Core Logs from Soda Lake San Bernardino County California

By SIEGFRIED MUESSIG, GEORGE N. WHITE, *and* FRANK M. BYERS, JR.

GEOLOGIC INVESTIGATIONS IN THE MOJAVE DESERT AND ADJACENT REGION, CALIFORNIA

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A description of the cores from a desert basin and an interpretation of the late Pleistocene physical history of the basin and contiguous areas

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ABSTRACT

In 1952–53 five core holes were drilled for the U. S. Geological Survey in the basin of Soda Lake, a playa in San Bernardino County, Calif. The holes were from 78 to 1,070 feet deep and penetrated unconsolidated to semiconsolidated clastic sediments whose constituents range from clay to pebble gravel but are predominantly silty clay to medium sand. One stratum of clay that contains ostracodes was penetrated in every hole at depths between 30 and 120 feet. Several volcanic-ash falls are represented in the cores.

Soda Lake is surrounded by mountainous outcrops of calcareous rocks of Paleozoic age, igneous and volcanic rocks of Mesozoic(?) age, and volcanic rocks and gravels of Cenozoic age. The central part of the playa has a puffy salt-caked surface; this is fringed by bare dry mud flats. Giant polygonal cracks and channels furrow the surface of the northern part of the playa; they are attributed to the drying of surficial muds.

In flood, the Mojave River sometimes drains into the Soda Lake basin. This drainage was once ponded to form a lake, called Lake Mohave. At high level, the lake spilled over its northern divide and drained northward into Death Valley.

The lacustrine clay stratum with ostracodes is correlated with Lake Mohave which is probably of late Pleistocene age.

Detailed logs of the five cores are included.

INTRODUCTION

In 1952 and 1953 five core holes were drilled by a contractor for the U. S. Geological Survey in the basin of Soda Lake, a playa in San Bernardino County, Calif. (fig. 4). The holes ranged in depth from 78 to 1,070 feet (see table below) and were drilled as part of an investigation of saline deposits in the Mojave Desert region. Plate 3 shows the graphic logs of the holes drilled; detailed logs of the five cores follow the text.

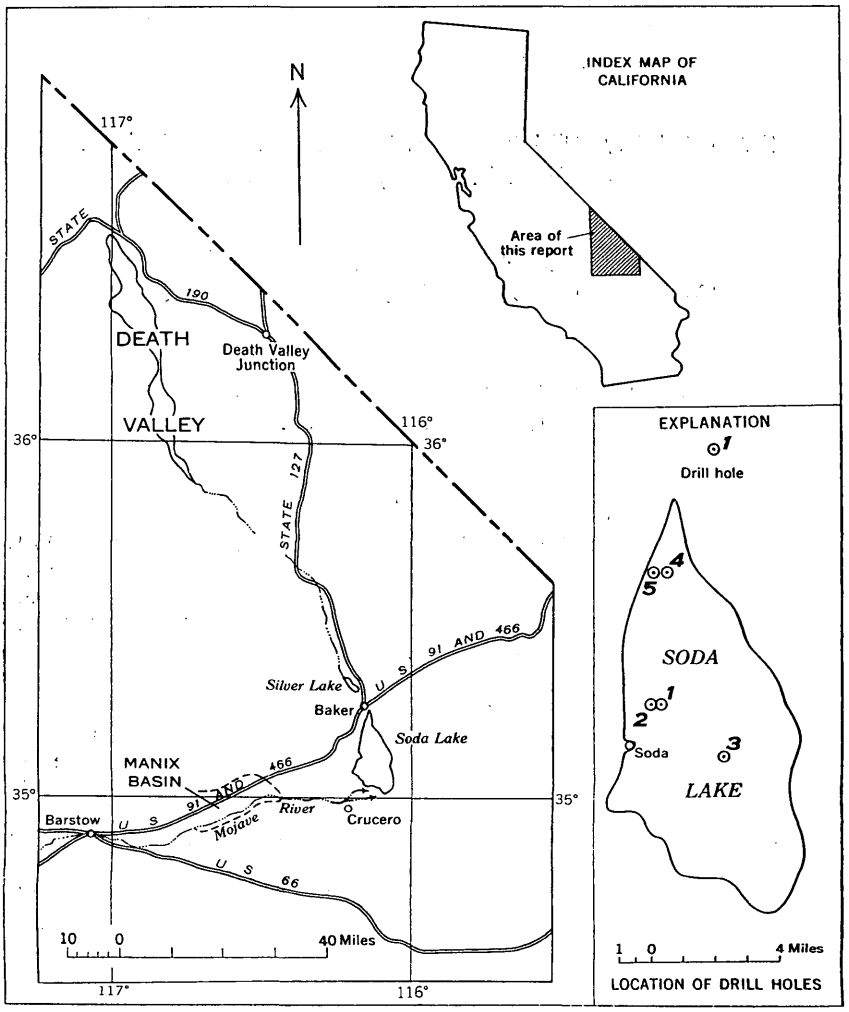

FIGURE 4.—Index map showing the location of Soda Lake and of the core holes drilled.

Summary of data on drill holes

Drill hole	Depth (feet)	Core recovery (percent)	Dates drilled	Location (San Bernardino base line and meridian)
1	730	51	September–October 1952	NE¼ sec. 1, T. 12 N., R. 8 E.
2	1,070	55	October–November 1952	70 ft west of drill hole 1.
3	970	49	November–December 1952.	SW¼ sec. 8, T. 12 N., R. 9 E.
4	320	48	December 1952	NE¼SW¼ sec. 12, T. 13 N., R. 8 E.
5	78	25	January 1953	150 yd east of W¼ cor., sec. 12, T. 13 N., R. 8 E.

SUMMARY OF LOGS

The sediments cored in Soda Lake are predominantly unconsolidated to semiconsolidated muds and sands. Most of the sediments range from silty clays to medium sands; coarse sand and gravel beds also occur but are less common than the finer clastic sediments. The sediments are mostly pale yellowish brown (10*YR* 6/4) (Goddard, 1948). Except where noted in the accompanying logs, the materials are poorly sorted and the grains are angular to subangular. Most of the core is massive,[1] although in places it is marked by horizontal laminae of clay, silt, or fine sand, or by changes in grain size. The beds are gradational with each other in color, grain size, and other lithologic characteristics. No crossbedding was seen in the cores.

Except as otherwise noted, the "clay" described in the logs is composed of clay-sized particles of the common rock-forming minerals, such as quartz, feldspars, and micas, rather than clay minerals.

Correlation of strata between holes is possible only in the upper parts of the holes; at shallow depth each hole penetrated an olive-green clay that is about 75 feet thick in drill holes 1, 2, and 3; 20 feet thick in drill hole 4; and about 5 feet thick in drill hole 5. The clay is chiefly massive, is very plastic, and shrinks as much as one-third of its total volume on drying. A differential thermal analysis made by Robert D. Allen, of the U. S. Geological Survey, shows that the unit is made up chiefly of the montmorillonite group of clays. Ostracodes occur in this unit, and one fish scale was noted; no other fossils were found in the cores. Volcanic ash beds occur in several of the cores, but none could be correlated from one core to another.

GEOLOGIC SETTING

Soda Lake occupies part of a depression in a northward-trending linear basin that extends northward to Death Valley. The playa is nearly 12 miles long and has a maximum width of 6 miles in its southern half; it narrows toward the north and assumes a wedge-shaped outline. It is sharply bordered on the west by a relatively steep-sided outlier of the Soda Mountains; along its eastern and northwestern flanks, the playa merges with alluvial fans; and to the south the playa gives way to a sand- and alluvial-covered plain.

Rocks that lie within the local drainage basin of the playa are as follows: quartz monzonite and metavolcanic rocks of Mesozoic(?) age, Tertiary volcanic rocks, and Quaternary gravels, which form most of the outcrops on the western and northwestern side of the basin; and calcareous rocks of Paleozoic age, some quartz monzonite,

[1] "Massive" is used here to mean that stratification is difficult or impossible to see with the unaided eye. It is not used to describe splitting properties of the sediments as suggested by McKee and Weir (1953).

and Quaternary basalt, which comprise most of the outcrops to the east.

Most of the playa has a puffy salt-encrusted dry mud surface that is scored by numerous shallow dry washes alined in a complex northward-trending braided pattern. This area of puffy ground is centrally located and is separated from surrounding areas of alluvial fans by a narrow band of smooth dry mud flats that seems to be a transitional stage between the two types of surfaces. Pebbles and boulders of basalt scoria litter the surface of these dry mud flats. The southern and southeastern borders of the playa are covered by windblown sand.

Along the northern borders of the playa the fringing dry mud flat is furrowed by linear and concentric cracks and channels that may be several feet in width and depth. In contrast to the generally barren dry mud flat, the cracks contain much vegetation. Most of the channels are arranged in crude polygonal patterns, but in several areas they form large circles as much as 400 feet in diameter that have smaller circles within them, thus forming bull's-eye patterns. Along some of the cracks, or within the circular or polygonal patterns formed by them, are small basins as much as 3 feet deep into which water flows from the contiguous shallower cracks and channels.

The cracks are probably the result of desiccation of the surficial muds. The initial cracks are evidently widened and deepened by erosion and subsidence; the small basins, which probably result from solution of disseminated salt in the near-surface sediments, furnish a sump and the gradient for slowly flowing waters that erode the cracks. Drilling seems to have eliminated the possibility that solid beds of salt lying below the surface have any part in the formation of the cracks or the associated shallow basins. Why some of the cracks form bull's-eye patterns, rather than polygons, is unknown.

Lang (1943) and Knechtel (1952) have reported similar cracks and channels at the Playa de los Pinos, N. Mex. Both writers attribute them to shrinkage of surficial mud during drying. A photograph by Knechtel (1952, pl. 1, fig. 4) shows a "desiccation fissure" apparently identical with some at Soda Lake.

The Soda Lake basin forms a sink into which the Mojave River sometimes drains when in flood. Extensive shoreline remnants, the highest of which at Soda are about 20 feet above the present surface of the playa at an altitude of 947 feet, show that this drainage was formerly ponded to form a lake.[2] This lake, which also covered the

[2] A strandline and associated beach deposits occur at an altitude of 1,111 feet, about 180 feet above the playa, a few miles south of Crucero on the Union Pacific Railroad. As nothing is known about the lake responsible for the strand and deposits, they are not treated further here. It is probable that the associated lake-bottom sediments are below the depth cored in Soda Lake.

Silver Lake basin north of Baker, has been called Lake Mohave (Thompson, 1921). At its highest level, water from the lake spilled over a bedrock divide at the northern end of Silver Lake and drained northward into Death Valley. Some of the water of the lake, however, must have percolated into the alluvium east of the bedrock divide and gone northward, out of the Silver Lake basin (Thompson, 1929, p. 562). The absence of salt beds in the Soda Lake cores (see below) would seem to affirm the conclusion that Lake Mohave disappeared by spilling and percolating rather than by drying up. At present, flood water from Soda Lake drains through a narrow outlet into Silver Lake where it either seeps into the ground or evaporates.

GEOLOGIC RECORD OF THE CORES

The sediments of the Soda Lake basin, as seen in the cores to a depth of 1,070 feet, indicate that the basin was the site of a playa like the present one most of the time for the period of record. The yellowish-brown muds and sands that make up most of the stratigraphic section are like those presently being deposited on Soda Lake and give evidence that the climate during their deposition was much like the present. Only once was the basin filled by a lake of sufficient duration to leave an unmistakable sedimentary record: the green clays lying between depths of 30 and 120 feet below the surface are the only undoubtedly lacustrine deposits penetrated by the drill holes. Furthermore, the absence of salt beds just above the lacustrine section indicates that the waters of that lake left the basin rather than evaporating.

It is probable that the green clays were deposited in Lake Mohave, one of the Pleistocene(?) lakes of the Mojave River drainage system. The age of Lake Mohave is uncertain, but the position of the shorelines in the Manix basin (upstream from Lake Mohave) has led previous workers to suggest that it is probably younger than the second of the three lakes of Lake Manix (Blackwelder and Ellsworth, 1936; Thompson, 1929, p. 565). Blackwelder and Ellsworth suggest that their Second Lake is of Blackwelder's (1931) Tioga age, but the evidence cited—the degree of erosion of the lake beds and of decomposition of beach pebbles—is weak if used independently; local base level and the position of the ground-water table may be more important in determining rates of erosion and decomposition locally, than is length of exposure, considered in a regional sense. Paleontologic evidence sheds no light on the problem other than that the Manix beds are Pleistocene and the upper 23 feet of sediments are late Pleistocene (Howard, 1955, p. 205).

Ash beds in the cores are as yet of no help in correlating the Soda Lake basin sediments with those of contiguous areas; so far, no ash

beds have been found in stratigraphic sections that may be correlative with the section at Soda Lake. The nearest source for the ash is the basaltic cones that lie 15 to 20 miles east of Soda Lake in the Ivanpah quadrangle. These cones and the associated lava flows are probably late Pleistocene in age (Hewett, 1956). Some of the vesicular basalt fragments in the core probably came from the flows, but Tertiary basalt flows also crop out locally in the drainage area of Soda Lake.

It is disappointing that the present study of the cores does not make possible a matching of physical events of the Soda Lake basin with those of other nearby basins in the desert region; a more detailed study, perhaps one involving pollen and spore analyses, would probably help. The cores do not represent all the basin fill, but even if they did, perhaps one should not expect uniform correlation over the whole region, or even from one basin to the next. Even if we assume that a broadly uniform climate existed over a large area, and that climatic changes took place contemporaneously over the same area, we cannot assume that climate is the ultimate factor controlling where or when a lake exists, especially if a chainlike drainage system is involved. Structural events, such as the damming of a drainage by faulting, may localize a lake and no others may exist up or down the drainage at the same time. Furthermore, basins that are now closed may have been open during all or part of the pluvial periods and may thus have contained no lakes.

LOGGING METHODS AND ACKNOWLEDGMENTS

Core size was 2⅝ inches throughout and the core barrel was 10 feet long. Where the core from any given run [3] was incomplete, there was generally no reliable way of telling the exact place, within the run, from which the recovered core was taken. For the logs that follow, the recovered core was arbitrarily assigned to the lower end of the run and the missing part to the upper.

Sediment names agree with those suggested by Wentworth (1922). Colors are for the dry core and have been named and numbered according to the Rock-Color Chart (Goddard, 1948).

All cores were logged wet at the drill site within a few hours after being removed from the holes. In the field Muessig logged drill hole 1; White logged drill holes 2, 3, and 4; and Byers logged drill hole 5. The logs presented here were made in the laboratory by Muessig, who used a hand lens and binocular microscope to examine the dry core. This was done to obtain uniformity of detail for all the logs. The text was written by Muessig.

Robert D. Allen, of the U. S. Geological Survey, made some of the mineral identifications with immersion oils.

[3] The term "run" refers to the length of hole drilled in taking a core. Generally a "run" was 10 feet.

CORE LOGS FROM SODA LAKE DRILL HOLES

Drill hole 1

[51 percent of core recovered]

Depth (feet)	Unit thickness (feet)	Description
2	2	Silt, clayey, yellowish-gray (5*Y* 7/2) to grayish-orange (10*YR* 7/4), calcareous, porous; contains as much as 50 percent disseminated noncrystalline halite.
3. 5	1. 5	Sand, fine to very fine, yellowish-gray (5*Y* 7/2), calcareous, salty, high muscovite content; flakes parallel to bedding; very thin bedded to laminated.
15	11. 5	No core. Probably like 0 to 2-foot unit with pealike gypsum crystal aggregates.
41. 5	26. 5	Clay, silty, light yellowish-brown (10*YR* 6/4), calcareous, very salty, chiefly massive but some very thin bedded to laminated. Very poor core.
59	17. 5	Clay, yellow-gray to light olive-gray (5*Y* 7/2) to (5*Y* 5/2), calcareous, salty; plastic with hackly and conchoidal fracture when wet; a few thin beds verging on pale olive (10*Y* 6/2); lower 4 ft grayish yellowish green (5*GY* 7/2). Chiefly massive, but some micaceous silt and very fine sand partings and laminae; randomly distributed biotite flakes throughout. Contains a few ostracodes. Grades into unit below.
		No core: 50–55 ft.
116	57	Clay, olive-gray to greenish-gray (5*Y* 5/1–5*GY* 6/1); some yellowish-gray (5*Y* 7/2) mottling. Otherwise as unit above but more ostracodes throughout. Core shrunk about one-third on drying.
		No core: 60–66, 70–72, 90–91, 100–101, 110–115 ft.
117	1	Clay, silty, verging on light greenish-gray (5*G* 8/1). Scattered fine to medium sand grains and biotite flakes throughout; calcareous; massive; extremely plastic when wet.
118	1	Silt, clayey, yellowish-gray (5*Y* 6/4) and olive-black (5*Y* 2/1), calcareous, massive; plastic when wet. Grades into unit below.
120	2	Silt and very fine sand, clayey, yellowish-gray (5*Y* 7/2), micaceous, calcareous, massive.
128	8	No core.
198	70	Silt, very fine sand, and silty and sandy clay, pale yellowish-brown (10*YR* 6/4); in alternating gradational beds ranging from a few inches to several feet in thickness; some fine micaceous sand partings and interlaminated beds of clay and silt; calcareous. At 196.2–196.4 ft there is coarse sand with quartz and quartz monzonite granules.
		No core: 130–135, 140–142, 160–163, 176–182.5, 190–196 ft.
198. 5	0. 5	Sand, medium to coarse, pale yellowish-brown (10*YR* 6/4), calcareous; contains some black basalt scoria pebbles.

Drill hole 1—Continued

Depth (feet)	Unit thickness (feet)	Description
246.5	48.0	Silt to fine sand, very thinly interbedded with silty clay; some laminated; pale yellowish-brown (10*YR* 6/4); calcareous. Several thin beds of coarse to very coarse granular sand. At 218.3 ft is a basalt scoria pebble.
		No core: 200–202, 210–211.5, 220–221.5, 230–232.5, 240–241.5 ft.
256	9.5	Silt to coarse sand, pale yellowish-brown (10*YR* 6/4), calcareous. Bedding indistinct: some granular beds.
		No core: 250–254 ft.
257.5	1.5	Sand, very fine to medium; very pale orange (10*YR* 8/2); mottled by yellowish-gray (10*Y* 8/1) calichelike stringers and irregular calcareous nodules.
273	15.5	Like 246.5–256 ft.
		No core: 260–261 ft.
288	15	Clay, silty, pale yellowish-brown (10*YR* 6/4), calcareous, micaceous; massive with hackly and conchoidal fracture when wet.
		No core: 280–281.5 ft.
311	24	Sand, very fine to medium; silt; and silty and sandy clay; pale yellowish-brown (10*YR* 7/2) to (10*YR* 6/4); intergradational in poorly defined thick beds. Calcareous, with calcareous nodules of fine sand as much as 1 in. across sparsely distributed through unit; bedding goes through nodules. Some thin zones of very coarse granular sand in upper 3 ft; granules are predominantly quartz and quartz monzonite.
		No core: 290–294, 300–302 ft.
334	23	Clay, mostly silty, pale yellowish-brown (10*YR* 6/4), calcareous, massive; hackly and conchoidal fracture when wet. Some calcareous silty clay nodules sparsely distributed throughout.
399	65	Silt, clayey silt, and some very fine to fine sand, pale yellowish-brown (10*YR* 7/2), calcareous. Mostly massive but some thin beds and laminae. Very pale orange (10 *YR* 8/2) nodules and irregular stringers of calcareous silt throughout unit.
		No core: 340–345, 350–355.5, 360–361, 370–378, 380–388, 390–399 ft.
400	1	Volcanic ash, fine- to medium-grained, moderate yellowish-brown (10*YR* 5/4) to white. Index of refraction of glass is 1.498.
490	90	Like 334–399 ft, and some medium sand.
		No core: 400–407.5, 410–413.5, 415–415.5, 420–427.5, 430–437.5, 440–443.5, 445–449, 450–457, 460–465, 470–478, 480–487.5 ft.
490.1	.1	Volcanic ash, average index of refraction 1.49. Thickness of ash not known, as that recovered came out of the hole at the end of the core barrel.

Drill hole 1—Continued

Depth (feet)	Unit thickness (feet)	Description
688	197. 9	Like 400–490 ft, but with a few coarse sand and pebbly beds. Salty throughout. Hard calcareous nodules, stringers, and beds increase with depth. Thin calcite veinlets and irregular masses in lower 20 ft. At 600 ft is a ½-inch-thick bed of white volcanic glass with average refractive index 1.500; has crystallites that are anisotropic and have wavy extinction. No core: 490.1–498.5, 500–501, 510–517, 520–529, 530–535, 540–542, 550–557, 560–565.5, 570–576.5, 580–588.5, 590–596, 600–608, 610–618, 620–623.5, 627–629, 630–639, 640–648, 650–658, 660–668.5, 670–677.5, 683–688 ft.
695	7	Limestone, silty and sandy, very pale orange (10*YR* 8/2). Wavily bedded and banded, druses roughly parallel to bedding contain calcite crystals; looks like travertine. Only 1.5 ft of core recovered but drilling characteristics indicate most of interval is limestone. Quartz, plagioclase, biotite, hornblende, and zircon in angular fragments are distributed throughout limestone matrix.
705	10	Silt, very clayey, and sand, moderate yellowish-brown; intermixed with ground-up limestone fragments. Only 1.5 ft of core but drilling characteristics and cuttings indicate that 698.5–701 ft is limestone as unit above.
730	25	Like 490–688 ft without calcite veinlets. No core: 705–714, 715–718.5, 720–728.5 ft.

Drill hole 2

[Hole 70 feet due west of drill hole 1; 55 percent of core recovered]

		Description
667	667	No core: fishtail bit used.
670	3	Limestone, very sandy and silty, very pale orange (10*YR* 8/2); interbedded in thin beds with very calcareous and clayey medium-grained sandstone.
730	60	No core. Limestone found in drill hole 1 at 688–705 ft not found in drill hole 2.
840	110	Silt, clayey, and fine sand, moderate yellowish-brown (10*YR* 6/4), calcareous, salty; chiefly massive, but clayey beds are laminated in places. Some coarser beds throughout; some calcareous silt and sand nodules and beds as in drill hole 1. Black basalt scoria pebbles at 775 ft. No core: 730–737.5, 740–748, 750–758, 760–768.5, 770–779, 800–801, 810–815, 820–823.5 ft.
860	20	Sand, fine to very coarse, interbedded and intergradational with clay and clayey silt beds, moderate yellowish-brown (10*YR* 6/4), calcareous, salty. Fine beds are laminated. Some gravel beds with angular black basalt scoria pebbles; some calcareous nodules. No core: 840–845, 850–856 ft.
880	20	Sand, medium to coarse, silty and clayey, moderate yellowish-brown (10*YR* 6/4), calcareous, with some calcareous nodules; salty, massive. Some finer grained beds.

Drill hole 2—Continued

Depth (feet)	Unit thickness (feet)	Description
967. 8	87. 8	Silt, clayey, and fine to medium clayey and silty sand, interbedded and intergradational with lesser amount of coarse sand and granular and pebbly beds. All are moderate yellowish brown, salty, and calcareous. Coarse fragments are of angular granitic, dioritic, and basaltic rocks. Hard, calcareous nodules throughout. Much coarse materials in cuttings.
		No core: 880–881.5, 890–891, 900–908, 910–915, 920–925, 930–933.5, 940–942.5, 950–957, 960–963.5 ft.
969. 8	2	Volcanic ash, bentonitic, pinkish-gray to white (5*YR* 8/1 to *N* 9), noncalcareous, massive. Fine-grained equant glass grains, average index of refraction 1.496.
1, 070	101. 2	Sand, medium to very coarse, granular and pebbly, moderate yellowish-brown to pale yellowish-brown (10*YR* 6/4 to 10*YR* 7/2), calcareous. Beds are generally massive and intergradational and are interbedded with thin zones (as much as several feet) of clayey silt and fine sand. Where bedding is seen, it is formed by changes in grain size. Granules and pebbles are igneous, basaltic, and subangular to angular. Basalt fragments are vesicular. Some calcareous nodules as above; some hard calcareous sandstone beds. Coarseness increases with depth. Hard ¼-inch hematite streak at 1,110 feet.
		No core: 970–976.5, 980–986, 990–996, 1000–1006, 1010–1014, 1020–1025, 1030–1034, 1040–1044, 1050–1057, 1060–1068 ft.

Drill hole 3

[49 percent of core recovered]

		Description
4	4	Clay to clayey silt and some fine sand, moderate yellowish-brown (10*YR* 7/4), salty, micaceous, laminated. Exposed in sump hole.
20	16	No core, but probably grayish-brown silty clay with small gypsum crystals.
25	5	No core. Cuttings are moderate brown (5*YR* 3/2) plastic clay and some silt and gypsum crystals.
32	7	No core.
35	3	Sand, very fine, silty and clayey, pale yellowish-brown (10*YR* 6/3), calcareous, salty, massive; contains much light-brown mica.
38. 5	3. 5	No core.
40	1. 5	Clay, silty, light olive-gray (5*Y* 5/2), calcareous, salty, massive; some light-brown mica. Plastic when wet.
115. 5	75. 5	No core, but cuttings indicate clay as above, but pale olive (10*Y* 6/2). Two units here are same as clay zone 41.5–116 ft in drill hole 1.

Drill hole 3—Continued

Depth (feet)	Unit thickness (feet)	Description
126. 5	11	Sand, very fine, clayey and silty; and some silty and sandy clay; pale orange-brown (10*YR* 7/2), calcareous, massive to laminated.
		No core: 120–124 ft.
130	3. 5	Sand, fine to medium; some coarse sand stringers; pale orange-brown (10*YR* 7/2). Chiefly massive but some laminae; noncalcareous, but upper 0.5 ft. contains creamy calcareous nodules, 1 to 10 mm in diameter.
138. 5	8. 5	Sand, very fine, and silt; both clayey; pale orange-brown (10*YR* 7/2); calcareous, with calcareous nodules; predominantly massive, some laminae.
		No core: 130–134 ft.
140	1. 5	Sand, fine to medium, clayey and silty, moderate yellowish-brown (10*YR* 5/4); some laminae; noncalcareous.
146	6	No core.
150	4	Sand, very fine, and clayey silt, pale orange-brown (10*YR* 7/2); some stringers of very coarse sand; massive, calcareous; much brown mica.
155	5	No core.
160	5	Sand, fine to medium, moderate yellowish-brown (10*YR* 6/4), massive, noncalcareous; some small irregular black stains that are probably manganese oxides.
169	9	No core.
234	65	Sand, very fine, clayey and silty, moderate yellowish-brown (10*YR* 6/4) to grayish-orange (10*YR* 7/4). Some medium sand beds. Lithologic characteristics are gradational. Mostly massive but some laminae caused by changes in grain size. Calcareous except in several 1-ft-thick fine to medium sand beds; cream calcareous nodules and stringers; much brown mica. Medium-gray (*N* 5) dense limestone pebble with crinoid stems at 231 ft. At 179 ft is a 1-ft-thick medium sand with black rootlike incrustations that look like rootlets replaced by manganese oxide; no organic material found. Basalt scoria pebble at 200 ft.
		No core: 170–175, 180–185, 190–193, 200–206, 210–218.5, 220–226 ft.
240	6	Sand, fine to medium, silty and clayey, pale orange-brown (10*YR* 7/2), calcareous, massive.
281	41	Silt to fine sand, clayey, pale orange-brown (10*YR* 7/2), calcareous; much cream-colored mottling which is calcareous cement; calcareous nodules and irregular stringers of light-colored more firmly cemented material. Grades into unit below.
		No core: 240–249, 250–259, 270–278.5 ft.
283	2	Like unit above, but noncalcareous and medium sand.
284	1	Like 240–281 ft.
286	2	Clay to fine sand, silty, pale orange-brown (10*YR* 7/2), calcareous; laminated and thin bedded.

Drill hole 3—Continued

Depth (feet)	Unit thickness (feet)	Description
306	20	Sand, silty, fine to medium, orange-brown (10*YR* 6/2); calcareous, with some calcareous nodules; massive.
		No core: 290–297, 300–304 ft.
319	13	Sand, fine to very coarse, very silty and clayey, light-brown (5*YR* 6/4) to pale orange-brown (10*YR* 7/2), mostly noncalcareous. Granules, pebbles, and cobbles of black vesicular basalt and quartz monzonite included.
		No core: 310–318.5 ft.
340	21	Sand, fine to medium, silty; some coarse sand stringers; pale yellowish-brown (10*YR* 6/3) to medium yellowish-orange (10*YR* 7/6), mostly noncalcareous, with few calcareous nodules at top; some pebbles of quartz monzonite. Becomes more silty toward base.
		No core: 325–327, 330–334 ft.
372	32	Sand, fine; some silt and medium sand; all very silty; grayish-orange (10*YR* 7/4); mostly calcareous, with some calcareous nodules; some thin-bedded and laminated zones as much as 6 in. thick consisting of interbedded silt, very fine sand, and silty clay. At 347 ft is a 2-in. bed of dense very light gray (*N* 8) bentonitic altered volcanic ash containing biotite.
		No core: 340–342, 355–358, 365–366 ft.
477.5	41.5	Sand, fine to very coarse, silty and clayey, grayish-orange (10*YR* 7/4); granules and pebbles throughout; calcareous, with many calcareous nodules; massive. Poor core.
		No core: 440–448, 450–459.5, 460–461, 470–474 ft.
500	22.5	Sand, medium to very clayey silt, grayish-orange (10*YR* 7/4); calcareous, with many calcareous nodules throughout. Some bedding visible.
		No core: 480–483, 490–492.5 ft.
520	20	As unit above but with gravel. Some thin calcareous sandstone beds and some vesicular basalt pebbles.
		No core: 500–509, 510–519 ft.
538	18	Sand, very fine, and very clayey silt; grayish-orange (10*YR* 7/4); calcareous, with many calcareous nodules; massive; black vesicular basalt pebble at 526 ft.
		No core: 520–525.5, 530–535 ft.
545	7	Sand, fine to medium, somewhat silty; grayish-orange (10*YR* 7/4), calcareous; angular pebble gravel at 540 and 545 ft.
728	183	Silt to medium sand in gradational beds, very clayey and silty; grayish-orange (10*YR* 7/4) to moderate yellowish-brown (10*YR* 5/4); mostly calcareous, with abundant calcareous nodules in some zones. A few basalt pebbles.
		No core: 545–550, 565–573, 575–579, 580–584, 590–593, 600–603.5, 610–617, 620–629, 630–632, 635–636.5, 645–652, 665–671.5, 675–684, 685–687, 690–694.5, 710–712, 718–720.5 ft.

Drill hole 3—Continued

Depth (feet)	Unit thickness (feet)	Description
740	12	Silt and silty clay, grayish-orange (10*YR* 7/4) and yellowish-brown (10*YR* 6/4); mostly calcareous, with abundant calcareous nodules and irregular masses, which from 734 to 740 ft make up more than half the core.
744	4	No core.
760	16	Silt, clayey, grading with depth to medium sand in lower 2½ feet, grayish-orange (10*YR* 7/4); calcareous, with abundant calcareous nodules. Some laminae in zone 749–750 ft.
		No core: 750–752.5 ft.
769.5	9.5	Silt, clayey, grading with depth to medium sand in lower 3.5 ft; grayish-orange (10*YR* 7/4); calcareous, with fewer calcareous nodules than unit above.
786	16.5	Silt, clayey, and silty clay, grayish-orange (10*YR* 7/4); calcareous, with few calcareous nodules.
		No core: 770–776.5 ft.
789.5	3.5	Sand, medium to very coarse; grayish-orange (10*YR* 7/4), calcareous; some granules of quartz monzonite.
865	75.5	Like 545–728 ft, no basalt pebbles.
		No core: 790–795, 800–801.5, 805–806, 828–834.5, 838–839.5, 848–854, 858–859 ft.
960	95	Sand, fine and medium, in gradational beds, grayish-orange (10*YR* 7/4), calcareous. Some silt and clayey silt beds; some quartz monzonite granules, pebbles, and cobbles.
		No core: 868–873.5, 878–879, 888–893, 898–900, 908–915, 920–929.5, 930–937, 940–946, 950–952 ft.
970	10	No core. A few calcareous pebbles as cuttings.

Drill hole 4

[48 percent of core recovered]

		Description
1	1	Sand, coarse, pale orange-brown (10*YR* 7/2), calcareous.
3.5	2.5	Silt, clayey, yellowish-brown (10*YR* 6/4), calcareous, very salty, poorly compacted. Contains numerous gypsum nodules as much as 2 mm in diameter and some gypsum stringers; much light-brown mica.
8.5	5	No core, probably salty brown silty clay.
9.0	.5	Clay, moderate yellowish-brown (10*YR* 5/2), calcareous, very salty; indistinct laminations show bedding; contains much gypsum.
12.5	3.5	No core, but probably same as above.
14	1.5	Clay, silty, moderate yellowish-brown (10*YR* 5/2), calcareous, very salty, indistinct laminations; some ½-mm gypsum nodules at base.
19	5	No core but probably same as unit above.
25.5	6.5	Clay, slightly silty, moderate yellowish-brown (10*YR* 5/2), calcareous, very salty, massive and porous; contains numerous ¼-mm calcite rhombs.

Drill hole 4—Continued

Depth (feet)	Unit thickness (feet)	Description
27.5	2.0	Clay, plastic, pale-olive (10Y 6/2), calcareous, salty, massive; contains some biotite. Has a few ostracodes; one fish scale seen.
30	2.5	Clay, moderate yellowish-brown (10YR 5/2), calcareous, salty, massive and porous; has a very few ostracodes.
30.5	.5	No core.
38	7.5	Clay, silty and plastic, pale-olive (10Y 6/2), thinly interbedded and interlaminated with moderate yellowish-brown (10YR 5/2) calcareous clay. Some light-brown mica and ostracodes.
44.5	6	Clay, silty and plastic, pale-olive (10Y 6/2), calcareous, very thinly bedded and laminated. Has light-brown mica and ostracodes.
44.7	.2	Clay, as in unit above, enclosing fossil hash of ostracode tests. Abundance of ostracodes increases with depth.
49.5	4.8	Sand, fine, silty and clayey; color in upper 1.5 ft is pale olive (10Y 6/2) grading with depth into yellowish gray (5Y 6/2), calcareous, thin-bedded. Very coarse sand-sized fragments and granules of quartz and volcanic debris; basalt cobble at top; much biotite which increases downward. Some ostracodes in upper foot.
58	8.5	No core.
66.5	8.5	Sand, medium, silty and clayey, grayish-orange (10YR 7/4), calcareous. Some thin beds; some biotite; very coarse sand-sized fragments and granules of quartz and granitic debris.
		No core: 60.0–64.5 ft.
68.5	2	Sand, medium, grayish-orange (10YR 7/4), noncalcareous.
110	41.5	Silt, clayey, to medium sand, grayish-orange (10YR 7/4) and pale orange-brown (10YR 7/2), in gradational beds, calcareous. Some very thin beds; some very coarse sand stringers and a few granules and pebbles of vesicular basalt; several thin firmly cemented granular beds, especially near base. Poor core throughout.
		No core: 70–79, 80–85.5, 90–92.5, 100–104.5 ft.
145	35	Silt, clayey, to very coarse sand, grayish-orange (10YR 7/4), calcareous. Numerous granules and pebbles of black and red vesicular basalt and granitic rock. Unrecovered core is probably conglomerate.
		No core: 110–116.5, 120–128, 130–139, 140–141.5 ft.
150	5	Silt, very clayey, and fine sand with granules grading imperceptibly with depth to very coarse sand; grayish-orange (10YR 7/4); calcareous; vesicular basalt granules and pebbles at base.
158.5	8.5	No core. Cuttings indicate limestone, basalt, and igneous rock conglomerate in matrix as in unit above.
170	11.5	Silt, clayey, grayish-orange (10YR 7/4); noncalcareous except for a few very pale orange (10YR 8/2) calcareous nodules. Some granules throughout; very thin bedded and laminated. Very pale orange (10YR 8/2) clay beds in lower part.
177.5	7.5	No core.

Drill hole 4—Continued

Depth (feet)	Unit thickness (feet)	Description
178. 5	1. 0	Clay, highly plastic, very pale orange (10*YR* 8/2), noncalcareous, very thin bedded and laminated; much brown mica, some of which forms partings.
180	1. 5	Silt, clayey and granular, and many calcareous nodules and irregular masses; very pale orange (10*YR* 8/2). Calcite cements mass in lower 0.5 ft.
280	100	Sand, fine to very coarse, silty and clayey, in gradational beds, grayish-orange (10*YR* 7/4), calcareous; some thin beds and laminae. Core contains about 5 percent very pale orange (10*YR* 8/2) calcareous firmly cemented grit beds as much as 6 in. thick; a few vesicular basalt pebbles; much light-brown mica throughout.
		No core: 180–186.5, 190–199, 200–207.5, 210–219, 220–227.5, 235–237.5, 240–247, 250–256.5, 260–261.5, 270–273 ft.
320	40	Silt and fine sand, clayey throughout, grayish-orange (10*YR* 7/4), calcareous; thin bedded in most parts; much light-brown mica; a few thin granule beds.
		No core: 280–281.5, 290–293, 298–302, 305–307, 310–313 ft.

Drill hole 5

[25 percent of core recovered]

		Description
15	15	Silt, clayey, yellowish-brown (10*YR* 6/4), calcareous, salty. Very little bedding discernible.
		No core: 1.5–5, 6.5–7.5, 8.7–10, 10–15 ft.
30	15	Silt as in unit above but moderate yellowish-brown (10*YR* 5/4) and less salty. Grades into unit below.
		No core: 17–27 ft.
32	2	Clay, pale-olive (10*Y* 6/2), calcareous; very coarsely sandy, granular, and pebbly. Clasts are igneous, metamorphic, and basaltic.
35	3	Pebble gravel in matrix of olive clay as in unit above. Only 1 ft of core recovered.
78	43	Granule and small pebble gravel, some large pebbles. Clasts are chiefly granitic and dark metavolcanic rocks. No core; all cuttings.

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