OPTIONAL FORM NO. 10
5010-101

UNITED STATES GOVERNMENT

Memorandum

TO : Alaska Geology Branch
Menlo Park, California

DATE: November 14, 1968

FROM : J. R. Randolph, Special Reports Unit, WRD(4025 0001)
Washington, D.C.

SUBJECT: PUBLICATION - Open-file reports, lists

The citation on the attached copy of a request for an open-file report was apparently taken from a list prepared in your office. Please change your list to show that this report was published under the title "Origin of a salt-water lens in permafrost at Kotzebue, Alaska," in Geol. Soc. America Bull., v. 72, p. 1427-1432, Sept. 1961. Incidentally, the report was presented at a GSA meeting in Toronto in 1953 but was not approved for release to the open file until 1955.

J R Randolph
J. R. Randolph

Attachment

November 21, 1968

Mr. Randolph:

Thank you for calling this to our attention. This report has now been deleted from our list.

Della
Della L. Kennedy
Technical Information Specialist

#215

A TEST WELL AT KOTZEBUE, ALASKA*

By D. J. Cederstrom**

In the summers of 1949 and 1950 a test well was drilled at Kotzebue, Alaska, in an endeavor to locate a source of potable water that might be utilized by the townspeople (largely Eskimos) and the Alaska Native Service Hospital. This work was done as part of the United States Geological Survey's program of ground-water investigations in Alaska, which is under the general direction of A. N. Sayre, Chief of the Ground Water Branch of the Water Resources Division. Field work at Kotzebue was directed by the writer.

Kotzebue is in northwestern Alaska, 60 miles north of the Arctic Circle, about 180 miles north-northeast of Nome, and 150 miles south-southeast of Point Hope. It lies near the northern end of a long, narrow peninsula forming the east shore of Kotzebue Sound; a narrow body of water, Hotham Bay, separates this peninsula from the mainland to the east. The peninsula itself and the mainland across the bay are mantled by recent silt and fine sand. The area appears to be underlain by unconsolidated deposits of deltaic, estuarine, and perhaps glacial origin. The mainland to the north is hard rock. The waters surrounding the north end of the peninsula are very shallow and only slightly brackish; at times of strong flow from the mouth of the Noatak, about 5 miles across the bay, the water is fresh enough to drink.

Ordinarily, drinking water is obtained at Kotzebue from a few shallow wells occupying thawed basins in the permafrost (greatly contaminated by fuel oil and organic material), from melted ice and snow, or from somewhat distant lakes or rivers. It was hoped that a deep well there might penetrate

---

* Publication authorized by the Director, U. S. Geological Survey.
** Geologist, Ground Water Branch, Water Resources Division, U. S. Geological Survey, Charlottesville, Va.

fresh-water strata beneath the frozen ground and make possible the acquisition of a safe, dependable supply for the community of 500 or more people.

Drilling was done by the cable-tool method. On several occasions, small tools were loaned by Archie Ferguson of Kotzebue and by the U. S. Smelting and Refining Co. of Nome, to whom appreciation is here expressed.

The ground at Kotzebue, with the exception of a thin stratum of gravel, is frozen from the surface to a depth of 238 feet. Beneath 19 feet of beach gravel is blue clay which is of marine origin, as indicated by foraminiferal content, extending to a depth of 79 feet (fig. 1). There an unfrozen stratum about 7 feet thick was encountered, seemingly another beach gravel (fig. 2), which showed promise of yielding water abundantly. Static level was 15.9 feet below the surface (or about sea level). However, upon analysing a sample it was found that the water contained 26,000 parts per million (ppm) of chloride (Table 1). This salinity is appreciably greater than that of sea water (generally 18,000 to 20,000).

Below the thawed layer, frozen marine blue clay extended to 190 feet, at which depth a gravelly layer 28 feet thick was encountered (fig. 1). The sample taken at 194 feet in this layer appeared to be a stream-laid deposit. However, when the particle-size analysis of the sample taken at 212 feet was plotted, a curve tipical of till was apparent (fig. 3). It is possible that the 194-foot sample also is till, but it has been greatly altered by the drill and its grain-size characteristics obscured. (Some samples of till from cable-tool wells in the Anchorage area plot up much like water-laid material.)

At 218 feet marine blue clay was again penetrated at 226 feet another "gravel bed" was reached. This bed, 12 feet thick, also may be glacial till. Particle-size analysis of a sample taken at 234 feet shows a long diagonal slope when the cumulative percentages are plotted (fig. 3).

Table 1. -- Analyses of ground water samples from test hole at Kotzebue, Alaska (Results expressed in parts per million.) Analyses by U. S. Geological Survey

	Depth (feet)			
	82	130*	260	273
Silica	9.7	5.1	42	51
Iron	68	...	...	...
Calcium	640	...	184	41
Magnesium	1,890	...	...	348
Sodium and potassium	14,100	...	2,850	3,490
Bicarbonate	1,770	221	1,200	1,800
Sulfate	1,610	...	...	9.0
Chloride	26,200	515	4,680	5,670
Dissolved solids	45,300	...	...	10,600
Hardness (as $CaCO_3$)	9,370	130	1,390	1,890
Specific conductance (micromhos at 25oC)	63,500	2,110	15,000	17,800
PH	7.2	...	7.6	7.6

* Sample of permafrost ice

Smith and Mertie (1930, p. 242) note that the Baird and DeLong Mountains to the north were glaciated, and from these mountains "tongues of ice extended outward into the lower country..." Here, in the Kotzebue well, may be evidence of an ice tongue about 50 miles from the nearest known glaciated area, probably southward from the mouth of the valley of the Noatak.

All sediments between the surface and a depth of 238 feet, except the thin unfrozen stratum noted, were frozen.

At 238 feet unfrozen ground was encountered. This was a spectacular event in that an accumulation of gas, probably methane, was encountered below the permafrost. Upon penetrating the zone the heavy cable tools were thrown 10 or 12 feet upward and the area was showered with mud and silt. Gas issued under pressure for about an hour and then the pressure rapidly decreased; the next morning only a very small amount of gas flow could be observed.

Gas occurrence beneath the permafrost layer is not unique. At Fairbanks a short-lived accumulation of gas was found beneath the permafrost in a Geological Survey test hole on the Farmers Loop Road, in 1948. At Eielson Air Force Base, east of Fairbanks, a gas accumulation was struck beneath the permafrost on the valley flats in a water well drilled by the Army in 1952. Here the gas issued under pressure for several days.

Upon reaching unfrozen ground at 238 feet in the Kotzebue test hole, the drill penetrated silt and fine sand, possibly of continental origin, which penetrated to a depth of 325 feet. This fine-grained material was saturated with water, which was somewhat salty. Static level was 42 feet below the surface. Samples at 260 feet and 273 feet contained respectively 4,680 and 5,670 ppm of chloride (Table 1). It was believed that more saline water probably would be encountered at greater depths, and the hole at Kotzebue was therefore discontinued. The frozen sediments between 238 and 325 feet were, as noted, of fine sand to silt size and the formation is regarded as non-water-bearing insofar as development of a producing well is concerned.

The sediments being considered are estuarine in largest part and hence were covered by waters above the freezing point during most of the depositional cycle. It follows, therefore, that these sediments were not frozen--or at least were not frozen throughout--until after deposition had ceased and the area was elevated above sea level.

The origin of the highly saline water between 79 and 86 feet poses an interesting question, as presumably the sediments were laid down in slightly brackish water similar to but probably less concentrated than that existing in the ocean of today. It is suggested that this highly saline water may have originated through a process of fractionation by freezing of the original slightly brackish water with which the sediments were saturated. The result would be an ice of very low chloride content and a high-cloride liquid residue.

The following succession of events is postulated: Freezing began at the surface and moved downward. As freezing of the waterlogged sediments progressed, formation of ice in the ground created a tight, impermeable mass and excess liquid (equivalent to roughly a tenth of the volume of water) was driven downward. As the original liquid with which the sediments were saturated was slightly brackish, the separation of nearly pure-water ice from the system increased the salinity of the unfrozen liquid below the ice front. As freezing progressed, hydrostatic pressure was built up, but this pressure was relieved largely by lateral movement through the permeable gravel layer. Thus, in part by a process of displacement, the salt content of the originally slightly brackish water in the gravel layer was augmented by that of the high-chloride water migrating downward.

Movement of water in the gravel layer, other than that which accompanied relief of freezing pressure, must have been negligible because, if normal artesian circulation existed, essentially fresh water would be found in the gravel bed today instead of the highly saline water.

As the ice front approached the gravel layer, the freezing point of the sediments saturated with slightly brackish water probably was only a little below 0°C. The effective environmental temperature was slightly lower and gradually declined appreciably below 0°C. Freezing of the saturated sediments progressed slowly downward and above the 0°C isotherm the bulk of the frozen sediments were chilled several degrees below the effective freezing point. However, as the subzero cold migrated downward, the salinity of the aqueous residue after fractionation by freezing finally became great enough that the effective temperature would not produce freezing. Nevertheless, the cold front continued to advance downward. Upon passing through the gravel stratum, the "cold front", or the effective temperature developing subsequent passage downward of the "cold front," was sufficiently cold to freeze the sediments beneath (below 86 feet), because here the sediments still contained only slightly brackish water. Because of the low permeability of sediments below 86 feet, saline water migrating downward moved laterally in the gravel, and the water in the beds below the gravel bed was essentially undisturbed. Thus freezing proceeded downward to a point where the flow heat from great depths was sufficient to prevent it. 1/

1/ Mr. Ted Loftus of the Fairbanks Exploration Company, Fairbanks, reported (oral communication, Aug. 12, 1954) that in Nome small bodies of salt water are encountered within frozen alluvium. Presumably these salt water "lenses" likewise could have originated by the fractionation process outlined above.

It might be considered quite a coincidence if the salinity of the liquid residue after fractionation by freezing increased to the point that would prevent freezing, just as gravel bed at 79 feet was reached by the cold front. It is just as reasonable to assume that the freezing point of the residue may have been depressed to produce a nonfreezing condition after, say, 60 feet of sediments had been converted to permafrost. The cold front would then have proceeded as outlined above and the final result would be a permafrost mass with an unfrozen gravel layer overlain by about 20 feet of unfrozen silty clay. How, then, could solidification have advanced through the 20 feet of unfrozen silty clay to the gravel layer and have stopped at that point, to produce the conditions now existing?

No easy explanation is at hand, but one is ventured here for what it may be worth. Taber's experiments on frost heaving seem to point the way, even though these experiments were performed on sediments saturated with (1930, p. 306) shows that, in the downward freezing of cylinders of saturated column of sand will freeze solid without drawing in excess water. The force of molecular cohesion in the fine-grained sediments between an ice face and free water particles immediately adjacent is strongly emphasized by Taber (p. 309).

Returning now to a consideration of the Kotzebue problem: We have postulated a thick permanently frozen mass, in which an unfrozen layer of gravel at 79 to 86 feet is overlain by 20 feet, more or less, or unfrozen clay. The salinity of the liquid is the unfrozen material is such that its freezing point is just below that of the temperature of its environment. It is suggested that under these conditions, without any necessity of lowering the temperature further, the forces of molecular cohesion in the fine-grained sediments would come into play, and that the ice faces in contact with the saline solution would continue to grow, although perhaps more slowly. However, below the contact of the clay stratum with the gravel stratum, the saline solution is present in large voids, molecular cohesion in negligible, and the solution remains in liquid form.

This hypothesis requires that a second body of highly concentrated water from below the gravel and be pushed downward below the maximum depth of freezing. Inasmuch as the samples of water taken from the hole at 260 and 273 feet were only slightly brackish, it would seem that the freezing must have extended below the depth of the lowest sample, and the present bottom of the permafrost at 238 feet represents a thawing back in a time of rising temperature. However, even if such thawing back has not occurred, the low salt concentration of the solution below 238 feet might well be ascribed to dilution due to normal ground-water movement in the subpermafrost zone.

It might be possible that the salt-water gravel represents a beach deposit formed during a glacial maximum when the sea water was more concentrated than average, and the fine-grained sediments above and below were deposited in fresh or only slightly brackish water during periods of vigorous melting of ice. If a gravel deposit were laid down, then quickly covered and isolated hydrologically (no ground-water movement occurring in the mass after burial) the observed conditions might be explained without calling upon fractionation hypothesis. However, fractionation does occur in the Arctic, as seen in the fresh ice harvest by the Eskimos from the sea as a source of drinking water and ~~as noted~~ in the salt water lenses found in the alluvial plain at Nome, referred to above. The entrapment of a salt case of special pleading.

The question has been raised as to the possibility that the thawed zone reached at 238 feet at Kotzebue might be a talik (an unfrozen horizontal layer) and that frozen ground might be again encountered at greater depths. From experience in the Fairbanks area, it is believed that the unfrozen zone encountered at 238 feet at Kotzebue continues downward without interruption by any other frozen layer or frozen mass. In fact, it is the writer's feeling that a horizontal talik formed well down in the permafrost mass (as compared to a thawed zone between the surface winter frost and the permafrost) is an uncommon phenomenon, one that can exist only under special conditions such as conditions of strong ground-water movement.

Many difficulties were encountered in the course of drilling but only a few of these were a function of the geography and geology. Our experience may be summarized by the trite statement that careful planning, first-class equipment, experienced personnel, and ample finances would have eliminated most of the difficulties.

Permafrost was found to be somewhat of a problem. Frozen ground can be drilled readily enough, but casing the hole is not so easy. Introduction of a little heated water from time to time or use of salt in drilling will take care of the actual making of hole, but there is still the inevitable tendency of the casing to freeze to the walls. In several instances the hole at Kotzebue was thawed by steam to free the casing. This is somewhat troublesome, and probably equally good results could be obtained by circulating hot water through a small-diameter line. It was found, however, that the best plan to prevent freezing of the casing was to drill as continuously as possible and to move the casing frequently.

To alleviate the present water shortage at Kotzebue, consideration might be given to melting the upper 10 feet or so of the permafrost over a sizable area, to create a reservoir of some magnitude (Cederstrom, 1952, p. 36). The melting would be accomplished by stripping the muskeg and admitting solar heat, circulating ground water in the thawed zone by pumping, and applying warm pond waters in summer. Care should be taken to prevent undue loss of heat in winter, by building and preserving a maximum snow cover through use of snow fences of one sort or other. The efficiency of such a thawed reservoir would depend on depth of thaw, degree of retention of heat, and inflow of water from adjacent thawed zones lying between the winter frost and the permafrost.

Figure 1

U.S.G.S. TEST WELL - KOTZEBUE

Beach gravel, frozen	0 - 19
Blue silty clay, frozen	19 - 79
Gravel, salt water, thawed	79 - 86
Blue silty clay, frozen	86 - 190
Glacial till, frozen	190 - 218
Blue clay, frozen	218 - 226
Glacial till, frozen	226 - 238
Brown silt, brackish water, thawed	238 - 325

NOTE: Graphic log of original report reproduced here as shown.

Fig. 2 and 3 not reproduced (mechanical analyses of water bearing material).

REFERENCES

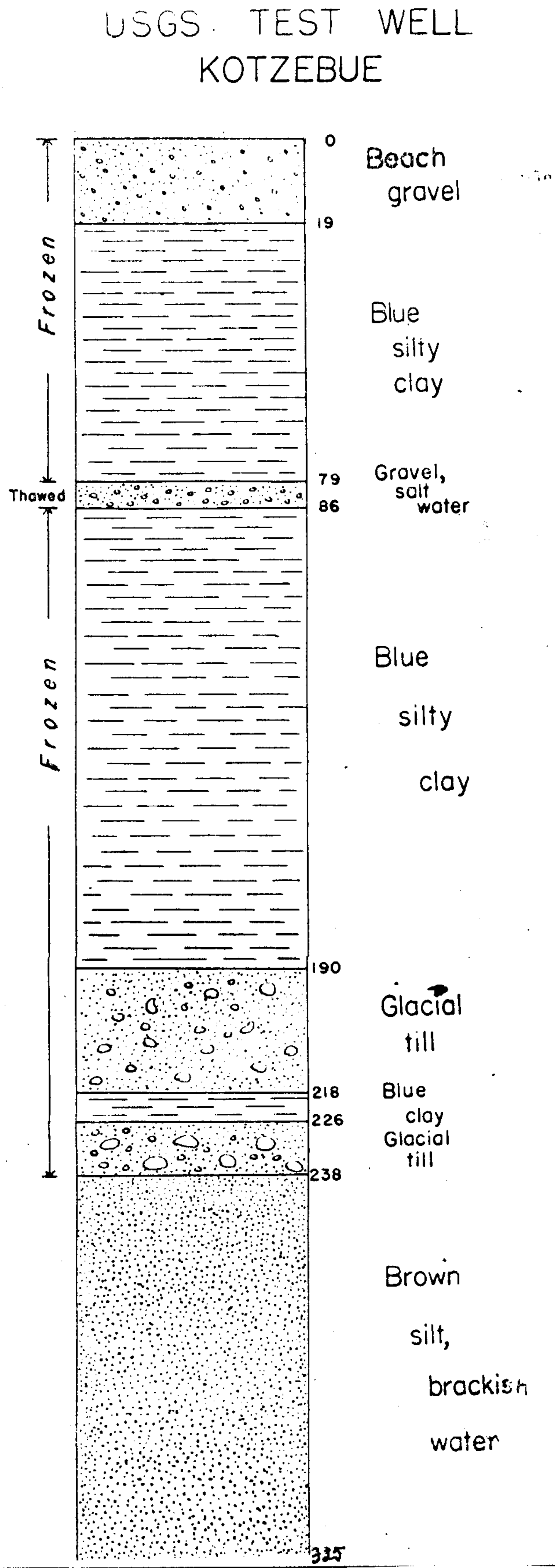
1. Cederstrom, D. J., Summary of ground-water development in Alaska, 1950: U. S. Geological Survey Circular 169.

2. Smith, P. S., and Mertie, J. B., Jr., 1930, Geology and mineral resources of northwestern Alaska: U. S. Geological Survey Bulletin 815.

3. Taber, Stephen, 1930, The mechanics of frost heaving: Jour. Geology, v. 38, p. 303-317.

ILLUSTRATIONS

Figure 1.—Log of USGS test well at Kotzebue



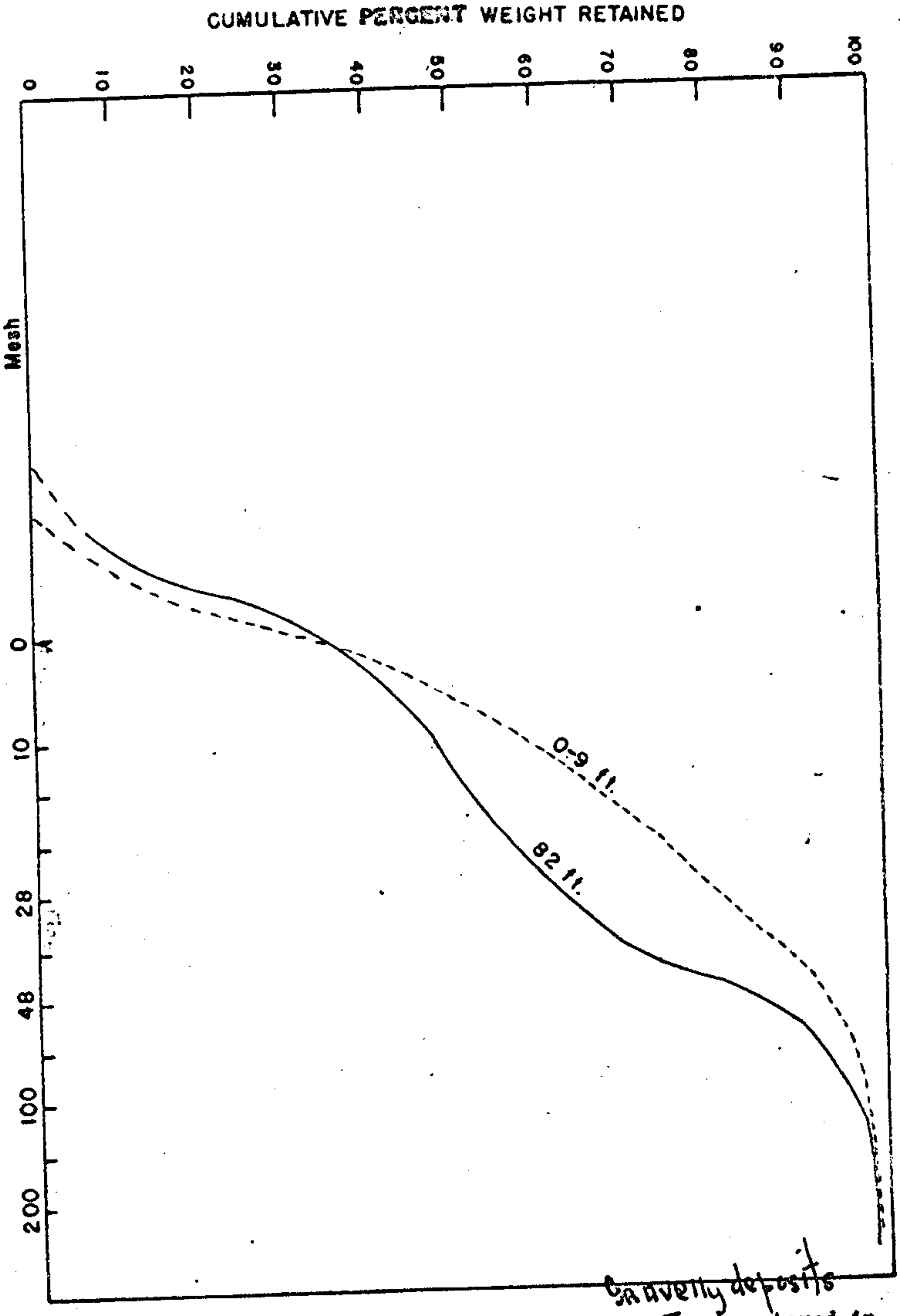


Figure 2.--Mechanical analyses of upper ~~sands~~ gravelly deposits ~~encountered~~ penetrated in well at Kotzebue.

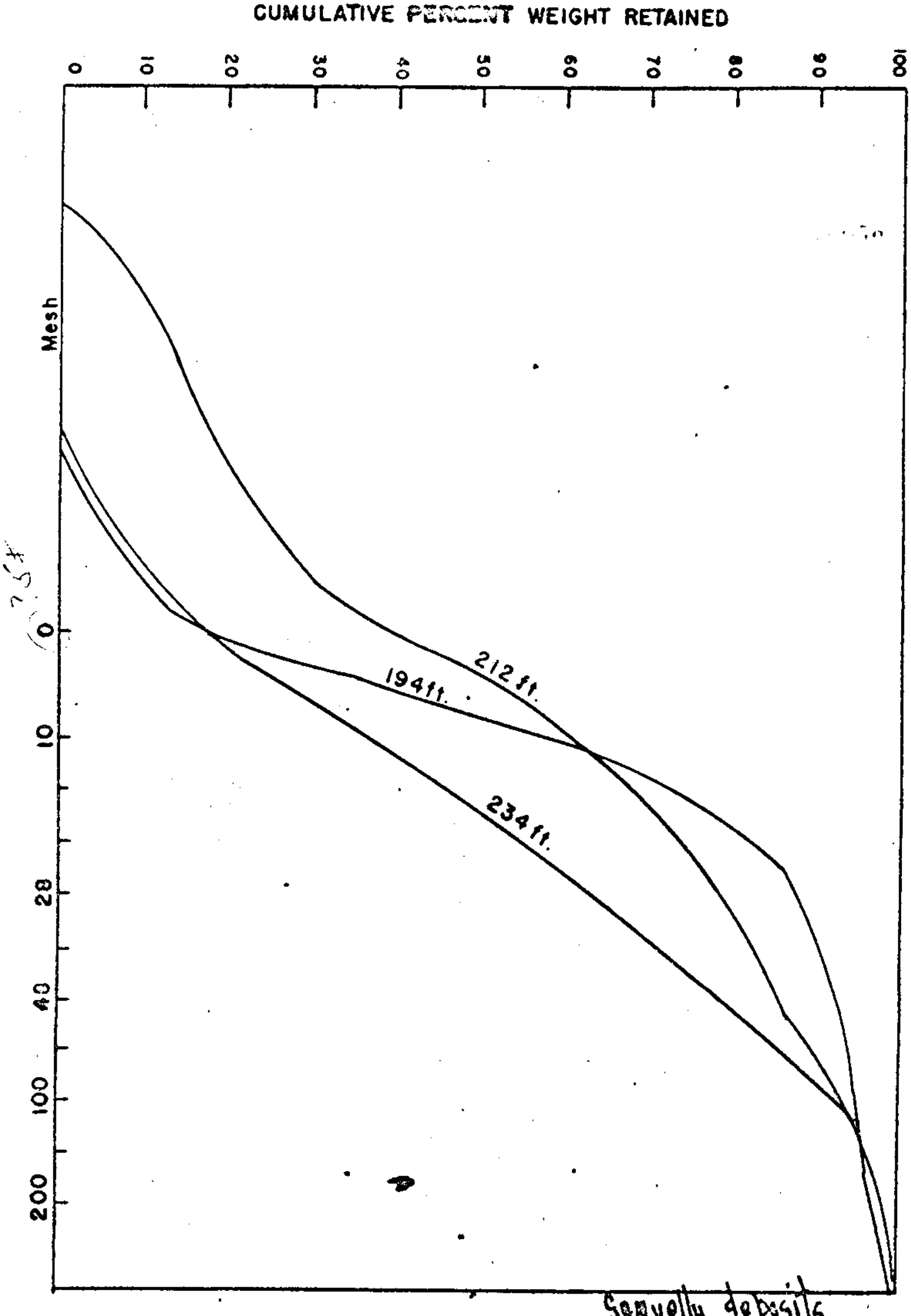


Figure 3.--Mechanical analyses of deeper ~~sands encountered~~ gravelly deposits penetrated in well at Kotzebue.