorted are breccias (samples #4, #17) and of the three that are normally sorted one is a well compacted bed of pumice, lake bed, and basalt pebbles (sample #76), one is a breccia (sample #8), and the other is the bed of black volcanic cinders found in the fan at Arrow Sink (sample #49).

The logarithm to the base 10 was taken of the So values in order that the So values could be directly compared (2).

The quartile deviation (measure of average spread) of the curves of most of the sediments is not very great but this is to be expected because of the good sorting. The samples in which the quartile deviation were large were the same as the normally and poorly sorted sediments.

The amount of skewness of the curves is also slight, although there were only two curves (samples #12, #20) which were symmetrical.

1. Trask, P. D., Origin and Environments of Source Sediments of Petroleum, pp. 67-76, 1932.
2. Krumbein, W. C., & Pettijohn, F. J., Manual of Sedimentary Petrography, p. 232, 1938.

Materials of Sediments

Rock Fragments

Occurrence and Origin

Thirty-seven out of the seventy-eight samples contained amounts of rock ranging from a trace to thirty-nine percent of the total. The samples from the dark sandy layers found at Fossil Lake had the largest percentages. The beach ridges are composed almost wholly of basalt pebbles and cobbles, and shingle beaches of basalt are quite common at the 4470 and 4520 foot elevations.

An interesting occurrence of basalt fragments is in the lag materials found in the wind excavated depressions. At Fossil Lake proper, they are especially numerous and they are scattered all over the basin floor. Their sizes range from granules up to boulders - one boulder noticed was nearly three feet across in its longest dimension. Fragments ten and twelve inches in size are common. Although no pieces larger than a few inches across were found in digging the trenches, these large fragments have unquestionably weathered out of the sediments as they were most numerous where wind has formed "blow-outs". Fragments of this size could not have been blown out to Fossil Lake by volcanic explosion as the nearest vent of any size is many miles away. The method of transportation of the boulders to the basin that seems the most plausible is rafting by ice. Evidence that ice formed on the basin is found in the badly disturbed beds at the base of Southwest Pit which have been interpreted as affected by ice shove. Yamsay Mountain at the head of Bridge and Buck Creeks of Silver Lake basin shows evidence of having been glaciated. The weather at the time the lake was in the basin was surely cold enough for the formation of ice for even today the U. S. Geological Survey water checking station on Silver Creek records ice hampering the flow of water during the months of February and March. Mr. H. M. Parks of the Poplars Ranch remarked that frost may occur in any month of the year. It seems entirely possible that masses of ice bordered the ancient lake. The boulders of basalt were probably in part brought down to the lake shore by torrential wash of the streams and in part plucked from the basalt ledges and buttes (such as Bunch Grass Butte) that are within the basin. One may easily imagine ice forming around the basalt boulders, later to be broken up as ice floes or icebergs carrying their boulder cargos to all parts of the lake, where, upon melting of the ice the boulders were dropped as erratics.

The reason why the boulders are most numerous in the area of the loose sandy beds is not clearly understood by the writer. The weather at the time the silts were deposited must have been as cold as when the sands were deposited, also the availability of boulders must have been similar. There was, however, a decided difference in the areas of the two lakes--the lake that deposited the silts was larger, as will be shown in later pages of the thesis. Perhaps the greater area of the large lake resulted in the ice floes attaining a wider distribution and therefore when the ice dropped its load the boulders were widely scattered. In the smaller lake the boulders were dropped in a smaller area and consequently were more noticeable.

Description

The fragments of rock which were found in the samples were of very fine sand to pebble sizes. In the field many boulders were seen lying on the ground in the blow-outs, The rock was mostly black colored, fine-grained, and often vesicular, and as far as could be determined, was basalt. Occasionally small red grains were noticed that were pieces of volcanic cinders probably derived from tuffs or scorias. Some of the very fine sand and fine sand showed some rounding as did some of the pebble sizes, but most of the sand and practically all of the granule and larger size material was angular.

Fragments Composed of the Underlying Lake Beds

Occurrence and Origin

The material composed of the underlying lake beds does not make up a very large percentage of the total of the sediments but its occurrence as conglomerates and breccias and the presence of the sand sizes in minor amounts in almost every bed makes it important. The beds that contained the greatest amount of pebbles were found on top of the lake silts and in the bottom beds of the loose sandy upper beds. The sand and granule sized material was scattered through the loose upper beds.

The most notable occurrence of the breccias is found in the Dune Pit where there are three beds composed entirely of angular pieces. These beds were 13 inches, 6 inches, and 21 inches thick and were at the surface (sample #8), and 41 inches (sample #4), and 69 inches (sample #2) from the surface, respectively. The pieces range in size from fine sand to granules and show no sign of rounding or any definite shape or size arrangement. Conglomerates were seen in a few pits and a sample (#70) taken from a well three miles northeast of Arrow Sink was a conglomerate with flat pebbles up to one and three-quarters inches in diameter.

The conglomerates, the flat pebbles, and round sand sized particles and the granules with well rounded edges were undoubtedly formed by the reworking of the underlying silts. It is possible that much of this material was frozen during transportation and rounding. The breccias were probably formed by the wetting, drying, and cracking of the lower silts during periods of low water when the beds were repeatedly exposed, and as such can be considered "dessication breccias" (1), or they might have been formed by repeated freezing and thawing of the silts.

Description

The fragments composed of lake silts are cream to white colored, fine-grained, and can be crushed easily between the fingers. The sands are usually well rounded; the granules are well rounded when they are found in minor quantities of a bed but are angular when composing all of a bed; the pebbles are usually flat and have well rounded edges.

1. Twenhofel, W. H., Principles of Sedimentation; p. 281, 1939.

Glass

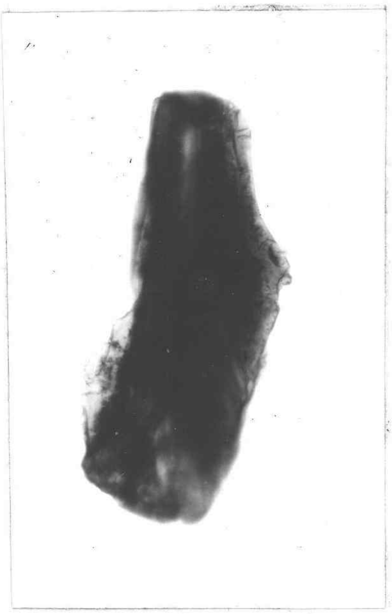
Occurrence and Origin

Disregarding the breccias and conglomerates, the lowest amount of glass found in any of the samples was 19 percent (sample #25); amounts of 50 percent and more are common. Fine- and very-fine sand sizes are predominant in the upper loose, sandy beds and silt sized particles in the lower beds. Pebbles and granules of pumice are found scattered over the surface of the entire basin. Two beds (sample #47, and #59) at Arrow Sink were composed wholly of pumice pebbles and granules and one bed (sample #63) at the same place, was 56 percent pumice granules. Several of the other samples contained minor amounts of pumice granules.

As glass is found associated with and clinging to the mineral grains the origin of the two is probably the same, therefore the source of the minerals and the glass will be discussed together on a later page.

Description

Glass is found in sizes varying from minute shards to pebbles of pumice. Some of the glass of fine sand size and smaller is transparent and clear, but most of it is of a dull, whitish color. The pieces take the form of fibers, bubble walls, finely striated filaments, and grains with smooth sides. The shapes are all angular, and the edges are



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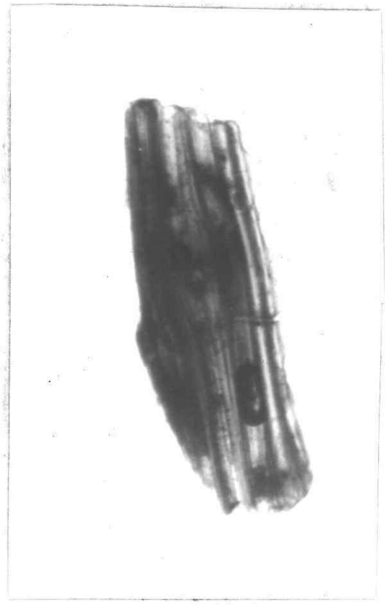

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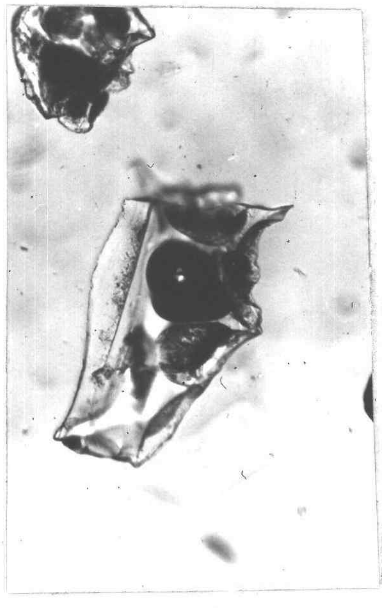


4.

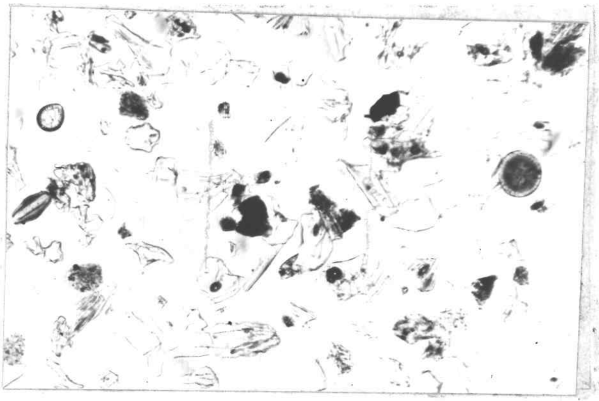
Typical glass shards found in the sediments. Note bubble in the vesicle of 2 and the bubble walls in 3 and 4. Magnification = 105X usually rough. Under crossed nicols the fragments show total extinction. Many of the larger pieces have mineral grains as inclusions.

The pumice of sample #47 occurs in pieces up to 3½ inches in size and in hand specimens it is grayish in color and has a satiny lustre on fresh fractures. It can be easily crumbled and is finely vesicular; the walls of these vesicles resemble nests with fibrous coiled structures of fine glass filaments. In sample #59 the pebbles are cream colored and are fairly well rounded. Weathering has tinged the outside a light yellow.

Mineral Grains

Occurrence

The mineral grains that are found in the sediments are plagioclase feldspar, pyroxene, magnetite, hornblende, and biotite. These mineral grains are second only to glass in quantity of material of the sediments. They make up as much as 75 percent of the total of some beds (sample #25) and rarely less than 5 percent. With the exception of biotite, the minerals are all present in every sample. Biotite was found in six samples - all from the Fossil Lake area. Five of the samples were from the Dune Pit (samples #9, #7, #6, #5, and #3) and the other was in the sample taken from the recent dune sands (sample #12). The samples contained



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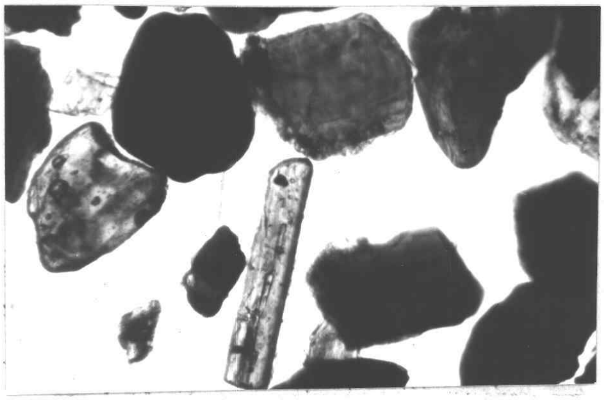


2.

Grain Scatters

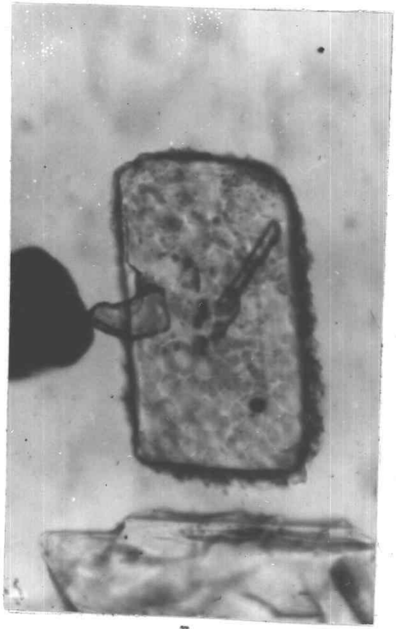
1. Typical grain scatter of upper sandy beds at Fossil Lake showing glass, hypersthene, and feldspars.
2. Grain scatter of volcanic ash found at Dune Pit, sample #10. Colorless grains are glass and dark grains are minerals. Note diatoms
Magnification 105X, plain light.

trace, 0 percent, 2 percent, 3 percent, trace, and trace, respectively. In the sandy beds the feldspars will usually make up about one-third of the total of the material, and they are found in lesser amounts in the compact silts. Pyroxene makes up a far less percentage of the sediments than the feldspars, in no instance much over 10 percent of the total, and usually about 2 percent; however, it is the next most abundant mineral. Magnetite occurs as individual grains nearly as abundantly as the pyroxenes. Hornblende was seen in such small quantities in the sediments that it was not included in the percentages of the mineral count. It occurs, however, in every sample. Because of the similarity of the large grains of hornblende to hypersthene and the small ones to augite, it is possible that some hornblende has been counted with these minerals. A very careful check on 10 of the samples proved that hornblende is by far the least numerous of the minerals and thus if some has been counted with the pyroxenes, it will not have changed their values by an appreciable amount.

Description

The plagioclase feldspars are the most common minerals. They vary from minute silt-sized particles to grains nearly 2 mm. in length. Stocky rectangular subhedral to euhedral crystals are often seen in the more sandy beds. The grains range in composition from oligoclase to labradorite and the greatest number are andesine. The determinations made from their index of refraction gave maximum values for oligoclase of Ab 72-An 28 and for labradorite of Ab 22-An 56. Andesine with a composition of about Ab 64-An 36 was found most frequently. Most of the grains are clear and show no alteration. Some, however, are completely masked by alteration and some are slightly attacked. The secondary products are grouped in fan-shaped clusters and under the highpower objective, are blade-like and show high birefringence suggesting sericite. Many of the grains contain inclusions of hypersthene, magnetite, apatite, and brown glass. Clear glass is found on the edges of most of the grains and in some instances it entirely surrounds them. Zoned crystals are seen occasionally and less frequently crystals exhibiting polysynthetic twinning.

Hypersthene is the more common pyroxene and there are minor amounts of augite. The hypersthene occurs in greenish black, rod-shaped crystals up to 1½ mm. in length. It is pleochroic, from apple green to light bronze in color, usually has many inclusions of magnetite, and is high in iron. Only a little of the augite occurs in sizes more than 1/2 mm. in length. It is fragmentary and does not have good crystal outlines. Like the feldspars, many grains of the pyroxenes have little pieces of glass attached or encompassing them.



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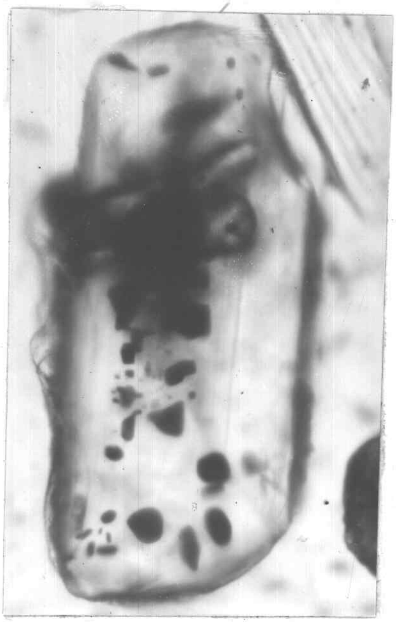

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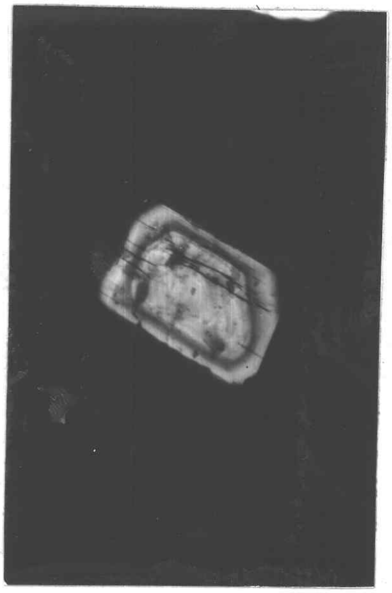
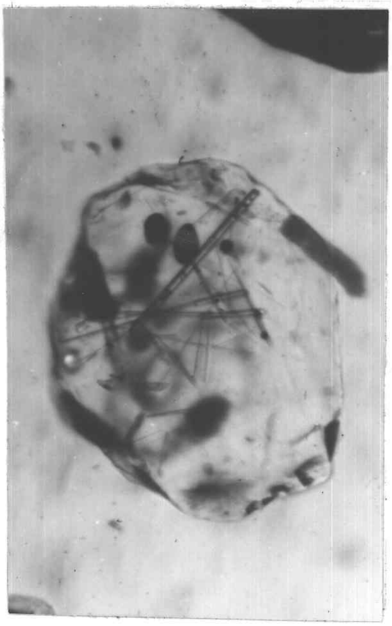


3.

Plagioclase Feldspar Grains. Note the glass on the edge of the grains in 1 and 2. The rod-like inclusion in 1 is hypersthene. The large dark mass on the grain in 2 is alteration around hypersthene and magnetite inclusions; other inclusions are magnetite and brown glass. 3 is a zoned feldspar. Crossed nicols. Magnification 105X.



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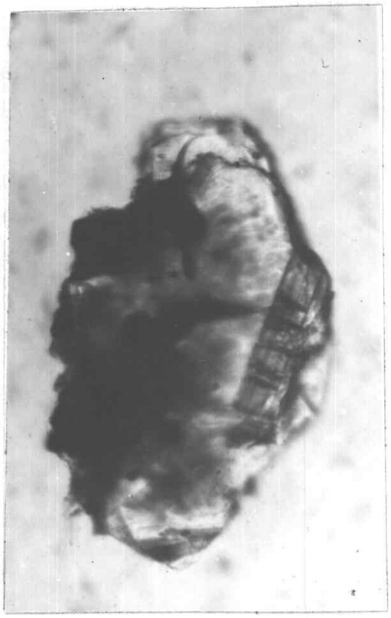
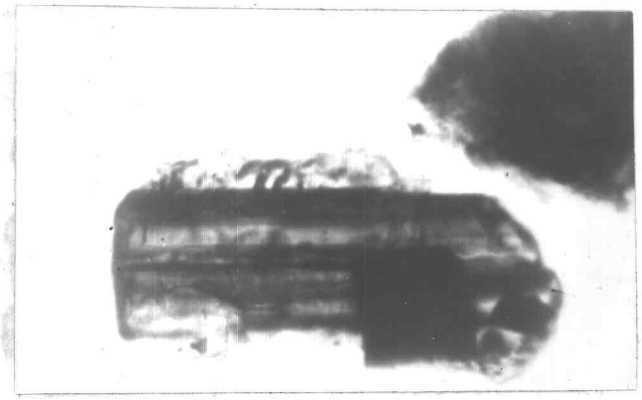


2.

3.

Inclusions in Plagioclase Feldspar Grains. The long needle-like inclusions in 1 and in the grain of the upper right hand corner of 3 are apatite, and the thicker rod-like inclusions of 1, 2, and 3 are hypersthene. The dark inclusions in the grain of 1 and the lower grain of 3 are magnetite and brown glass. The grain on the left edge of 3 is glass with feldspar and hypersthene. Plain light; Magnification 105X.



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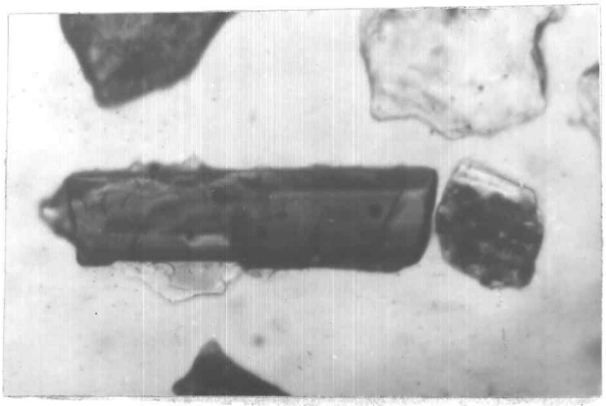


2.

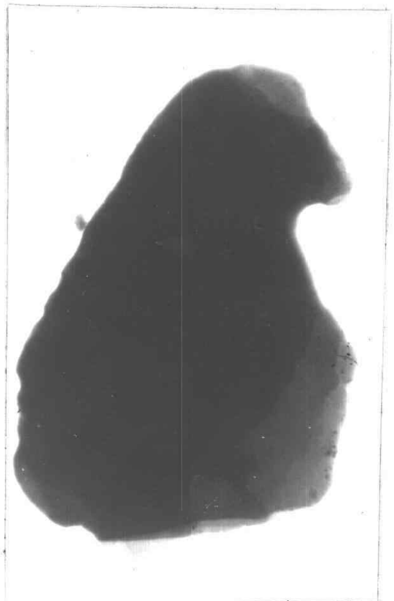
Hyperstheme Grains.

1. Note glass on edge and well-developed grain of magnetite partly included in hypersthene. Glass grain at right.
2. The grains in the center and upper left are hypersthene. Note glass on edge and inclusions of magnetite in center grain. Grain in upper right is a feldspar and others are glass.

Plain light; magnification 105X.

1.

2.



3.

1. Grain in center is magnetite surrounded by glass. Feldspar at right. Small grain between feldspar and magnetite is augite.
2. Upper grain is magnetite, feldspar, and glass. Lower grain is magnetite with augite attached to it.
3. Typical biotite grain.

Plain light; magnification 105X

Magnetite occurs as inclusions, especially in hypersthene, more often than by itself. The grains are small and few show good crystal outline, being like augite in that respect. Particles of glass and other minerals are usually found on its sides. The minor amounts of hematite that occur in the sediments are thought to have been derived largely from alteration of the magnetite.

The biotite is in black, tabular flakes up to 2 mm. in diameter. It does not have inclusions, show any alteration, or have attached mineral particles or glass. The grains do not exhibit any pleochroism and they are dark under crossed nicols.

The larger grains of hornblende look very much like the grains of hypersthene, the only difference being that the hornblende is usually pleochroic from light green to dark green and its index of refraction was slightly lower. The smaller grains were angular and had rough edges.

Mineral Efflorescence

Qualitative chemical analyses were run on the following samples:

a. Mineral efflorescence which formed in a few days on the sides of the freshly cut trenches at Arrow Sink, sample #50.

b. Crack filling in sample #56, sample #52 (also from

Arrow Sink).

c. The salts of sample #35 soluble in water (surface of Alkali Flat).

d. The salts of sample #37 soluble in water (subsurface beds at Alkali Flat).

e. The salts of sample #42 soluble in water (subsurface beds at Alkali Flat).

The following ions were identified:

Sample No.	SO_4^{--}	Cl^- ppt.	CO_3^{--}	Na^-	Ca^{--}	Mg^{--}
a (#50)	Heavy	Medium	Strong	Heavy	Slight	Trace
b (#56)	Heavy	Slight	Strong	Heavy	Slight	None
c (#35)	Heavy	Trace	Strong	Heavy	Slight	None
d (#37)	Heavy	Trace	None	Heavy	Trace	None
e (#42)	Heavy	None	None	Heavy	Trace	None

By comparison with the analyses of the salts, water, and soils listed by Waring (1) Na_2SO_4, $NaHCO_3$, $CaCO_3$, NaCl, and $MgCl_2$ are thought to be the salts represented by the above ions.

1. Waring, G. A., Geology and Water Resources of a Portion of South-Central Oregon; U. S. Geol. Survey, Water Supply Paper #220, pp. 72, 74, 1908.

Fossils

The Fossil Lake area has been a famous collecting ground for fossil mammal and bird bones since 1876 when Governor Whiteaker, Oregon's first governor, made an expedition through this country. In fact, Fossil Lake gets its name from the abundance of the fossil bones found here. Most of the fossil bones are found in a roughly triangular area that has its apex about 1½ miles west of the modern playa of Fossil Lake, and its base, about a half a mile long in a north-south direction just west of the modern playa. The principal zone that contains the bones is a thin, grayish-colored fine sand containing lake silt granules. It is found at an elevation of about 4298 feet, just above the intraformational conglomerates or lake silts and near the base of the loose sands. The source was confirmed by the finding of large bones of mammals, such as horse and elephant, in place. Evidently the animals had come down to the lake when it was shallow and had waded out to drink. It was inevitable through the years that many animals should die here and their remains are what we now find as fossils. The species of mammal bones that have been identified by E. D. Cope, N. Hollister, W. D. Mathew, J. S. Gidley, A. M. Alexander, H. O. Elftman, and C. Stock include:

antelope	ground sloth
badger	2 horses
bear	jackrabbit
beaver	mouse
3 camels	ocelot
coyote	2 peccaries
elephant	puma
fox	wolf (dire)
gopher	wolf (timber)

Several hundred bird bones were found by Dr. Allison and his field party during the summer of 1940 in the vicinity of Bird Bone Pit. The bird fauna identified by E. D. Cope, R. W. Shufeldt, and L. H. Miller include:

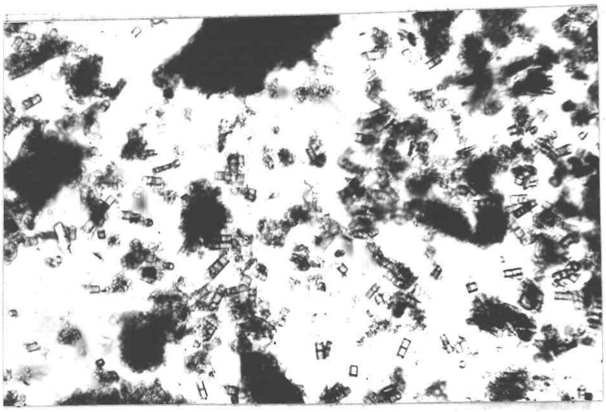
6 gulls	1 blackbird
1 hawk	1 cormorant
1 heron	1 crow
2 mudhens	13 ducks
1 owl	2 eagles
1 pelican	1 flamingo
1 phalarope	7 geese and brant
1 prairie chicken	6 grebes
1 quail	3 grouse
3 terns	

Fish bones were found in nearly every bed examined from the lowest lake silt to the upper sandy beds and in various parts of the basin. For the most part, the bones were fragmental but a few fish jaws showing dentition and many vertebrae were collected by Dr. Allison. D. S. Jordan has identified the King or Chinook salmon from this area, and E. C. Cope and E. Starks have identified one species of silverling, two species of suckers, and two species of Siphateles.

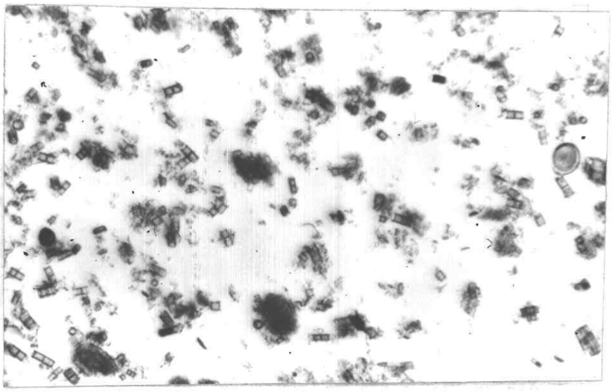
Of the 53 species of birds identified, 20 are extinct, and of the 23 species of mammals, 15 species are extinct. The King salmon is the only living representative of the fish life.

The large quantities of diatoms in the lower compact silts is another of the world wide occurrences of the association of diatomaceous earth and volcanic products. The reason for this association is attributed to the unusually great amounts of silica present during volcanic outbursts. It is thought that the silica is made available for use by the diatoms in the form of hydrous aluminum silicates (1) and silicic acid. Hydrous aluminum silicates are much more soluble than silicic acid so it probably furnishes the bulk of the silica necessary for the formation of their tests. To obtain the soluble silicates calls for the alteration of the volcanic material. It has been shown that the change of basaltic, rhyolitic, and dacitic glasses is negligible when allowed to stand in sea water (2) and so it is suggested that the alteration takes place prior to deposition - in the vents, or very close to them, by gases or solutions emanating from the vents and the volcanic material itself (3). Altered volcanic ash is considered by Taliaferro (4)

1. Murray and Irving, On Silica and the Siliceous Remains of Organisms; Proc. Roy. Soc. Edinburg, vol. 18, pp. 229-250, 1891.
2. Taliaferro, N. L., The Relation of Volcanism to Diatomaceous and Associated Siliceous Sediments; Univ. Calif. Pub. in Geol. Sciences, vol. 23, #1, pp. 45-46, 1931.
3. Hewitt, D. F., Geology and Oil and Coal Resources of the Oregon Basin, Meeteetse, and Grass Creek basin quadrangles, Wyoming; U. S. Geol. Surv., Prof. Paper 145, p. 58, 1926.
4. Taliaferro, N. L., Ibid., p. 54, 1936.



1.



2.

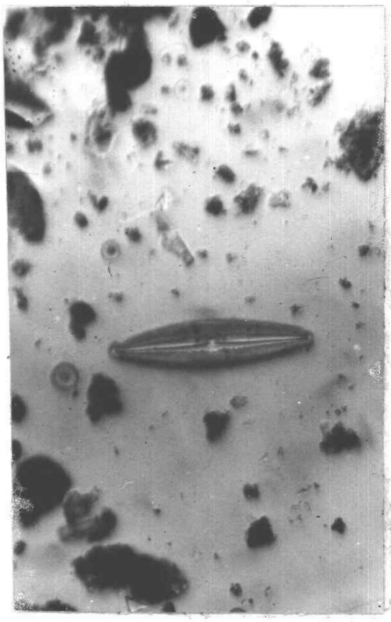
Grain scatters from the compact silts showing the high percentage of diatoms.
1. From sample #72
2. From sample #65
Magnification 105X

to be the chief source of supply for the rapid and continued growth of diatoms and other siliceous organisms in the Tertiary of California.

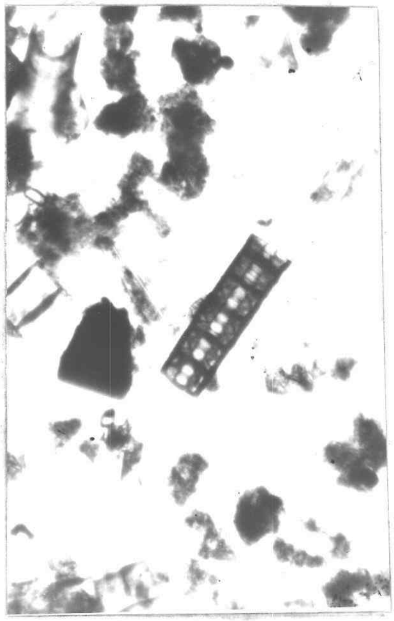
Undoubtedly the source of the silica for the diatoms in this area has also been altered volcanic ash. The presence of glass shards, glass fringed mineral grains, and layers of pumice and volcanic ash making up the bulk of the sediments is definite proof of that. The locale has also been favorable to their rapid growth. Conclusive proof of favorable environment is furnished in the absence of coarse detritus and the almost 100 percent presence of silt-sized particles. The very surprising thing is that larger deposits of pure diatomite are not found. Reasons why they are not may be the lack of alteration of the ash or the lack of nitrates and phosphates which Murray and Irving have shown to be necessary (1). The addition of quantities of material so rapidly as to retard their growth is not likely, for the rate of growth is thought to be directly in proportion to the availability of the necessities.

Regardless of the reasons for the different quantities of diatoms in the compact silts the occurrence is interesting because their relative abundance helps bear out the presence of a comparative deep lake when little coarse

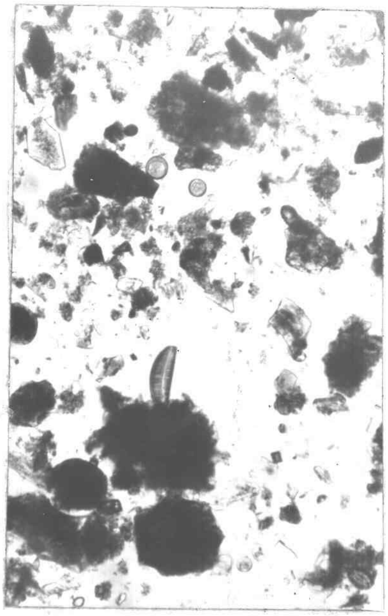
1. Murray and Irving, Ibid., pp. 229-250, 1891.



1.



2.



3.

4.

Grain scatters from the loose sandy beds
showing various diatoms.
Magnification 105X

material was being deposited and of a shallow lake when the material was coarser. The large numbers of diatoms also suggests that volcanic ash has been the main source of the materials.

There are undoubtedly many different species of diatoms represented in the sediments for several different sizes and shapes were noticed. No attempt will be made to describe or identify them but photographs of several of the varieties are given.

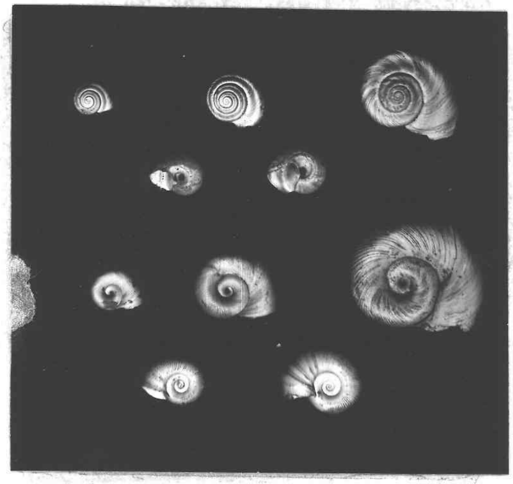
At several places on the basin floor near Fossil Lake the ground is nearly white with the many gastropod and pelecypod shells that have weathered out of the beds. These shells occur mostly in the upper sands. In the analysis of the sediments the shells are most of the "other fossils" percentages. Ostracods were found associated with the gastropods and pelecypods. They were but a few millimeters long and were white and although they were not identified, they are all thought to belong to one genus because they appear to be similar. Four different genera of gastropods were found and one genus of pelecypod. These are described on the following pages.

Phyllum MOLLUSCA
Class GASTROPODA
Family POMPHOLIGIDAE
Genus Carinifex Binney
Carinifex ? sp. cf. C. Ponsonbyi
Fig. 1, A. and B.

The only mention of C. ponsonbyi is found: Henderson, Rodeck, Journ. Paleon. Sept. 1934, p. 269. "In C. ponsonbyi usually the spire is slightly elevated above the top of the last whorl."

The shells consist of five whorls separated by well-defined sutures. Spire elevated slightly above the last whorl and this is more marked in some individuals. The shoulder is somewhat keeled, umbilical crater is moderately broad and deep, defined by a high, sharp ridge. Greatest width of umbilical pit, 11 mm. Apical angle obtuse. Growth lines numerous, varying in prominence and spacing. Body whorl expands slightly at aperture. Outer lip thin. The top surface of each whorl more or less undulating, due to high ridge on shoulders. Altitude 10.3 mm., width 16 mm.

There are several specimens which may be closely allied to the above described specimens. They differ in having higher apical spires and less prominent ridges around the umbilical crater.



A
B
C
D

Figure 1
About 3/4 natural size.

Family PLANORBIDAE
Genus PLANORBIS Guettard
Planorbis (Gyraulus) vermicularis Gould
Fig. 1, C. and D.

Planorbis vermicularis. Stearns, Proc. Acad. Nat. Sci. Phila., 1881, p. 100; Utah Lake, Utah. Baker, Bull. Amer. Mus. Nat. Hist., XLI, 1917, pp. 529, 532; Lily Lake, near Eldora, Colo., altitude 8,375 ft. Henderson, Naut., XXXVII, 1924, p. 79; Lily Lake, near Lake Eldora, Colo.
Planorbis parvus. Henderson and Daniels, Proc. Acad. Nat. Sci. Phila., LXIX, 1917, pp. 53, 58, 64, 76, query as to pp. 51, 57, 73, 77; near McCammon and north end Bear Lake, Ida; Newton town Reservoir and Provo, Utah.
Planorbis (Gyraulus) vermicularis Gould. Henderson, Univ. Colo., studies, XIII, no. 2, 1924, p. 180, 1924.

Shell, planorboid, composed of 4½ regularly increasing whorls, somewhat expanded at aperture. Apical cavity of about 120°, apex slightly depressed, nearly below median plane of whorls. Lines of growth are numerous, fine, and even. Umbilicas deep. Aperture somewhat triangular, rounded on thin outer lip. Diameter 14 mm., height 6.9 mm.

Genus Parapholyx Hanna
Parapholyx packardi Hanna
Fig. 2, A.

Parapholyx packardi Hanna. Hanna, C. Dallas, Fossil Fresh-water Mollusks from Oregon, Univ. Oregon Publication, vol. 1, no. 12, August 1922, p. 6.

Shell moderately small, composed of 3½ whorls which increase rapidly in size; suture deeply impressed around the last whorl. Spire is elevated above the body whorl, apex flattened and smooth. Whorls marked by conspicuous growth lines. Four specimens were measured, with altitudes ranging from 4.8, 5.4, 7.5, 7.9, and diameters ranging from 5.5, 6, 8.7, 9.2 respectively.

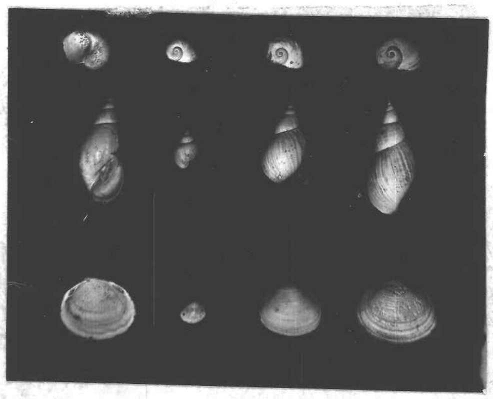


Figure 2
About 3/4 natural size.

FamilyLYMNAEIDAE Keferstein
Genus LYMNAEA Lamarck
Lymnaea stagnalis appressa (Say) ?
Fig. 2, B.

Limnea stagnalis. Ingersoll, 8th Ann. Rept. Hayd. Surv. (for 1874), p. 405: between the Animas and La Plata, Colo.; Southern Utah; Proc. Dav. Acad. Nat. Sci., II, 1877, p. 132; Utah Lake and Spring Lake, Utah.
Limnaea stagnalis. Binney, L. and F. W. Shells N. Am., Pt. 2, 1865, p. 25; southern Utah. Tryon. Proc. Acad. Nat. Sci. Phila., XXV, 1873, p. 286; Utah. Yarrow, Wheeler Surv., V. 1875, p. 941 (part); Loma, Rio Grande and Del Norte, Col.; Utah Lake, Panquitch Lake and ditches near Salt Lake City, Utah. Cockerell, Science Gossip, 1888, p. 26; Colo.; Journ. Conch., V. 1889, p. 64; San Juan District, Colo. (Ingersoll). Call, U. S. Geol. Surv., Bull. 11, 1884, p. 17; Semi-fossil in Sevier Desert, Utah; living near Salt Lake City and in Utah Lake at American Fork, Utah. Elrod, Univ. Mont. Bull. 10, 1902, p. 160; Swan Lake, Mont.
Limnaea stagnalis appressa. Elrod, Univ. Mont., Bull. 10, 1902, pp. 112, 160, 173; Bitter Root River and Swan Lake, Mont.; Naut., XV, 1902, p. 110; same localities.

Lymnaea stagnalis appressa (Say). Henderson, Mollusca of Colorado, Utah, Montana, Idaho and Wyoming, Univ. Colo. Studies, V. XIII, No. 2, 1924, p. 161.

Shell large, elongate, somewhat fusiform, thin. Consists of about five whorls. Apical angle acute, apex sharply pointed, outer lip thin. Thin callous on pareital wall. Lines of growth crossed by distinct impressed spiral lines, satin finish, shiny. Sutures distinct, somewhat impressed. Height 17.8 mm., diameter 8.5 mm.; aperture ovate, height 8.9 mm., diameter 4.5 mm.

Closely resembles L. stagnalis jugularis Say, but differs in size and number of whorls. The number of whorls (5) corresponds to L. stagnalis appressa (Say).

Class PELECYPODA
Family SPHAERIIDAE
Genus PISIDIUM Pfeiffer
Psidium variable Prime, cf. magnum Sterki
Fig. 2, C.

Pisidium variable Prime, Bost., Proc. IV, 1851, p. 163.
Pisidium variabile magnum. Sterki, Ann. Carnegie Museum, X, 1917, p. 453; Wash., Carnegie Institution of Pittsburg.

Shell small, obliquely cuneiform; inequilateral, anterior side longer; hinge line straight. Surface finely irregularly striated, not polished, but shining. Length 14.5 mm., height 11.5 mm.

INTERPRETATION OF SEDIMENTS

Source of Materials

The similarity in the minerals and the mineral content and the presence of glass on the edge of the minerals and in large amounts in the sediments must be more than a coincidence; it must mean that the materials of the sediments were derived from a similar source.

The large amounts of glass in the beds and the glass still clinging to the minerals suggest that the main source of the sediments was volcanic ash. There is a very regular 2 inch layer of white ash near the top of the section in the Dune Pit, (sample #10) which is undoubtedly an ash fall that was deposited in the lake, and marks a time of an eruption of a nearby volcano. It is not a sign of deep water because the change in color and size of particles between it and the bed lying on and under it is very abrupt. When this ash was examined it was found to contain the same minerals and the minerals were in similar proportions to each other as was found in the rest of the beds. The size median of this sample was less than 1/16 mm. In fact, 91.4 percent of the material passed through 200 mesh. This agrees very closely with the size median of the lower compact beds. Most of the material in the loose upper beds, however, have medians in the very fine sand range (1/8 to 1/16 mm.). The material from which these sediments were derived must have been much coarser. As the fine and very fine sand sizes of the pumice layer at Arrow Sink (sample #59) were composed essentially of the minerals which were found in the other sediments, the pebbles of pumice were ground up to see if they contained those same minerals. A heavy mineral separation was made and 15.3 percent of the weight was found to be composed of these minerals. Furthermore, the minerals on examination had glass still clinging to them and they compared favorably to the sizes of the mineral grains in the loose upper sands.

The materials from which the minerals and the glass of the lake sediments were derived then, must have been volcanic ash and weathered or comminuted pumice. Ash and pumice containing the same minerals as the sediments, the abundance of glass in the sediments, and especially the glass fringed minerals definitely establish that. The amount that ash and the amount that coarser pumice contributed is difficult to estimate. Because of the size of particles it seems logical that the silts should be made up almost entirely of ash although pumice that was ground up or disintegrated and subsequently transported to the lake as fines may have been a factor. In the upper beds of sand sizes the material has probably been derived mostly from sandy pumice with ash falls playing the minor role.

The most obvious sources of ash and pumice that could have supplied this area are the Crater Lake and Newberry Crater vents. The edge of Crater Lake is southwest approximately 55 miles air-line distance from the postoffice of Fort Rock, and East Lake within Newberry Crater, is north-northwest approximately 25 miles air-line distance. Other possible sources include the Devil's Hill area, northwest nearly 55 miles air-line and the numerous volcanic cones surrounding the northern edge of the basin. Measurements are from the postoffice of Fort Rock as it is a few miles inside the western margin of the basin of the former lake.

B. N. Moore (1) and Howel Williams (2) have mapped the distribution of pumice from Crater Lake, Newberry Crater, and Devil's Hill. Their maps show that the pumice of Devil's Hill is limited and lacks at least thirty miles of reaching the edge of the lake basin. The volcanic cones on the northern edge of the basin so far as known have not thrown out pumice; therefore, these areas have not been a source of pumice for the lake sediments. It is not at all unlikely, however, that fine ash could have come from Devil's Hill and that at some time in the history of the cones to the north ash or cinders were erupted. The amount

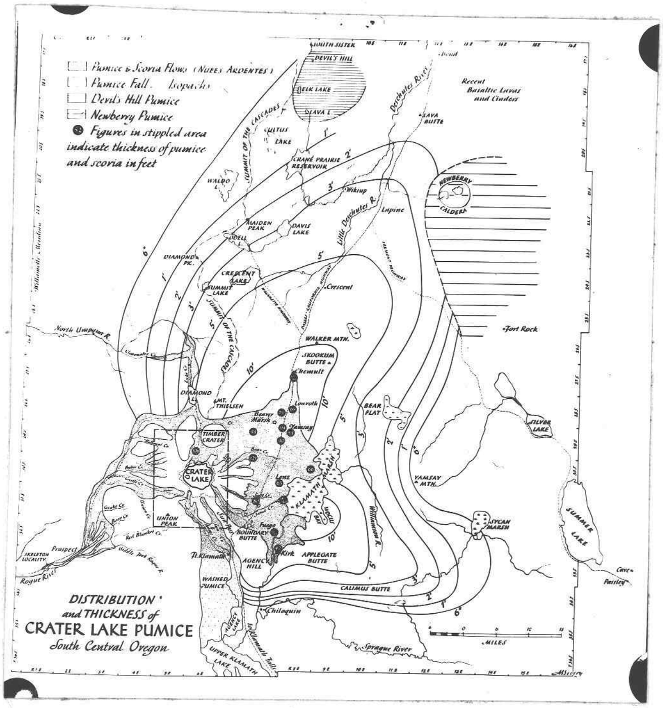
1. Moore, B. N., Nonmetallic Mineral Resources of Eastern Oregon; U. S. Geological Survey Bulletin #875, pl. 16, 1937.
2. Williams, Howel; personal communication.

of material that they have contributed to the sediments is probably very small, if any at all. That leaves as the possible sources of the sedimentary material Crater Lake and Newberry Crater.

Moore has mapped the eastern limit of the "younger pumice of Crater Lake" to the edge of Fort Rock basin. The material as mapped was "about one foot thick along the boundary" (1). Williams agrees fairly well with him, although his six-inch isopach line is slightly farther to the west of Moore's boundary in some places and at others a little farther to the east. No matter which map one follows material from Crater Lake is close enough to indicate that Mt. Mazama must have blown considerable pumice and ash into the basin. The streams that were draining into the lake from the west would bring large quantities of this pumice to the basin and the winds would probably bring much more.

The Newberry Crater pumice as mapped by Moore is quite restricted and not shown within the Fort Rock Basin. Williams has mapped the Newberry Crater pumice as occurring well within the basin. Pumice lies on the lavas that come down into the lake basin north of Fort Rock, undoubtedly from the Newberry area, so the extent of the pumice that Williams has shown is probably the more nearly correct one.

1. Moore, B. N., Nonmetallic Mineral Resources of Eastern Oregon; U. S. Geological Survey Bulletin #875, p. 158, 1937.



Distribution and thickness of Crater Lake pumice as mapped by Howel Williams. (Print reproduced by permission of Dr. Williams.)

If so, then Newberry Crater could also have furnished material to the basin.

Very important in the determination of the source which furnished the materials of the sediments are the three pumice layers found in the cuts at Arrow Sink. One of these (sample #63) is a 13-inch thick layer that occurs on the lowest lake silt observable at the bottom of the sink, 29 feet from the top of the section. Another, seven and a half feet higher, is a 15-inch layer of pebble pumice (sample #59). In the fan on the west side of Arrow Sink is a 27-inch thick layer of pumice with pieces up to 3½ inches in size (sample #47), 3 feet from the top of the section. Pumice from these samples was ground to pass 100 mesh and heavy mineral separations were made. Bromoform with a specific gravity of 2.4 was used for the separation. Three separations showed sample #63 to contain an average of 4.2 percent heavy minerals. Two samples each of sample #59 and sample #47 showed 15.3 percent and 3.6 percent heavy mineral content, respectively. Ten gram samples were used for sample #63 and sample #47 and 15 gram samples were used for sample #59.

The pumice from sample #47 and sample #59 that was crushed for the heavy mineral separation was pebble size and the pumice from sample #63 was granule size. Perhaps the smaller sized particles of pumice may account for the low percentage of mineral grains found in sample #63. Evidence that this may be so is found in the fines of this bed which show a high percentage of feldspars plus a lesser percentage of pyroxene and magnetite. It was noticed, also, that in several pieces of the lump pumice from Crater Lake some of the mineral grains occurred in clusters in the pumice. Weathering and erosion would tend to loosen these clusters causing them to fall out, thus lessening the mineral content considerably.

The heavy mineral separations from these pumice beds were compared with two heavy mineral separations made on a sample of pumice taken from a railroad cut on the west side of China Hat, a definite Newberry source, and 13 samples taken from road cuts and from lump pumice found on the top of the ground along the side of Oregon State Highway #62 between Prospect and Trail, a definite Crater Lake source. The China Hat pumice contained an average of 0.63 percent heavy minerals and the 13 samples from Crater Lake varied from a low of 9.7 percent to a high of 14.9 percent with an average of 10.2 percent heavy minerals. Fifteen gram samples were used in the separations.

The heavy fractions from the Arrow Sink pumice separations were next examined for mineral content. Samples #63 and #59 contained the same minerals that occur in the sediments, that is, plagioclase feldspars, hypersthene, augite, hornblende, and magnetite. The plagioclase feldspars range from oligoclase to labradorite and showed the same crystal outlines that were observed in the rest of the sediments. Hypersthene was in rod-shaped grains and had inclusions of magnetite. Augite and magnetite occurred as small angular grains without good crystal outlines and the magnetite usually had some other mineral attached to it. Hornblende was present only in traces. The ratio of the amounts of the different minerals to each other compared favorably to those observed in the sediments. The sizes of the grains were similar to the mineral grains of the upper sandy beds. In fact the remarkable similarity of the mineral grains of the pumice and the mineral grains of the sediments can leave little doubt that their source must have been identical. The heavy fractions of sample #47 were almost all plagioclase feldspars. Whereas the heavy fractions of the other pumice beds looked gray because of the dark minerals mixed with the white spars, by contrast the heavy fraction of sample #47 was almost pure white. The mineral grains were much smaller and did not show any good crystal outlines and because the grains were so small and the pumice was not ground any finer than 100 mesh the grains were usually enclosed by glass. This made their determination by their index of refraction very difficult. The few determinations that were made showed a range from labradorite to andesine. The few dark minerals present were identified as augite.

The examination of the heavy minerals of Crater Lake and China Hat showed that the Crater Lake heavy minerals were similar to the heavy minerals of sample #63 and sample #59 in every respect. The composition, the sizes, and the shapes were all similar. The heavy minerals of the pumice from China Hat were plagioclase feldspars and minute dark minerals identified as green augite and hypersthene. The mineral grains were smaller than the minerals from the pumice of Crater Lake and they did not show good crystal outlines. Augite was more prominent than in the Crater Lake pumice or the sediments.

The results of the heavy mineral separations on the pumice layers at Arrow Pink and the pumice from China Hat and Crater Lake can be summed up as follows:

1. Pumice from Crater Lake has a higher percentage of heavy minerals than the pumice from China Hat (10.2 percent versus 0.63 percent).

2. The heavy minerals from the Crater Lake pumice are almost exactly like the heavy minerals of sample #59 and sample #63 and the mineral grains of the loose upper sandy beds.

3. The heavy minerals from the Crater Lake pumice are the same minerals that are found in all the sediments with the exception of the biotite found at the Dune Site, and the ratios of the minerals to each other are similar to the mineral ratios found in the sediments.

4. The percentage of heavy minerals found in sample #59 compares favorably with the percentage of heavy minerals found in the pumice from Crater Lake, whereas the percentage of heavy minerals from sample #47 and sample #63 (3.6 percent and 4.2 percent, respectively) is less than the percentage of heavy minerals from Crater Lake (10.2 percent) although greater than the percentage of heavy minerals from the pumice of China Hat (0.63 percent).

5. The percentage of heavy minerals in sample #63 is thought to be low because of the size of the pumice particles that were used for grinding. The true values presumably would be close to the values for sample #59 and the source of these two is probably the same.

The similarity of the pumice of sample #63 and sample #59 to the pumice from Crater Lake suggest that the pumice layers were derived from a Crater Lake source. Also the similarity of the minerals in the sediments to the minerals in the pumice suggests that they had a common source. The last statement is borne out by the occurrence of the pumice layers in the lake silts. The possibility that material from Crater Lake could be a source is shown by the proximity of Crater Lake pumice as mapped by Williams and by Moore.

The size of the pieces, the difference in mineral content, and the position in the fan over the lake silts of sample #47 shows that during the later stages of the lake, that is, when the deep lake had almost disappeared and a fan was being built out onto the basin floor by streams, pumice from a source other than Crater Lake was being brought to the lake. This source is thought to be the Newberry Crater area, although it must be confessed there is very little proof. It should be pointed out however, that the one sample taken from Newberry Crater for comparison was from the west side of China Hat and according to Williams (1) there were four cones within the crater and two, including China Hat, outside which were sources of pumice.

The source for the biotite found in the Dune Pit and the dune sand has not been satisfactorily determined. No pumice that was found in the area is known to contain biotite and few of the rocks of the area contain it. One possible explanation is that at some time a light ash fall containing biotite was deposited in the shallow lake and due to continued washing, most of it was driven to the east side. Then by reworking, lesser quantities were washed into the overlying beds and later blown into the dune sand from the disintegration of the beds.

1. Williams, Howel, Newberry Volcano of Central Oregon; Geol. Soc. Amer. Bull. #2, vol. 46, p. 273, 1935.

Conditions of Sedimentation

The conditions under which the two classes of sediments - the upper loose sands and the lower compact silts - were laid down, are definitely different. As the record of the compact silty lake beds is best exposed at Arrow Sink and the loose sandy lake beds at the pits in the Fossil Lake area these two areas will be discussed in detail and considered as representative of the conditions of sedimentation.

Careful measurements by leveling with an alidade within Arrow Sink proved that there had been no sliding or faulting of the beds - the same beds were continuous on all sides. Excavations in the bottom showed the lowest exposed lake silts conformable with the overlying lake silts. The record is not marred by any outside factors.

The materials and sizes of the silty beds are the same throughout, the only difference appearing in the percent of diatoms present. Therefore all these beds must have been formed under similar conditions. The conditions necessary appear to be quiet waters and a distance great enough from the source of material that sizes larger than silt would have already settled. The large percentage of diatoms in the material also demands quiet waters.

Arrow Sink is about 2000 feet from the cliffs of pyroclastic rocks north of Table Mountain. There are several dry washes coming from the cliffs and blocks of talus are at their base. If a lake had been lapping against this cliff or if streams had been pouring down its sides, material of at least fine sand sizes would be found where the silts are. The reason why sands are not there must be that the lake was deep enough to cover the benches and extend beyond the cliffs. That waters did do this is certain as there are wave-cut benches above the cliffs and wave-cut caves on the sides of Table Mountain. Lake levels at elevations indicated by the high beaches would mean that 160 to 210 feet of water would be above the site of the top lake silt and this would answer the requirements necessary for the deposition of the silty beds and provide water quiet enough for rapid diatom growth. The low percentage of diatoms in the top silt (sample #53) is probably due to the lake declining in depth sufficiently so that the currents of the waters were strong enough to reach the bottom and disturb the diatom growth, but not strong enough to carry fine sands out. The difference in the diatom percentage of the other lake silts may be attributed to the interruption of their growth by the deposition of the sandy seams.

The thin seams of very fine sand such as samples #54, #55, and #61 which separate the silts were probably the result of the lake becoming shallower so that this size material could be carried out into the lake. The beds of pebble size pumice which separate the silts were probably carried out in the lake from the shores. They might possibly have been carried there by winds during an eruption or as floating particles afterward.

The eight feet of loose material which lies on top of the compact silty lake beds at the main section of Arrow Sink is divisible into two zones. The lower zone which is two feet two inches thick is a laminated zone of alternating layers of sand and silt and the upper five feet ten inches is loose material containing roots and other organic material and is probably of aeolian origin.

On the western side of Arrow Sink opposite a dry gully coming out of the cliffs this loose material forms a lenticular deposit very suggestive of a fan. This was trenched down to the lake silt and samples and measurements were taken. The lower 18 inches was a zone of alternating sands and silts mostly about one inch thick; it was marked, however, by one two-inch layer of black volcanic cinders, one three-inch layer of coarse pumice sand, and one four-inch layer of silt. Above this zone came a two-foot three-inch layer of pebble pumice which had some pieces reaching a size of $3\frac{1}{2}$ inches. This was covered with three feet of loose material that contained roots and other organic material. The frequency of the sand layers alternating with the silt at the bottom of the section suggest that the lake had dwindled to a size such that a stream flowing from the gully was depositing these sediments in the lake at different times, or, more likely, the lake was fluctuating and the sandy layers mark the shallower periods when the stream was able to carry the sand sizes farther out on the basin floor. The volcanic cinders and the pumice layers mark periods of eruptions of some nearby crater, and the thick pumice layer denotes a time of an eruption large enough to deposit quantities of pumice over the surrounding terrain so that the stream was carrying pumice as the bulk of its load. The upper three feet of loose material is undoubtedly debris carried there by the winds.

The record from the bottom of the lake silts to the top of the loose material is thought to be continuous, the fan formed from the stream protecting the lake silts from erosion and preserving the deposits of the deep lake. The top of the loose material may be partially destroyed, but a sufficient amount is left to correlate with the loose material of other pits and trenches.

The other "blow-outs" which exposed considerable depths of lake silts were very similar to this one at Arrow Sink. They had the massive-appearing lake silts capped by loose material and this loose material in the section in the "blow-out" to the north-northeast of Arrow Sink had faint long crossbedding. At the top of the lake silts and below the loose material at Four-Mile Sink there was a lake silt conglomerate. This is perhaps comparable to the sand-silt phase which overlies the silts of Arrow Sink and further proves the existence of shallow water at that period. The dug well about three miles northeast of Arrow Sink (sample #70, #71) also shows a well-developed lake-bed conglomerate under the loose material and on top of the lake silts.

The bases of the trenches at Fossil Lake showed rather compact massive-appearing lake silts or breccias and conglomerates made up of the underlying lake beds. The silts were undoubtedly laid down under the same deep water conditions as the silts in the Arrow Sink area, and the conditions of formation of the conglomerates and breccias above the silts are probably comparable to the shallow water conditions that formed the conglomerate of Four-Mile Sink and that deposited the sand-silt phase of Arrow Sink. Above the silts, in the trenches at Fossil Lake, came a series of rather thin sandy beds that varied over short distances laterally. Some of the sand layers are quite dark and have low percentages of glass and large amounts of rock fragments. This indicates that the lake in which the silts were deposited was then shallow enough so that material of sand and pebble size could be carried out into the basin. In a pit on the north side of Fossil Lake, visited several days after it was excavated, ripple marks in the sands had been etched into relief by the wind. In several of the sandy beds minute cross-bedding was visible. The thin beds and the small structures within them prove that the lake in which the sands were deposited was only a few feet deep. The presence of quantities of shallow water mollusca and ostracods and the low diatom content of the beds also point to a shallow lake. Because the bones are found only in a rather limited area in the middle of the basin, the lake at the time the bones were incorporated in the sediments may have covered only a small portion of the area of the basin floor. However, many fish bones found in some of the upper sandy beds show that the lake meanwhile did not dry up entirely.

The tops of the sections at Dune Pit, Fish Bone Site Pit, and Bird Bone Site Pit are a cream to white-colored silt approximately 6 inches thick. A light colored silt covers a sandy bench that borders the north end of the Fossil Lake area and many of the hillocks within this area. The silts are probably the remnants of the deposits of a lake that was deep enough that only silt-sized particles were being deposited, and as such mark a time when the lake again was fairly deep. Only remnants of the deposits of this stage of the lake are found as the wind has removed most of the material. The sand dunes to the east are largely the result of the material removed from sandy beds underlying this silt cap.

CONCLUSIONS

From the study that has been made of the sediments of the Fort Rock-Christmas Lake-Fossil Lake basin the following conclusions can be drawn:

1. A lake whose shores were at elevations of 4470 and 4520 feet stood within the basin for long periods of time. This meant 150 to 200 feet of water over much of the present floor.

2. The lower compact silts of the sediments were deposited in this deep lake.

3. The deep lake shrank to a size that was only a few feet deep and much reduced in area.

4. The upper loose sands of the sediments were deposited in a lake of shallow depth and smaller size.

5. The main mammal bone horizon is near the base of the upper sandy beds and the top of the lower silts.

6. The size medians of the sediments of the upper beds is between 1/4 and 1/16 mm.

7. The sediments on the whole are well sorted.

8. The materials of the sediments are mainly of volcanic origin.

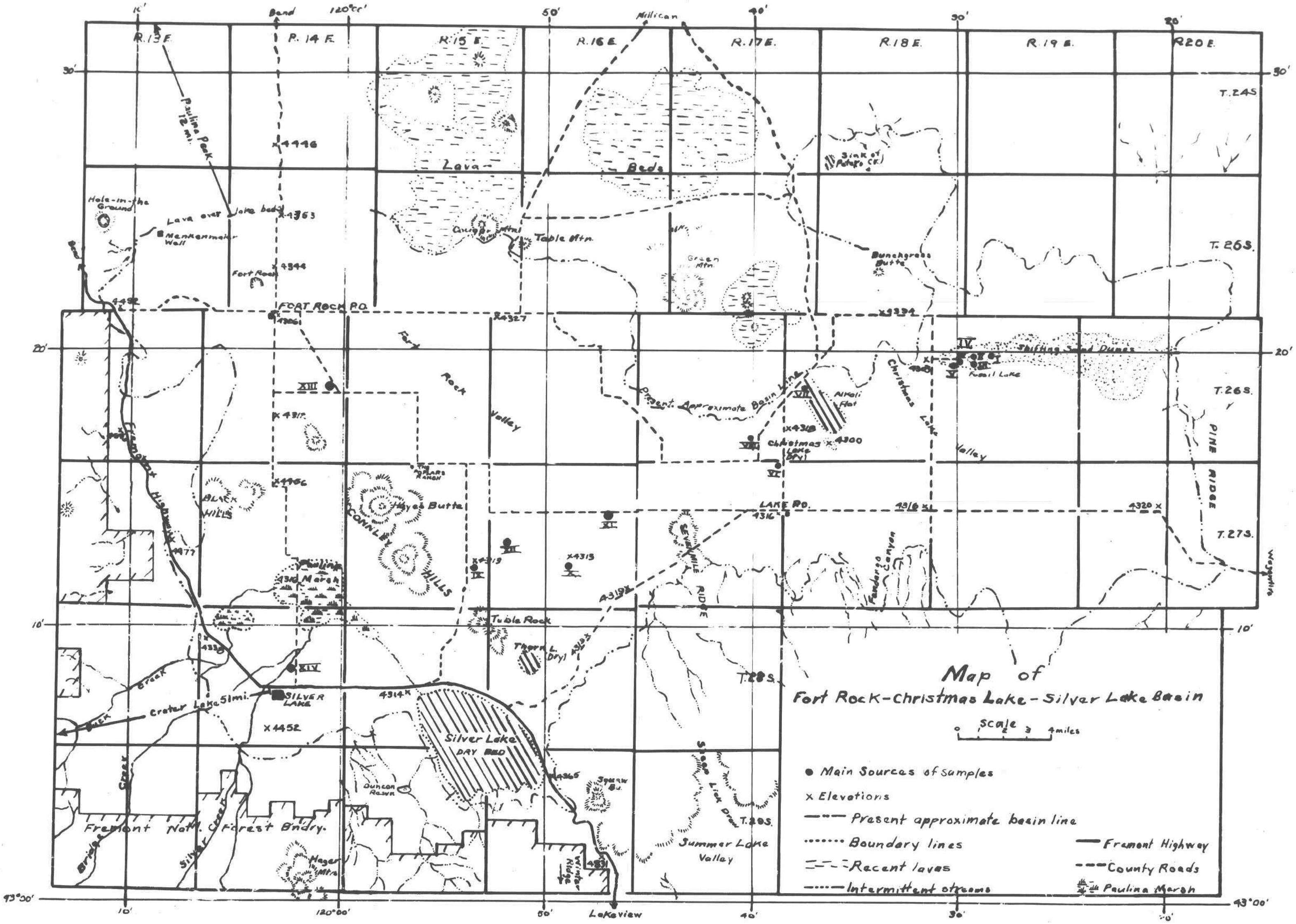
9. The bulk of the material of the sediments is volcanic glass.

10. The variety of the minerals in the sediments is

not great, and with one exception, all minerals are found in every sediment.

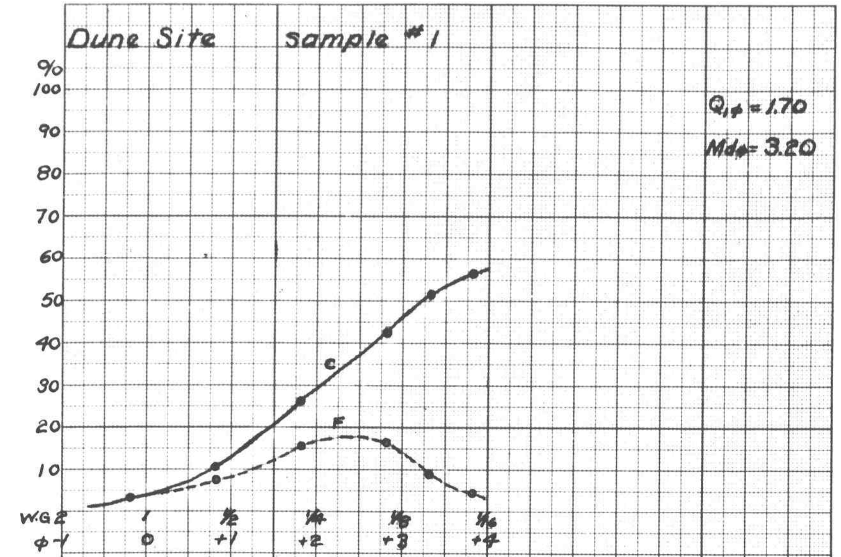
11. The similarity of the minerals of the sediments and the lower pumice layers of Arrow Sink to the pumice and minerals of the pumice from a definite Crater Lake source suggests that the origin of most of the materials of the sediments was Mt. Mazama.

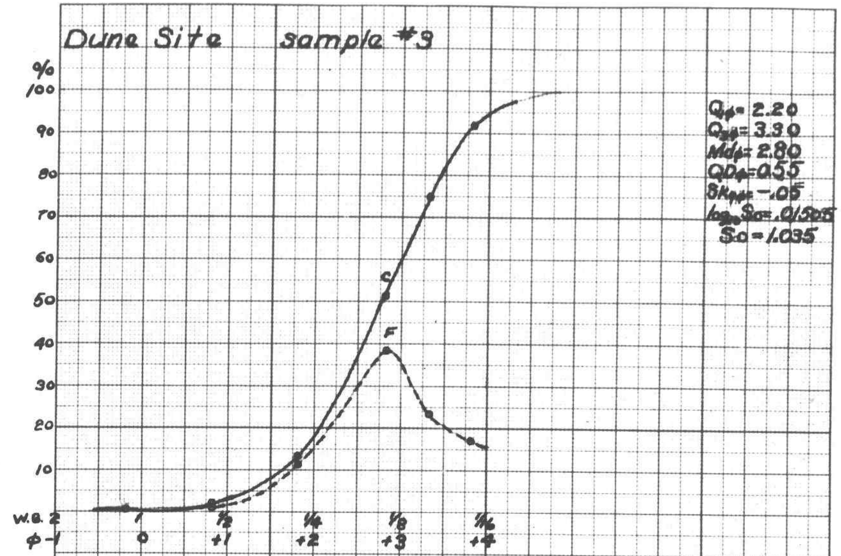
APPENDIX

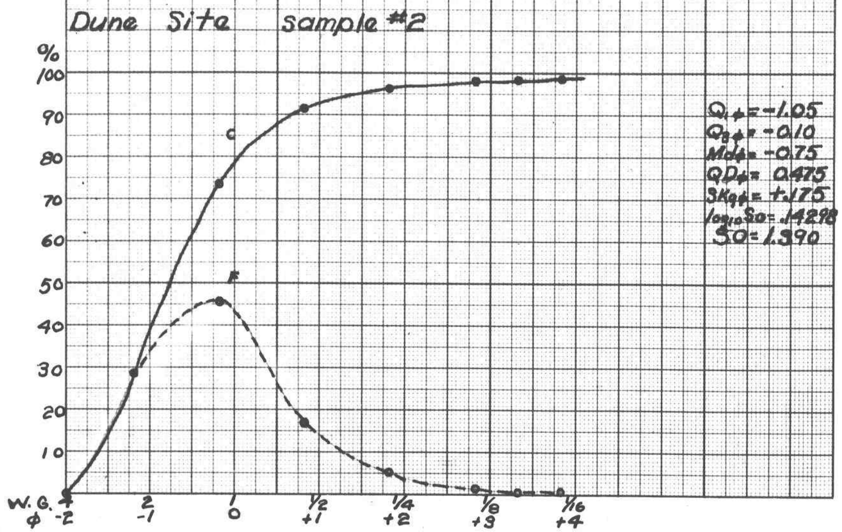

Map of
Fort Rock-Christmas Lake-Silver Lake Basin
Scale
4 miles
Main Sources of Samples
Elevations
Present approximate basin line
Boundary lines
Recent lavas
Intermittent streams
Fremont Highway
County Roads
Paulina Marsh
R.13 E.
R.14 E.
R.15 E.
R.16 E.
R.17 E.
R.18 E.
R.19 E.
R.20 E.
T.24 S.
T.25 S.
T.26 S.
T.27 S.
T.28 S.
Bend
Millican
Lakeview
Lava
Beds
Hole-in-the Ground
Lava over lake beds
Paulina Peak 12 mi.
Fort Rock
Fort Rock P.O.
Table Mtn.
Green Mtn.
Bunchgrass Butte
Sink of Pelage Cr.
Fort Rock Valley
Present Approximate Basin Line
Alkali Flat
Christmas Lake Valley
Christmas Lake Dry
Fossil Lake
Shifting Sand Dunes
Pine Ridge
Lake Rd.
Black Hills
Hayes Butte
Connley Hills
Paulina Marsh
Table Rock
Thorn L. Dry
Fremont Highway
Silver Lake
Silver Lake Dry Bed
Crater Lake 51 mi.
Duncan Reserv.
Squaw Bu.
Hager Mtn.
Fremont Natl. Forest Bndry.
Silver Creek
Summer Lake Valley
Sycan Marsh
Winter Ridge
Ponderosa Canyon
Egli Ranch
120°00'
43°30'
43°00'

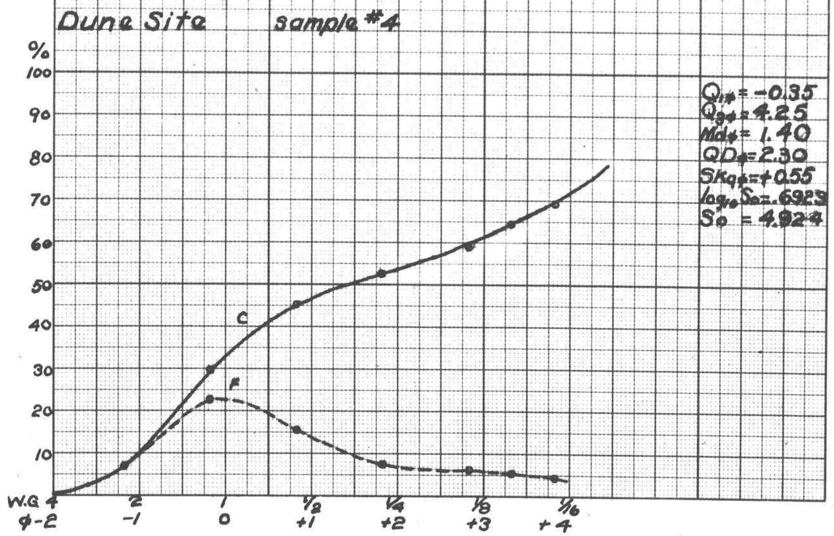
Analyses of Sediments

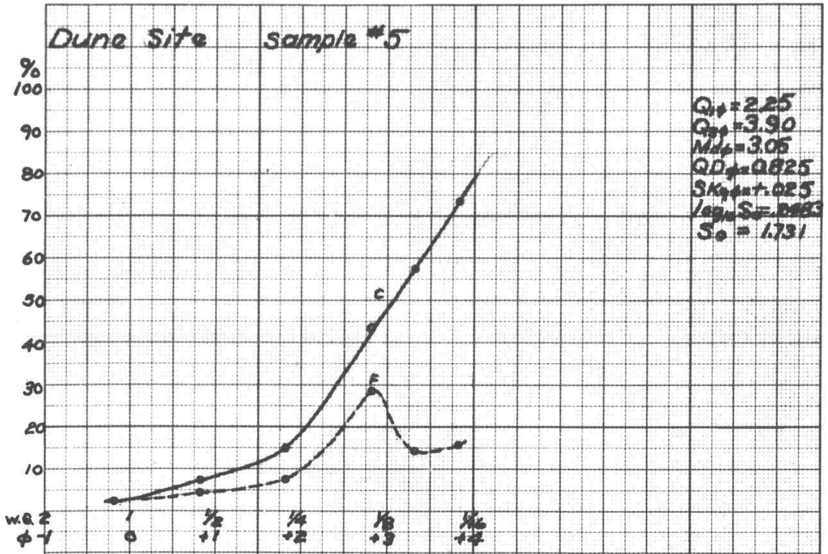
Sample No.	% of Rock Frag	% of Lk. Bed Frag	% of Glass	% of Feld.	% of Pyrox.	% of Mag.	% of Bio	% of Diatom	% of Other Fossils	Total %	Total Grains Counted		$Q_{1\phi}$	$Q_{3\phi}$	Md_{ϕ}	QD_{ϕ}	$Sk_{q\phi}$	$\log_{10} So$	So	Thickness of Bed	Name of Pit
1	4	13	60	17	2	2	0	1	1	100	500		1.70		3.20					22"+	Dune Pit - base
2	Lk. bed breccia												-1.05	-0.10	-0.75	0.48	+.175	.1430	1.390	21"	"
3	1	4	42	42	5	2	trace	trace	4	100	525		2.20	3.30	2.80	0.55	-.05	.1656	1.464	1½"	"
4	LK bed breccia												-0.35	4.25	1.40	2.30	+.55	.6923	4.924	6"	"
5	trace	12	53	23	2	1	3	2	4	100	400		2.25	3.90	3.05	0.83	+.025	.2483	1.771	2"	"
6	trace	10	51	30	3	1	2	trace	3	100	500		2.15	3.60	2.85	0.725	-.025	.2182	1.653	15"	"
7	trace	3	50	33	4	5	1	trace	4	100	600		2.20	3.35	2.70	0.575	+.075	.1731	1.490	5"	"
8	Lk. bed breccia												0.05	3.05	1.20	1.50	+.35	.4515	2.83	13"	" surface at base of hillock
9	trace	2	65	27	3	2	trace	trace	1	100	500		2.55	3.45	3.10	0.45	-.10	.1355	1.366	31"	"
10	0	0	80	18	trace	trace	0	2	0	100	365		Volcanic ash - 91.4% thru -200 mesh							2"	"
11	trace	trace	65	28	2	5	0	trace	0	100	375		2.50	3.35	2.90	0.425	-.025	.1279	1.343	32"	" under cover
12	trace	trace	54	40	3	3	trace	trace	trace	100	800		2.15	3.05	2.60	0.45	0.00	.1355	1.366	20"±	Dune Sand
13	trace	1	61	30	5	3	0	trace	trace	100	400		2.60	3.60	3.30	0.50	-.20	.1505	1.414	6"	South End of Fossil Lake
14	1	35	47	14	2	2	0	trace	0	101	400		2.15		3.85					4"	"
15	0	0	58	25	2	trace	0	15	0	100	est.		compact silt - not screened							24"±	"
16	1	7	30	47	9	6	0	0	0	100	920		1.80	3.30	2.40	0.75	+.15	.2258	1.682	9"	Bird Bone Site Pit
17	0	54	35	10	1	1	0	trace	trace	101	400		-0.95	3.40	1.20	2.175	+.025	.6547	4.515	8"	"
18	trace	1	78	16	2	trace	0	2	1	100	400		2.85	4.10	3.45	0.625	+.025	.1882	1.542	5½"	"
19	trace	7	36	43	5	9	0	trace	trace	100	967		2.35	3.30	2.90	0.475	-.075	.1430	1.390	8"	"
20	5	23	31	26	6	4	0	4	trace	99	1027		0.85	3.15	2.00	1.15	0.00	.3462	2.219	4"±	"
21	trace	3	67	21	2	1	0	1	5	100	425		2.05	3.75	3.15	0.85	-.25	.2559	1.802	27"±	"
22	Fine lake bed conglomerate												not screened							10"	Elephant Site Pit
23	0	0	78	10	3	trace	0	7	2	100	est.		compact silt - not screened							?	"
24	3	39	31	20	3	1	0	1	2	100	626		1.45	3.85	2.55	1.20	+.10	.361	2.297	2"	South West Pit
25	1	3	19	53	10	13	0	1	trace	100	390		1.65	2.70	2.15	0.525	+.025	.1580	1.439	3"	"
26	1	19	43	27	4	1	0	1	3	99	628		1.60	4.00	2.65	1.20	+.15	.3612	2.297	15"	"
27	4	14	53	24	2	1	0	3	trace	101	683		2.55	3.95	3.40	0.70	-.15	.2107	1.624	1"+	"
28	trace	9	41	37	6	2	0	4	trace	99	1125		2.15	3.25	2.75	0.55	-.05	.1656	1.464	3"	"
29	1	5	58	31	5	1	0	trace	trace	101	678		2.75	4.35	3.40	0.80	+.15	.2408	1.741	74"±	"
30	trace	1	82	4	trace	trace	0	10	3	100	325		2.35		3.65					3"	2 Mi. North of Lake Pit
31	trace	3	7	19	2	trace	0	3	3	100	425		1.80	3.70	3.00	0.95	-.25	.286	1.932	13"	"
32	1	10	64	9	2	1	0	7	6	100	419		1.35		2.85					14½"	"
33	5	4	47	39	4	1	0	0	0	100	400		1.40	3.05	2.20	0.825	+.025	.2483	1.771	2½"	"
34	2	2	52	36	5	2	0	trace	0	99	425		1.65	3.20	2.45	0.775	-.025	.2333	1.751	22"	"
35	Mineralized crust, mostly granules of basalt & lk. bed												not screened							1"±	
36	Lk bed breccia												not screened							5"±	Alkali Flat Pit
37	0	0	60	30	8	2	0	trace	0	100	est.		not screened							22"	"
38	2	7	58	26	6	1	0	trace	0	100	400		1.25	3.45	2.45	1.10	-.10	.3311	2.143	6"	"
39	0	0	80	15	2	trace	0	3	0	100	est.		not screened							15"	"
40	0	0	70	20	10	trace	0	trace	0	100	est.		not screened							10"	"
41	0	0	39	43	11	7	0	trace	0	100	420		not screened							8"	"
42	0	0	60	9	1	0	0	30	0	100	est.		not screened							33"	"
43	10	5	45	35	6	trace	0	0	0	101	400		1.20	2.75	2.20	0.775	-.225	.2333	1.751	27"	West of ZX Well Pit
44	0	0	56	34	7	3	0	trace	0	100	307		3.45		3.85					16"	"
45	Lk bed conglomerate												not screened							?	"
46	Top soil												0.30	2.30	1.05	1.00	+.25	.301	2.00	36"	Arrow Sink cut
47	Pebble Pumice bed.												pieces of pumice up to 3½"							27"	"
48	2	11	79	7	1	trace	0	0	0	100	400		-0.35	1.60	0.40	0.975	+.225	.2935	1.965	3"	"
49	2	9	81	7	trace	trace	0	trace	0	99	433		-0.15	2.40	1.05	1.325	+.075	.3988	2.505	2"	"
50	Mineral afflorasence																				
51	2	5	43	39	6	1	0	3	trace	99	461		1.45	3.10	2.15	0.825	+.125	.248	1.771	72"±	Arrow Sink Pit
52	Mineral salt crack filling in #56												not screened								"
53	0	0	90	8	trace	trace	0	2	0	100	est		compact silt - not screened							38"	"
54	8	4	60	25	trace	trace	0	3	0	100	est		sandy seam - not screened							1"	"
55	10	6	52	20	1	1	0	10	0	100	est		sandy seam - not screened							1½"	"
56	0	0	50	20	trace	trace	0	30	0	100	est.		compact silt - not screened							46"	"
57	0	0	40	25	trace	trace	0	35	0	100	est		compact silt - not screened							4"	"
58	0	0	35	5	trace	trace	0	60	0	100	est.		compact sitt - not screened							40"	"
59	Pebble Pumice bed													1.65	-1.50					18"	"
60	0	0	67	12	1	1	0	19	0	100	est.		silicified silt - not screened							5"	"
61	0	0	38	20	5	2	0	35	0	100	est.		sand & silt layer - not screened							8"	"
62	trace	2	27	8	3	trace	0	60	0	100	est		compact silt - not screened							76"	"
63	25	2	56	12	2	2	0	1	0	100	453		-0.65	1.50	0.20	1.075	+.225	.3236	2.106	13"	"
64	0	0	33	5	1	1	0	60	0	100	est.		compact silt - not screened							?	"
65	0	0	94	5	1	trace	0	0	0	100	400										Four Mile Sink - pumice dike
66	0	0	43	7	trace	trace	0	50	0	100	est										"
67	0	0	10	5	trace	trace	0	85	0	100	est.										"
68	Sand dike - thin section showed material to be principally glass with few mineral grains of plag feld.																				"
69	0	0	12	3	trace	trace	0	85	0	100	est.		compact silt - not screened								Well Dump - 9.7 mi. E. of Poplars
70	22	42	29	7	trace	trace	0	0	0	100	385		Lk. bed conglomerate - not screened							44"	Well 3 mi. N.E. of Arrow Sk.
71	0	0	30	9	1	trace	0	60	0	100	est.		compact silt - not screened							?	"
72	0	0	5	trace	trace	trace	0	95	0	100	est.		compact silt - not screened								N.E. corner of Connley Hill
73	Very fine silt (clay?)												not screened							1/16"- 1/4	Race Track Flat Pit
74		ditto											not screened							1¾"	"
75	Lk. bed breccia												not screened							30"	"
76	39	15	36	8	2	1	0	0	0	101	400		-1.75	2.10	-.50	1.925	+.675	.5794	3.797	?	"
77	1	5	62	30	2	trace	0	trace	0	100	400		1.60	3.15	2.25	0.775	+.125	.233	1.711		Silver Lake gravel pit
78	0	0	40	30	8	8	0	14	0	100	est.		not screened								" " " "

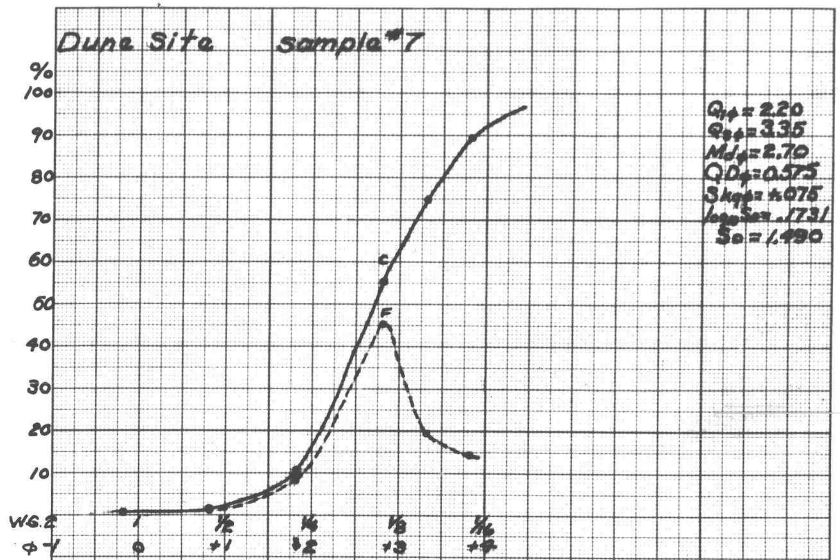

Dune Site sample #1
Q1φ = 1.70
Mdφ = 3.20
C
F

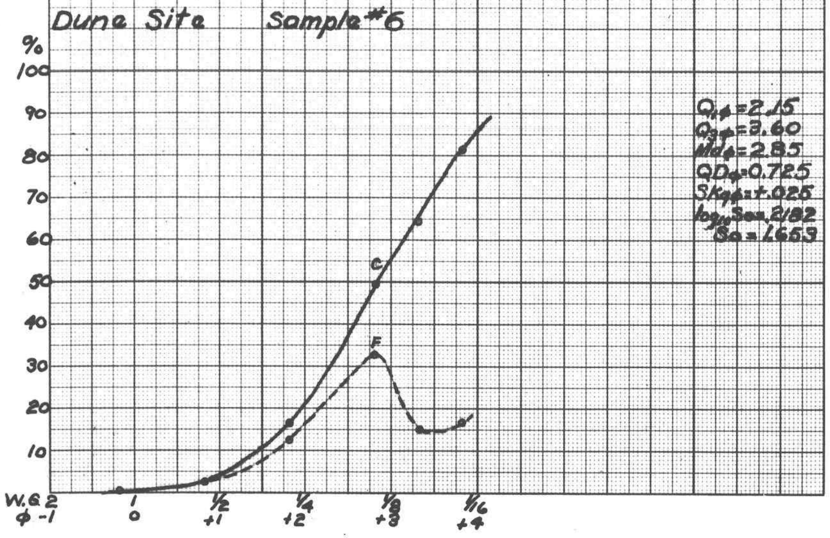

Dune Site sample #3
Q1φ = 2.20
Q3φ = 3.30
Mdφ = 2.80
QDφ = 0.55
Skqφ = -.05
log10 So = .01505
So = 1.035
C
F

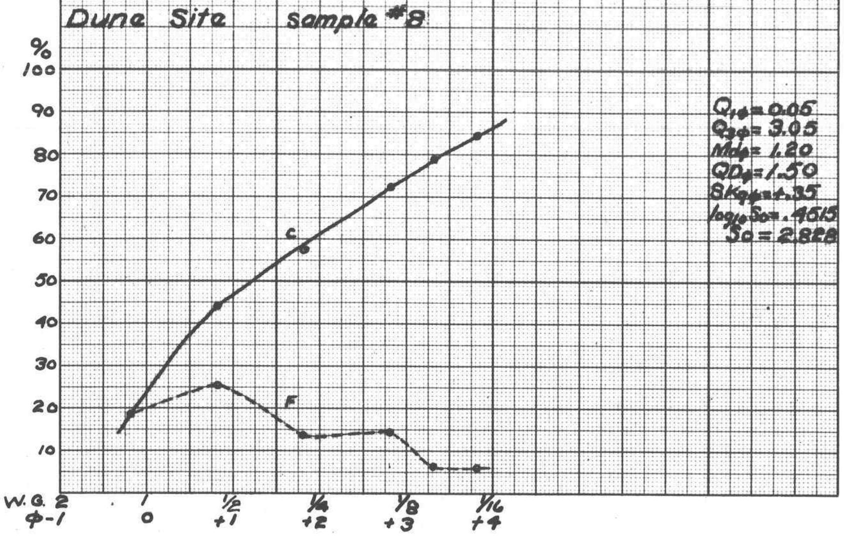

Dune Site sample #2
Q1φ = -1.05
Q3φ = -0.10
Mdφ = -0.75
QDφ = 0.475
Skqφ = +.175
log10 So = .14298
So = 1.390
C
F

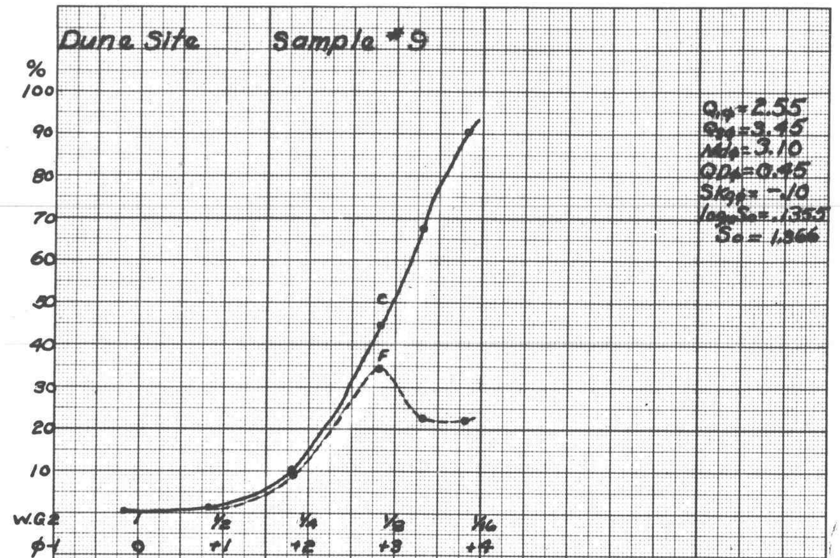

Dune Site sample #4
Q1φ = -0.35
Q3φ = 4.25
Mdφ = 1.40
QDφ = 2.30
Skqφ = +0.55
log10 So = .6923
So = 4.924
C
F

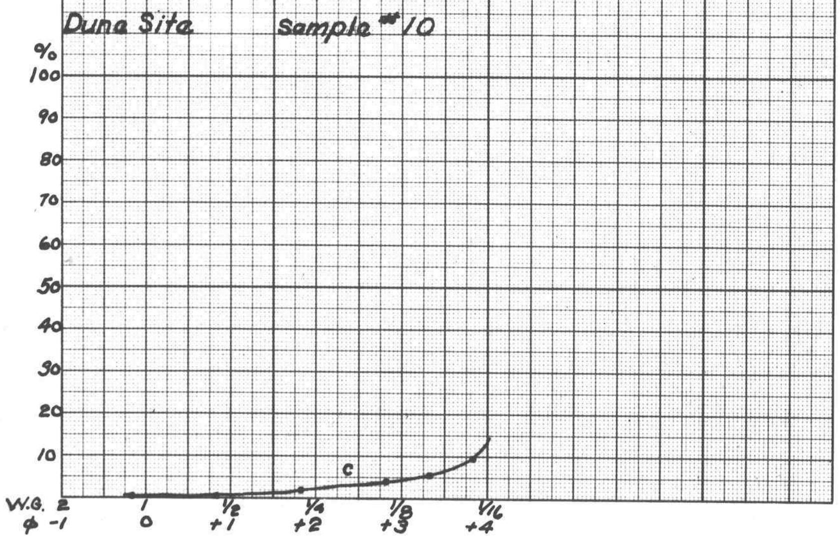

Dune Site sample #5
%
Q1φ=2.25
Q3φ=3.90
Mdφ=3.05
QDφ=0.825
Skqφ=+.025
So = 1.731
C
F
W.G. 2
φ -1

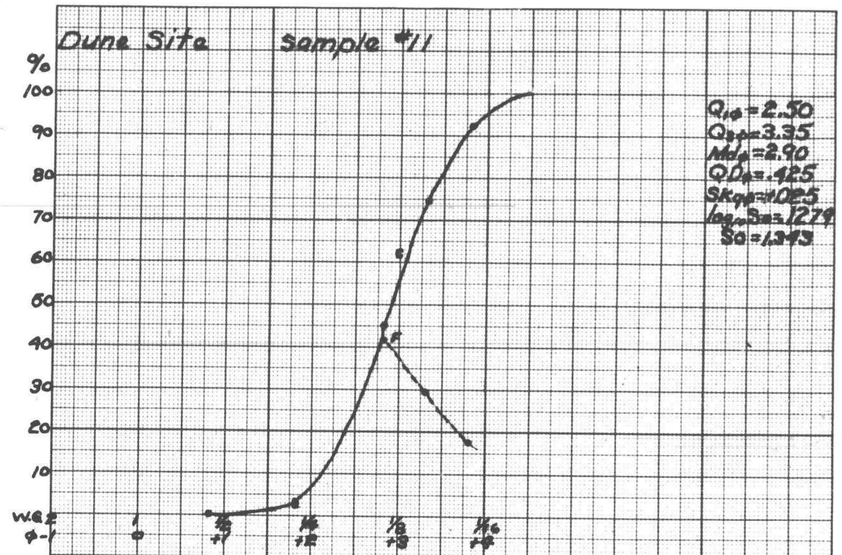

Dune Site sample #7
%
Q1φ= 2.20
Q3φ=3.35
Mdφ=2.70
QDφ=0.575
Skqφ= +.075
log10 So= .1731
So = 1.490
C
F
W.G. 2
φ -1

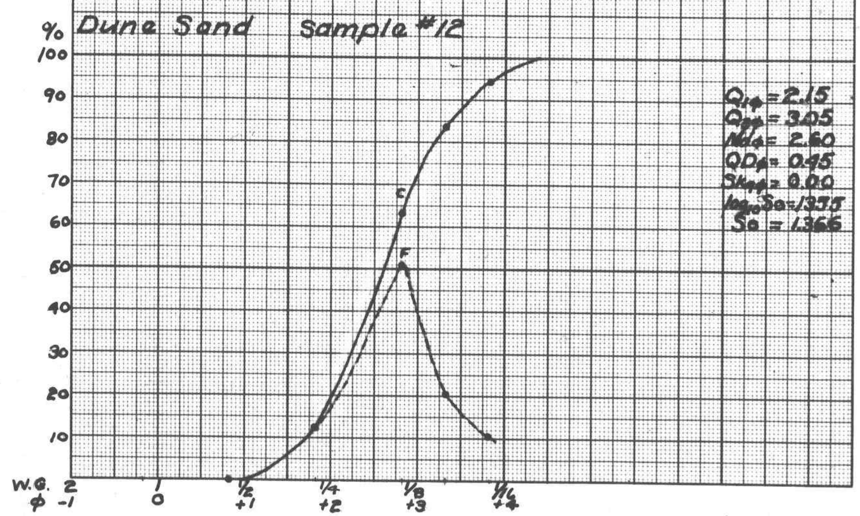

Dune Site Sample #6
%
Q1φ=2.15
Q3φ=3.60
Mdφ=2.85
QDφ=0.725
Skqφ=+.025
log10 So=.2182
So=1.653
C
F
W.G. 2
φ -1

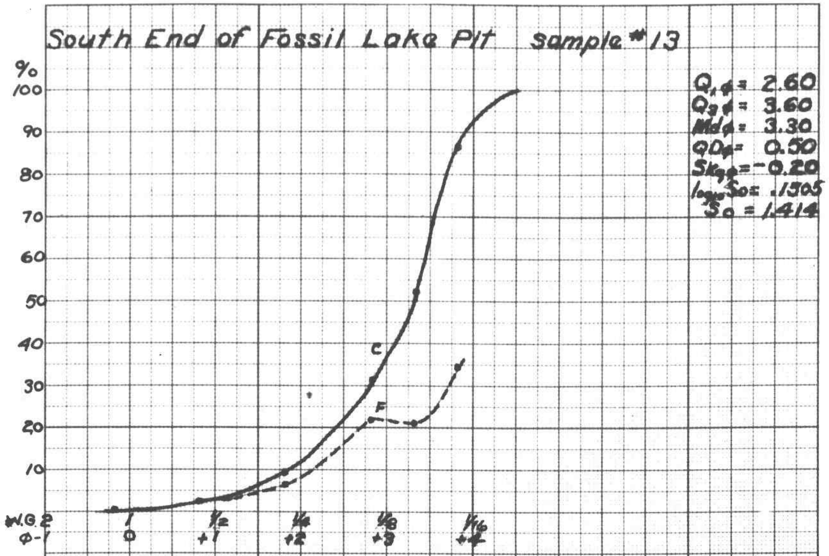

Dune Site sample #8
%
Q1φ= 0.05
Q3φ= 3.05
Mdφ= 1.20
QDφ=1.50
Skqφ=+.35
log10 So= .4515
So = 2.828
C
F
W.G. 2
φ -1

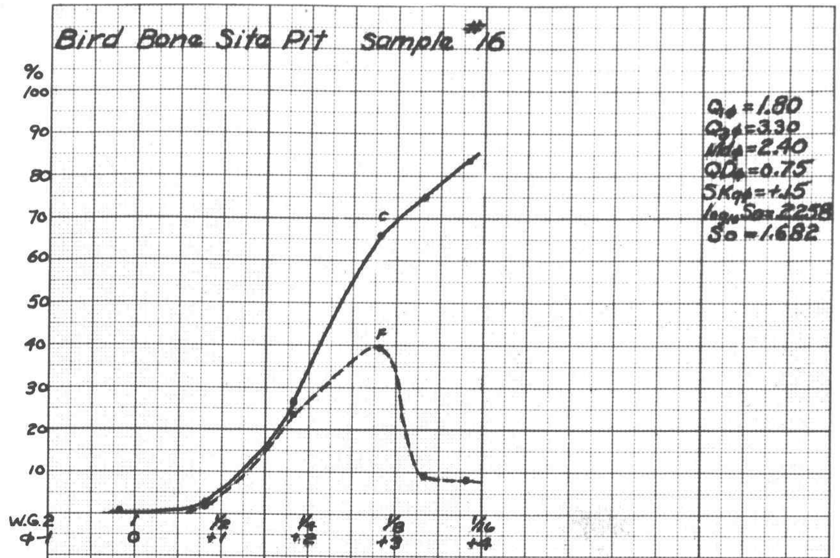

Dune Site Sample #9
%
100
90
80
70
60
50
40
30
20
10
$Q_{1\phi}$ = 2.55
$Q_{3\phi}$ = 3.45
Md_ϕ = 3.10
QD_ϕ = 0.45
Skq_ϕ = -.10
$\log_{10} So$ = .1355
So = 1.366
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

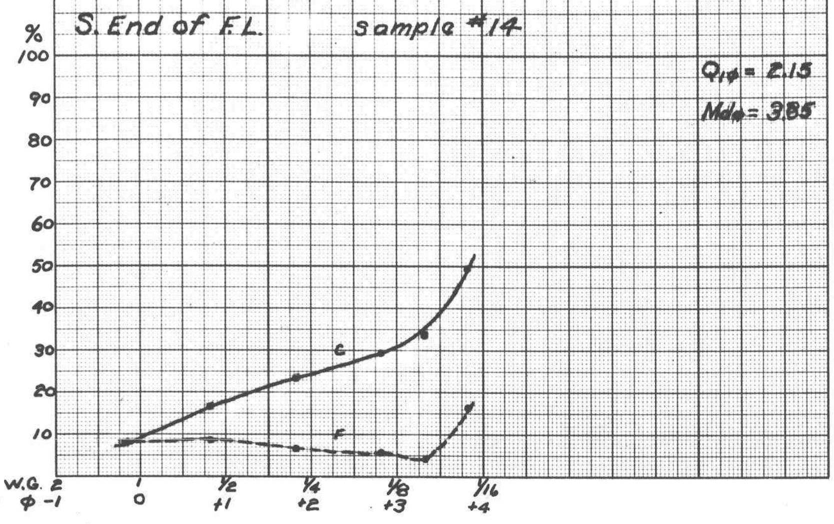

Dune Site Sample #10
%
100
90
80
70
60
50
40
30
20
10
C
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

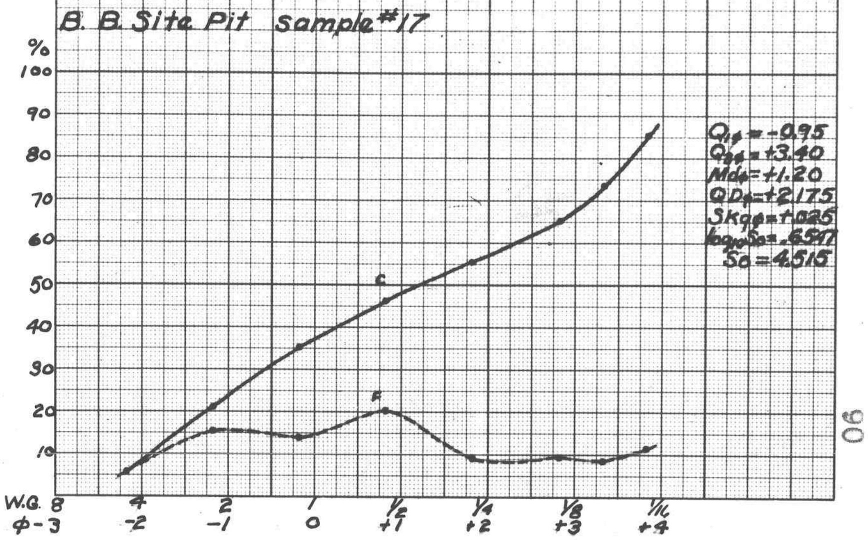

Dune Site Sample #11
%
100
90
80
70
60
50
40
30
20
10
$Q_{1\phi}$ = 2.50
$Q_{3\phi}$ = 3.35
Md_ϕ = 2.90
QD_ϕ = .425
Skq_ϕ = +.025
$\log_{10} So$ = .1279
So = 1.343
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

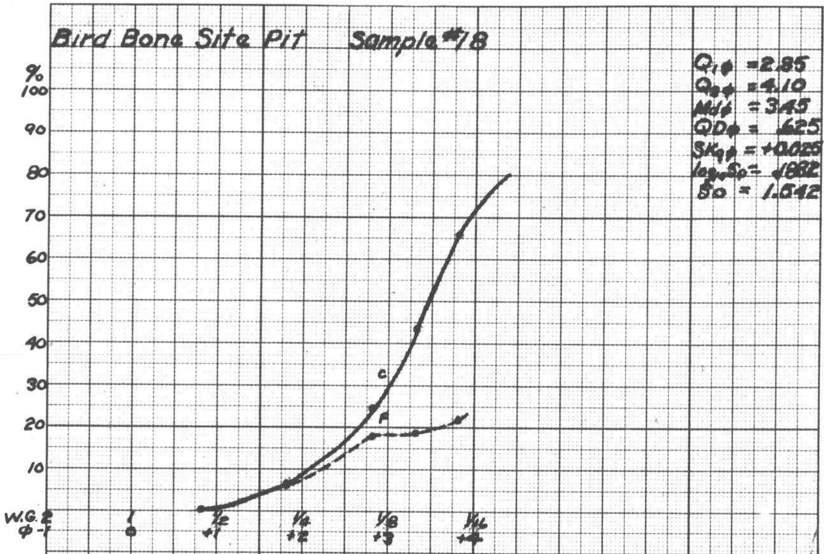

Dune Sand Sample #12
%
100
90
80
70
60
50
40
30
20
10
$Q_{1\phi}$ = 2.15
$Q_{3\phi}$ = 3.05
Md_ϕ = 2.60
QD_ϕ = 0.45
Skq_ϕ = 0.00
$\log_{10} So$ = .1355
So = 1.366
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

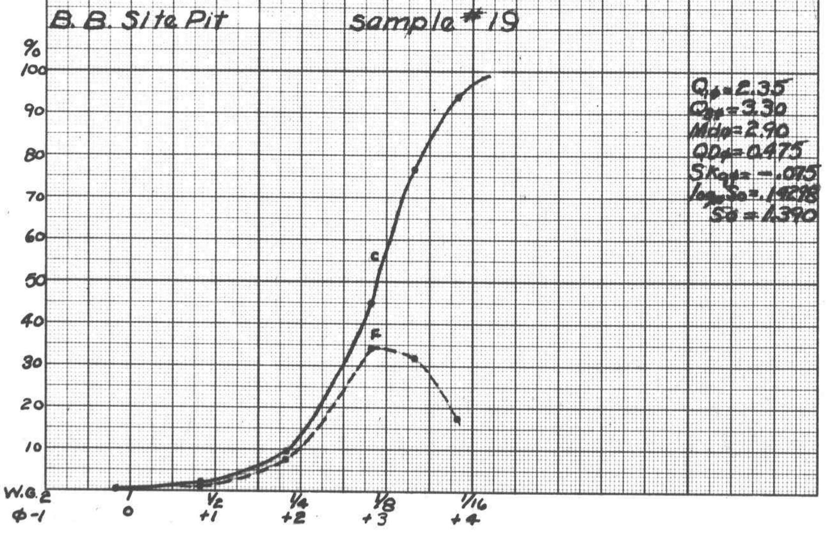

South End of Fossil Lake Pit sample #13
$Q_{1\phi}$ = 2.60
$Q_{3\phi}$ = 3.60
Md_{ϕ} = 3.30
QD_{ϕ} = 0.50
$Sk_{q\phi}$ = -0.20
$\log_{10} So$ = .1505
So = 1.414
%
100
90
80
70
60
50
40
30
20
10
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

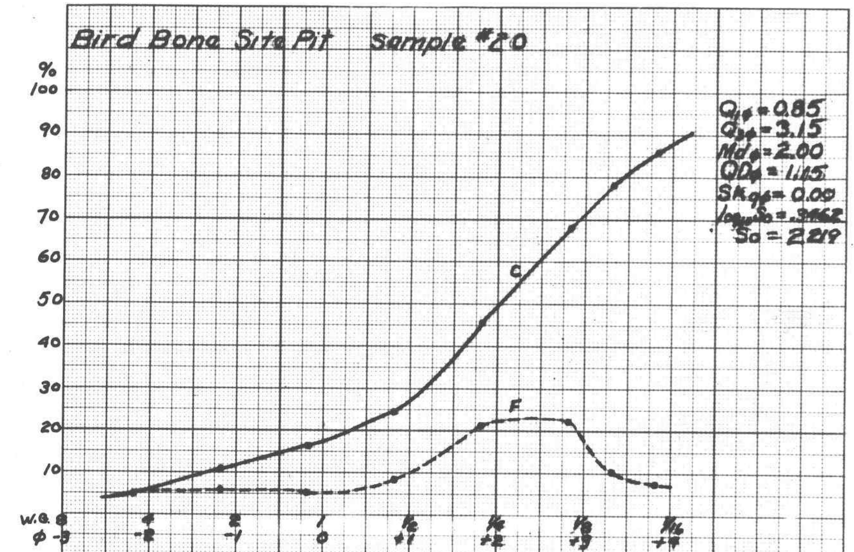

Bird Bone Site Pit sample #16
$Q_{1\phi}$ = 1.80
$Q_{3\phi}$ = 3.30
Md_{ϕ} = 2.40
QD_{ϕ} = 0.75
$Sk_{q\phi}$ = +.15
$\log_{10} So$ = .2258
So = 1.682
%
100
90
80
70
60
50
40
30
20
10
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

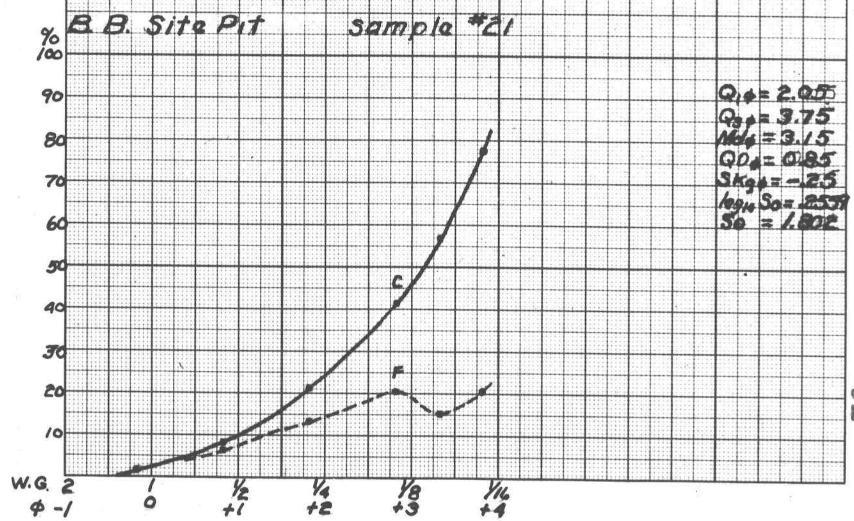

S. End of F.L. sample #14
$Q_{1\phi}$ = 2.15
Md_{ϕ} = 3.85
%
100
90
80
70
60
50
40
30
20
10
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

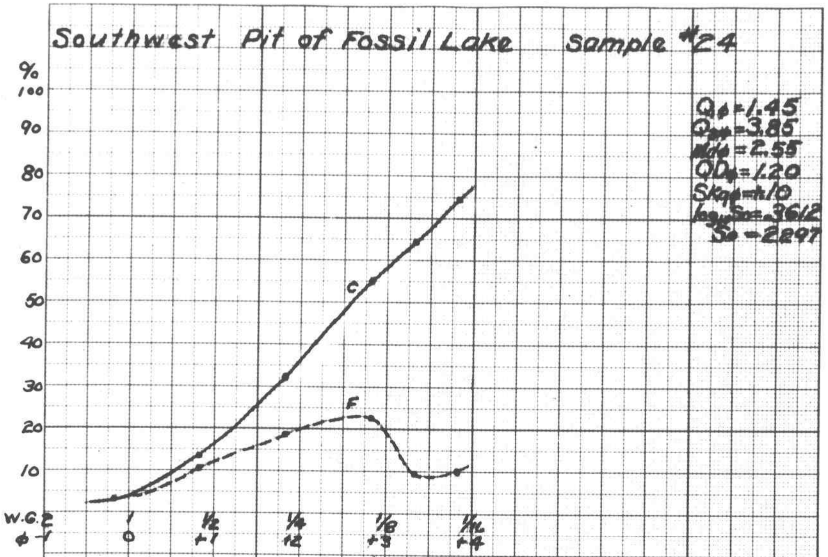

B. B. Site Pit sample #17
$Q_{1\phi}$ = -0.95
$Q_{3\phi}$ = +3.40
Md_{ϕ} = +1.20
QD_{ϕ} = +2.175
$Sk_{q\phi}$ = +.025
$\log_{10} So$ = .6547
So = 4.515
%
100
90
80
70
60
50
40
30
20
10
C
F
W.G. 8 4 2 1 1/2 1/4 1/8 1/16
φ -3 -2 -1 0 +1 +2 +3 +4

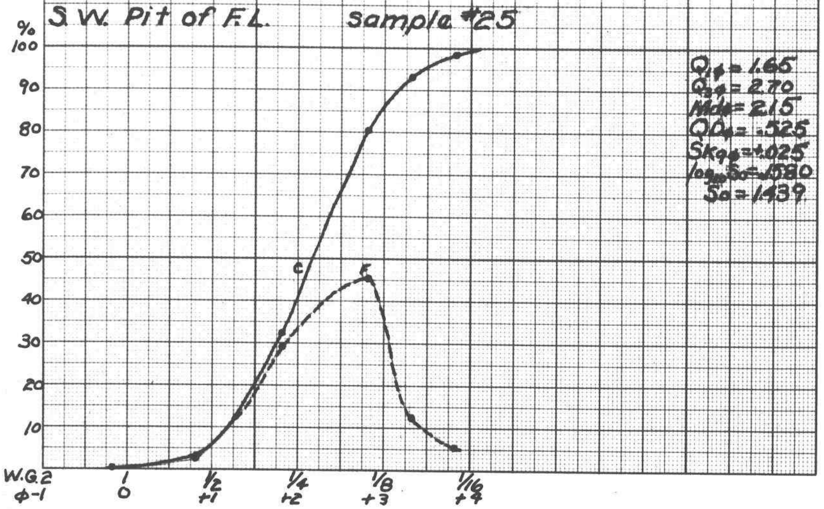

Bird Bone Site Pit Sample #18
Q1φ = 2.85
Q3φ = 4.10
Mdφ = 3.45
QDφ = .625
Skqφ = +0.025
log10 So = .1882
So = 1.542
%
W.G.
φ

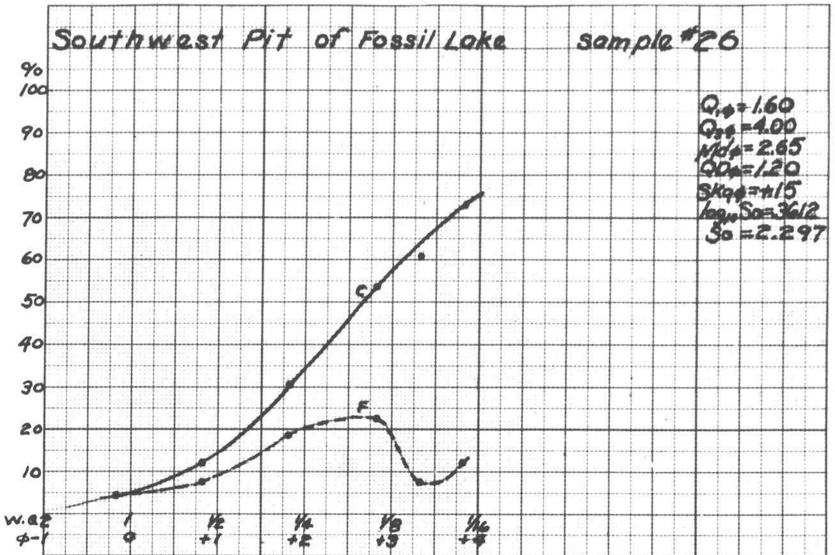

B. B. Site Pit sample #19
Q1φ = 2.35
Q3φ = 3.30
Mdφ = 2.90
QDφ = 0.475
Skqφ = -.075
log10 So = .1428
So = 1.390
%
W.G.
φ

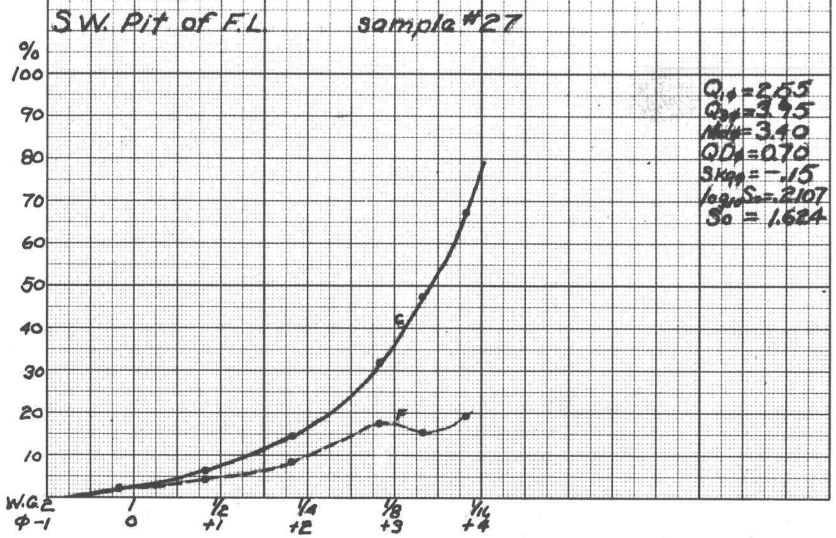

Bird Bone Site Pit sample #20
Q1φ = 0.85
Q3φ = 3.15
Mdφ = 2.00
QDφ = 1.15
Skqφ = 0.00
log10 So = .3462
So = 2.219
%
W.G.
φ

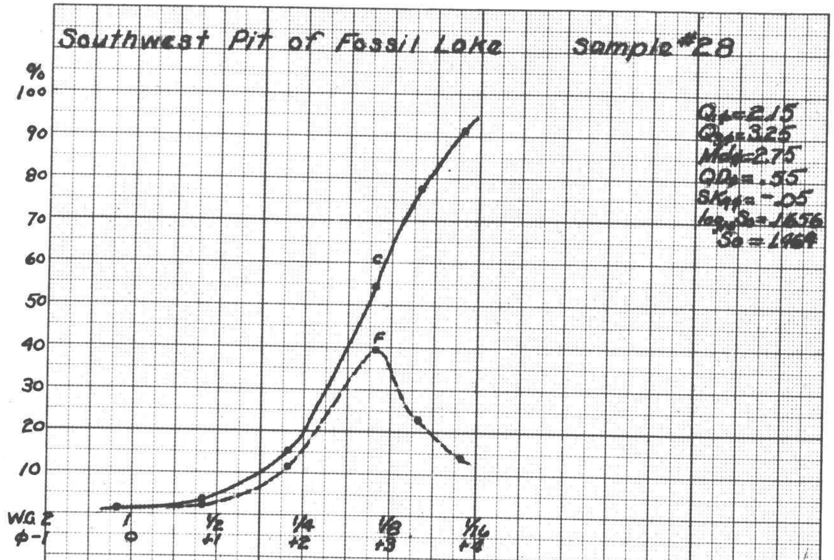

B. B. Site Pit Sample #21
Q1φ = 2.05
Q3φ = 3.75
Mdφ = 3.15
QDφ = 0.85
Skqφ = -.25
log10 So = .2559
So = 1.802
%
W.G.
φ

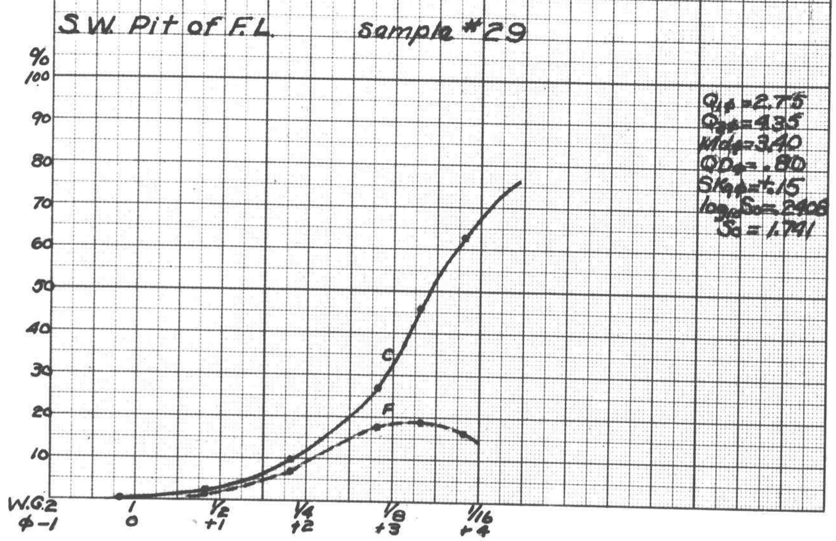

Southwest Pit of Fossil Lake sample #24
$Q_{1\phi}$=1.45
$Q_{3\phi}$=3.85
Md_ϕ=2.55
QD_ϕ=1.20
Skq_ϕ=+.10
$\log_{10}So$=.3612
So=2.297
C
F
W.G.2
φ-1

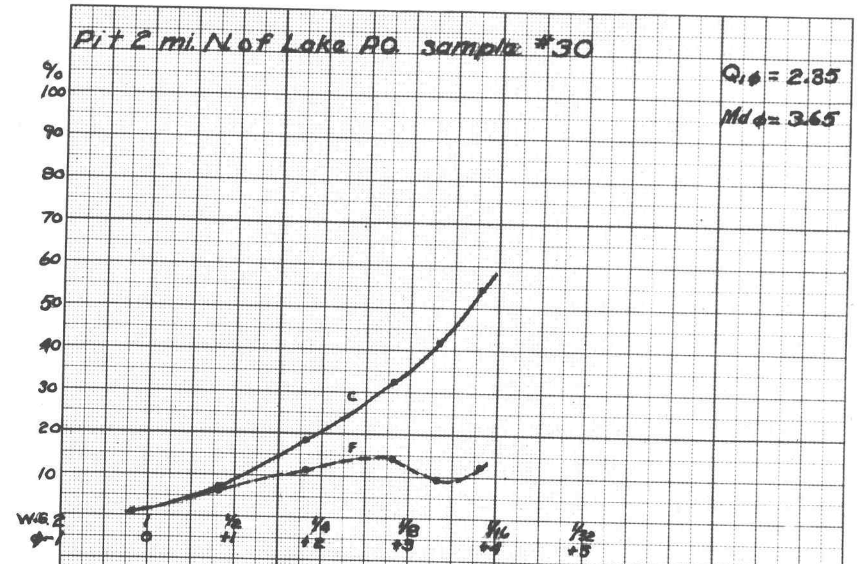

S.W. Pit of F.L. sample #25
$Q_{1\phi}$=1.65
$Q_{3\phi}$=2.70
Md_ϕ=2.15
QD_ϕ=.525
Skq_ϕ=+.025
$\log_{10}So$=.1580
So=1.439
C
F
W.G.2
φ-1

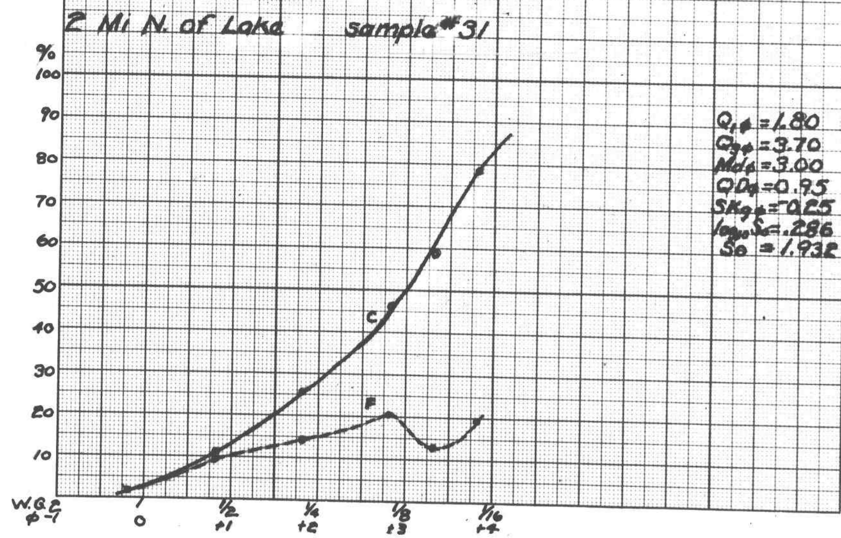

Southwest Pit of Fossil Lake sample #26
$Q_{1\phi}$=1.60
$Q_{3\phi}$=4.00
Md_ϕ=2.65
QD_ϕ=1.20
Skq_ϕ=+.15
$\log_{10}So$=.3612
So=2.297
C
F
W.G.2
φ-1

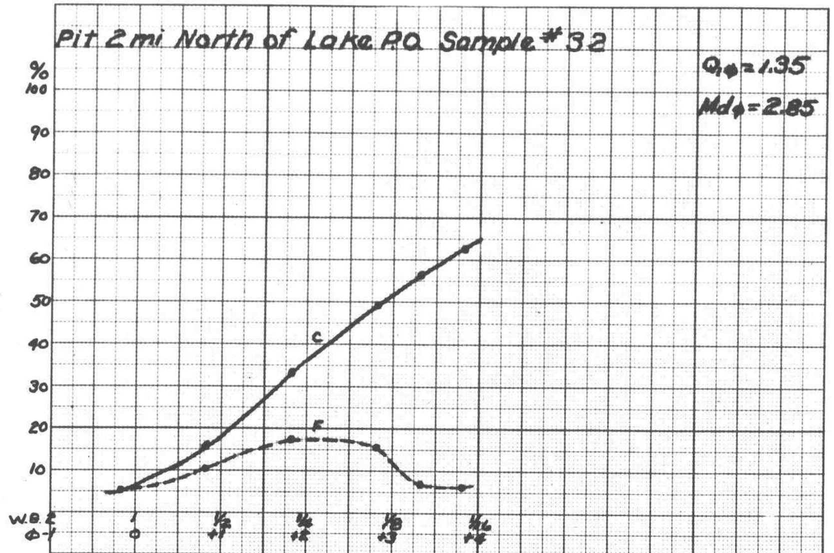

S.W. Pit of F.L. sample #27
$Q_{1\phi}$=2.55
$Q_{3\phi}$=3.95
Md_ϕ=3.40
QD_ϕ=0.70
Skq_ϕ=−.15
$\log_{10}So$=.2107
So=1.624
C
F
W.G.2
φ-1

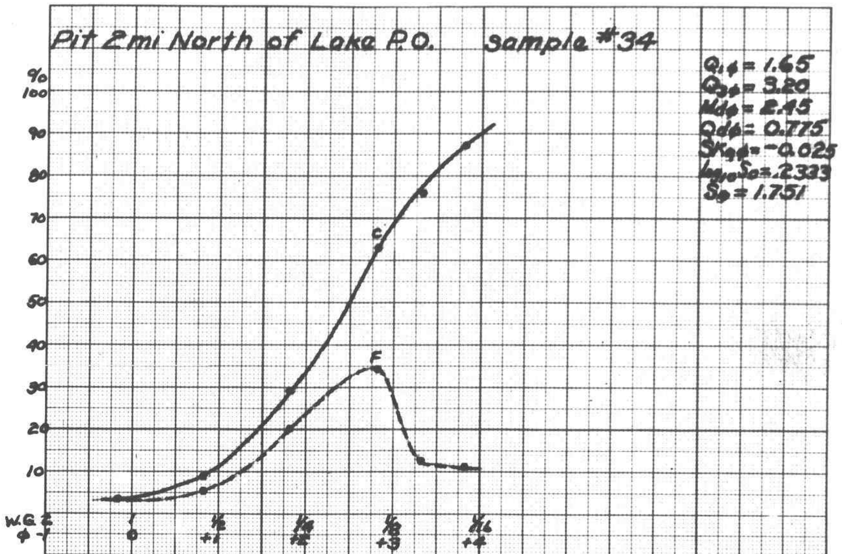

Southwest Pit of Fossil Lake sample #28
Q1φ = 2.15
Q3φ = 3.25
Mdφ = 2.75
QDφ = .55
Skqφ = -.05
log10 So = .1656
So = 1.464
W.G.2
φ -1
C
F

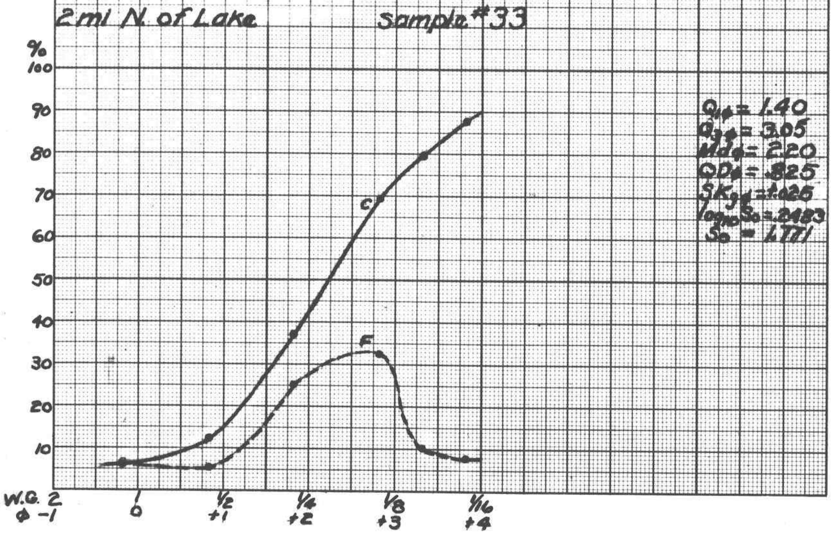

S.W. Pit of F.L. sample #29
Q1φ = 2.75
Q3φ = 4.35
Mdφ = 3.40
QDφ = .80
Skqφ = +.15
log10 So = .2408
So = 1.741
W.G.2
φ -1
C
F

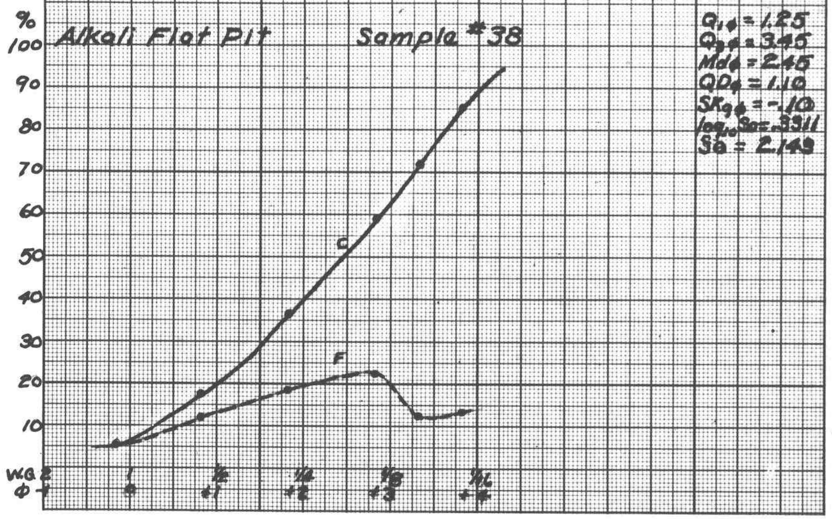

Pit 2 mi. N of Lake P.O. sample #30
Q1φ = 2.85
Mdφ = 3.65
W.G.2
φ -1
C
F

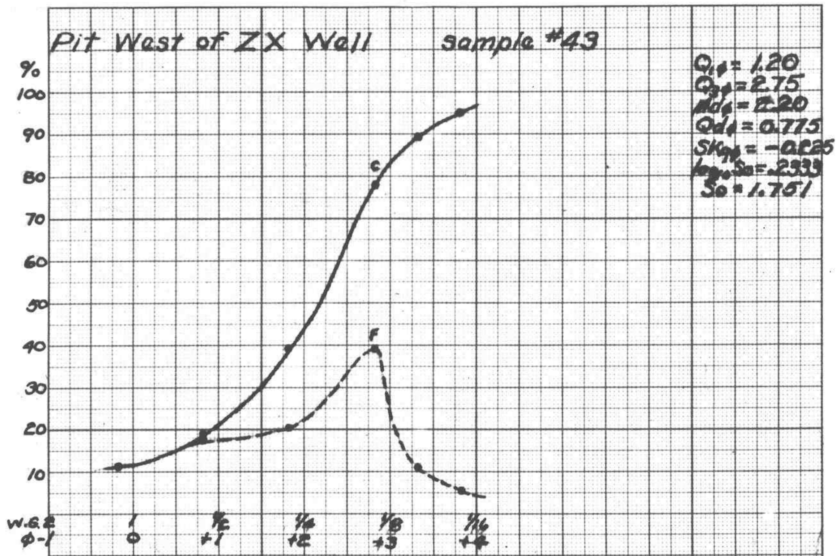

2 Mi N. of Lake sample #31
Q1φ = 1.80
Q3φ = 3.70
Mdφ = 3.00
QDφ = 0.95
Skqφ = -0.25
log10 So = .286
So = 1.932
W.G.2
φ -1
C
F

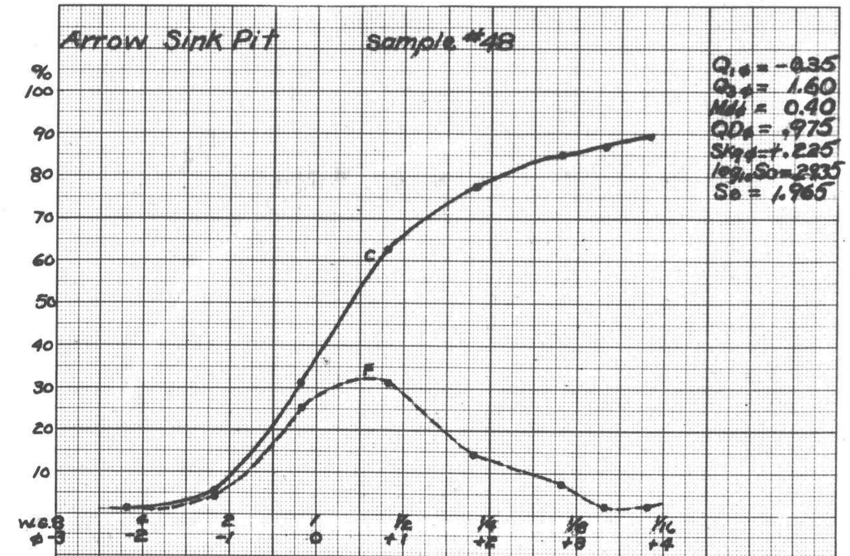

Pit 2 mi North of Lake P.O. Sample #32
$Q_{1\phi}$ = 1.35
Md_ϕ = 2.85
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

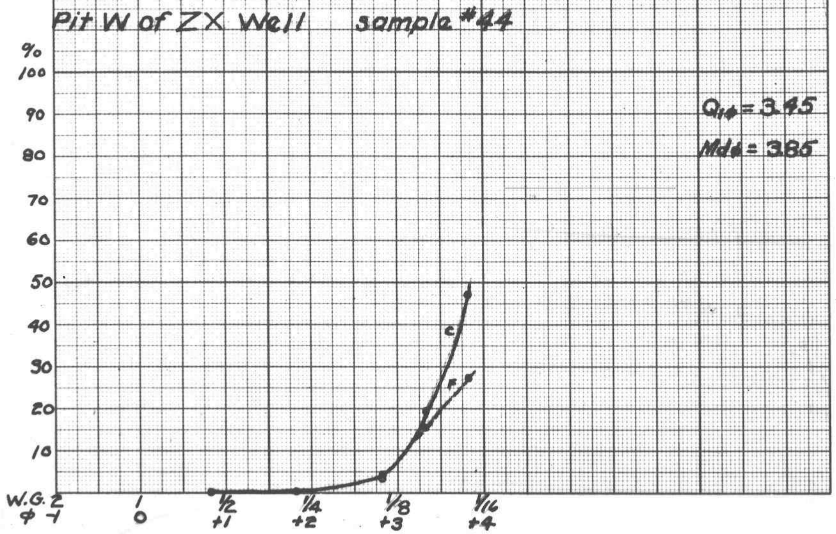

Pit 2 mi North of Lake P.O. Sample #34
$Q_{1\phi}$ = 1.65
$Q_{3\phi}$ = 3.20
Md_ϕ = 2.45
Qd_ϕ = 0.775
$Sk_{q\phi}$ = -0.025
$\log_{10} S_o$ = .2333
S_o = 1.751
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

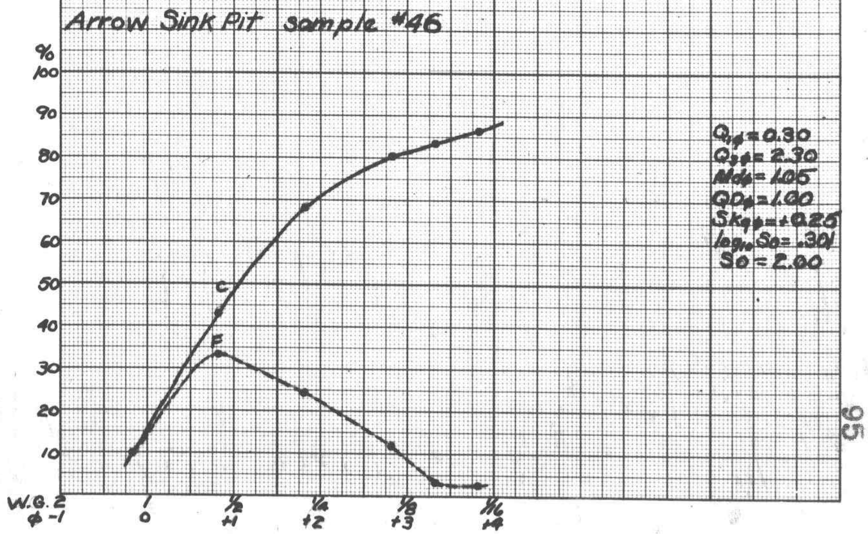

2 mi N. of Lake Sample #33
$Q_{1\phi}$ = 1.40
$Q_{3\phi}$ = 3.05
Md_ϕ = 2.20
QD_ϕ = .825
$Sk_{q\phi}$ = .025
$\log_{10} S_o$ = .2483
S_o = 1.771
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

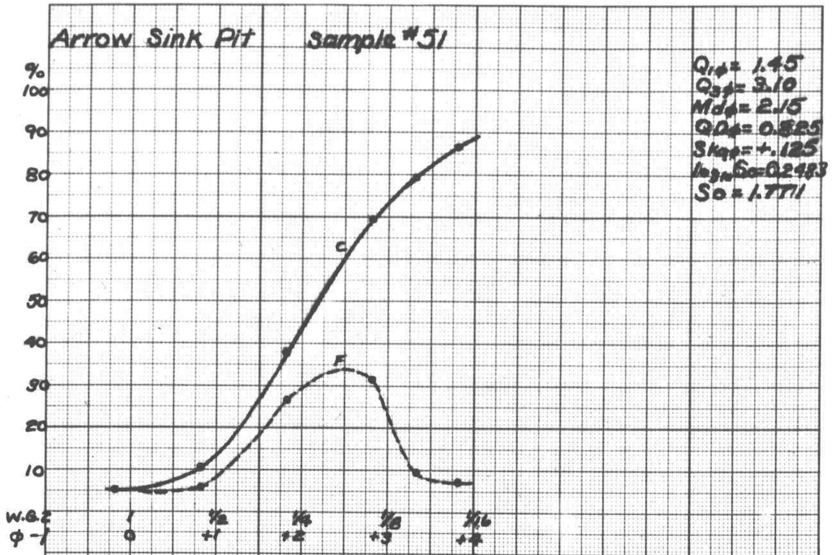

Alkali Flat Pit Sample #38
$Q_{1\phi}$ = 1.25
$Q_{3\phi}$ = 3.45
Md_ϕ = 2.45
QD_ϕ = 1.10
$Sk_{q\phi}$ = -.10
$\log_{10} S_o$ = .3311
S_o = 2.143
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

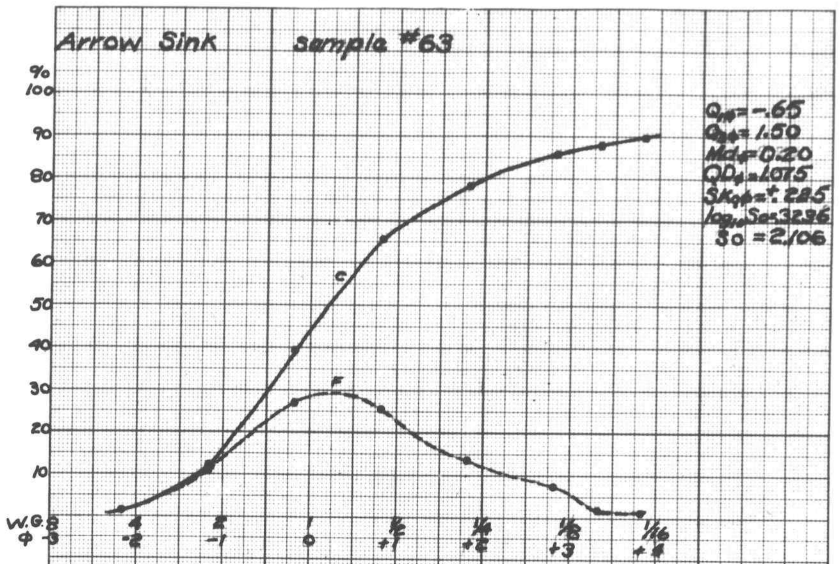

Pit West of ZX Well sample #43
%
$Q_{1\phi}$ = 1.20
$Q_{3\phi}$ = 2.75
Md_ϕ = 2.20
Qd_ϕ = 0.775
$Sk_{q\phi}$ = −0.225
$\log_{10} So$ = .2333
So = 1.751
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ −1 0 +1 +2 +3 +4

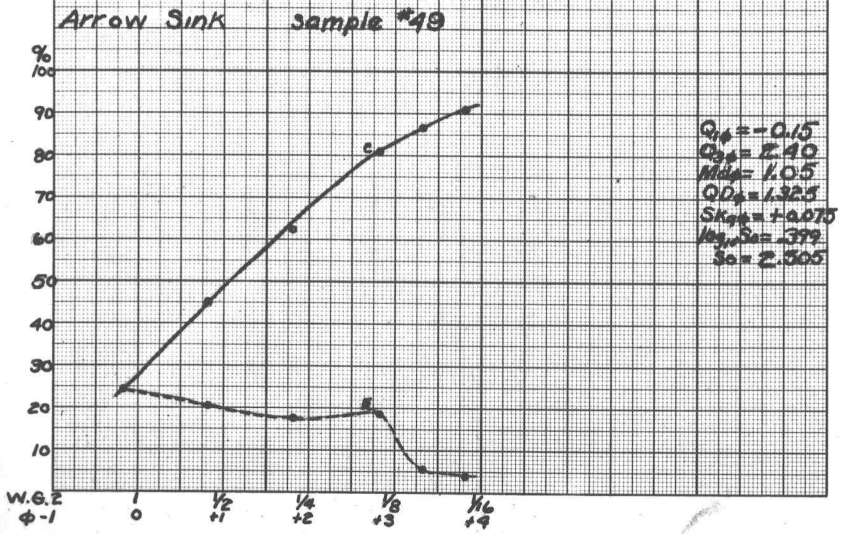

Arrow Sink Pit sample #48
%
$Q_{1\phi}$ = −0.35
$Q_{3\phi}$ = 1.60
Md_ϕ = 0.40
QD_ϕ = .975
$Sk_{q\phi}$ = +.225
$\log_{10} So$ = .2935
So = 1.965
C
F
W.G. 8 4 2 1 1/2 1/4 1/8 1/16
φ −3 −2 −1 0 +1 +2 +3 +4

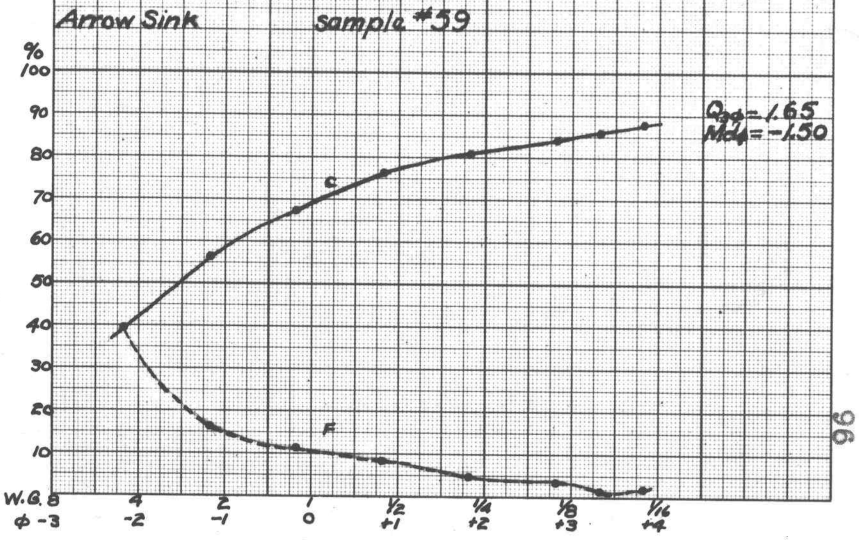

Pit W of ZX Well sample #44
%
$Q_{1\phi}$ = 3.45
Md_ϕ = 3.85
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ −1 0 +1 +2 +3 +4

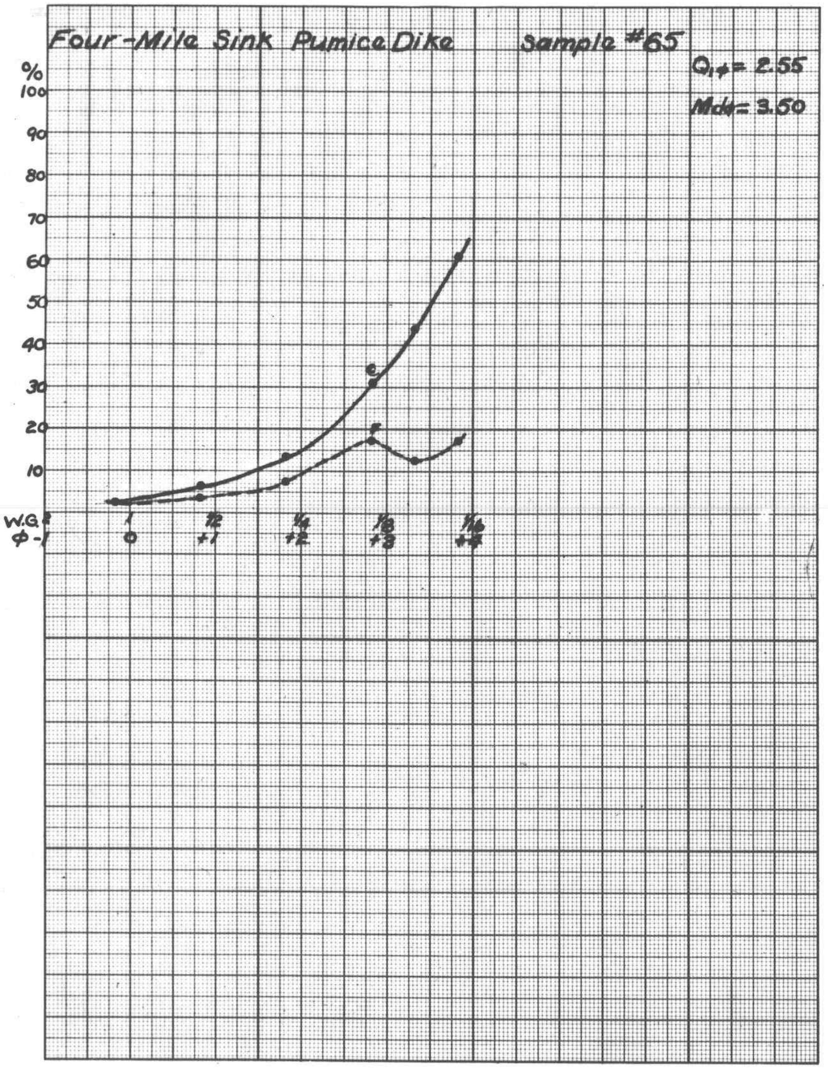

Arrow Sink Pit sample #46
%
$Q_{1\phi}$ = 0.30
$Q_{3\phi}$ = 2.30
Md_ϕ = 1.05
QD_ϕ = 1.00
$Sk_{q\phi}$ = +0.25
$\log_{10} So$ = .301
So = 2.00
C
F
W.G. 2 1 1/2 1/4 1/8 1/16
φ −1 0 +1 +2 +3 +4

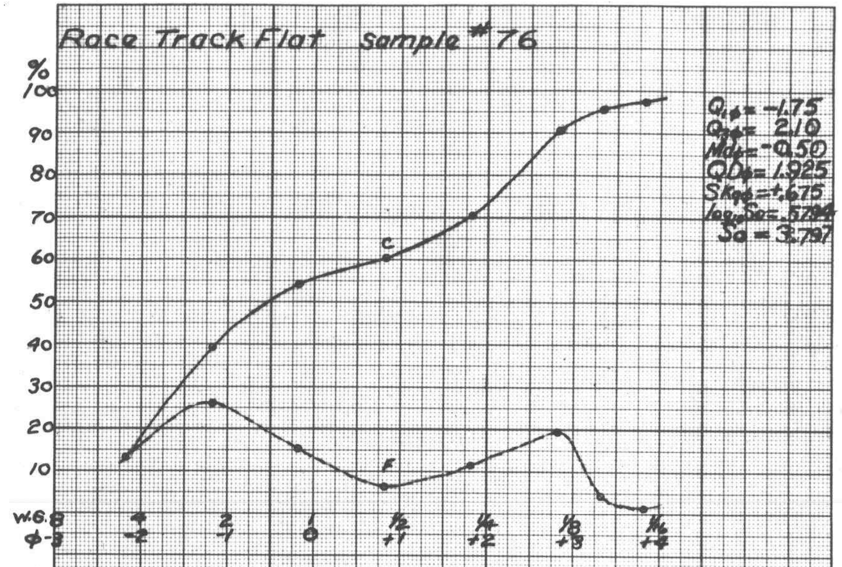

Arrow Sink Pit sample #51
Q1φ = 1.45
Q3φ = 3.10
Mdφ = 2.15
QDφ = 0.825
Sk qφ = +.125
log10 So = 0.2483
So = 1.771
C
F
%
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4

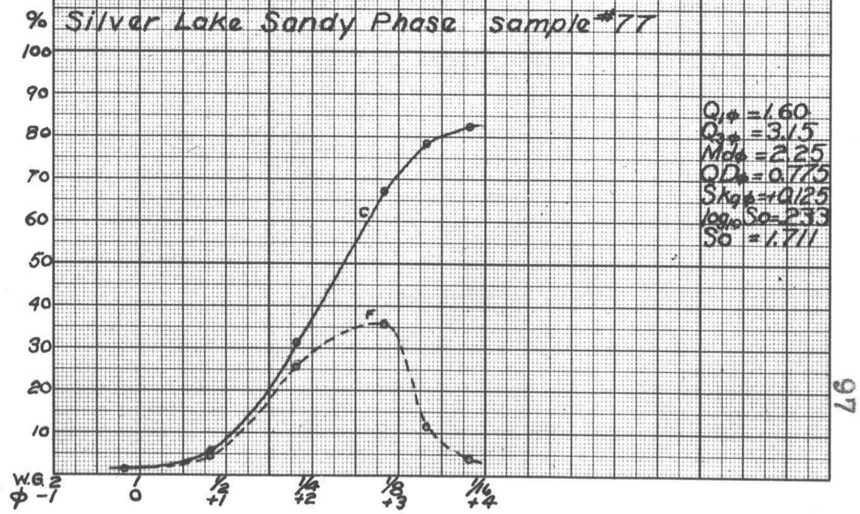

Arrow Sink sample #63
Q1φ = -.65
Q3φ = 1.50
Mdφ = 0.20
QDφ = 1.075
Sk qφ = +.285
log10 So = .3236
So = 2.106
C
F
%
W.G. 8 4 2 1 1/2 1/4 1/8 1/16
φ -3 -2 -1 0 +1 +2 +3 +4


Arrow Sink sample #49
Q1φ = -0.15
Q3φ = 2.40
Mdφ = 1.05
QDφ = 1.325
Sk qφ = +0.075
log10 So = .399
So = 2.505
C
F
%
W.G. 2 1 1/2 1/4 1/8 1/16
φ -1 0 +1 +2 +3 +4


Arrow Sink sample #59
Q3φ = 1.65
Mdφ = -1.50
C
F
%
W.G. 8 4 2 1 1/2 1/4 1/8 1/16
φ -3 -2 -1 0 +1 +2 +3 +4


Four-Mile Sink Pumice Dike sample #65
$Q_{1\phi}$ = 2.55
Md_ϕ = 3.50
%
W.G. 2
φ -1
C
F


Race Track Flat sample #76
%
$Q_{1\phi}$ = -1.75
$Q_{3\phi}$ = 2.10
Md_ϕ = -0.50
QD_ϕ = 1.925
$Sk_{q\phi}$ = +.675
$\log_{10} So$ = .5794
So = 3.797
W.G. 8
φ -3
C
F


Silver Lake Sandy Phase sample #77
%
$Q_{1\phi}$ = 1.60
$Q_{3\phi}$ = 3.15
Md_ϕ = 2.25
QD_ϕ = 0.775
$Sk_{q\phi}$ = +0.125
$\log_{10} So$ = .233
So = 1.711
W.G. 2
φ -1
C
F

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