State of Washington
ALBERT D. ROSELLINI, Governor

Department of Conservation
EARL COE, Director

DIVISION OF MINES AND GEOLOGY
MARSHALL T. HUNTTING, Supervisor

Bulletin No. 49

SALINE LAKE DEPOSITS IN WASHINGTON

By

W. A. G. BENNETT

STATE PRINTING PLANT, OLYMPIA, WASH.
1962

FOREWORD

Because large tonnages of sodium sulfate are consumed in the paper and paperboard and other industries in the Pacific Northwest, there has been a continuing interest in developing natural sources of this material here. As a result of requests received in this office for information on Washington deposits of sodium sulfate, sodium carbonate, epsomite, and other salts, the Division of Mines and Geology in the winter of 1944 started field examinations of the saline-lake deposits of the State. The field work was completed in 1945, analyses were made of samples of salts and brines, maps of the principal deposits were drafted, and tonnages were calculated for the salts in these deposits. Dr. W. A. G. Bennett, who was in charge of the work, wrote his report on the saline-lake deposits of Washington soon after completion of the survey, but, because of slackening of interest in local sources of these salts, the manuscript was not finally prepared for publication until early in 1962.

In the intervening years many requests for information on our saline-lake deposits have been filled by releasing the manuscript data to those who have asked for it. The continuing inquiries and the inconvenience and cost of reproducing the requested sections of the report were influential in the decision to publish the report at the present time.

Just when the manuscript was ready for submission to the printer, the Area Redevelopment Administration of the U.S. Department of Commerce announced a Technical Assistance Project to determine the feasibility of producing sodium sulfate and other salts from deposits on the Colville Indian Reservation in Okanogan County. All the relevant data in this report have been released to the investigators for the Area Redevelopment Administration, and it is expected that their survey will add materially to the knowledge about many of our saline-lake deposits reported in this bulletin.

Marshall T. Huntting, Supervisor
Division of Mines and Geology
Olympia, Washington

August 1, 1962

CONTENTS

Page

Deposits—continued
Sodium sulfate lakes—continued
Okanogan County—continued

ILLUSTRATIONS

TABLES

SALINE LAKE DEPOSITS IN WASHINGTON

By W. A. G. BENNETT

INTRODUCTION

Location and Climatic Features

The area considered in this report is located in a dry belt of Washington, mostly between the 47th and 49th parallels of latitude, that lies immediately east of the Cascade Mountains (fig. 1). This area, which receives an average annual precipitation of about 6 inches on the south and 12 inches on the north (Fisher, 1941, p. 1170-1181), is particularly favorable to concentration of salts in basins having no surface or subsurface drainage. Farther east, certain undrained but weakly saline lakes occur in southwestern Spokane County and in adjacent parts of Lincoln and Whitman Counties; but there the average annual precipitation increases to about 16 inches, and the mean summer humidity and temperature are respectively higher and lower, factors among others that have a bearing on the rate of evaporation and ultimate concentration of salts.

Purpose and Scope of the Report

The report includes descriptions of those deposits of crystallized salts and of brines that occur in the so-called saline, alkali, soda, bitter, or soap lakes of the State, omitting those brines that occur in certain springs and wells. Its purpose is to provide additional information on the several known deposits of sodium carbonate and sodium sulfate, about which numerous inquiries have been received by the Division of Mines and Geology, especially since the end of hostilities in World War II. Incidentally, a few other lakes, in particular those that appeared to contain appreciable quantities of carbonates, were mapped and sampled and brief tests were made on the brines of a few of the many that are more or less saline. As the field investigations progressed they were expanded to include magnesium sulfate and gypsite. The latter ordinarily is not included in the general category of salines but, at least in this State, is closely connected to them with respect to occurrence and origin.

History and Production

Salts resulting from artificial evaporation of the water of Medical Lake or Medical Lake spring, Spokane County, were sold, together with the water itself, in 1885 (Peale, 1886, p. 541). This is apparently the first recorded sale of salines in the State (at that time the Washington Territory). Sales of both these products, but recently only of salts, have been reported from Soap Lake, Grant County, the water of which has been of interest to the public for its asserted therapeutic value since about the beginning of the 20th century. The sale of these and other mineral waters up to 1923, when the canvass was discontinued by the U.S. Bureau of Mines, has probably exceeded $500,000 (Glover, 1936, p. 69).

The first production of sodium sulfate (salt cake) was from Sulphate Lake, Grant County, in 1916; mirabilite was mined, air dried to thenardite, and several hundred tons shipped to kraft paper mills in Minnesota. But most of the efforts to produce this salt, at intervals during the 25 to 30 years prior to 1945, centered in Okanogan County. Efforts to produce sodium carbonate at Carbonate and Mitchell Lakes, Grant County, were made at various times from 1927 to 1940.

The total production of sodium salts recorded by the U.S. Bureau of Mines is small, the actual amount being concealed, but it does not include that from Sulphate Lake; the reported output is, therefore, considerably less than the actual production.

Magnesium sulfate, from natural brines and crystalline salt bodies, makes up by far the largest part of the State's total production of salines. Production has come from two lakes, near Tonasket and Oroville, Okanogan County, at intervals from 1915 to 1945. The production for the latter part of the period has been compiled by the U.S. Bureau of Mines, though the figures have been concealed except for 1943, when 358,000 pounds, valued at $10,000, was sold. The production for the earlier years is unknown but is said to have been large in 1915-16—according to one report, 250 tons per day, and to another, several cars per week—yet the amount of solid salts that could have been taken from Bitter Lake probably did not exceed 25,000 tons. The record is confused somewhat by the fact that 2,500 tons of salts was hauled to Oroville from Canadian deposits, and this production was included in the Washington production figures. In 1923, when the U.S. Geological Survey for the first time reported the production of natural magnesium sulfate, the production in Washington, California, and Michigan was 14,300,000 pounds, valued at $231,000. In spite of the fragmentary nature of the records, it seems reasonable that 20,000 tons of epsomite, with a value of about $500,000, has been produced in Washington.

Earlier Investigations

Most of the information on the saline lakes of the State is included in the following list of reports that have been briefly annotated. Some additional references have been included in the text. However, no thorough search was made in various mining journals for items more or less of mining news character. Private reports on certain deposits or groups of deposits have been made from time to time by mining and chemical engineers and others, and some of these reports are on file in the Division office.

Anonymous, 1941, C. A. Kearney Company epsom salt production at Tonasket, Washington: Mining World, vol. 3, no. 7, July 1941, p. 29-31. Gives a brief description of the deposit at Poison Lake, the mining methods used, and a detailed illustrated account of the refining process.

Byers, H. G., 1902, The water resources of Washington, potable and mineral water: Washington Geol. Survey Ann. Rept. 1901, pt. 5, p. 8-11. Gives analyses of the water of Soap, Medical, and Moses Lakes.

Clarke, F. W., 1893, Report of work done in the division of chemistry during 1891-92 and 1892-93: U.S. Geol. Survey Bull. 113, p. 113. Contains a restatement of the analysis of Soap Lake water published in Bull. 108.

——————— 1924a, The composition of the river and lake waters of the United States: U.S. Geol. Survey Prof. Paper 135, p. 180. Gives statements of analyses of water from Omak, Soap, Medical, and Moses Lakes.

——————— 1924b, The data of geochemistry: U.S. Geol. Survey Bull. 770, p. 164-179. Analyses of the water from Soap, Moses, and Omak Lakes are stated in percent of total anhydrous residue for the purpose of comparison and classification. Magnesium sulfate is called a very unusual saline deposit, page 243.

Glover, S. L., 1936, Nonmetallic mineral resources of Washington, with statistics for 1933: Washington Div. Geology Bull. 33, p. 42-43, 97-99. Gives general information on location, size, depth, and grade of deposits in Carbonate, Mitchell, and Sulphate Lakes in Grant County and of Hauan and Murray Lakes in Okanogan County, including locations of other well-known deposits of sodium sulfate; and describes the epsomite deposits at Poison and Bitter Lakes.

Handy, F. M., 1913, An investigation of the mineral deposits of northern Okanogan County, Washington: Washington State Coll. Bull. 100, p. 25. Describes magnesium sulfate from Bitter Lake, and mentions large shipments resulting from a great increase in price of the salt.

Jenkins, O. P., 1918, Spotted lakes of epsomite in Washington and British Columbia: Am. Jour. Sci., 4th ser., vol. 46, p. 638-644. The Bitter Lake deposit is described; details are given on mining methods and development, form, and occurrence; and a theory of origin of the epsomite is stated.

Ladoo, R. B., 1925, Nonmetallic minerals, occurrence, preparation, utilization. New York, McGraw-Hill, p. 207-211, 558-577. Mentions magnesium sulfate and sodium compounds.

——————— 1947, Sources of soda ash and other sodium compounds for Columbia River Basin industry: Raw Materials Survey (Portland, Oregon) Rept. 2, 25 p. Gives information on sources, production and consumption, utilization, and prices of sodium carbonate and sodium sulfate; mentions substitutes for soda ash in glass making.

Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation, Washington: U.S. Geol. Survey Bull. 677, p. 179-180. Mentions the saline district of the Okanogan Plateau, including an analysis for potash from one lake, but gives special attention to Omak Lake as a possible source of salines.

Patty, E. N., and Glover, S. L., 1921, The mineral resources of Washington, with statistics for 1919: Washington Geol. Survey Bull. 21, p. 105-107. Describes briefly the epsomite deposit at Bitter Lake and states extent, depth, origin, mining and refining methods used; gives statement of size, depth, and production of sodium sulfate at Sulphate Lake, Grant County.

Russell, I. C., 1893, A geological reconnaissance in central Washington: U.S. Geol. Survey Bull. 108, p. 92-96. Contains notes on Soap Lake, an analysis of its water, and a brief mention of Moses Lake.

Shedd, Solon, 1924, The mineral resources of Washington, with statistics for 1922: Washington Div. Geology Bull. 30, p. 137-138. Bitter and Poison (Epso) Lakes are mentioned. The statement is made that in Poison Lake the salt body is a single mass, 30 feet thick, that underlies 20 feet of mud and an area of 15 acres, and that epsomite is mined underground.

Taylor, G. C., 1948, Ground water in the Quincy Basin, Wahluke Slope, and Pasco slope subareas of the Columbia Basin Project, Washington: U.S. Geol. Survey open-file report, 182 p. Two new analyses of the water of Soap and Moses Lakes (page 180) are included.

Valentine, G. M., 1960, Inventory of Washington minerals—pt. 1, Nonmetallic minerals. 2d ed., revised by M. T. Huntting: Washington Div. Mines and Geology Bull. 37, pt. 1, v. 1, 175 p.; v. 2, 83 p.; originally published in 1949 as one volume. The location, size, tonnage of principal salt, and estimate of value of various saline lakes, including those that contain gypsite, are given.

Walker, T. L., and Parsons, A. L., 1927, Notes on Canadian minerals, tremolite, clinohumite, stromeyerite, natron, and hexahydrite: Toronto Univ. Studies, Geol. Ser. 24, p. 21-23. The efflorescent crust (called hexahydrite) that forms on epsomite under certain atmospheric conditions is described; the report includes two analyses of samples collected near Oroville.

Methods of Field Work

The field work was carried on at intervals between October 1944 and November 1945, most of it being done between March and August. All lakes except Soap, Salt, Omak, and Wannacut, the larger brine lakes, were surveyed, using a plane table and alidade, and located with respect to section corners. A boat was used in late July to give access to most of the lakes to determine the depth, temperature, and specific gravity of the brine; to take samples of it for analysis; and to make other observations, including the presence, if any, of salt pans, their size, shape, and distribution. The boat was hauled about on a small trailer. Most of the test-hole drilling was done after a crust had formed on the lakes in the fall, and an Iwan 3-inch cup-type earth auger of the common post-hole boring variety was used. A coal auger 1½ inches in diameter and 2 feet long, split at the lower end to form two steeply pitched cutting edges, was found useful for rapid boring through hard salt layers and in sticky lake-bed clay. A cylindrical or hollow spiral auger, one of several types manufactured by Clayton Mark and Co., was used at first, but it failed to cut the harder salt layers and was difficult to free of mud. In drilling holes deeper than 15 feet, a tripod, fitted with adjustable legs and transported on ski racks atop a car, was used. During the field work 81 samples were collected; of these 27 were of brine or of spring water and 54 of solid salts. Of the lakes included in this report, all except one are represented by one or more brine samples. Samples of the crystallized salts were taken in one or more holes in most of those lakes in which drilling was done, and in other lakes an occasional sample was taken of the efflorescent crust that forms on mud around the shore line. More samples were taken at Carbonate Lake than at any other, partly because of the value and importance of sodium carbonate, and partly because of the irregular distribution and complexity of its salts. Samples, in fruit jars as well as in paper sacks, were usually taken at short intervals in the auger cuttings, but some were later composited in order to reduce the cost of analysis, especially where there appeared to be no particular advantage in making analyses of short depth units in material that appeared to be uniform.

The samples were analyzed at the Department of Chemistry and Chemical Engineering, University of Washington, as well as at the U.S. Bureau of Standards, in Seattle, where special facilities were available for recovery of platinum in making determinations of potassium, resulting in a reduction in the cost of the analyses. Because of this, more determinations were made for potassium, which was looked for qualitatively by flame tests on many of the samples, than had otherwise been planned. Most of the samples, before analysis, were dried in an oven at a temperature of 150° C., the rest at 110° C. Those that contained mainly the common sodium salts, which are readily soluble in water, were analyzed by taking 5 grams of material that was leached by application of several portions of hot water totaling 150 milliliters. The analyses have been reported by the analysts in several ways, as follows: (1) those of the soluble salts (45 in number), as constituents (radicals or ions) and as hypothetical compounds; (2) the brines (27 in number), as constituents in parts per million (milligrams per liter); (3) the more complete analyses (27 in number) of the "insoluble ores" as reported by the analysts (salts of the lake-bed "mud" in Poison and Bitter Lakes, Lenton Flat, and the gaylussite zone in Mitchell Lake), as constituents mostly in the form of oxides; and (4) the mineral epsomite, as constituent oxides and as hypothetical combinations showing epsomite and its alteration product. Further calculations of the analyses have been made by the writer to show brine constituents in percentage of total solids for purposes of comparison and classification in accordance with the method of Clarke (1924, p. 175-180) and to show conventional combinations in percentage of total solids for calculation of tonnages of the salts that would be expected to be recovered from the brines. The complete analyses (third category above) have been calculated, also by the writer, into compounds, of which some are more-or-less hypothetical, for the purpose of making estimates of tonnage, especially of gypsite.

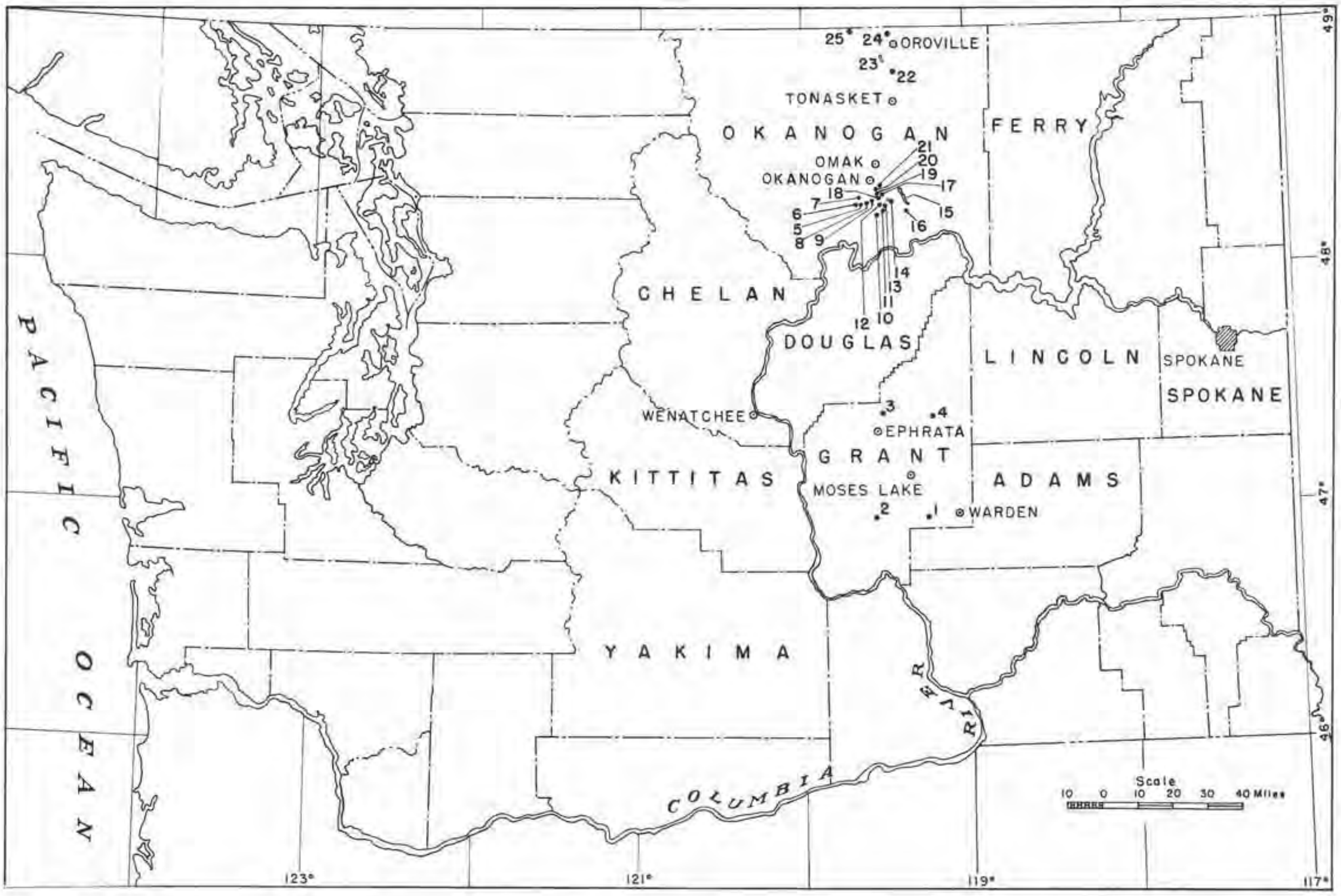
Acknowledgments

During the course of the field work, a part of which was done in snowy, freezing weather, the writer was ably assisted by Mr. Stephen H. Green and Mr. Alton K. Guard, at that time members of the staff of the Division of Mines and Mining. Mr. C. A. Kearney, who had much experience as an operator of the epsomite lakes, helped with the field work for a short time in the spring of 1945. The use of a small boat and trailer, for making examinations while the lakes were still covered with brine, was generously provided by Mr. Harry Fischnaller, proprietor of the James J. Hill Hotel in Omak, who also with Mrs. Fischnaller extended many other courtesies. At the start of the work Mr. J. W. Melrose, at that time geologist for the Chicago, Milwaukee, St. Paul and Pacific Railroad, kindly loaned certain drilling equipment. To Mr. Roy E. Leigh, at that time also geologist for the "Milwaukee Road," goes the credit for finding, at Sulphate Lake, the first crystals of halite ever found in the State, so far as the writer is aware.

Especial thanks are due Dr. H. K. Benson and Dr. R. W. Moulton, of the Department of Chemistry and Chemical Engineering, University of Washington, and Mr. P. G. Hebner, who did much of the laboratory work during odd hours over a period of 10 months, for undertaking and carrying out the task of analytical work, the results of which form such an important part of this report. Dr. George B. Rigg, professor emeritus of botany at the University, kindly identified a plant that grows abundantly in many of the lakes.

The writer is indebted in various ways to present and former members of the Division staff, but especially to Mr. Sheldon L. Glover, who planned the project from the beginning and to

Mr. Marshall T. Huntting for much advice as well as work in completion of the manuscript for publication; also to Mr. Grant M. Valentine, formerly of the Division staff, for spectrographic analyses.



1. Carbonate Lake
2. Sulphate Lake
3. Soap Lake
4. Mitchell Lake
5. Salt Lake
6. B-J Lake
7. Virginia Lake
8. Lake 32
9. Stevens Lake
10. Lawson Lake
11. Morris Lake
12. Hauan Lake
13. Deposit No. 13
14. Murray Lake
15. Omak Lake
16. Deposit No. 16
17. Patterson Lake
18. "Rimrock Lake"
19. Cook Lake
20. Penley Lake
21. Cameron Lake
22. Poison Lake
23. Wannacut Lake
24. Bitter Lake
25. Lenton Flat

FIGURE 1.—Index map showing location of saline lake deposits in Washington.

REGIONAL GEOLOGIC SETTING AND DISTRIBUTION

As may be seen in figure 1,* the saline lakes considered in this report are grouped into three areas: (1) the predominantly sodium carbonate lakes of the southern district, in Grant County, underlain mainly by the Columbia River Basalt and in part surrounded by fluvioglacial deposits; (2) the predominantly sodium sulfate lakes of the central district, in south-central Okanogan County, underlain (a) by granitic rocks, (b) by an extension of the Columbia River Basalt that forms the Okanogan Plateau, and (c) by surficial deposits of glacial drift, till, and stratified silts; and (3) the predominantly magnesium sulfate and gypsite lakes of the northern district in northern Okanogan County west of the Okanogan River, underlain chiefly by metasedimentary rocks and interbedded lenses of limestone (these rocks being more or less mineralized), and in part by granitic rocks and glacial outwash deposits.

DEPOSITS

GENERAL FEATURES

Although the lakes surveyed range in size between 3 and 3,800 acres, most of them are less than 20, averaging about 13. Both brine and crystalline salts are found in the smaller lakes, but only brine in the larger. The brine of the smaller lakes usually disappears from the surface by early fall, but in a few lakes it remains throughout the year. It is mostly shallow and, though weakly concentrated in the spring, becomes saturated as the lakes are crusted over in the fall. The specific gravity of the brine of the larger lakes ranges from 1.036 (near that of sea water) to 1.006; these brines are often separated into masses of different density between the surface and the bottom, but whether of different composition is not known. However, the brine that permeates the permanent salt deposits and the mud of at least two lakes of the smaller group differs in composition from that on the surface of the one and from that in other parts of the lake bed of the other. The densest brines are found among the carbonate and magnesium sulfate lakes of the group of smaller lakes, reaching a maximum specific gravity of 1.40 at Poison Lake, which apparently is exceeded only by the so-called bitterns, or predominantly chloride brines of Ohio and West Virginia. The brine in some of the smaller lakes is turbid during the spring and summer, because of inwashed colloidal clay but clears as its density increases in the fall. The only colored brine is that of Carbonate Lake, which is reddish brown, especially as viewed from around the rim of the enclosing basin and as its concentration reaches a maximum.

Most of the brines are noteworthy for their indigenous plant and animal life. One plant, which presumably represents a single species and which grows in many of the smaller lakes on mud ridges sur-

---

* See also Washington Div. of Mines and Geology, 1961, Geologic map of Washington.

rounding the salt deposits as well as in one of the larger brine lakes to a depth of 20 feet, has been identified by Dr. George B. Rigg (written communication, Feb. 24, 1949) who writes as follows:

> The material . . . proved to be rather fragmentary . . . . I did not find any whole leaves or whole flowers. I did, however, find stems and also the small drupes which contain the seeds. It is difficult to make a positive identification on the basis of this evidence but I am reasonably sure that it is a species of "ditch grass" (Ruppia occidentalis). This plant is known to grow in saline ponds. It belongs to the Pondweed Family (Najadaceae).

Diatoms, algae, and other plants representing higher forms have been reported in Soap Lake, and a few diatoms have been found in Poison Lake. Greenish free-floating globular plants as large as half an inch in diameter were observed in abundance in Murray Lake.

Animal life is represented, especially in the brines of the smaller lakes, by myriads of pinkish or reddish organisms which are said to be fire shrimp. Black flies, called soda flies by Cummings (1940, p. 3-5, 42), have been observed at some of the sodium carbonate lakes, usually on the black mud at the water's edge but in one instance in masses on the bottom in shallow water.

The crystallized salts, which will usually be referred to farther on in this report as crystal, form both intermittent (seasonal) and permanent deposits. The intermittent crystal forms on the surface of both the mud and the permanent salts, as the brine evaporates, and is dissolved again as the lake level rises during the rainy season; it is usually fine grained, hydrous to dry and powdery, and generally does not exceed an inch in thickness. Its deposition is controlled mostly by concentration of the brine but in part by temperature changes, not only during cold weather but from day to night in the summer. The salts that form during cold weather have been called winter crystal, part of which probably does not dissolve through the summer and thus becomes a part of the permanent salts.

PERMANENT CRYSTAL

The deposits of permanently crystallized salts occur mostly as circular to irregularly circular, separate lenses at the surface of the lake beds, in part as disseminated crystals below, in one instance as a single relatively large lens, and as a bed at the bottom of a brine pool. The lenses, which in this report will often be referred to as "pans," have been called "bowls" or "crystal bowls," (Goudge, 1926, p. 88; Cummings, 1940, p. 14-16, 36) and "pot holes," (Allison, 1947, p. 7-11) and are the "spots" of the "spotted lakes" of Jenkins (1918, p. 638-644). The surface of each lens or pan lies a few inches lower than the level of the tops of the surrounding rings and ridges of lake-bed mud. It is believed that at depth there is generally no connecting bed of salts from pan to pan, such as that at Bitter Lake described by Jenkins (1918, p. 641). The pans generally range in diameter from a few feet to 75 feet and in thickness from a few inches to 12 feet; their ratio of diameter to thickness ranges between 2 to 1 and 15 to 1 but is commonly between 3 to 1 and 5 to 1.

Some pans appear to be coarse aggregates of crystals, whereas others are made up of alternating layers that may be hard to soft or coarse to fine grained. There may be layers of mud, or mud with disseminated crystals, on top, within, or at the bottom of the pans. Those made up of coarsely granular, unstratified aggregates of crystals, as shown by an example in each of two lakes, have outward-tapering curved-down rims that extend under the surrounding ridges of mud (fig. 2); in one instance a stratified pan 3 feet thick and 10 feet in diameter had straight sides to a depth of 1 foot but did not extend under the mud ridges; still another type is shown in figure 3 from Carbonate Lake.

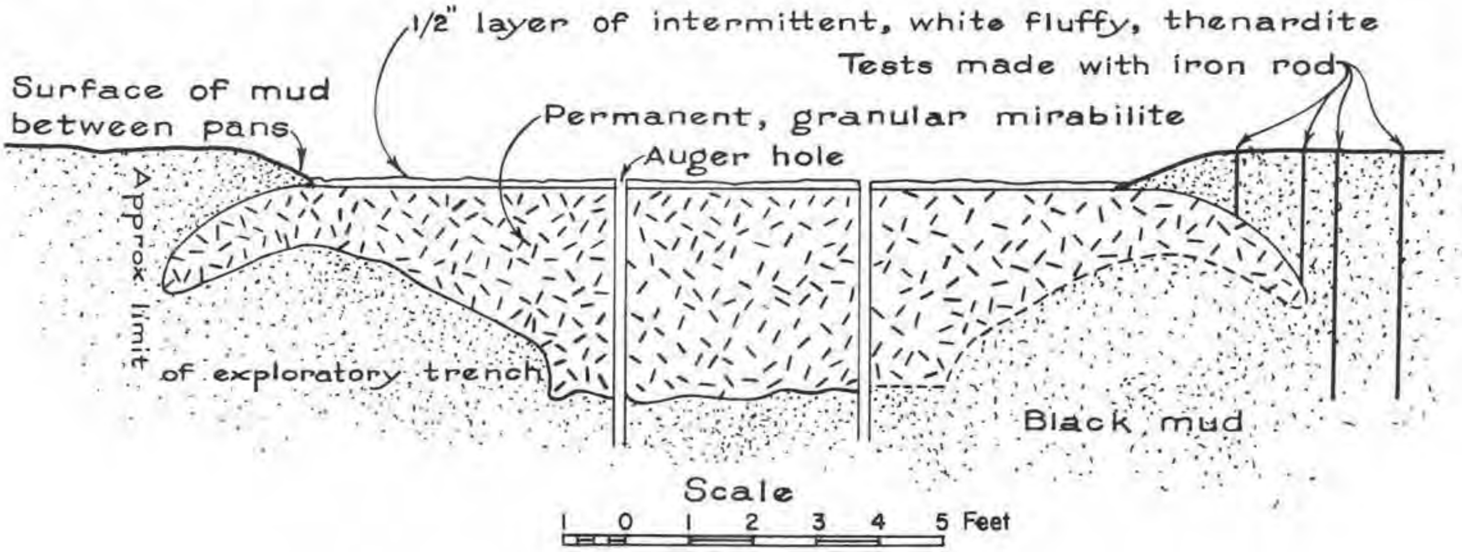


Figure 2.—Section of individual salt pan near northeast edge of Lake 36.

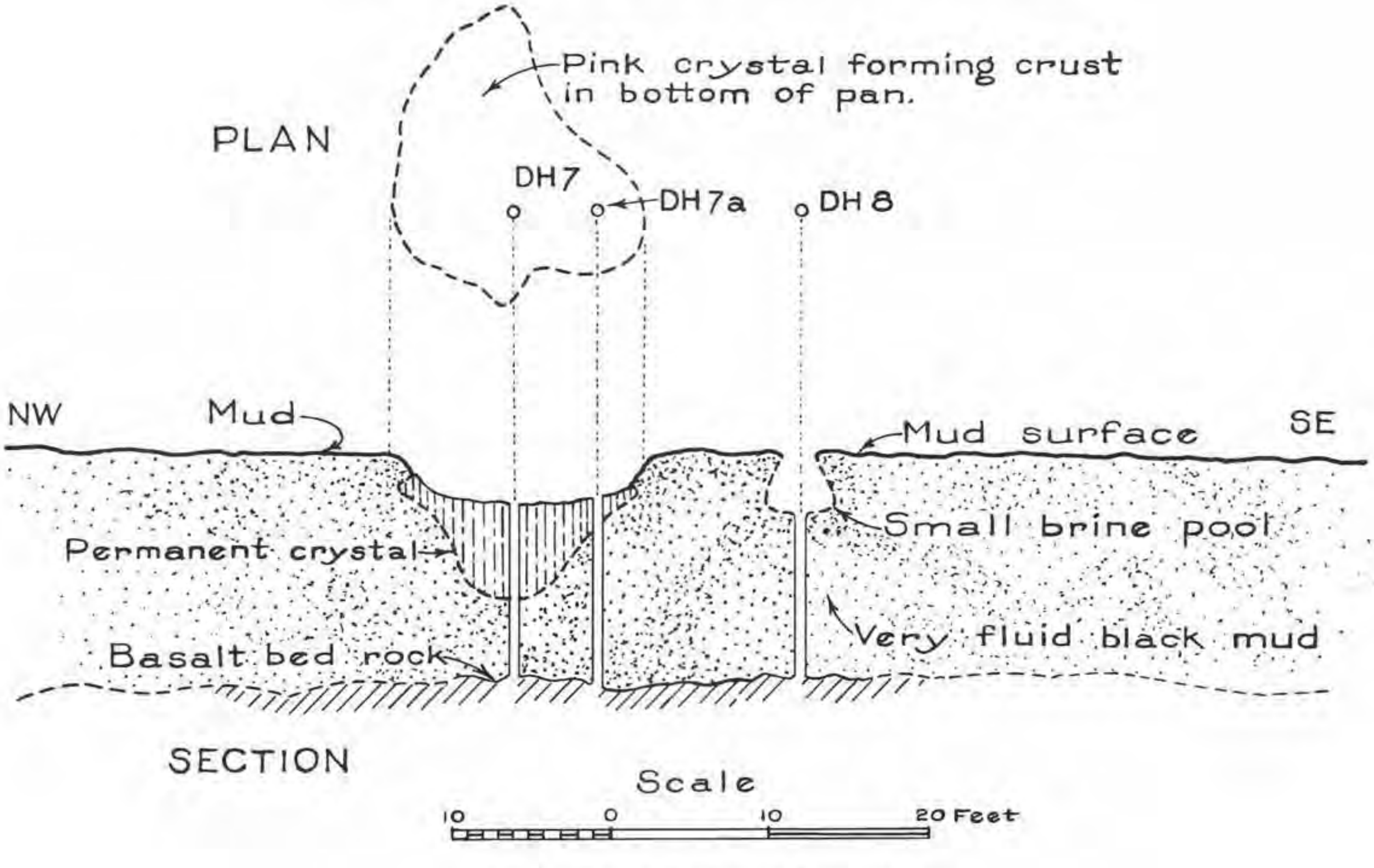


Figure 3.—Diagram of salt pan in Carbonate Lake.

The salt body in Poison Lake, of which very little remains, is reported to have been 300 feet long, 200 feet wide, and between 8 and 25 feet thick, having been a single lens enclosed in a lake bed of gypsite in the deepest part of the basin. It was mined at first by underground methods. At Carbonate Lake part of the permanent crystal was a bed, about 1½ feet in average thickness, that lay at the bottom of the larger brine pool and was formed after mining operations ceased in 1930. Crystal beds, somewhat thinner, in other smaller pools nearby may have remained through several successive dry seasons and then disappeared as the brine became dilute in wet seasons.

The permanent salts also occur, commonly as perfectly formed crystals, disseminated in the lake-bed mud, sometimes only at the surface, sometimes in the mud that surrounds pans, and sometimes in the bottom mud of the larger brine lakes.

What appear to be solution channels were found in some of the pans of Lawson and Hauan Lakes. They are funnel shaped, are located usually in the center, and in one instance extend to the bottom mud at a depth of 4 feet. In the epsomite lens of Poison Lake a cavernous opening was discovered during the initial development by underground mining.

INTERMITTENT CRYSTAL

Intermittent salts form a crust on both the surficial mud and permanent salts in late summer and early fall and are dissolved as the lake level rises during the wet season. The crust is usually thick enough or firm enough to support a man's weight. Most of the intermittent salts are white and powdery as a result of dehydration in the atmosphere. Some, however, as in the apparently perennial main brine pool at Carbonate Lake, form as the brine reaches a certain concentration (1.30+) but dissolve as it becomes unusually dilute following a winter of more than average precipitation. The salts thus formed appear to be mixtures of different saline minerals.

LAKE MUDS

The lake muds are gray to black and, on the basis of only two analyses, contain from about 36 percent to about 87 percent of material insoluble or only partly soluble in hot water. The sodium carbonate lake muds of British Columbia have been reported (Goudge, 1926, p. 84) to contain from 5 to 8 percent calcium carbonate and from 8 to 36 percent magnesium carbonate. One sample of the mud of Mitchell Lake, besides abundant and conspicuously large crystals of gaylussite, contained, as compounds recast from an analysis, sodium carbonate, sodium chloride, sodium sulfate, and basic magnesium carbonate (assumed to be hydromagnesite), in addition to items regarded as components of clay or silt. The gray bottom mud of Penley Lake contains, as water-soluble constitutents in order of abundance, calcium sulfate, sodium sulfate, magnesium sulfate, and sodium chloride. Small gypsum crystals usually occur in the mud just below the bottom of the pans.

The muds of the magnesium sulfate lakes, unlike those of the soda lakes, contain from 37 to 73 percent calcium sulfate as gypsite, or earthy gypsum. According to Goudge (1926, p. 66), the epsomite lakes in British Columbia contain from 45 to 60 percent calcium sulfate and from 2 to 7 percent organic matter. All or most of the following compounds are considered to exist in the gypsiferous muds: magnesium sulfate, calcium carbonate, magnesium carbonate, and basic magnesium carbonate, which is assumed to be hydromagnesite but may be some other of the basic magnesium carbonate minerals. The possibility of other such minerals existing in the muds is indicated by the excess of one or the other of magnesium carbonate or magnesium hydroxide, when, in recasting the analyses into compounds, the mineral hydromagnesite is assumed to be present.

Some of the black muds, which change to gray on exposure to the air, are fluid, are fetid because of contained hydrogen sulfide, and are present especially in those lakes which have dense brines and deposits of permanent salts. As the lakes become saline the heavier brines settle to the bottom (stratify), inhibiting circulation and oxygenation of the bottom waters, and organic matter accumulates. Under these conditions bacteria, which live in the absence of free oxygen or only on that combined in organic matter, reduce sulfates to sulfides and liberate hydrogen sulfide that reacts with iron salts to produce the black amorphous monosulfide of iron (Twenhofel, 1939, p. 443-471; Pettijohn, 1949, p. 458). The end result is supposed to be the production of carbonate. Thus, sodium sulfate and carbon give carbon dioxide (which appears to escape in part) and sodium sulfide; then sodium sulfide, carbon dioxide, and water give hydrogen sulfide and sodium carbonate; hydrogen sulfide and iron carbonate then give iron sulfide and carbonic acid. According to Sneed and Maynard (1942, p. 1073), sodium sulfide (or other alkali sulfide) will react with ferrous salts to give a black precipitate of ferrous sulfide, and, in this instance, sodium carbonate. The black color and fetidness of the muds, therefore, seem easily attributable to biochemical processes, but the extent to which salts have been formed by such processes, in comparison to those wholly chemical in nature, is not obvious, though likely of minor importance.

MINERALOGY

Nearly 50 minerals, including carbonates, sulfates, and chlorides, mostly of sodium, potassium, calcium, and magnesium in simple and complex combinations and usually containing more or less water of crystallization, comprise the salts of the saline group. The famous Stassfurt deposits in Germany, which are the result of evaporation of waters once connected with the sea, include some 30 saline minerals. In comparison, saline-lake deposits usually contain relatively few minerals; although in Searles Lake, California, which is remarkable especially for the variety of its saline materials, at least 19 saline minerals, most of which are unknown in the Stassfurt deposits, have been described.

Although a detailed mineralogical study of the deposits included in this report has not yet been made, the following minerals have been recognized:

Trona.—Trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), which formed most of the fine-grained crust in the vat at the south end of Carbonate Lake (Deposit No. 1), was found on the walls of cavities as tabular crystals, as much as 5 mm long, attached at one end to a white fine-grained base of the same composition, especially on the walls of vugs. The larger crystals appear, in the usual manner, elongated on the b axis and flat parallel to 100 and the best cleavage.

Burkeite or burkeite series of minerals.—The compound $2Na_2SO_4 \cdot Na_2CO_3$, which in 1919 was first prepared artificially by the American Potash and Chemical Corporation in the process of producing salts from the Searles Lake brine, was named burkeite by Teeple, after its discoverer, W. E. Burke (Foshag, 1935, p. 50-56). But its occurrence as a mineral, although predicted by Teeple, was not found until 15 years later by Foshag in studying a drill core of the Searles Lake salts. According to Dub (1947, p. 2), the sulfate and carbonate of sodium form an isomorphous series, called the burkeite series, of decahydrates.

Preliminary chemical and optical mineralogical studies of the Carbonate Lake salts (see also description of the deposit) indicate not only a double salt of sodium in which the proportions of sulfate and carbonate vary, but also a wide range in percent of water of crystallization. A burkeite salt whose water content is low formed thin-banded fine-grained crusts on trona at the south end of the lake. The close association of burkeite and trona was noted by Foshag (1935, p. 51). Another member of the burkeite series, which contained much water of crystallization (64 percent), crystallized in the main brine pool at the north end of the lake as a result of changes in concentration, temperature, and perhaps also of composition. The data showing variations in composition and optical properties of these minerals are shown in the following table:

Optical properties of sodium carbonate, sodium sulfate, and mixed sodium carbonate-sulfate minerals

Mineral	Location	Composition	Alpha	Beta	Gamma	2V	2E	Authority
Natron		$Na_2CO_3 \cdot 10H_2O$	1.405	1.425	1.440	71	112	Larsen, (1934, p. 148
Mirabilite		$Na_2SO_4 \cdot 10H_2O$	1.393	1.395	1.397	76	118	Larsen, (1934, p. 148)
Burkeite	Searles Lake	$2Na_2SO_4 \cdot Na_2CO_3$	1.448	1.489	1.494	34		Foshag, (1935, p. 54)
			1.449	1.488	1.491			Foshag, (1935, p. 54)
			1.450	1.490	1.492			Foshag, (1935, p. 54)
Burkeite salt	Carbonate Lake	$3Na_2SO_4 \cdot 2Na_2CO_3 \cdot 2H_2O$	1.446	1.485	1.488	35 (a) 10	53 16	Bennett, (1950, p. 1520)
Burkeite salt	Carbonate Lake	$2Na_2CO_3 \cdot Na_2SO_4 \cdot 25H_2O$	1.408	1.435	1.437	36 (b) 10	53 16	Bennett, (1950, p. 1520)

(a) artificial salt (b) after heating

Natron.—Natron ($Na_2CO_3 \cdot 10H_2O$) has not been identified optically, although qualitative chemical tests on certain individual crystals indicate its presence at both Mitchell and Carbonate Lakes. Much of the salt mass at Mitchell Lake probably is natron, but its distribution in Carbonate Lake is uncertain because of the presence of burkeite. Numerous qualitative tests on salts that are strongly carbonate usually show, especially at Carbonate Lake, more or less sulfate and chloride.

Gaylussite.—Gaylussite ($Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O$) occurs disseminated in the mud beneath the pans in Mitchell Lake, where it forms a zone about 2 feet thick in the center of the lake; it also forms a zone only a few inches thick at a depth of 10 feet in the west side of the brine pool at Carbonate Lake. Gaylussite crystals at Mitchell Lake are as much as half an inch across. Most of them are water clear and sharply euhedral in outline and, unlike most other salts of the deposits, do not lose their water of crystallization in the atmosphere. Gaylussite is said to be commonly elongated on the a crystallographic axis (Gale, 1915, p. 306), but specimens of the mineral from Oregon, shown here (fig. 4) through the courtesy of F. W. Libbey, former Director, Oregon State Department of Geology and Mineral Industries, appear to be elongated on the c axis.

Thermonatrite.—Thermonatrite ($Na_2CO_3 \cdot H_2O$) commonly results from dehydration of natron. It therefore is, at least in part, the thin intermittent crust that forms on the mud rings at Mitchell Lake. According to Gale (1915, p. 300), natron "liquefies at 34° C. in its water of crystallization, secreting monohydrated salt and leaving a liquid portion containing over 10 molecules of water, and again solidifying when the temperature is reduced to 33½° C." It may also crystallize from solution.

Figure 4.—Gaylussite crystals; the larger, from Mitchell Lake, Grant County, Washington; the smaller and more elongated, from Alkali Lake, Lake County, Oregon. About natural size.

Figure 5.—Cellular, partly layered, hard crust of thenardite, 6 to 8 inches thick, from Sulphate Lake.

Thenardite.—Thenardite (Na_2SO_4) was most abundant at Sulphate Lake in Grant County, where it formed a hard cavernous crust (fig. 5), mostly at the site of old workings. It occurred also as clear to translucent pyramid-shaped crystals that graded into a finer grained crust that formed the upper surface of the pans, and it occurred as porous granular white aggregates made up of poorly defined crystals. All these occurrences were crystallizations from solution. Thenardite also occurred as white flourlike powder, the result of complete dehydration of mirabilite. Although not definitely determined, it is believed to form the hard, rather thin layers that occur in some of the sodium sulfate lakes of Okanogan County. It formed a part of the mixture of salts at Carbonate Lake.

Mirabilite.—Mirabilite ($Na_2SO_4 \cdot 10H_2O$), the decahydrate of sodium sulfate, is the predominant mineral in the permanent salt deposits of the sodium sulfate lakes in both Grant and Okanogan Counties. It occurs as fine-grained masses in parts of the pans, as coarse granular aggregates of crystals containing numerous mud inclusions, and as pure crystals in a mushy layer several inches thick on the surface of pans as in B-J Lake.

Epsomite.—Epsomite ($MgSO_4 \cdot 7H_2O$), which was formerly abundant in Poison and Bitter Lakes, occurred as a massive lenticular bed and as smaller, mostly separate lenses. An undetermined part of the Poison Lake deposit is said to remain in the bottom of the lake bed. In 1946 fragments of epsomite were found, however, in the gypsite piles around the main pit. The mineral is colorless but appears dark because of numerous mud inclusions. In a dry atmosphere (humidity probably less than 40 percent) it loses part of its water of crystallization, forming at first a white porcelainlike crust that later becomes friable and powdery and has the feel of fine sand or silt. According to Walker and Parsons (1927, p. 21-23) the efflorescent product is hexahydrite, although the optical characters do not correspond to those published for that mineral. The efflorescent product is strongly hygroscopic, especially when much water is driven off, and seems to gain or lose water depending upon the amount of moisture in the atmosphere.

Gypsum.—Gypsum ($CaSO_4 \cdot 2H_2O$) forms minute crystals in the mud immediately beneath many of the pans in the sodium sulfate lakes. In the earthy form, as gypsite, it makes up most of the lake mud that encloses the epsomite deposits; it also occurs as crystals an inch or more long in a zone or thin bed in the gypsite of Bitter Lake and Linton Flat.

Halite.—Halite (NaCl) formed clear cubes, about one-eighth of an inch across on porous granular aggregates of thenardite at Sulphate Lake. It was found on the bottom of thenardite crusts that formed on the surface of pans in the fall of 1944 but not at other times. It occurred sparsely in an aggregate of salts that formed a crust around the shore of the main brine pool at Carbonate Lake.

Hydromagnesite.—Hydromagnesite ($3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$), or other minerals among the basic magnesium carbonate group, is present in the gypsite deposits of the magnesium sulfate lakes. It appears to exist as minute plates and aggregates among the much larger tabular grains of gypsum that form the gypsite.

ORIGIN

The deposits of salts are the result of evaporation under arid or semiarid conditions in basins in which there is no visible outflow or in which the underground outflow is less than the inflow. Mineral deposits of this class rather recently have been referred to as evaporites (Bateman, 1942, p. 187-192; Pettijohn, 1949, p. 354-362). The mineral matter for each deposit is derived mainly by leaching of the rocks that underlie each drainage basin, in part by the surface runoff, but probably in large part by precipitation that sinks into the ground (ground water). The facts that the lakes all have brines, which range from very strong to very weak and vary considerably in composition, and that only some of the lakes have deposits of crystallized salts, seem to result from several factors. Among these are kind and extent of material being leached, solubility, porosity, and permeability of the material, and, as mentioned before, whether or not there is leakage from the basin.

The deposits are rather easily classified, on the basis of the predominant salt present, into a threefold division of sodium carbonate, sodium sulfate, and magnesium sulfate and gypsite. The deposits of predominant sodium carbonate seem related to either ground or surface water along old stream channels, mostly in areas of basalt but partly in areas of granitic rocks. River waters are almost uniformly rich in carbonates. Omak Lake, which is in an area of granitic rocks from which most or all of its drainage is received, is fed principally by two streams at either end, hence the predominance of sodium carbonate in its water. In contrast, the sodium sulfate deposits are mainly away from principal drainage lines in upland areas of granitic, basaltic, and metamorphic rocks. Deposits of glacial till, drift, and stratified silts are also closely associated with the sulfate deposits, especially sodium sulfate. Deposits of magnesium sulfate are closely related to metamorphic (metasedimentary) rocks in which considerable limestone is interbedded, all these rocks being more or less mineralized with metallic minerals.

The crystallization of salts is controlled partly by solubility (the least soluble salt crystallizing out first), partly by temperature, and partly by the proportions and concentration of other salts present (Wells, 1923, p. 5-12; Teeple, 1929, 182 p.); and time is a factor. For instance, sodium sulfate will crystallize out of solution as the decahydrate (mirabilite, $Na_2SO_4 \cdot 10H_2O$) up to a temperature of 32.38° C. (about 90° F.), above which the anhydrous form (thenardite) crystallizes, but if common salt (NaCl) is in solution the transition point is reduced to 17.9° C., and with the additional presence of aphthitalite (sodium-potassium sulfate) the transition point is reduced further to 16.3° C. The considerable amount of hard, crystallized thenardite at Sulphate Lake, the only deposit in which this salt formed in significant amounts, seems to result from two factors: an unusual amount of sodium chloride in the brine (indicated by the presence of halite, NaCl, in the salts) and heat reflected from adjacent high cliffs during the hot part of the summer. The converse of these factors probably accounts for the lack in the Okanogan Plateau area of important amounts of thenardite of the type that crystallizes from solution. At a temperature of 30° C. (86° F.) mirabilite is eight times more soluble in water than it is at 0° C. (32° F.); for this reason it crystallizes readily from strong brines in cold weather, furnishing the so-called winter crystal. Natron ($Na_2CO_3 \cdot 10H_2O$), or sal soda, is 20 times more soluble in water at the boiling point than at the freezing point; thus, in carbonate lakes with stronger brines natron will readily crystallize in cool weather, and in cold weather it may form from carbonate lakes with weaker brines. Gypsum, ($CaSO_4 \cdot 2H_2O$) is said to form from saturated calcium sulfate solutions below a temperature of 42° C., above which anhydrite forms. Natron is said to be stable below a temperature of 37° C. (about 98° F.), above which trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) commonly forms. Whereas mirabilite loses water in the air to form the powdery variety of thenardite (Na_2SO_4), which in the summer forms a crust on the sodium sulfate lakes, natron dehydrates to form a crust of thermonatrite ($Na_2CO_3 \cdot H_2O$). The crystallization of salts from the water of Owens Lake, California, which consists of about equal amounts of carbonate and chloride with minor amounts of sulfate and other salts among the negative radicals, was studied by Chatard (1890, p. 59-67), Clarke (1924, p. 240), and Gale (1915, p. 285-288), who found that, as the water evaporates, the following sequence of salt crystallization occurs: trona, sodium sulfate, sodium chloride, and sodium carbonate. Many systems of salts have been studied by Teeple and others (1929) in connection with the recovery, under plant conditions, of salts from the brine of Searles Lake, California, which contains, among negative radicals, much chloride, as well as sulfate, carbonate, borate, and other minor components. But chloride in the carbonate lake brines of Washington was always subordinate to carbonate and usually was subordinate to sulfate. A different assemblage of salts, therefore, may be expected to crystallize from them. However, the conditions of crystallization of salts as interpreted from studies at Searles Lake are particularly instructive and they illustrate what may be expected to crystallize from natural brines, particularly those of the carbonate type.

The following equilibrium data, representing only a few of the many salt combinations described by Teeple (1929, p. 66, 68, 94, 102, 104, 162), show the solid phases (expressed here as minerals) that crystallize at temperatures of 20° C. and 35° C. out of water solutions of the several carbonates, sulfates, and chlorides of sodium and potassium, the concentration of the solutions being expressed as grams of salt per hundred grams of water.

Solid phases	Grams per 100 grams of water						
(at 20° C.)	$NaHCO_3$	Na_2CO_3	Na_2SO_4	NaCl	K_2CO_3	K_2SO_4	Total
Nahcolite, natron, mirabilite, thenardite, and trona	3.6	19.5	14.0	4.7	---	---	41.8
Nahcolite, mirabilite, thenardite, and trona	1.7	5.3	13.8	25.2	---	---	46.0
Nahcolite, mirabilite, and trona	2.6	12.4	13.6	9.8	---	---	38.4
Nahcolite, thenardite, and trona	1.5	4.6	11.3	28.3	---	---	45.7
Nahcolite, thenardite, halite, and trona	1.5	4.3	10.4	29.8	---	---	46.0
Natron, mirabilite, burkeite, and trona	1.6-	19.0	13.7	9.2	---	---	43.5
Natron, halite, burkeite, and trona	0.6	21.3	5.4	23.3	---	---	50.6
Mirabilite, thenardite, burkeite, and trona	1.0	9.5	13.7	22.3	---	---	46.5
Halite, thenardite, and trona	1.3	4.6	10.4	30.4	---	---	46.7
Halite, thenardite, burkeite, and trona	0.7	8.7	10.0	27.7	---	---	47.1
Natron, mirabilite, and burkeite	---	18.8	13.8	11.5	---	---	44.1
Natron and burkeite	---	19.7	11.2	17.3	---	---	48.2
Natron and mirabilite	---	19.2	13.8	7.2	---	---	40.2
Natron, halite, and burkeite	---	21.1	6.2	23.2	---	---	50.5
Natron, burkeite, and thenardite	---	11.0	14.1	21.4	---	---	46.5
Thenardite, halite, and burkeite	---	8.3	10.5	28.5	---	---	47.3
Halite, $Na_2CO_3 \cdot 7H_2O$, burkeite, and glaserite (aphthitalite)	---	15.8	5.8	25.2	8.1	---	54.9
Halite, burkeite, hanksite, and glaserite	---	13.6	6.6	26.0	8.0	---	54.2
(at 35° C.)							
Halite and thenardite	---	----	9.2	33.6	---	---	42.8
Thermonatrite and halite	---	24.8	----	23.9	---	---	48.7
Thermonatrite and burkeite	---	45.8	6.9	----	---	---	52.7
Thenardite and burkeite	---	18.5	34.3	----	---	---	52.8
Thermonatrite, halite, and burkeite	---	24.2	2.7	23.2	---	---	50.1
Thenardite, halite, and burkeite	---	4.6	8.8	30.7	---	---	44.1
Thermonatrite, burkeite, and glaserite	---	40.5	8.4	----	7.8	---	56.7
Thenardite, burkeite, and glaserite	---	17.0	31.8	----	---	6.9	55.7
Halite, thermonatrite, burkeite, and glaserite	---	12.8	3.3	28.8	13.7	---	58.6

Aphthitalite (glaserite), $(K, Na)_2SO_4$; burkeite, $2Na_2SO_4 \cdot Na_2CO_3$; halite, NaCl; hanksite, $9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$; mirabilite, $Na_2SO_4 \cdot 10H_2O$; nahcolite, $NaHCO_3$; natron, $Na_2CO_3 \cdot 10H_2O$; thenardite, Na_2SO_4; thermonatrite, $Na_2CO_3 \cdot H_2O$; trona, $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$.

RESERVES

The tonnages of salts present in the more important saline lakes in Washington are given in table 1.

TABLE 1.—Data on the more important saline lakes in Washington.

(Short tons, anhydrous basis)

Lake	Area (acres)	Na_2CO_3	$NaHCO_3$	Na_2SO_4	$MgSO_4$	K_2SO_4	$CaSO_4$	NaCl	Remarks
Soap	864	628,000	----	301,000	----	----	----	241,000	Brine; contains also 20,000 tons K_2CO_3.
Mitchell	8	11,000	----	600	----	----	----	800	Solid salts; contain also 3,000 tons gaylussite. Also 10,000 tons salts in solution.
Omak	3,820	880,000	----	411,000	13,000	130,000	----	79,000	Weak brine only, sp. gr., 1.006.
Salt or Soap	157	24,000	35,000	194,000	800	----	----	19,000	Brine only, sp. gr., 1.041.
B-J	19	200	100	8,700	----	----	----	300	Brine.
		----	----	15,000	----	----	----	----	Solid salts; include 400 tons other salts.
Virginia	3½	----	----	2,000	----	----	----	----	Brine.
		----	----	4,000	----	----	----	----	Solid salts
Lake 32	7	----	----	1,900	----	----	----	----	Brine; contains also 400 tons other salts.
Stevens	8	500	----	1,700	----	----	----	100	Brine. 4,000 tons solid salts per ft. of depth.
Lawson	20	----	----	2,000	----	----	----	----	Brine. About 8,000 solid salts (mostly Na_2SO_4) per ft. of depth.
Morris	19	----	----	1,700	60	----	----	65	Brine. 11,000 tons solid salts per ft. of depth.
Hauan	21	20	----	19,800	875	940	----	1,700	Brine.
		----	400	53,900	530	530	----	400	Solid salts.
Deposit No. 13	10½	----	----	3,000	5,000	70	----	1,000	Brine.
		40	----	14,000	330	----	200	40	Solid salts.
Murray	13½	40	----	7,000	640	----	----	100	Brine. Solid salts, at 5,000 tons per ft. of depth, may be present.
Deposit No. 16	19	300	200	600	----	----	----	100	Brine only, weak.
Patterson	17	----	----	300	300	----	----	----	Weak brine.
Cook	10-15	----	----	3,700	1,200	----	----	----	Weak brine.
Penley	11	50	----	14,600	650	----	100	600	Brine
		----	----	23,700	200	----	350	100	Solid salts.
Cameron	9	180	----	8,000	----	----	----	400	Brine. Solid salts, 27,000 tons.
Poison	19	----	----	2,400	12,000	210	----	200	Brine to depth of 10 ft. in lake bed.
		----	----	6,000	23,000	----	355,000	----	Solids include also 26,000 tons of hydro-magnesite and/or magnesite and less than 10,000 tons of epsomite.
Wannacut	334	4,500	----	47,900	155,000	----	15,900	2,200	Brine only, sp. gr., 1.006 to 1.020.
Bitter	3	10	5	2,800	220	----	15	400	Brine.
		----	----	----	8,900	----	86,000	----	Solid salts; contain also 11,000 tons magnesite and 16,000 tons hydro-magnesite.
Lenton Flat (dry lake)	80	----	----	----	----	----	----	----	Some 500,000 to 1,000,000 tons of gypsite ($CaSO_4$), marl, hydromagnesite, and clay. About 63% of lake bed is gypsite.

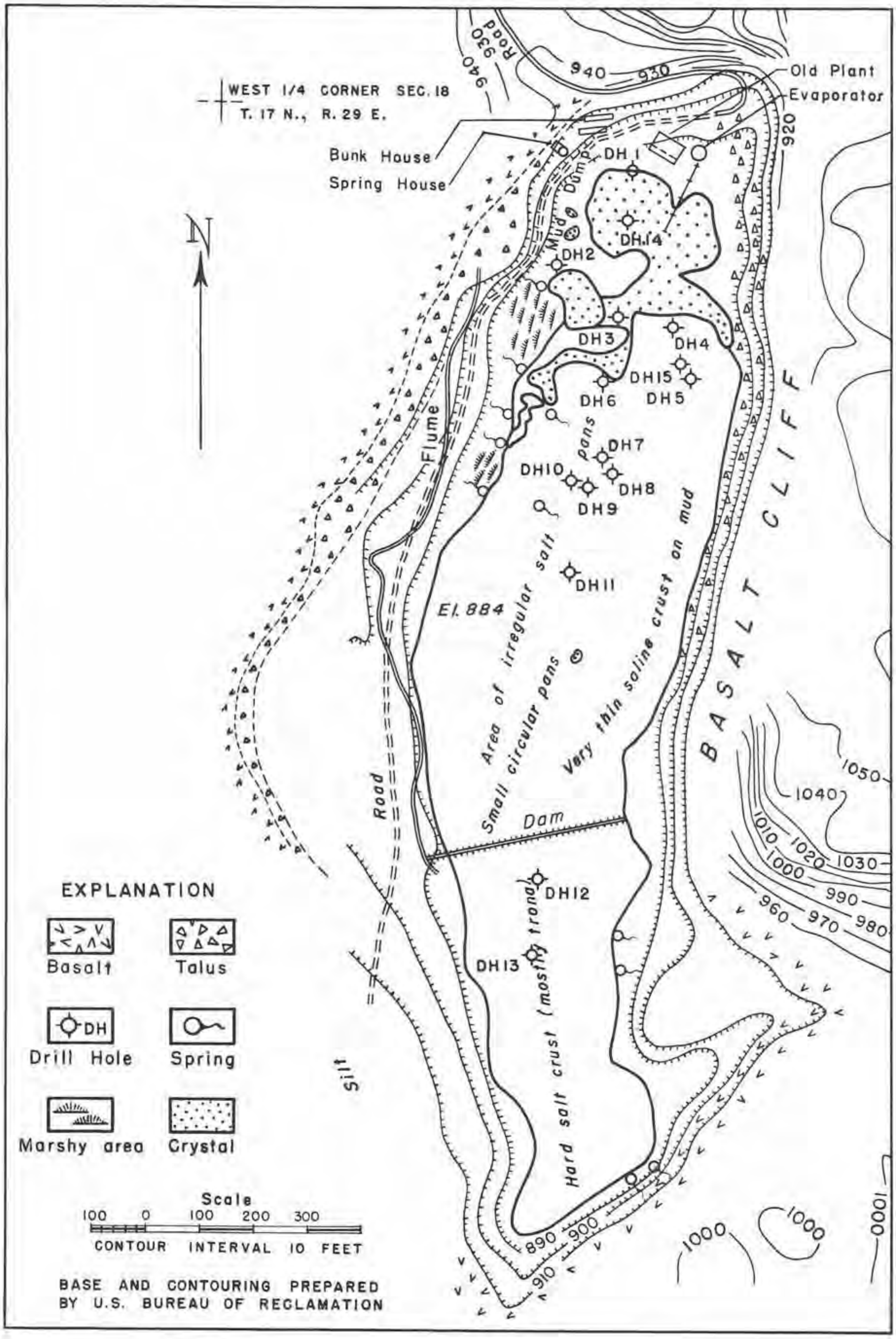


Figure 6.—Map of Carbonate Lake.

SODIUM CARBONATE LAKES

GRANT COUNTY

Carbonate Lake

Location, Size, and Access

Carbonate Lake (fig. 6), which included about 15 acres, was in the W$\frac{1}{2}$SW$\frac{1}{4}$ sec. 18, T. 17 N., R. 29 E., and was between 9 and 10 miles west of Warden, the nearest railroad point, in Grant County. The lake was reached by graveled road from Warden or by a dirt and graveled road that leads south to the Crab Creek area from a junction with State Highway 18 about 4 miles east of Moses Lake. This latter route, which follows the east margin of a sand dune area, is the shortest (about 17 miles) between the deposit and the town of Moses Lake. The road south, which leads to Othello, is little used.

Carbonate Lake was destroyed in about 1950 when the U.S. Bureau of Reclamation built a dam at the south end of the basin occupied by the lake. The reservoir behind this dam, a part of the Columbia Basin irrigation project, covers the original lake bed to a depth of about 100 feet.

Topography and Geology

The lake occupied an undrained depression, nearly half a mile long and several hundred feet wide, in a barren tract of basaltic scabland that lies along the valley of Crab Creek, the major stream of the area. It was about 200 feet below a basalt surface that has been dissected into characteristic depressions and flat-topped erosion remnants or small buttes. It was partly surrounded by small cliffs that rose precipitously from near shore (figs. 7 and 8). The level of the lake bed, about 890 feet above sea level, was near that of Crab Creek, which is 1$\frac{1}{4}$ miles to the west, but the bedrock surface at the north end is about 20 feet below the level of Crab Creek and at the south is more than 30 feet below.

These topographic features are the general result of erosion, mostly by the Columbia River, when, in the glacial period, it was blocked below the site of Coulee Dam by the Okanogan Valley lobe of the continental ice sheet and forced to cut a new channel along what is now upper and lower Grand Coulee and parts of Crab Creek. Many features, among them the depressions such as Carbonate Lake, are so unusual as to lead Bretz (1932; 1956; 1959, p. 56), who has extensively studied the physiographic problems of the plateau region, to believe they are the result of erosion by great rivers. Other writers believe the features are the result of erosion by normal-sized streams.

The Carbonate Lake bedrock surface, as indicated by the results of 15 auger drill holes, is nearly flat and free of sand or gravel except at the south end, where there is a sand-filled deeper depression in front of a cliff. This seems to indicate that while the waters were flowing, currents were powerful enough to keep the basin almost free of detritus. For comparison, flood-stage currents in the Pend Oreille River canyon just below Metaline Falls have been observed to remove a 50-foot bed of sand that accumulates in the channel during low water. The black mud that made up the greater part of the lake bed probably was mostly of wind-blown silt that was colored black, partly from organic matter and partly from the monosulfide of iron. Because the bottom of the basin is below the level of Crab Creek, there was a slow though steady inflow of ground water, most of which came in along the west side from the middle and toward the north end.

History and Production

Mining operations at Carbonate Lake were started in 1927 by A. M. McDonald and others who were incorporated as the Washington Sodium Products Co. (Donaldson, Paul, oral communication). U.S. Bureau of Mines reports, as late as 1941, mention other firm names—Thoro Chemical Co. and Acme Products Co., but it reports only a few hundred dollars' worth of salts produced from the lake. Mr. Donaldson stated that the cost of producing anhydrous salts was about $25 a ton, which left little or no profit. An attempt was made to sell recrystallized hydrous salts to fruit growers for washing fruits that had been sprayed with arsenical insecticides, but this market disappeared when other types of insecticides came into general use.

Figure 7.—Carbonate Lake. Note the mottled appearance of the salt bed in the brine pool in the foreground at the north end of the basin, irregular salt crusts surrounded by gray, fluffy mud areas in the center of the basin, and a vat of salts from evaporated brine at the extreme south end. An old evaporator (left) and settling tank stand in the foreground. October 1945.

The plant seems to have been modeled after one used in Canada by the B. C. Chemical Co. The Canadian plant, which cost about $50,000, for a time successfully produced clean pulverized soda ash (Nichols, 1930, p. C230), but results from this plant later on were reported as unsatisfactory (Cummings, 1940, p. 57-58). At Carbonate Lake the salts and included mud were brought from the lake, at first by small ore cars but later by conveyor belt, and introduced into a punt-shaped steel tank equipped with steam pipes for heating and with a slowly moving link belt for removing the mud. The clarified solution was then pumped to a cyclone-type evaporator (fig. 7), in which a fine spray of brine was introduced at the top of the cone in hot air (600° F.). Anhydrous pulverulent soda ash was drawn off at the bottom.

At the time of examination (1945) the plant building had been demolished and all machinery except a heavy steel evaporating tank and evaporator had been removed.

The Salts

Brine.—The brine occurred both underground and in pools. The pools were mostly along the west side of the basin. The largest were at the north end of the basin (figs. 7 and 8), and they gradually decreased in size to the south, concurrently with a decrease in specific gravity of the brine from a

Figure 8.—West side of main brine pool at Carbonate Lake. Note disintegrated wooden post encrusted with salts in right foreground, columnar basalt in background, and hole 12 being drilled from platform.

remarkably high value of 1.372 (1944) down to 1.06. At the south end there was obvious dilution from fresh-water seepage.

The most important occurrences of brine underground were in sand that lay beneath the reservoir at the south end of the basin and in fluid mud beneath the pools. These were areas where the brine was most easily extracted as well as areas of maximum density (specific gravity, usually 1.30 or greater). In the central part of the lake bed the brine was less dense and apparently was confined to fewer and smaller percolative areas. The composition of the brine is shown in table 2.

The two bodies of dense brine, represented by samples 1 and 7, showed an unexpected difference in composition, sodium sulfate interchanging with sodium chloride as the salt second in abundance to sodium carbonate. This suggests little or no percolation of the brine from south to north, even though there was a northward slope to the surface of the lake bed and apparently also of most of the bedrock surface. The lower density of the brine in the central part of the basin also suggests lack of percolation. The salts below the surface at the south end showed a higher ratio of sodium sulfate to sodium carbonate than those at the north. It seems then, that brines of different composition existed at either end of the basin for a long period because of a lack of diffusion or percolation as lake muds accumulated and as the density of the brines increased. During the 15-year period after the end of mining operations a salt bed accumulated in the brine pools. It showed a variable ratio of sodium sulfate to sodium carbonate, and perhaps there was some increase in the content of sodium chloride at the expense of the sodium sulfate that crystallized with sodium carbonate.

Crystal.—Crystalline salts occurred (1) as "pans," which were circular to irregular depressions in the mud surface of the lake bed, especially in the central part, and which extended more or less as inverted cones to depths of as much as 8 feet; (2) to some extent as layers of disseminated crystals in mud around the main brine pool; (3) as a bed that averaged about 2 feet thick at the bottom of the main pool; and (4) as a thin crust in an old brine reservoir at the south end of the basin (fig. 7). Analyses of the salts are presented in table 3.

The table shows that, excluding the insoluble material and recalculating, the composition of the salts underground ranged between 72 and 94 percent sodium carbonate, between 3 and 20 percent sodium sulfate, and nearly 10 percent sodium chloride. The surface crusts, although represented by fewer analyses than the salts underground, contain between 64 and 90 percent sodium carbonate, as much as 30 percent sodium sulfate (in the old brine reservoir at the south), and between 2 and 6 percent sodium chloride. The salt bed in the larger brine pool, represented by two analyses, ranges between 56 and 79 percent sodium carbonate, between 10 and 41 percent sodium sulfate, and between 1.4 and 6.3 percent sodium chloride.

Table 2. —Analyses of brine and spring water from Carbonate Lake.

Constituents (radicals) in parts per million and in percentage of total solids.

Sample no.	1		7		8		9	
Constituents	Parts per million	Percentage of total solids	Parts per million	Percentage of total solids	Parts per million	Percentage of total solids	Parts per million	Percentage of total solids
Ca (calcium)	None	None	None	None	None	None	None	None
Mg (magnesium)	None	None	None	None	None	None	None	None
Al (aluminum)	None	None	None	None	None	None	None	None
Fe (iron)	None	None	None	None	None	None	None	None
Na (sodium)	91,100	37.1	106,300	38.8	74	33.3	210,000	38.7
K (potassium)	10,500	4.2	----	----	----	----	----	----
HCO_3 (bicarbonate)	None	None	None	None	75	----	None	None
CO_3 (carbonate)	72,400	29.5	78,600	28.7	25	44.5(1)	172,000	31.7
SO_4 (sulfate)	26,400	10.7	68,300	24.9	24	10.8	152,000	28.0
Cl (chloride)	44,800	18.2	20,400	7.4	25	11.2	8,380	1.9
	245,200	99.7	273,600	99.8	223	99.8	542,380	99.9
Specific gravity at 26° C. (78.8° F.)	1.290		1.285		0.998		1.430	

Hypothetical or conventional combinations in percentage of total solids.

Sample no.	1	7	8	9
NaCl (sodium chloride)	31.0	12.2	18.3	2.5
Na_2CO_3 (sodium carbonate)	51.8	51.9	19.7	56.0
$NaHCO_3$ (sodium bicarbonate)	None	None	46.1	None
Al	None	None	None	None
Fe	None	None	None	None
$CaSO_4$ (calcium sulfate)	None	None	None	None
$MgSO_4$ (magnesium sulfate)	None	None	None	None
Na_2SO_4 (sodium sulfate)	8.1	36.9	15.6	41.4
K_2SO_4 (potassium sulfate)	9.5	----	----	----
	100.4	101.0	99.7	99.9

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 1. From the north shore of the main brine pool. Collected in October 1944. The sample was sealed in a fruit jar with zinc lid. Gas pressure, which formed inside the jar after several months in the laboratory, distended and ultimately cracked the lid, part of the sample being lost because of the growth of a hard plumose efflorescent crust along the line of fracture. The specific gravity of the brine at the time of collection was 1.30 but after a rain on November 7, 1944, it dropped to 1.258 at 49° F. A qualitative spectrographic analysis shows the presence of calcium, iron, sodium, potassium, strontium, aluminum, silicon, and magnesium.

Sample No. 7. Brine from hole 13. Specific gravity at the time of collection in October 1944 was 1.30.

Sample No. 8. Water from shallow well inside small house west of plant site.

Sample No. 9. Hydrous salts from edge of main brine pool, collected in October 1944. The sample was sealed in a fruit jar, but at time of analysis it had apparently dissolved in its own water of crystallization; refer to samples 14 and 15, table 3, from salt bed in center of pool. Other samples of hydrous salts from the same pool contained about 64 percent of water of crystallization, as determined by the writer. The sample is considered to be a hydrous salt of the burkeite series, as described on page 12.

Table 3. —Analyses of salts from Carbonate Lake.

Constituents in percentage of total weight.

Sample no.	2	3	4	5	6	10	11	12	13	14	15	16	17	18	19
Insoluble residue	16.3	3.9	24.6	5.3	61.6	5.0	0.1	36.5	30.8	0.3	43.4	66.7	63.7	31.4	0.4
Ca (calcium)	None	None	None	None	None	None	None	None	None	None	None	0.03	None	None	None
Mg (magnesium)	None	None	None	None	None	None	0.04	0.12	None	0.06	0.06	None	0.04	0.04	None
Al (aluminum)	None	None	None	None	None	None	None	None	None	None	None	None	Trace	None	None
Fe (iron)	None	None	None	None	None	None	None	None	None	None	None	None	Trace	None	None
Na (sodium)	35.4	39.9	31.8	37.8	14.6	37.6	41.7	26.0	28.4	41.0	22.8	13.2	15.1	27.9	39.1
K (potassium)	----	0.39	----	----	----	----	----	----	----	0.13	----	----	----	0.58	0.28
SiO_2 (silica)	----	----	----	0.7	----	----	----	----	----	----	1.3	----	----	2.3	----
HCO_3 (bicarbonate)	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
CO_3 (carbonate)	44.5	48.7	39.6	41.9	13.9	34.6	49.2	28.7	30.4	49.1	25.2	12.1	17.1	35.0	36.4
SO_4 (sulfate)	1.6	3.9	2.1	10.4	5.7	18.5	7.4	4.8	6.7	7.6	4.5	4.1	2.8	1.8	20.7
Cl (chloride)	0.8	1.4	0.7	1.2	2.1	3.4	0.85	2.9	3.0	0.9	2.2	3.0	1.1	0.9	2.3
	98.6	98.19	98.8	97.3	98.0	99.1	99.29	99.02	99.3	99.79	99.46	99.13	99.84	99.92	99.18

Conventional combinations in percentage of total weight.

Sample no.	2	3	4	5	6	10	11	12	13	14	15	16	17	18	19
Insoluble residue	16.3	3.9	24.6	5.3	61.6	5.0	0.1	36.5	30.8	0.3	43.4	66.7	63.7	31.4	0.4
NaCl (sodium chloride)	1.3	2.3	1.1	1.9	3.5	5.6	1.4	4.8	4.9	1.4	3.6	5.0	1.8	1.4	3.8
Na_2CO_3 (sodium carbonate)	78.6	86.1	70.1	4.0	24.5	61.1	86.8	50.7	53.7	86.7	44.6	21.4	30.2	61.9	64.3
$NaHCO_3$ (sodium bicarbonate)	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
R_2O_3 (iron and aluminum oxides)	None	None	None	None	None	None	None	None	None	None	None	None	0.1	None	None
$CaSO_4$ (calcium sulfate)	None	None	None	None	None	None	None	None	None	None	None	0.1	None	None	None
$MgSO_4$ (magnesium sulfate)	None	None	None	None	0.3	None	0.2	0.6	None	0.3	0.3	None	0.2	0.2	None
Na_2SO_4 (sodium sulfate)	2.4	5.0	3.1	15.4	8.1	27.4	10.7	6.4	9.9	10.7	6.3	6.0	3.9	1.3	30.1
K_2SO_4 (potassium sulfate)	----	0.86	----	----	----	----	----	----	----	0.3	----	----	----	1.3	0.62
SiO_2 (silica)	----	----	----	0.7	----	----	----	----	----	----	1.3	----	----	2.3	----
	98.6	98.26	98.9	97.3	98.0	99.1	99.2	99.0	99.3	99.7	99.5	99.2	99.9	99.8	99.22

Sample No. 2. From hole 3, at 8 to 10 feet; 2-foot salt bed between thicker mud layers.

Sample No. 3. Pinkish salt that forms crust in bottom of pan around hole 10.

Sample No. 4. From hole 5, at 6 to 9.2 feet; salt layer below 6 feet of mud.

Sample No. 5. Salt crust, 6 inches thick, from bottom of pan near hole 12.

Sample No. 6. From hole 12, at 0.5 to 4 feet; disseminated, mostly tabular crystals in mud.

Sample No. 10. From hole 13, 0 to 4 inches; includes 0.5 inch hard upper crust with 3.5 inches of crystals disseminated in mud.

Sample No. 11. From hole 13, 4 to 6 inches; hard salt layer.

Sample No. 12. From hole 13, 6 inches to 3 feet.

Sample No. 13. From hole 13, 3 to 8.5 feet.

Sample No. 14. From hole 14, at 0 to 2 feet; from salt bed that is 1.5 feet below surface of brine pool.

Sample No. 15. From hole 14, at 2 to 2.5 feet and to bottom of salt bed.

Sample No. 16. From hole 14, thin zone of gaylussite at 10 feet. Calcium does not appear in significant amount in the analysis because of the low solubility of the mineral in successive hot water leaches used for solution of the sample.

Sample No. 17. From hole 15, at 0 to 4.5 feet.

Sample No. 18. From hole 15, at 4.5 to 8.5 feet.

Sample No. 19. Salt crust from south end of the lake bed.

In order to determine, at least in part, what the foregoing results mean in terms of minerals, the following analyses, supported by optical data, have been made by the writer:

Analyses of salt crust in the old brine reservoir and of salts in the larger brine pool

	A	B	C
Na_2CO_3 (sodium carbonate)	33.77	14.43	31.34
Na_2SO_4 (sodium sulfate)	62.37	79.24	1.85
NaCl (sodium chloride)	.86	1.82	2.77
H_2O (water)	3.00	4.51	64.04
	100.00	100.00	100.00

A. Finely banded crust, between 1 and 2 mm thick, that in places occurs on the walls of cavities in trona; from the brine reservoir at the south end of the lake bed. It appears to be a hydrous double salt, of the burkeite series, that has the approximate chemical formula, $3Na_2SO_4 \cdot 2Na_2CO_3 \cdot 2H_2O$ (neglecting sodium chloride), and the following optical characters: alpha, 1.446; beta, 1.485; gamma, 1.488; 2V, 35°; and 2E, 53°. After heating, 2V and 2E change to 10° and 16° respectively. A spectrographic test by G. M. Valentine showed abundant sodium, traces of magnesium, silicon, aluminum, and calcium, and a faint trace of potassium.

B. A rather porous, fragile, largely dehydrated sample of salts from near the surface of the brine in the larger brine pool, collected in October 1945 from the edge of a board walk that projects westward from an old car track. At the time of collection the salts contained much water of crystallization. Numerous clear monoclinic crystals, half an inch to an inch across, had formed on the base of the smaller crystals. After long exposure of the sample to the open air of the laboratory, a very fragile white efflorescent mass formed. The larger crystals, however, are represented externally by harder, more rigid shells within which the material is fine grained and easily pulverized between thumb and finger. This powdery (dust free) internal material was analyzed. The composition of the brine from which the sample was taken is represented by sample 1, table 1. A qualitative spectrographic analysis of the sample shows much sodium, as would be expected, a trace of magnesium, a trace of iron, and some potassium, but no calcium and no silicon. The analysis suggests the following chemical formula: $4Na_2SO_4 \cdot Na_2CO_3 \cdot 2H_2O$. Under the microscope crushed fragments of the harder shells show abundant aggregates of minute plates, larger crystal fragments that enclose minute prismatic crystals that have parallel extinction, very rarely minute fragments of a deep-red mineral (botryogen ?, magnesium-iron sulfate), halite (enclosing minute prismatic crystals), and very rarely a uniaxial optically positive mineral having an index of about 1.49 (aphthitalite ?, potassium-sodium sulfate). In spite of the difficulties of obtaining satisfactory optical data on efflorescent minerals, enough data have been obtained to suggest that the predominant mineral in the sample is a double salt of sodium sulfate and sodium carbonate, as is suggested by the analysis, and that the mineral is a member of the burkeite series of hydrous isomorphous compounds of sodium sulfate and sodium carbonate.

C. A sample, much the same as B and from the same brine pool, collected in October 1948, when the brine was about 2 feet above its level of 1945 but much cooler and less concentrated. The sample was collected from near the shore and from around boards and other objects in the shallow brine, where the salts were in the process of crystallizing, or only recently had crystallized. It consists of a porous, rather even granular aggregate of platy monoclinic crystals. Material from beneath the surface of the sample was taken for analysis, and was weighed quickly to avoid loss of water in the air. The crystals start to melt in the heat of the hand, and with somewhat greater heat rapidly dissolve in their own water of crystallization, like natron and mirabilite. The analysis suggests the following chemical formula, neglecting, as in B, the sodium chloride: $2Na_2CO_3 \cdot Na_2SO_4 \cdot 25H_2O$. The sample consists mostly of a mineral with the following optical characters: alpha, 1.408; beta, 1.434; gamma, 1.437; 2V, 36°; and 2E, 53°; dispersion probably is strong; an acute bisectrix figure, when exactly centered, gives anomalous greenish-gray interference colors. No halite or other minerals were found under the microscope, except in aggregates of grains where the occasional presence of a mineral with a 2V of about 70° suggested natron. The predominant mineral, however, is considered to be a hydrous double salt of sodium carbonate and sodium sulfate possibly containing some sodium chloride in solid solution.

The conditions under which such salts crystallize at Owens Lake, California, have been described by Dub (1947, p. 2, 9, 10) as follows:

> Solutions in closed basins dessicate if in arid regions and become many component systems subject to phase rule. Salts of various composition wili with evaporation, cooling, heating, or dessication be precipitated. At Owens Lake, the following salts have been deposited at various times; sodium sesquicarbonate (trona), $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$, which deposits in warm weather and was called summer soda as distinguished from winter soda (sal soda); burkeite, a series of double salts of sodium sulphate-sodium carbonate, $Na_2CO_3 \cdot \pm 2Na_2SO_4$, which deposits also largely in warm weather; sodium sulphate, Na_2SO_4, which under certain conditions deposits both in cold and warm weather, hydrated or anhydrous; sodium chloride, $NaCl$, which deposits in warm weather, and sodium carbonate (natron or sal soda), $Na_2CO_3 \cdot 10H_2O$, which deposits upon chilling of alkaline solution. The latter is more-or-less pure depending on how much sodium sulphate was present at time of crystallization since the decahydrates of sodium sulphate and sodium carbonate crystallize isomorphously. . . .

Burkeite was originally described as an artificial anhydrous salt produced in the process of recovering salts from the brine of Searles Lake, California. Its occurrence in the natural state was predicted, and it was later found in a core from the Searles Lake salt bed (Foshag, 1935, p. 50-56), but it was not suspected of forming a series of hydrous isomorphous mixtures, such as those which, according to Dub, occur at Owens Lake, and which appeared to form, but in different states of hydration, in Carbonate Lake.

Trona probably was the predominant salt in the crust of the old brine reservoir at Carbonate Lake, with evidence in one instance indicating that it formed earlier than the hydrous double salt of sodium carbonate and sodium sulfate.

Logs of Holes

The lake bed was tested by 15 auger holes, the logs of which are as follows:

Hole 1

(north edge of main brine pool)

	Ft	in
Crystal bed		8
Black fluid mud (depth not determined)	5+	

Hole 2

Black fluid mud	6	
Black compact mud	5	

Hole 3

Crystal bed, slightly above surface of brine	1	6
Black fluid mud	6	6
Crystal bed (sample 2)	2	
Fluid mud on bedrock	3	6

Hole 4

	Ft	in
Surface crust		1
Black fluid mud	12	

Hole 5

	Ft	in
Mud	6	
Mud and disseminated crystals (sample 4)	3	8
Fluid mud	3	

Hole 6

	Ft	in
Crystal		8
Black fluid mud to bedrock	12	

Hole 7

(in center of 15-foot salt pan)

	Ft	in
Crystal	6	
Black mud to bedrock	5	

Hole 7a

(6 feet SE. of Hole 7)

	Ft	in
Crystal	1	
Black mud to bedrock	11	

Hole 8

(17 feet SE. of Hole 7; orifice of brine spring)

	Ft	in
Brine and very fluid mud to bedrock	12	6

Hole 9

(center of large irregular pan)

	Ft	in
Salt crust		4
Mud and disseminated crystals	2	

(The hole was abandoned after striking a boulder)

Hole 10

(30 feet W. of Hole 9, in same pan)

	Ft	in
White salt crust (sample 3)		2
Pinkish salt layer		1/8
Mud		1
White salt layer		1
Mud and disseminated water-clear crystals	1	6
Black fluid mud	11	
Black compact mud		6

Hole 11

(185 feet S. of Hole 9)

Black mud	4	
Black mud, very compact and difficult to drill		6

Hole 12

(100 feet S. of dam)

White crust containing trona and some burkeite (sample 5)		4-6
Mud with disseminated crystals (sample 6)	3	10
Fluid mud, brine (specific gravity, 1.35)	3	
Fine sand containing quartz and basalt	3+	

Hole 13

(250 feet S. of dam)

Pink salt layer		½
Granular salt layer (sample 10)		4
Mud, rather compact and containing disseminated crystals (sample 11)	2	
Mud, somewhat softer but containing disseminated crystals, some brine seepage (sample 12)	1	
Salt layers, alternately hard and soft, containing some mud (sample 13)	5	
Black mud and some brine	9	6
Sand	6	
Sand, some mud or silt	3	
Sand or silt to bedrock	6	

Hole 14

(center of W. part of main pool)

	Ft	in
Brine	1	6
White salt layer, some mud at bottom, (samples 14 and 15)	2	6
Black fluid mud	5	
Brownish mud containing disseminated crystals of gaylussite (sample 16)	1	6
Black fluid mud to bedrock	7	

Hole 15

(small pan 35 feet NW. of Hole 5)

Black mud containing disseminated crystals, easy drilling with auger (samples 17 and 18)	7	
Rather pure salt layer, hard and resistant to auger, requiring use of chisel bit (samples 17 and 18)	1	6
Black mud, depth not determined	2+	

Tonnage Estimate

The lake bed, as revealed both by auger holes and surface indications, was underlain by salts principally at the north and south ends. At the north end salts are believed to have occurred mainly in a wedge-shaped mass (800 by 400 by 4 feet thick) that lay between the larger brine pool and the center of the basin; at the south they occurred beneath the vat or area south of the dam. In computing the volume of salts, half the surface in each area has been taken, as it has been found that the total area occupied by pans in saline lakes is approximately half that occupied by the surrounding mud. Based on the average results of holes 13 and 15 for a ratio of salts to insoluble, a factor of 0.05 tons per cubic foot has been used in computing the tonnage of the block of ground as a unit. The average proportion of hydrous salts in the block has been determined from analyses that have been recalculated to include 60 percent water, which is an amount intermediate between that for natron and that for mirabilite. For example, an average of 60 percent sodium carbonate, 15 percent other salts, and 25 percent insoluble, would reduce, when 60 percent water is included, to 24, 6, and 10 respectively.

The brine has been estimated by assuming that it occupies a pore space of 30 percent of the volume of the lake bed; from its specific gravity its weight in tons can be calculated; and from the total salinity the amount of each element or compound can be computed in tons.

In accordance with the method as outlined, the tonnages of the several salts are tabulated as follows:

Anhydrous salts at Carbonate Lake in short tons

	Na_2CO_3	Na_2SO_4	NaCl	K_2SO_4
North part				
In the mud of the lake bed -----------	5,000	900	450	120
At bottom of brine pool -------------	1,600	580	50	5
Brine ----------------------------	13,000	2,000	7,700	2,300
South part				
In the mud of the lake bed -----------	8,500	700	600	125
Saline crust ----------------------	1,500	700	90	15
Brine ----------------------------	9,100	6,400	2,100	
Rounded total	36,000	11,000	11,000	2,500

Soap Lake

Location, Size, and Access

Soap Lake (fig. 9), which has an area of 864 acres, is the third largest saline lake in the State and is located in secs. 12, 13, and 24, T. 22 N., R. 26 E., and secs. 18 and 19, T. 22 N., R. 27 E., just north of the town of Soap Lake, in Grant County. It is easily reached by State Highway 7, one branch of which passes along the lake northward toward Grand Coulee Dam, the other eastward toward Davenport and Spokane, paralleling the main line of the Great Northern Railway.

Topography and Geology

Soap Lake, like Carbonate Lake and certain others in this region, is in an old abandoned channel of the Columbia River, the southern extension of Grand Coulee, where the canyon walls widen and level off southward into a broader valley. Figure 9, slightly modified from a map by Bretz (1932), shows that the lake is on a bedrock of basalt at the north end, but is otherwise surrounded by glacial deposits. The basalt presumably rises southward under the overburden to a level higher than that of the lake surface, preventing appreciable drainage through the gravel and thus making the lake saline. Its surface salinity is only slightly higher than that of sea water and about twice that of Lake Lenore, the next lake northward in a chain of four. Blue and Park Lakes are essentially fresh, Blue Lake being supplied by a rather large spring that issues from the hillside above. All of the lakes probably receive ground water from seepages both above and below their surfaces; and there probably is movement of

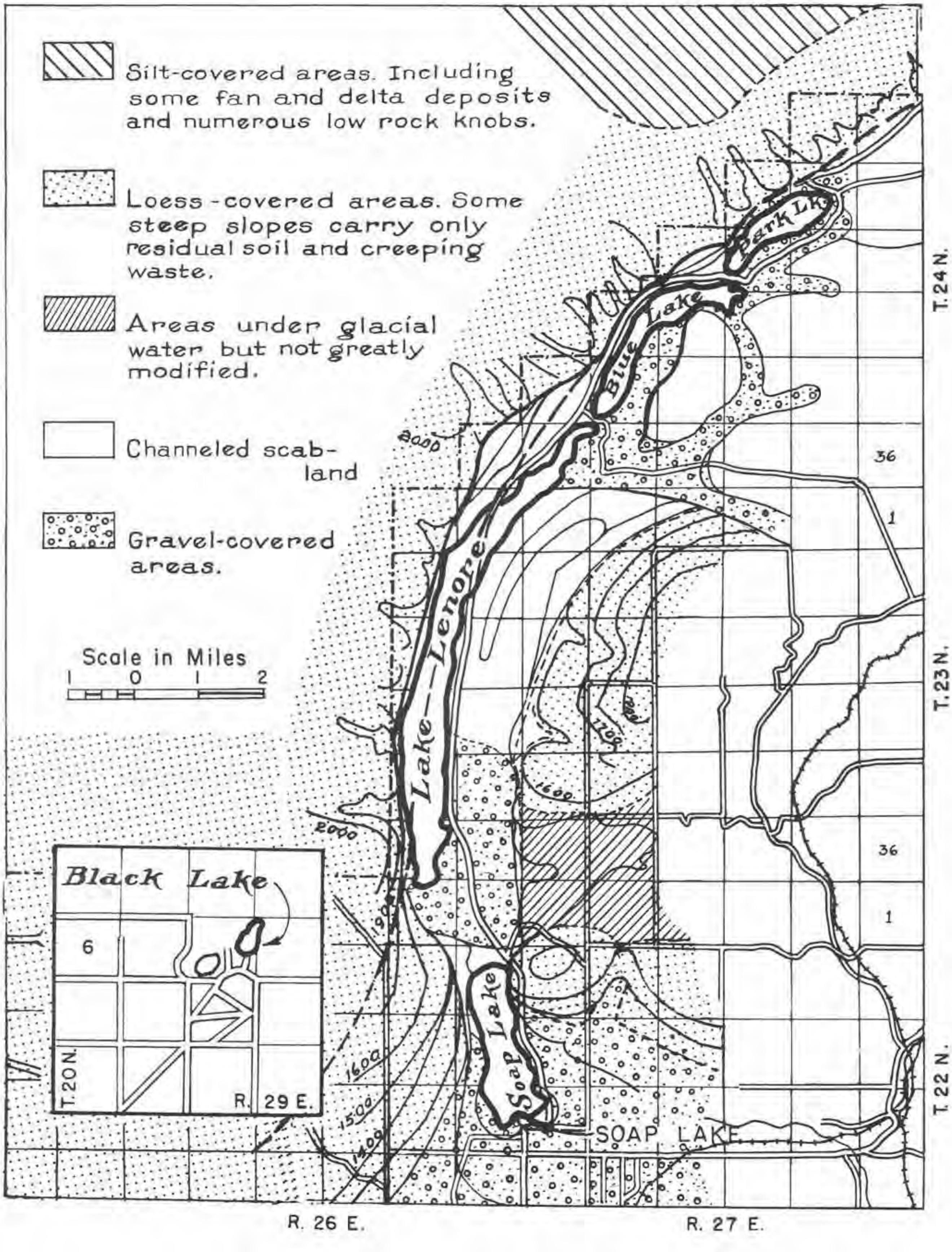


Figure 9.—Map of Soap Lake (with slight modification from by J Harlen Bretz, 1932) and of Black Lake (inset).

water southward down the coulee, each lake contributing its salinity to the next and resulting in a maximum concentration in the last lake of the chain.

History

Soap Lake, so named because of the fact that its water forms a conspicuous froth off the shoreline, especially on windy days, has been of interest to the public for more than 50 years (Byers, 1902, p. 10-11; Patty and Glover, 1921, p. 111; Glover, 1936, p. 69). It was known at the beginning of the century as Sanitarium Lake, and the belief that its water has therapeutic value continues to lead many people to visit the lake each year. The composition of its water in major constituents is no different from that of many other lakes, but it has been observed that the therapeutic value of a water used for bathing is not indicated by a chemical analysis (Collins, 1924, p. 235). About 1921 the Soap Lake Mineral Water Co. was formed presumably to sell the water, and for a number of years an evaporating plant, Thorson's Products Co., has produced salts in packages.

The Salts

Brine.—The lake is considered here as a source of sodium carbonate (sal soda) and other salts because of its relatively high concentration and large volume and its ease of access to highway and railroad. Its concentration is about six times that of Omak Lake (the largest of the saline lakes in the State), but it has only one-fourth the area. It has twice the surface concentration of Lake Lenore to the north but a little less than half the area. In comparison with Owens Lake in California, whose brine is being rather extensively used at the present time, the concentration of Soap Lake brine is only about one-third as great, as shown by the average value of 10 analyses made at different times between 1866 and 1914 (Phalen, 1919, p. 163). The surface salinity, during the 45 years prior to 1946, increased from 2.8 to 3.8 percent. According to studies by Charles A. Newhall[1] of the State Department of Health, this is considerably less than the bottom salinity at a depth of 55 feet. The following is quoted from Newhall's report:

> The outstanding natural characteristic that makes Soap Lake different from other saline lakes is the quantity and "toughness" of the foam that develops under certain conditions. . . . The foam contains an unexpected constituent, a water soluble heavy oil. . . . The composition and "toughness" of the foam varies considerably from time to time. A tough foam will persist for days at a time along the shore line and may be blown a considerable distance inland before it breaks down into its constituents. A light foam will disappear almost immediately when it is removed from the surface of the water. A sample of tough foam weighed only $2\frac{1}{2}$ ounces to the cubic foot. This foam when freshly formed was a snowy white, but on standing turned yellow, and finally after several days broke into an evil-smelling black muddy liquid. The black liquid consisted of approximately equal parts by weight of a bad-smelling brown oil, water, and solid matter. The oil rapidly thickened on heating or on exposure to the air and changed to a black waxy solid. The water was a solution of the mineral salts the same as found in the surface water

---

[1] Newhall, Charles A., Memorandum report for the Washington State Department of Health.

> of the lake. The solid matter consisted of amorphous mineral particles similar in composition to the soil dust that blows over the Soap Lake region. Another sample showed the amorphous mineral matter to be wholly limonite (hydrous ferric oxide). A sample of light foam showed no mineral dust. The oily matter was white, changing to light straw color and finally to a dark brown on exposure. . . .
>
> . . . [Besides] a heavy water soluble oil, [the lake water] contains sodium silicate, sulphur in various combinations ranging from sodium sulphide, sodium sulphite, to sodium sulphate, sodium carbonate and sodium bicarbonate, sodium chloride, nitrogen (in some organic combination), sodium fluoride, potassium chloride and magnesium bicarbonate. The other elements noted were detected in minute amounts by spectrographic methods. All the organic matter in the water passes through a parchment membrane on dialysis. Sodium silicate remains in the dialyzer.
>
> The muds contain free sulphur and at times this element is undoubtedly present in suspension in the water. . . . A sample taken from the surface in March 1936 after the winter runoff had ended showed a salinity of 3.64 percent. In August 1936 the salinity was 3.76 percent at the surface and 6.43 percent at a depth of 55 feet on the bottom. . . . The bottom water showed a very strong sulphide reaction while the surface water showed only a trace of suphide sulphur.
>
> . . . Diatomaceae, infusoria, algae and various higher forms of plant and animal life are present in the water. . . . The shore water, in summer, contains immense numbers of fly larvae.

The conditions under which solid salts crystallize in masses from a brine have not yet been reached in Soap Lake, although scattered crystals have been reported in mud dredged up from the bottom. The brine, the only important source of salts, has been analyzed, and the results are shown in table 4. Analyses of samples of water taken in August 1959 from Soap Lake and Lake Lenore are shown in table 5.

Tonnage Estimate

Assuming that the lake has an average depth of 25 feet, and on the basis of its surface salinity as indicated by the analysis made for this report, it is calculated that there are the following short tons of salts: sodium carbonate, 628,000; sodium sulfate, 301,000; and sodium chloride, 241,000. Among the minor constituents there are roughly 20,000 tons of potassium carbonate, estimated on the basis of the analysis by Knight (Byers, 1902, p. 11).

Table 4. —Analyses of brine from Soap Lake

Constituents (radicals) in parts per million and in percentage of total solids

Sample no.	31		A		B		C	
Constituents	Parts per million	Percentage of total solids	Parts per million	Percentage of total solids	Parts per million	Percentage of total solids	Parts per million	Percentage of total solids
Ca (calcium)	None	None	Trace	Trace	Trace	Trace	7.27	0.0200
Mg (magnesium)	None	None	10.85	0.04	79	0.29	52.40	0.1441
Al (aluminum)	None	None	----	-----	Trace	Trace	3.63	0.0100
Fe (iron)	None	None	----	-----	----	Trace	0.36	0.0010
Na (sodium)	14,300	37.5	10,504.11	39.60	10,450	38.14	13,836.95	38.0489
K (potassium)	----	----	----	-----	335	1.22	36.37	0.1000
HCO_3 (bicarbonate)	3,700	----	53.42	-----	----	-----	4,280.00	11.7700
CO_3 (carbonate)	8,480	31.8(1)	9,624.59	30.22(1)	8,147	29.73	7,000.00	19.2400
SO_4 (sulfate)	6,770	17.7	4,362.40	16.44	4,600	16.79	6,572.00	18.0700
Cl (chloride)	4,850	12.7	3,526.20	13.28	3,527	12.87	4,437.00	12.2000
F (fluoride)	----	----	----	-----	----	-----	3.00	0.0082
SiO_2 (silica)	----	----	113.00	0.42	128	0.47	74.00	0.2035
PO_4 (phosphate)	----	----	----	-----	134	0.49	----	-----
P (phosphorus)	----	----	----	-----	----	-----	None	None
B (boron)	----	----	----	-----	----	-----	None	None
Cu (copper)	----	----	----	-----	----	-----	0.03	0.0001
Li (lithium)	----	----	----	-----	----	-----	3.63	0.0100
Rb (rubidium)	----	----	----	-----	----	-----	0.36	0.0010
N (organic nitrogen)	----	----	----	-----	----	-----	33.10	0.0910
NO_2 (nitrite)	----	----	----	-----	----	-----	None	None
NO_3 (nitrate)	----	----	----	-----	----	-----	None	None
Oil (water soluble)	----	----	----	-----	----	-----	29.90	0.0822
	38,100	99.7	28,194.57	100.00	27,400	100.00	36,370.00	100.0000
Specific gravity at 26° C.	1.031				1.026			

Hypothetical or conventional combinations in percentage of total solids

Sample no.	31	A	B	C
NaCl (sodium chloride)	21.0	20.61	21.3	-----
$MgH(CO_3)_2$ (magnesium bicarbonate)	----	0.23	----	-----
Na_2CO_3 (sodium carbonate)	39.3	40.22	51.5	-----
$NaHCO_3$ (sodium bicarbonate)	13.6	15.65	----	-----
$MgSO_4$ (magnesium sulfate)	----	-----	1.4	-----
Na_2SO_4 (sodium sulfate)	26.2	22.89	23.2	-----
K_2CO_3 (potassium carbonate)	----	-----	1.8	-----
SiO_2 (silica)	----	0.40	0.4	-----
P_2O_5 (phosphorus pentoxide)	----	-----	0.4	-----
	100.1	100.00	100.0	

(1) Includes bicarbonate reduced to carbonate.

Sample No. 31. A sample collected in November 1944 from the east shore, about a mile north of town. Specific gravity, 1.037.

A. Sample collected by I. C. Russell, U.S. Geol. Survey Bull. 108, p. 92-96, 1893. Analysis by George Steiger; see also U.S. Geol. Survey Bull. 113, p. 113, 1893. The constituents in parts per million and the hypothetical or conventional combinations in percentage of total solids are as stated in their original form and the constituents in percentage of total solids are as recalculated by F. W. Clarke, U.S. Geol. Survey Bull. 770, p. 164, 1924. See also a statement by R. C. Wells, U.S. Geol. Survey Bull. 717, p. 20, 1923.

B. Analysis by H. G. Knight, Washington Geol. Survey Ann. Rept. 1901, v. 1, pt. 5, p. 11, 1902, is here stated as constituents in parts per million and as constituents in percentage of total solids as reclaculated by F. W. Clarke, U.S. Geol. Survey Prof. Paper 135, p. 180, 1924. The hypothetical combinations or conventional combinations in percentage of total solids are as recalculated by the writer.

C. Analysis by Charles A. Newhall, Washington State Department of Health, 1936.

Table 5.—Analyses of brine from Lake Lenore and Soap Lake, August, 1950.

	Lake Lenore Depth (meters)		Soap Lake Depth (meters)		
	0	8	0	10	20
Alkalinity: $CaCO_3$	2,590	4,630	11,480	13,040	47,220
$Ca(HCO_3)_2$	3,325	2,970	38,480	3,360	22,040
Acidity	0	0	0	0	0
Total solids	13,856	13,786	34,245	36,610	144,280
Chloride	394	394	1,473	1,598	4,282
Fluoride	7	7	6	6	-----
Iron	0.2	0.2	0.6	0.6	-----
Magnesium	16.0	28.3	15.3	21.4	27.0
Calcium	8.0	8.2	16.4	9.1	9.1
Sulfate	2,160	2,140	6,300	6,650	7,160
Phosphate	10	10	15	18	127
Silica	25	25	100	100	-----
Total nitrogen	5.6	5.6	12	10.8	148
Organic nitrogen	1.6	1.6	2.24	4.0	100
Sodium and potassium	4,002	4,715	10,557	11,661	37,835

Analyist, F. H. Dettmer, Washington Department of Game

Anderson, George Cameron, A limnological study of the seasonal variations of phytoplankton populations: University of Washington, Ph. D. thesis, Department of Zoology, 268 p., 18 tables in text and 61 in appendix, 31 figures, August 1954.

Mitchell Lake

Location, Size, and Access

Mitchell Lake is in the N½SW¼ sec. 13, T. 22 N., R. 29 E. (fig. 10). It is 1,100 feet long, mostly between 300 and 400 feet wide, and has an area of about 8 acres. It is a little more than a mile southwest of Wilson Creek, the nearest railroad station on the main line of the Great Northern Railway, with which it is connected by graveled road and paved highway.

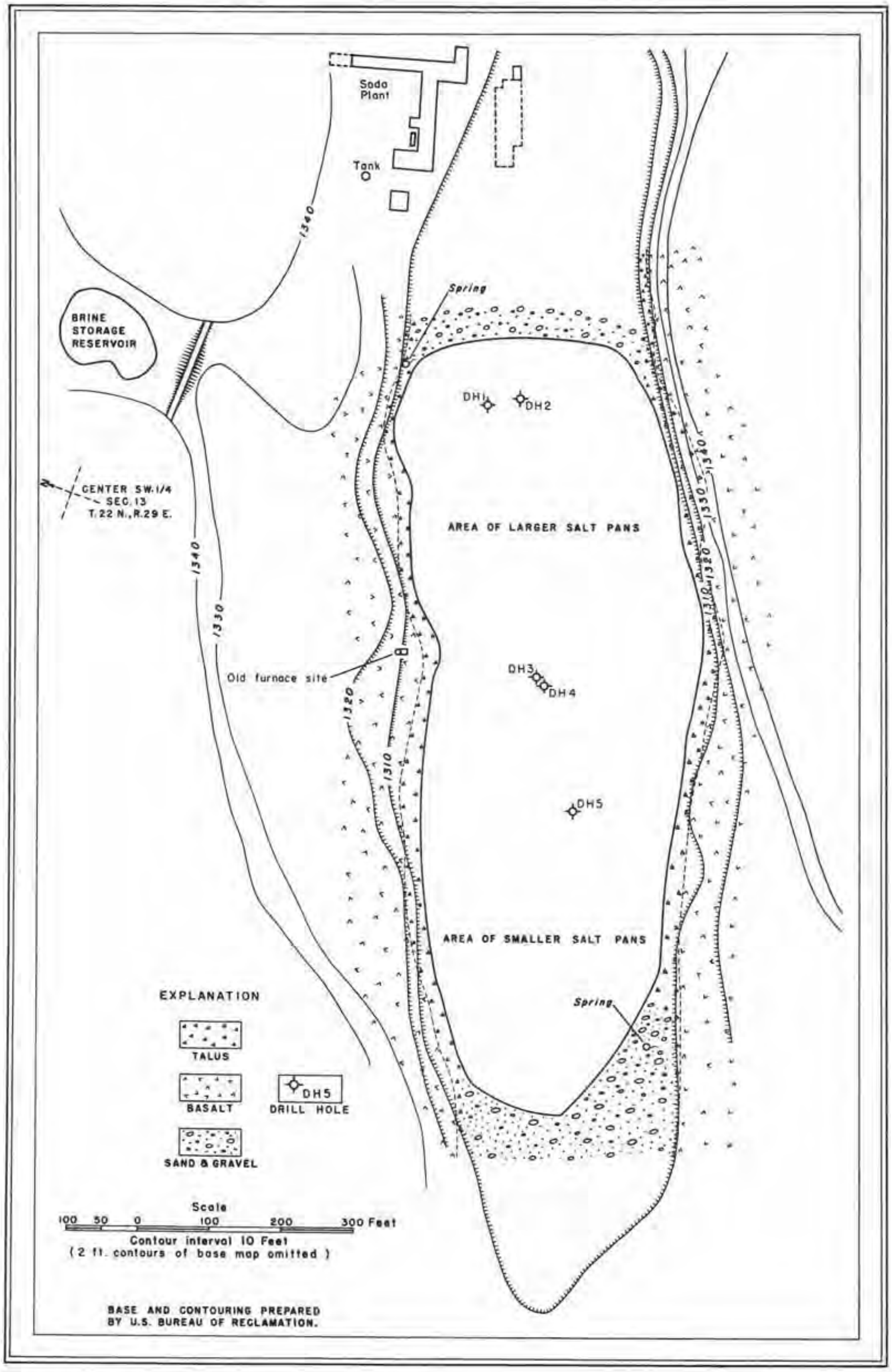


Figure 10.—Map of Mitchell Lake.

Topography and Geology

The lake is near the eastern entrance of the smaller and uppermost of two connecting coulees, part of the great system of stream channels cut in the basalt of the Columbia Plateau during glacial time. A prominent cliff or knob faces the lake on the south. Deposits of basaltic sand and gravel lie at the ends of the lake, but it seems probable that the lake is in a depression in the rock floor of the coulee from which there is little or no outflow. There is little visible seepage into the lake, but the ground water probably is near the lake level, as indicated by a shallow well near the north corner of the lake.

History and Production

The main period of development at Mitchell Lake, as reported by the U.S. Bureau of Mines, was between 1936 and 1941. A plant, including several buildings with evaporating equipment, a kiln, and other machinery, was operated by the Sodium Products Co. of Spokane, under the direction of J.E. Ince, President, and Dr. J. M. Gunning, Secretary. In 1941 the firm was reorganized under the name of Sodac Chemical Co. Before the construction of the large plant a small furnace or evaporator was constructed near the shore line opposite the center of the lake. Both operations apparently concentrated on using the brine rather than the salts in the pans. Pipes were laid on the lake bed and were driven into it, and a shaft 3 to 4 feet square was sunk in the center through the fluid mud to bedrock at 26 feet.

The Salts

Brine.—Brine is present in open pools over the salt pans and may rise above the surrounding mud after a winter of much precipitation. In 1944 the brine still formed pools in early fall, but in 1945 it had disappeared from the surface, so that in most places one could, with care, walk around on the thin saline crust. Usually the brine makes the lake mud so fluid that an iron bar will sink by its own weight. This is especially so along the walk that was built on posts for some distance from the north shore toward an old shaft in the center of the lake. In October 1944 the specific gravity of the brine at the surface was 1.14, which is near the saturation point for sodium carbonate at ordinary temperatures.

Crystal.—The crystallized salts of the deposit, like those of most other saline lakes in the State, make up a rather closely packed group of lenses or pans. These range from circular or irregularly circular to oval in shape, from 10 to 30 feet in diameter, and from 2 to 8 feet in depth. The smaller and thinner pans are nearest the shore and are most abundant at the south end. The deposit was tested by five auger holes and by soundings with an iron bar. At drill hole 1 (fig. 10) the salt layer in the center of the pan is 2 feet thick; at location 2 an iron bar was easily pushed to a depth of 18 feet in very fluid mud; at location 3 both the sounding rod and auger were easily forced to bedrock inside the shaft; at location 4, at the edge of a platform about 15 feet square surrounding the shaft, the salt in the center of a pan is 8 feet thick, including 2 feet of disseminated gaylussite crystals in mud at the bottom; and at location 5 a pan between 15 and 20 feet in diameter is 7 feet thick in the center, the lower 2 feet being a zone of disseminated gaylussite crystals in mud. This pan was covered by a salt crust, 1 inch thick, which was hardly firm enough to hold a man's weight, and which covered a fluid mud layer about a foot thick. The occurrence of gaylussite ($Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O$) in a zone at the bottom of holes 4 and 5 suggests that at the bottom there is a wider extent of the more solid salt (mostly sodium carbonate) that makes up the pans. Except for a thin layer in hole 12 at Carbonate Lake, this is the only known occurrence of gaylussite in the State. The composition of the deposit is shown by six analyses, one a complete analysis to show the percent of gaylussite (table 6).

Tonnage Estimate

The brine is assumed to occupy a pore space of 30 percent in the lake mud, although the fluidity of much of the mud suggests a higher volumetric ratio. Its specific gravity is believed to be uniform throughout to an average depth of 20 feet; its salinity is estimated, on the basis of the specific gravity of 1.14, to be about 14 percent. In round numbers, 10,000 tons of salts, most of which is sodium carbonate, appears to be in solution.

In estimating the crystalline salts, the pans are considered to occupy half the surface area of the lake bed. The average thickness is considered to be about 5 feet. The method of using the data from the analyses as explained under the description of Carbonate Lake gives the following estimate of short tons of anhydrous salts: sodium carbonate, 11,000; sodium sulfate, 600; sodium chloride, 800; and gaylussite, 3,000.

Table 6.—Analyses of salts from Mitchell Lake

Constituents in percentage of total weight

Sample no.	26	27	28	29	30	30A
Insoluble residue	1.5	18.0	51.7	15.7	65.8	----
Ca (calcium)	None	None	None	None	None	5.2(1)
Mg (magnesium)	0.04	None	None	None	0.04	4.8(2)
Al (aluminum)	None	None	None	None	None	4.3(3)
Fe (iron)	None	None	None	None	None	1.3(4)
Na (sodium)	40.9	34.2	20.1	35.9	11.7	20.1(5)
K (potassium)	----	----	0.73	----	1.26	----
SiO_2 (silica)	0.8	2.0	----	1.0	0.9	37.6
HCO_3 (bicarbonate)	None	None	None	None	None	----
CO_3 (carbonate)	52.3	43.1	24.4	45.4	12.9	19.2(6)
SO_4 (sulfate)	1.0	1.1	1.6	0.9	2.2	1.3(7)
Cl (chloride)	0.5	0.8	1.6	1.0	2.4	2.3
Ignition loss	2.2	----	----	----	----	22.9
	99.24	99.2	100.13	99.9	97.20	99.8

Conventional combinations in percentage of total weight

Sample no.	26	27	28	29	30	30A
Insoluble residue	1.5	18.0	51.7	15.1	65.8	----
NaCl (sodium chloride)	0.9	1.3	2.6	1.6	3.9	3.8
Na_2CO_3 (sodium carbonate)	92.5	76.3	43.2	80.2	22.9	19.2
$NaHCO_3$ (sodium bicarbonate)	None	None	None	None	None	----
Al_2O_3 (aluminum oxide)	None	None	None	None	None	4.3
Fe_2O_3 (iron oxide)	None	None	None	None	None	1.3
$CaSO_4$ (calcium sulfate)	None	None	None	None	None	----
$MgSO_4$ (magnesium sulfate)	0.2	None	None	None	0.2	----
Na_2SO_4 (sodium sulfate)	1.2	1.6	1.1	1.3	0.7	2.3
K_2SO_4 (potassium sulfate)	----	----	1.62	----	2.8	----
SiO_2 (silica)	0.8	2.0	----	1.0	0.9	37.6
Ignition loss	2.2	----	----	----	----	3.4
MgO	----	----	----	----	----	1.2
$CaCO_3 \cdot Na_2CO_3$ (gaylussite)	----	----	----	----	----	20.1(8)
$3MgCO_3 \cdot Mg(OH)_2$ (hydromagnesite)	----	----	----	----	----	6.6(8)
	99.3	99.2	100.22	99.2	97.2	99.8

(1) CaO (2) MgO (3) Al_2O_3 (4) Fe_2O_3 (5) Na_2O (6) CO_2 (7) SO_3

(8) The percentages do not include combined water, which was mostly driven off in a drying oven before the analysis was made.

Table 6.—Analyses of salts from Mitchell Lake.—Continued

Sample No. 26. Thin layer of tabular crystals (natron) lying on bottom of brine pool and on upper surface of permanent salt pan that was penetrated by hole 1.

Sample No. 27. From hole 1, at 0 to 2 feet and to bottom of salt pan.

Sample No. 28. From hole 4, at 0 to 8 feet and to bottom of pan.

Sample No. 29. From hole 5; sample represents material taken from 0 to 1 inch of surface crust and from 1 to 5 feet; the intervening 1 inch to 1 foot was briny mud and was not sampled.

Sample No. 30. From hole 5, at 5 to 7 feet, in zone of disseminated gaylussite crystals. Gaylussite does not show up in this analysis, as it was not dissolved by the hot water leaches used for solution of the sample.

Sample No. 30A. Same material as that of sample 30; analysis includes components that are both soluble and insoluble in hot water and includes the gaylussite crystals. Potassium presumably is included with soda, and the ignition loss includes both water and carbon dioxide. Silica, iron oxide, alumina, and magnesia presumably are combinaed as clay.

Other Lakes in Grant County

A few lakes, mostly in the vicinity of the well-known saline lakes, are probably of little importance commercially as saline deposits, but because either physical tests or chemical analyses are available, they are described here.

Lenore Lake

Lenore Lake was mentioned in the description of Soap Lake (fig. 9). Its salinity is low, probably less than 2 percent as indicated by its specific gravity of 1.019, but its surface area as well as its volume is large. Its composition probably is predominantly carbonate, the same as that of Soap Lake. Assuming that its depth averages 20 feet for the part south of the highway crossing, and assuming that its salinity is 2 percent, there would be approximately 1,000,000 tons of salts in solution.

Black Lake

Black Lake (fig. 9, inset map) lies in one of the characteristic undrained depressions in a coulee formed by glacial floodwaters. The lake, although of considerable size, is turbid, is probably shallow, and is low in saline concentration. Mud flats characterize its shore line at the north end, and on these a patchy efflorescence of salts was present at the time of examination (1945). A sample of the crust, which unavoidably includes some of the mud, has been analyzed as shown in table 7.

Moses Lake

Byers (1902, p. 9-10), in his early study of the State's water resources, sampled the Moses Lake water and recognized its low salinity, which is no more than that of some river waters. He suggested its possible use for irrigation but neverthless included it among other so-called alkali lakes. An analysis, taken from Byers' report but recalculated and stated in accordance with present-day practice, is as shown in table 8.

Table 7.—Analysis of salts from Black Lake

Sample No. 74

Components in percentage of total weight		Combinations in percentage of total weight	
Insoluble residue	26.8	Insoluble residue	26.8
Ca (calcium)	None	NaCl (sodium chloride)	18.4
Mg (magnesium)	0.06	Na_2CO_3 (sodium carbonate)	29.4
Al (aluminum)	None	$NaHCO_3$ (sodium bicarbonate)	None
Fe (iron)	None	R_2O_3 (iron and aluminum oxides)	Trace
Na (sodium)	26.8	$CaSO_4$ (calcium sulfate)	None
K (potassium)	1.03	$MgSO_4$ (magnesium sulfate)	0.3
SiO_2 (silica)	0.4	Na_2SO_4 (sodium sulfate)	20.9
HCO_3 (bicarbonate)	None	K_2SO_4 (potassium sulfate)	2.3
CO_3 (carbonate)	16.6	SiO_2 (silica)	0.4
SO_4 (sulfate)	15.6		98.5
Cl (chloride)	11.2		
	98.49		

Table 8.—Analysis of water from Moses Lake

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	25.2	8.41	NaCl (sodium chloride)	6.3
Mg (magnesium)	21.5	7.25	$CaCO_3$ (calcium carbonate)	21.0
Al_2O_3 (alumina)	3.3	1.11	$MgCO_3$ (magnesium carbonate)	25.4
Fe_2O_3 (iron oxide)			Na_2CO_3 (sodium carbonate)	36.8
Na (sodium)	59.0	19.86	R_2O_3 (iron and aluminum oxides)	1.1
K (potassium)	-----	-----	Na_2SO_4 (sodium sulfate)	4.2
HCO_3 (bicarbonate)	-----	-----	SiO_2 (silica)	5.0
CO_3 (carbonate)	153.1	51.56		99.8
SO_4 (sulfate)	8.5	2.87		
Cl (chloride)	11.5	3.88		
SiO_2 (silica)	15.0	5.06		
	297.1	100.00		

Note.—The analysis, by H. G. Knight, was first recalculated by F. W. Clarke, U.S. Geol. Survey Bull. 330, p. 125, 1908, whose statement contains an error in the position of the decimal point, in changing from parts per thousand to parts per million, which makes the salinity 10 times too great; this error persists in later editions of the Data of Geochemistry and in Prof. Paper 135, p. 180, 1924, from which the statement in the first column of figures is taken but corrected to accord with Knight's original. A further recalculation by the writer has been made in the last column of figures.

Tucker Lake

Tucker Lake is the westernmost of two small lakes that lie in the S½SE¼ sec. 15, T. 17 N., R. 28 E. It is about 3,200 feet southeast of Sulphate Lake and lies in another depression along the same general tract of basaltic scabland that skirts the eastern end of the Frenchman Hills. The lake, which is only a firm salt crust in the dry season, covers an area 200 by 400 feet. At the time of examination (1945) the crust, which is less than half an inch thick, was broken into a pattern of polygonal blocks bounded by ridges, the result of upturned edges of the crust. A few scattered crystals were observed in the mud beneath to a depth not exceeding 4 inches. The analysis (table 9) shows the composition of the salts.

Table 9. —Analysis of salts from Tucker Lake

Sample No. 25			
Constituents in percentage of total weight		Conventional combinations in percentage of total weight	
Insoluble residue	1.3	Insoluble residue	1.3
Ca (calcium)	None	NaCl (sodium chloride)	4.0
Mg (magnesium)	None	Na_2CO_3 (sodium carbonate)	6.3
Al (aluminum)	None	$NaHCO_3$ (sodium bicarbonate)	None
Fe (iron)	None	R_2O_3 (iron and aluminum oxides)	None
Na (sodium)	32.9	Na_2SO_4 (sodium sulfate)	88.4
HCO_3 (bicarbonate)	None		
CO_3 (carbonate)	3.6		
SO_4 (sulfate)	59.8		
Cl (chloride)	2.4		
	100.0		100.0

Sample No. 25. Salt crust from the center of the lake bed.

OKANOGAN COUNTY

Omak Lake

Location, Size, and Access

Omak Lake is the largest saline lake in the State, comprising 3,820 acres as determined with a planimeter on a fire control map of the Colville and Spokane Indian Reservations published in 1930 by the U.S. Department of the Interior (fig. 11). The lake is roughly 8 miles long and averages ½ mile wide. It lies mostly in the NE¼ T. 32 N., R. 28 E., but extends northward into T. 33 N., R. 27 E.

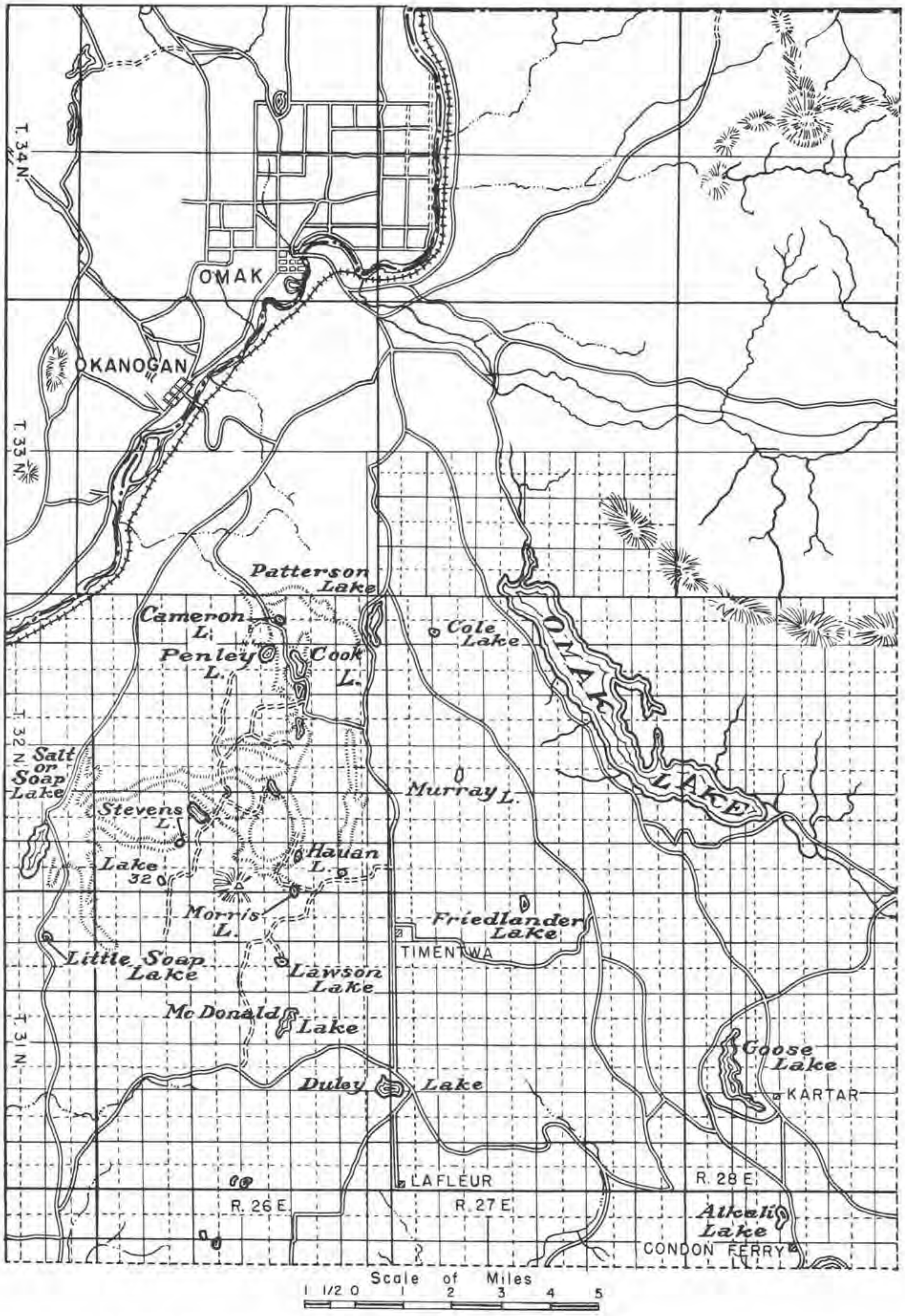


Figure 11.—Map of part of the Colville Indian Reservation showing Omak Lake, and other saline lakes on Okanogan Plateau to the west.

and eastward into T. 32 N., R. 28 E. Omak, a town on a branch of the Great Northern Railway, is about 6 miles distant by graveled road to the northwest; other graveled or dirt roads lead southward toward the Columbia River and southeastward toward Nespelem and Grand Coulee Dam.

Topography and Geology

Most of the lake is in a steep-sided valley cut in granitic or gneissic rocks, probably by the Columbia River as it was forced aside in places by the flows of the Columbia lava. The lake surface is at an altitude of 950 feet, about 150 feet above the Okanogan River at Okanogan. The lake recieves a small intermittent drainage from the sides and a larger and continuous flow from streams that enter on glacial deposits at either end. The depth of the lake is 110 feet at one place near the south end and is reported to be nearly 300 feet at other places. The lake level has not fluctuated appreciably in recent years but is said to have been about 14 feet higher at about the beginning of the century and was 11 feet higher yet at an earlier period. This higher level is indicated by the upper edge of the white border shown in figure 12. The lake seems to be suited, more so than any other saline lake in the State,

Figure 12.—Omak Lake. View of the northwest end of the lake and of the northeast arm from the southwest. The top of the thin salt crust that constitutes the white border, which indicates earlier surface levels, is about 25 feet above the present surface.

for use in making an estimate of the amount of time that has elapsed since the retreat of the Pleistocene ice that filled the basin—an estimate based on the number of years its salinity has been accumulating. A calculation, which includes an estimate of volume, of the amount of solids in solution, of the amount of solids added per year, and of an average daily rate of evaporation, gives an interval of about 10,000 years.

The Salts

Brine.—The Omak Lake water is far from being sufficiently concentrated for its salts to crystallize out of solution. This was observed by Pardee (1918, p. 179-180), but he noted that ". . . the water has a smooth, soapy feeling, froths along the shore, and tastes of sodium carbonate." A sample of the water taken from the bottom at a depth of 110 feet near the south end of the lake has been analyzed and the results are included together with those reported by Pardee in table 10.

The analysis made for this report shows a slightly higher concentration than that given by Pardee, which might be due to the fact that the sample was taken from the bottom in a stratum of higher concentration even though there was no suggestion of stratification as indicated by specific gravity, which was 1.004 at 17° C. In December 1944 the specific gravity of the water at the surface at either end was 1.006 at 6° C., but in July 1945 it was 1.004 at the surface, the same as that given by Pardee. Currents set up by inflow at the ends of the lake seem to make the density uniform from top to bottom, but, as Pardee suggests, the lake water may be more dense in the central portion. Most lakes show stratification, which according to Harding (1942, p. 230), may be caused by differences in temperature, suspended silt, or dissolved salts. Soap Lake, Big Soap or Salt Lake, and Wannacut Lake show stratification, but they are considerably more concentrated at the surface, are smaller and shallower, and have a much sma smaller inflow than Omak Lake.

Pardee remarks further that "whether or not salines can be profitably extracted from Omak Lake depends largely on the facilities available for evaporating the water, as to which few or no data are at hand. However, a bay that covers 100 acres on the east side of the lake and that is connected with the main water body by a strait only 400 feet wide at one place might perhaps be utilized as an evaporating basin." The plan would have the advantage of little or no pumping expense, but the bay is not accessible by road. Salts would need to be transported by barge to roads at the north end of the lake. Another plan worth considering would involve pumping the water from the north end to vats located near Okanogan, where, by solar concentration, the brine could perhaps be made usable in a process using carbon dioxide as a precipitant of sodium carbonate. The water, however, would have to be pumped 1½ miles against a head of at least 300 feet. Carbonate rocks occur abundantly in the vicinity of Okanogan and if burned as a source for lime would make byproduct carbon dioxide available. The rate of evaporation in Omak Lake is about an inch every 5 days for at least 6 months of the year; thus, 4 feet of water could be reduced to 1 foot, and its concentration increased to near that of sea water.

Table 10.—Analyses of brine from Omak Lake

Sample No. 52

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	5.7
Mg (magnesium)	11	0.2	Na_2CO_3 (sodium carbonate)	23.2
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	36.1
Fe (iron)	None	None	$MgSO_4$ (magnesium sulfate)	0.9
Na (sodium)	1,770	30.3	Na_2SO_4 (sodium sulfate)	25.8
K (potassium)	227	3.7	K_2SO_4 (potassium sulfate)	8.6
HCO_3 (bicarbonate)	1,530	----		
CO_3 (carbonate)	760	39.0(1)		
SO_4 (sulfate)	1,350	23.1		
Cl (chloride)	190	3.2		
	5,838	99.5		100.3

Specific gravity at 26° C. (78.8° F.) 1.001

Sample A

Constituents	I Parts per million	II Percentage of total solids	Conventional combinations	III Percentage of total solids
Ca (calcium)	13	0.23	Na_2CO_3 (sodium carbonate)	57.20
Mg (magnesium)	103	1.82	Na_2SO_4 (sodium sulfate)	22.62
Na (sodium)	1,831	32.60	K_2SO_4 (potassium sulfate)	9.93
K (potassium)	254	4.52	Other salts not calculated	10.25
B (boron)	None	None		
HCO_3 (bicarbonate)	173	-----		
CO_3 (carbonate)	1,979	36.75(1)		
SO_4 (sulfate)	1,185	21.12		
Cl (chloride)	116	2.96		
Total solids calculated	5,566	100.00	Total salts	100.00 0.57

Specific gravity at 25° C. (76.5° F.) 1.004

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 52. Collected in July 1945, from the bottom near the south end of the lake at a depth of 110 feet. Specific gravity determined in the field at that time was 1.004 at 17° C. (62.3° F.). In December 1944 the specific gravity was 1.006 at 6° C. (42.5°) at both ends of the lake.

Sample A. Analysis by George Steiger, is stated here in I and III as in the original report by J. T. Pardee in U.S. Geol. Survey Bull. 677, p. 179-180, 1918. The statement in II is based on a recalculation by F. W. Clarke, U.S. Geol. Survey Bull. 770, p. 164, 1924, and U.S. Geol. Survey Prof. Paper 135, p. 180, 1924, showing an increase in the concentration of most of the constituents and a total of 5,704 parts per million.

Tonnage Estimate

In calculating the tonnage of salts in solution in the water, the analysis of Sample No. 52 was used after it had been calculated into conventional compounds, which are often arbitrary combinations, especially among the minor constituents. For example, potassium is usually calculated as potassium sulfate or chloride, but it could be shown combined with bicarbonate or carbonate. The method consists in balancing the negative ions or radicals (Cl, SO_4, HCO_3, and CO_3) against the positive ions or radicals, (Na, Mg, etc.) in simple combination rather than as the more complex combinations that may exist in solution or that might crystallize out in the natural state as the water becomes more concentrated. Tonnage units, therefore, are given for commercial products that are expected to be recovered from the brine. Pardee made an estimate for an assumed average depth of 50 feet, which is used here, even though the lake is believed to be at least 200 feet in average depth. Calculations are made for the volume of water in cubic feet, for its weight in short tons as determined from its specific gravity, for the tonnage of dissolved solids as determined from the percentage of total salinity (parts per million), and for the tonnage of each compound as determined from its percentage of the total solids calculated from the analysis. In round numbers there are: 880,000 tons of sodium carbonate, 411,000 of sodium sulfate, 13,000 of magnesium sulfate, 130,000 of potassium sulfate, and 79,000 of sodium chloride.

"Rimrock Lake"

Deposit No. 18, which in the field was conveniently named "Rimrock Lake" from a nearby basalt-capped hilltop, is located on the Okanogan Plateau, in the NE¼SW¼ sec. 14, T. 32 N., R. 26 E. It covers an area of approximately 10 acres. It may be easily reached via the Okanogan-Timentwa county road or other less traveled roads on the plateau (figs. 11 and 13).

The lake lies between a knob of granite on the west and another basalt-capped granite knob on the east. Glacial drift lies at the north and south ends of the lake and separates it from other small lakes in the vicinity, such as Spiegelberg Lake to the south. A fresh water spring, which is a watering place for farm animals, issues from the basalt talus on the east shore, and is apparently the only source of inflow except the runoff from a catchment basin that is but little larger than its contained lake.

In late July 1945 the depth of brine was 3.5 feet in the center of the lake. The specific gravity of the brine was 1.046 at 33° C.

A field test showed the presence of considerable carbonate, a distinctive feature among other sulfate lakes in the vicinity. Its water has the composition shown in table 11.

The brine is a little more concentrated than sea water, but its volume is small. Salts probably have not formed on the bottom; at least, none could be found by prospecting from a boat. The deposit therefore has little or no commercial importance, except in connection with the utilization of salts in other lakes nearby, though it contains about 750 tons of sodium carbonate (including bicarbonate), 400 tons of sodium sulfate, and 100 tons of sodium chloride.

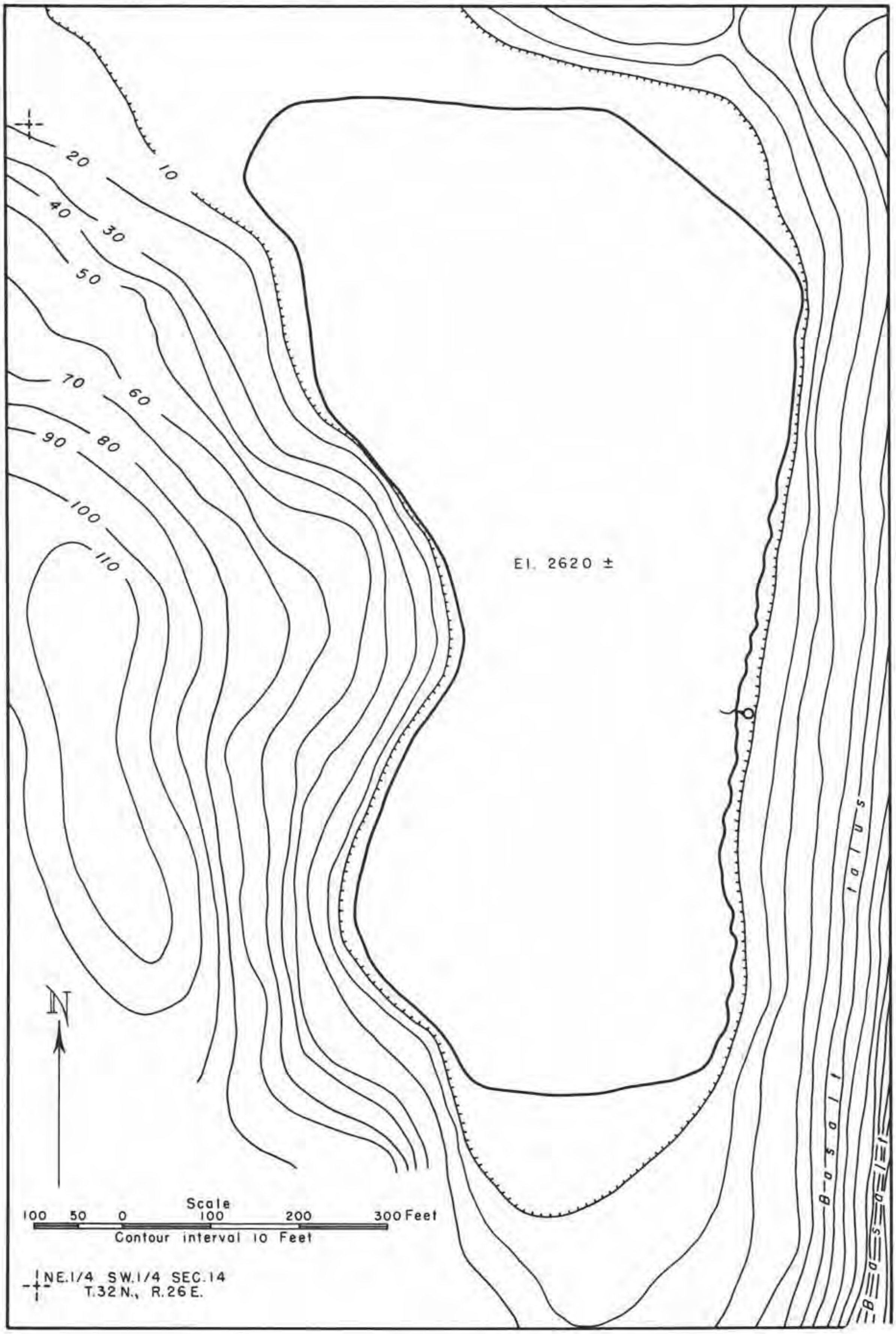


Figure 13.—Map of "Rimrock Lake".

Table 11. Analyses of brine from "Rimrock Lake"

Sample No. 45

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	6.7
Mg (magnesium)	15	0.03	Na_2CO_3 (sodium carbonate)	51.6
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	11.4
Fe (iron)	None	None	$MgSO_4$ (magnesium sulfate)	0.1
Na (sodium)	17,800	37.8	Na_2SO_4 (sodium sulfate)	30.0
HCO_3 (bicarbonate)	3,900	----		
CO_3 (carbonate)	13,800	37.5(1)		
SO_4 (sulfate)	9,610	20.4		
Cl (chloride)	1,930	4.1		
	47,055	99.8		99.8

Specific gravity at 26° C. (78.8° F.) --- 1.041

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 45. Collected in July 1945.

SODIUM SULFATE LAKES

GRANT COUNTY

Sulphate Lake

Location, Size, and Access

Sulphate Lake (fig. 14) was 10½ miles due south of Moses Lake, lying mostly in the SW¼SW¼NW¼ sec. 15, T. 17 N., R. 28 E. It included about 9 acres. It could be reached by a dirt road from Warden, a station on the main line of the Milwaukee Railroad about 13 miles to the east, or by a dirt road from Moses Lake.

Sulphate Lake was destroyed as a source of sodium sulfate in about 1950 when leakage from the Potholes Irrigation Reservoir flooded its basin.

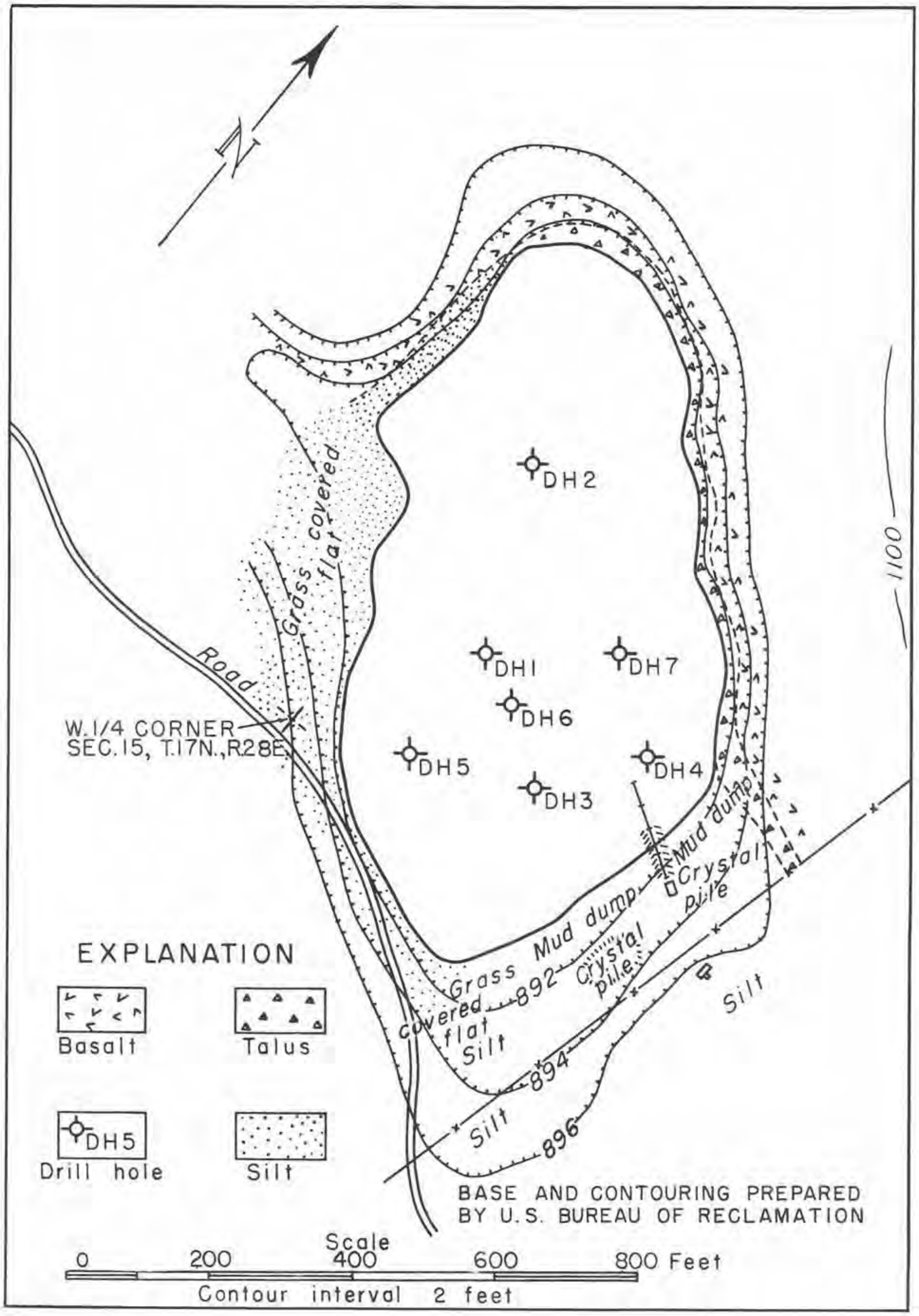


Figure 14.—Map of Sulphate Lake.

Topography and Geology

The deposit was at the eastern and lower end of a depression in the same tract of basaltic scabland that contained Carbonate Lake, but Sulphate Lake was west of Crab Creek, the principal stream of the area, and closer to the eastern end of the Frenchman Hills uplift. The lake bed, at an altitude of 890 feet above sea level, is between 200 and 300 feet below the tops of immediately surrounding ridges and knobs that characterize the scabland tract. A fresh-water marshy lake, which was apparently spring fed but which was at least partly supplied by a flowing well, lay 50 feet higher and 2,000 feet distant at the western end of the depression. Like Carbonate Lake, the deposit was close to or below the level of the ground water, which was graded to the level of Crab Creek. Some drainage may have come down the depression from the spring or well at the western end, although there was no conspicuous channel except for a short distance below the marsh. Most of the drainage doubtlessly percolated through the silts that lie on the floor of the depression and that in the dry season were coated with a thin salt crust.

History and Production

In 1916-17 the deposit was operated by Paul Donaldson (oral communication), who had a contract with the Ontario Power and Light Co., International Falls, Minnesota, to supply 2,500 tons of sodium sulfate, at a price of $17 a ton and at a shipping cost of $11.55 a ton. Most of the salt was taken from the northeast side of the lake bed, dumped along a car track elevated to reach a platform, and, before shipment, was spread thinly over boarded places on the ground to let it change naturally to the anhydrous, powdery form, thenardite, Na_2SO_4 (Glover, 1936, p. 97-98). According to Mr. Donaldson this was the first production of sodium sulfate for use in the manufacture of kraft paper. Several tons of the partly dehydrated salts still remained piled on shore, but some of this was hauled away or sold in 1946.

The Salts

Brine.—Brine, which covered the lake to a depth of several feet at the time Mr. Donaldson started operations, in 1945 covered only the salt pans to a depth of a few inches during spring and summer. In most auger holes the brine, which was found at a depth of between 2 and 3 feet, rose to within a foot or less of the surface; in hole 6 it was found at a depth of 8 feet under moderate hydrostatic head. In other places, especially beneath the large pans at the north end of the deposit, it added fluidity to the black odorous lake-mud. The brine was not sampled, but its range in specific gravity, from 1.10 to 1.26, suggests dilution from underground seepage.

Crystal.—Sodium sulfate occured (1) as extensive hard crusts of thenardite up to 6 inches thick, especially over the old workings along the northeast shore, and as smaller crusts and clusters of crystals on the surface of pans and (2) as mirabilite, the decahydrate, in the body of the pans, and as disseminated crystals, both in the black partly fluid mud at depth and in the sticky greenish-gray clayey mud that surrounded the pans at the surface. The composition of the solid salts is shown in table 12.

Table 12. —Analyses of salts from Sulphate Lake

Constituents in percentage of total weight

Sample no.	20	21	22	23	24
Insoluble residue	10.5	18.3	32.4	22.4	1.2
Ca (calcium)	None	None	None	None	None
Mg (magnesium)	0.06	0.04	None	0.02	None
Al (aluminum)	None	None	Trace	Trace	None
Fe (iron)	None	None	0.1	0.1	None
Na (sodium)	29.3	26.5	22.3	25.4	32.3
K (potassium)	----	----	----	----	----
SiO_2 (silica)	----	----	----	----	----
HCO_3 (bicarbonate)	0.5	None	0.4	0.4	None
CO_3 (carbonate)	0.5	0.4	0.9	0.5	0.7
SO_4 (sulfate)	60.0	54.4	43.1	50.8	65.3
Cl (chloride)	0.1	0.3	1.2	1.0	0.8
	100.96	99.94	100.4	100.62	100.3

Conventional combinations in percentage of total weight

Sample no.	20	21	22	23	24
Insoluble residue	10.5	18.3	32.4	22.4	1.2
NaCl (sodium chloride)	0.2	0.5	2.0	1.6	1.3
Na_2CO_3 (sodium carbonate)	0.9	0.7	1.5	0.9	1.2
$NaHCO_3$ (sodium bicarbonate)	0.7	None	0.5	0.5	None
R_2O_3 (iron and aluminum oxides)	None	None	0.1	0.1	None
$CaSO_4$ (calcium sulfate)	None	None	None	None	None
$MgSO_4$ (magnesium sulfate)	0.3	0.2	None	0.1	None
Na_2SO_4 (sodium sulfate)	88.4	80.2	63.8	75.2	96.5
	101.0	99.9	100.3	100.6	100.2

Sample No. 20. From hole 1, at 0.5 to 1.7 feet.

Sample No. 21. From hole 1, at 1.7 to 4.7 feet.

Sample No. 22. From hole 5, at 0.5 to 7 feet.

Sample No. 23. From hole 6, at 0.5 to 6.5 feet.

Sample No. 24. Thenardite from crust that lay over side of old workings northwest of old loading platform.

Sodium chloride (halite, or common salt) crystallized on crusts of thenardite under certain conditions. In the late fall of 1944 it was found in places as clear one-eighth inch cubes on crystals of thenardite. Considerable sodium chloride appears in the analyses of the solid salts, which suggests that it is abundant in the brine and plays an important part, along with much heat reflected from adjacent high cliffs, in the formation of hard thenardite by crystallization from solution.

Logs of Holes

The deposit was tested by seven auger holes the logs of which are as follows:

Hole 1

	Ft	in
Mud --		6
Crystals disseminated in mud ----------------------------------	1	3
Crystal ---	3	
Mud, apparently a small amount of sand or gravel; on bedrock ----		6
(Brine in the hole, sp. gr., 1.10)		

Hole 2

Efflorescent crust ---		2
Mud, greenish-gray --		6
Crystal ---	3	9
Crystals, some 2 inches long, in mud -------------------------	1	
Black fluid mud ---	3	
Hard salt bed ---	1	1
Mud; on bedrock ---	8	

Hole 3

White crystal containing patches of pink -----------------------		1
Mud, greenish-gray --		6
Mud and crystals ---	2	6
Sticky mud; bedrock not reached ----------------------------	7	
(Brine in the hole, sp. gr. 1.186)		

Hole 4

Hard thenardite; on boulder or bedrock -----------------------	1	6

Hole 5

(in center of 6-foot pan)

	Ft	in
Hard crystal		3
Crystals, hard and clear, disseminated in mud		4
Crystals in mud that became softer downward (brine at this depth, sp. gr. 1.260)	1	5
Black mud with disseminated crystals	5	
Black mud; bedrock not reached	4	

Hole 6

(in center of 10-foot pan)

	Ft	in
White crystal		2
Greenish mud containing few crystals		8
Aggregate of crystals with little mud		10
Interbedded sand and clay or sandy clay, coarse white sand layer 1 foot thick at bottom, from which brine flowed rapidly and rose to 2 feet from top of hole; underlain by bedrock	15	4

Hole 7

	Ft	in
Hard thenardite		1
Softer crystal layer		3
Hard crystal		1
Crystals disseminated in mud	8	
Mud; on bedrock		6

Tonnage Estimate

The brine, which was considered to occupy a 30-percent pore space in the lake bed, was estimated at 4,000 tons of total dissolved solids. Of the crystalline salts, 19,000 tons was sodium sulfate, 630 was sodium carbonate, 230 was magnesium sulfate, and 200 was sodium chloride. There was about 500 tons of the hard thenardite crust, most of which was free of mud or insoluble.

OKANOGAN COUNTY

Salt or Soap Lake

Location, Size, and Access

Salt Lake, as named on the Okanogan 30-minute quadrangle map, and named Soap Lake on more recent maps, includes an area of 157 acres, and is the largest brine lake, except Omak Lake, in the

Okanogan Plateau district. It is in secs. 25, 26, 35, and 36, T. 32 N., R. 25 E., 9 miles southwest of Okanogan and 4 miles southeast of Malott. It may be reached by a narrow dirt road from either Monse (8 miles to the south) or from Okanogan (fig. 11), but either route may be badly washed in places during the winter months and, because of infrequent travel, may not receive immediate repair.

Topography and Geology


Figure 15.—Salt or Soap Lake. View from south.

Salt Lake lies at an altitude of 1,169 feet above sea level, about 370 feet above the Okanogan River at Monse, and 1,000 to 1,500 feet below granite ridges and summits on the east and west. It is in a rather broad valley that opens southward into the Okanogan Valley in the vicinity of Monse and is in a local depression that is partly on a bedrock of granite and partly on glacial outwash deposits that cover the floor and lower slopes of the valley both north and south of the lake. The area of its drainage basin is relatively large, most of it lying on granitic rocks and only a small part on outlying masses of basalt near the extreme eastern border.

The Salts

Brine.—The brine is the only source of salts; its concentration, as shown in the analysis in table 13, is, however, much too low for the natural crystallization of salt bodies. The brine has become stronger than it was in the past. This is shown by a drop in lake level of between 10 and 15 feet, the higher level being marked by a line of white salts along the lake. As has been observed in other saline lakes of the brine type lacking in conspicuous inflow, the brine in Salt Lake shows a definite stratification, indicated by the following data:

Depth and temperature determinations at Salt or Soap Lake

Location	Depth (feet)	Specific gravity	Temperature	Remarks
At north shore	1	1.020		
50 feet from north shore	7			Tendrilled weeds (salt plant?) on the bottom
1,000 feet from north shore, in center of lake	33	1.040	18.5° C.	
1,500 feet from north shore but in east center of lake	37			
Midway between ends, 200 feet from east shore	30	1.024	25° C. (at the surface)	
Center of the lake	50	1.044	16° C.	

The brine may not be commercially usable except in conjunction with solid salts from other lakes in the region. It could, however, easily be pumped into vats that could be built at either end of the lake, although there would be a lift of about 100 feet over the low divide at the south if the brine were pumped to Monse. The concentration of the brine is about six times that of Omak Lake and could, of course, be increased still higher by solar evaporation. The lake, however, is not favorably located with respect to limestone deposits that could be used for production of carbon dioxide for use in a process that involves precipitation of the carbonates from the brine (see Omak Lake, p. 45).

Tonnage Estimate

Assuming that the average depth of the lake is 25 feet, and that its average specific gravity is 1.035, there are, using a salinity factor of 5 percent, the following salts (in short tons): sodium sulfate, 194,000 tons; sodium bicarbonate, 35,000; sodium carbonate, 24,000; sodium chloride, 19,000; and magnesium sulfate, 800.

Table 13.—Analysis of brine from Salt or Soap Lake

Sample No. 32

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) ---------	None	None	NaCl (sodium chloride) ----------	6.9
Mg (magnesium) -------	35	0.06	Na_2CO_3 (sodium carbonate) -------	9.0
Al (aluminum) --------	None	None	$NaHCO_3$ (sodium bicarbonate) -----	13.0
Fe (iron) ------------	None	None	$MgSO_4$ (magnesium sulfate) -------	0.3
Na (sodium) ----------	16,800	33.1	Na_2SO_4 (sodium sulfate) ----------	70.7
K (potassium) ---------	----	----		
HCO_3 (bicarbonate) ---	4,800	----		
CO_3 (carbonate) ------	2,600	14.4(1)		
SO_4 (sulfate) ---------	24,400	48.1		
Cl (chloride) ---------	2,130	4.2		
	50,765	99.8		99.9
Specific gravity at 26° C. (78.8° F.)		1.041		

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 32. From bottom at 50 feet, in the center of the lake; collected in July 1945.

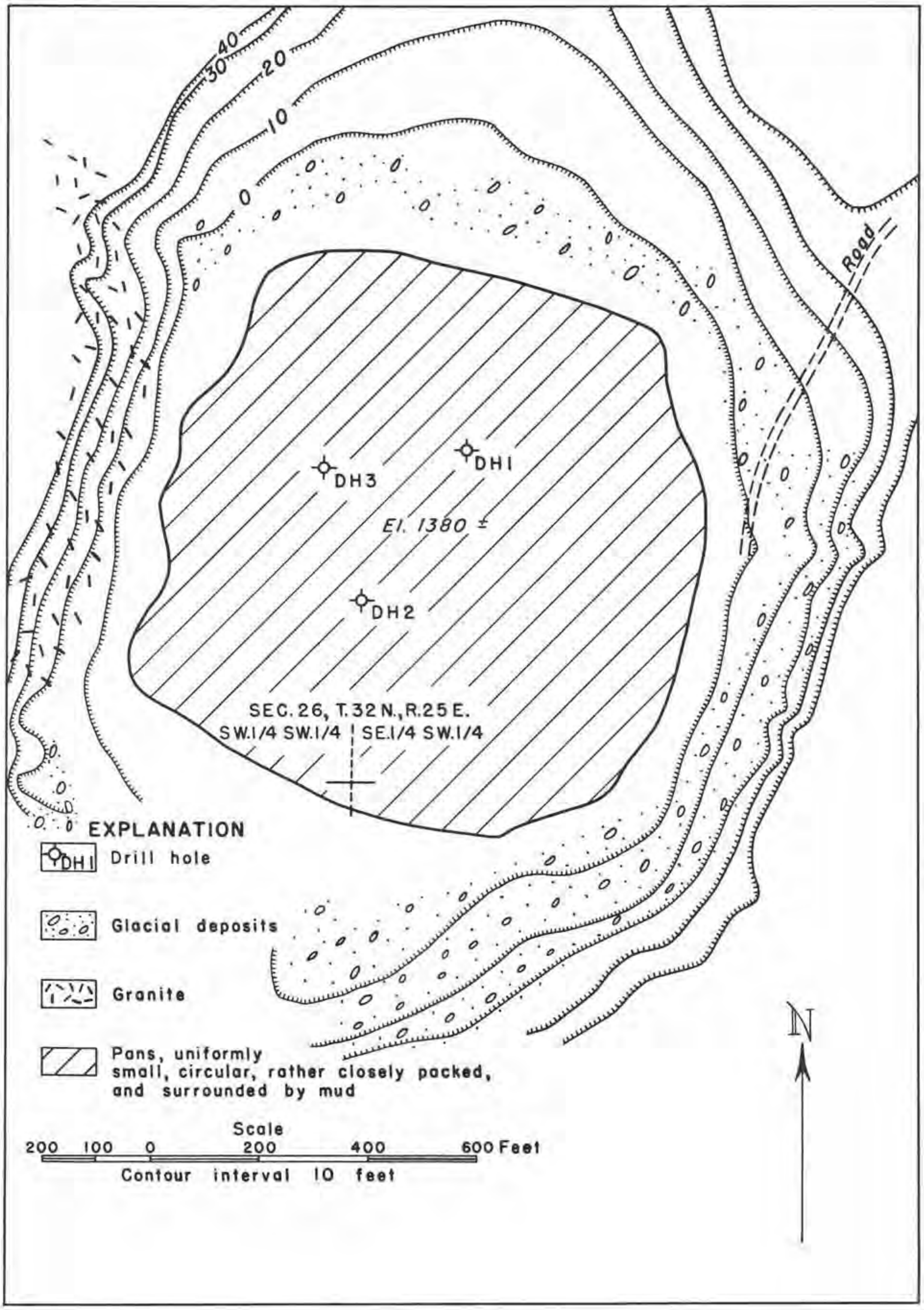


Figure 16.—Map of B-J Lake.

B-J Lake

Location, Size, and Access

B-J Lake (fig. 16), named for Bertha Johnson, is almost entirely in the S½SW¼ sec. 26, T. 32 N., R. 25 E., three-fourths of a mile west of Salt Lake. It covers an area of 19 acres and is reached by a steep, gullied, difficultly passable road that leads northwestward from the north end of Salt Lake, along the south side of a narrow ravine. At the point where this road turns northward approximately 2 miles from Salt Lake, a side road leads southward ½ mile to B-J Lake. In 1961 the lake was reported to be owned by C. A. Kearney, of Seattle.

Topography and Geology

The deposit is at an altitude of about 1,380 feet, approximately 210 feet above Salt Lake. It is the larger and more northerly of two lakes in an undrained depression that, followed on the south by still another, enters the Columbia Valley about 2 miles north of Monse. The B-J depression, although entirely in an area underlain by granitic rocks, contains glacial deposits that include sand and gravel and, especially under the lake itself, water-laid silts on which the salts have accumulated. The absence of seepage from ground water around the shore line, a feature commonly observed among other saline lakes, suggests that the salts have been derived mostly from surface runoff and surficial leaching.

The Salts

Brine.—The inflow is sufficiently great during the winter months to dissolve the intermittent salts on the surface of the pans and on the mud, so that a brine is present over the pans and surrounding mud ridges. In July 1945 the brine was 15 inches deep over the pans and 8 inches over the mud ridges, but in October it had disappeared from the surface. Its specific gravity in July was 1.060 at 26° C., and probably was considerably greater below the surface. The brine is present in the salts of the pans and in the surrounding mud, but it probably does not extend below a depth of 8 feet. This is the limit of the black mud that includes disseminated crystals. The results of an analysis of the brine are shown in table 14.

Crystal.—The B-J deposit is unusual compared with the other saline lakes of the region in its having a high sodium sulfate content, not only in the brine but also in the crystallized salts. Table 15 gives two analyses.

As commonly found in other saline depsoits of the State, the sodium sulfate (as the decahydrate, $Na_2SO_4 \cdot 10H_2O$, or mirabilite) forms pans. At B-J Lake these pans are remarkably uniform in size, form, and compactness. They have a ratio of width to maximum thickness that is about 3½ to 1.

In July 1945, when the brine was 15 inches deep over the surface of the pans, a layer of mirabilite about 1½ inches thick was pried off the upper surface of a pan in the center of the lake. This material was white, massive or fine grained, and showed small clear equidimensional crystals that projected from both the upper and lower surfaces. In early October, after the brine had disappeared from the surface, a 6-inch layer, consisting of an aggregate of crystals that ranged from ½ inch to 1 inch across, was found on the upper surface of the pans above a 1-inch layer of gray mud. This part of the salt pan apparently is intermittent, that is, it dissolves during the winter and spring and then reforms as the brine disappears from the surface in the late summer.

The lake bed was prospected by auger holes in three places (fig. 16). In hole 1, a 6-inch aggregate of crystals, as mentioned above, is underlain by a 1-inch layer of gray mud, then a 1-inch layer of hard crystal (rather resistant to jabbing with a chisel bit), followed by 4 feet of alternate hard and soft layers, and 4 feet of rather sparsely disseminated small crystals in dark-brown to black mud. At 8 feet a light-gray tough compact clay entirely free of crystals was encountered and found to be too difficult to drill with a coal auger. The same thickness of salts was found in holes 2 and 3.

Although the pans in some lakes, especially those composed of a granular aggregate of crystals, have depressed edges the surfaces of which are convex above but concave below, those in B-J Lake apparently are planoconvex lenses that have a cylindrical shape from the surface to a depth of 1 foot. The details of layering on this surface, from the top, are as follows: pure rather large granular crystals, 6 inches; greenish fine-grained crystals, ¼ inch; gray mud, 1 inch; hard massive crystal, 1 inch; mud, 3 inches; hard massive crystal, 4 inches; mud, 3 inches; and granular crystal, 5 inches.

Table 14.—Analysis of brine from B-J Lake

Sample No. 38

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) --------	None	None	NaCl (sodium chloride) ----------	3.6
Mg (magnesium) -----	Trace	Trace	Na_2CO_3 (sodium carbonate) ------	1.1
Al (aluminum) -------	None	None	$NaHCO_3$ (sodium bicarbonate) ----	1.3
Fe (iron) ------------	None	None	Na_2SO_4 (sodium sulfate) ---------	93.8
Na (sodium) ---------	23,000	32.6		
K (potassium) --------	----	----		
HCO_3 (bicarbonate) --	710	----		
CO_3 (carbonate) -----	460	1.6(1)		
SO_4 (sulfate) --------	44,700	63.4		
Cl (chloride) --------	1,640	2.3		
	70,510	99.9		99.8

Specific gravity at 26° C. (78.8° F.) ----- 1.060

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 38. Collected from bottom of brine at depth of 15 inches, near center of lake; Late July 1945.

Tonnage Estimate

The brine is considered to include the following salts (in short tons): sodium sulfate, 8,700; sodium carbonate, 200; sodium bicarbonate, 100; and sodium chloride, 300. The pans, assuming that their combined area is half that of the lake bed and that their average thickness is 2½ feet, contain the following salts (calculated on an anhydrous basis, short tons): sodium sulfate, 15,000; other salts, chloride, carbonates, and sulfates, 400.

Table 15.—Analyses of salts from B-J Lake.

Constituents in percentage of total weight			Conventional combinations in percentage of total weight		
Sample no.	37	61	Sample no.	37	61
Insoluble residue	0.6	8.1	Insoluble residue	0.6	8.1
Ca (calcium)	None	None	NaCl (sodium chloride)	None	0.6
Mg (magnesium)	Trace	0.1	Na_2CO_3 (sodium carbonate)	None	0.6
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	0.4	None
Fe (iron)	None	None	R_2O_3 (iron and aluminum oxides)	None	None
Na (sodium)	32.2	29.3			
K (potassium)	----	0.5	$CaSO_4$ (calcium sulfate)	None	None
SiO_2 (silica)	----	----	$MgSO_4$ (magnesium sulfate)	Trace	0.2
HCO_3 (bicarbonate)	0.3	None	Na_2SO_4 (sodium sulfate)	99.1	88.7
CO_3 (carbonate)	None	0.3	K_2SO_4 (potassium sulfate)	----	1.1
SO_4 (sulfate)	67.0	60.7		100.1	99.3
Cl (chloride)	None	0.4			
	100.1	99.4			

Sample No. 37. Mirabilite crystals scraped from surface of salt pans, which were covered with brine. Collected in July 1945.

Sample No. 61. Composite salt sample from drill hole 1, at 0 to 3 feet. Collected in October 1945.

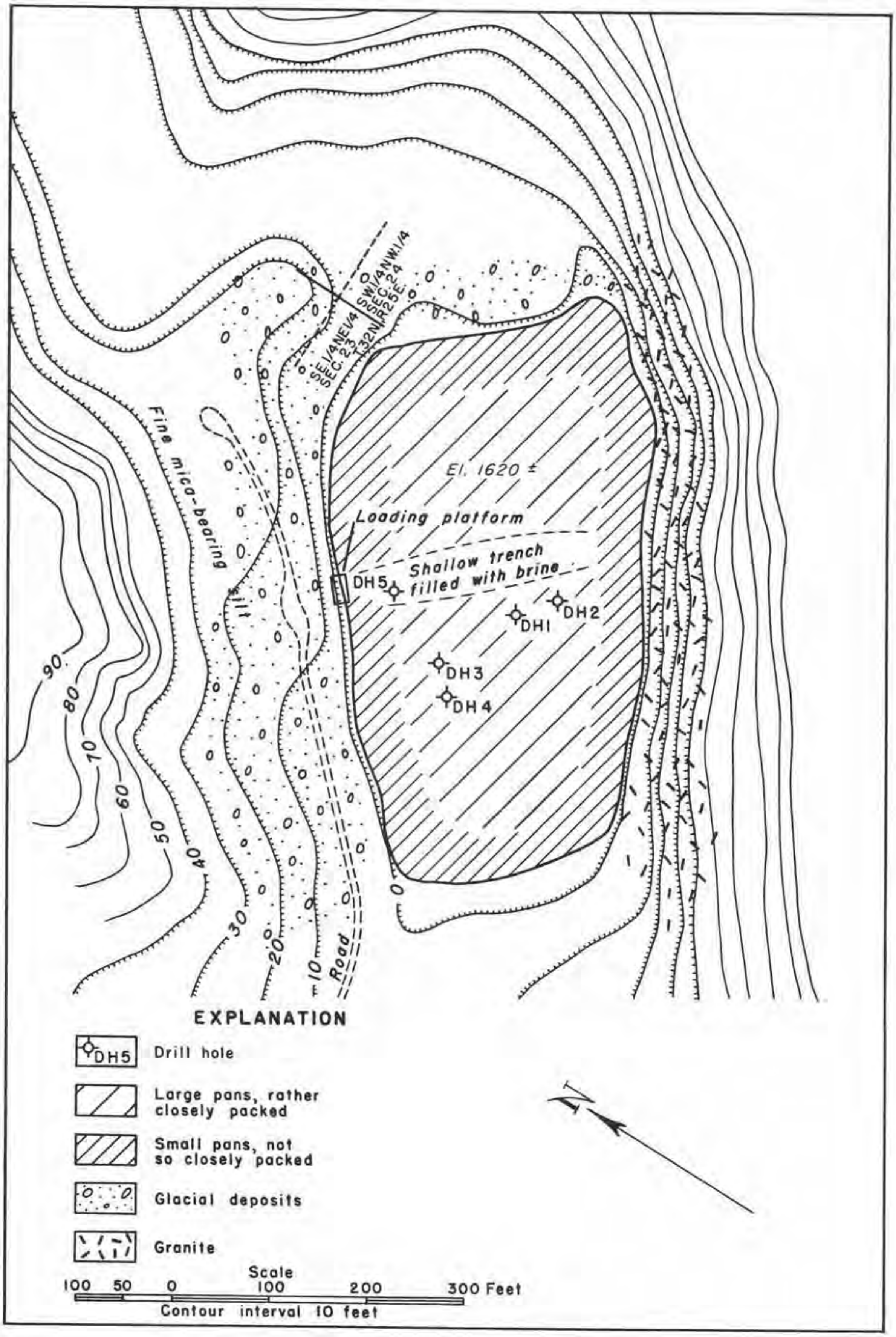


Figure 17.—Map of Virginia Lake.

Virginia Lake

Location, Size, and Access

Virginia Lake (fig. 17), containing 3½ acres, lies almost entirely in the SE¼NE¼ sec. 23, T. 32 N., R. 25 E. It may be reached by following the road to B-J Lake as far as the B-J Lake junction, thence 1¼ miles northeast to Virginia Lake, a total of 22 miles by road from Okanogan.

Topography and Geology

Virginia Lake, at an altitude of a little more than 1,600 feet, is in the same rugged upland of granitic rocks as B-J Lake but lies in a narrower valley, and is about 1,000 feet below the highest ridges that lie 2 miles to the west. The entire area was covered by the Okanogan lobe of the Cordilleran ice sheet. The deposits of sand and gravel which it left in some places blocked the old preglacial drainage lines. In the resultant undrained depressions stratified silts accumulated in ponded water from the melting ice. Such lakes, in basins of sufficient size to furnish a considerable inflow, have persisted to the present and have become continuously more saline.

History and Production

A small amount of salts has been excavated from a trench in the center of the Virginia Lake deposit, presumably by the old Naso Chemical Co. of Wenatchee, which mined salts at Lake 32 in the early thirties. A ramp and loading platform remained at the lake shore in 1945.

The Salts

Brine.—In July 1945 the brine, which covered the pans to a depth of 18 inches in the center of the lake, was 8 or 10 inches deep over the mud ridges and 2 feet deep in the trench. In October it was still present over much of the north half of the deposit but had disappeared from the south half except for two small pools, near the south shore, in which large clusters of crystals were forming. Beneath the lake bed the brine adds fluidity to the black mud, particularly that mud which contains disseminated crystals in a layer about 1 foot thick above the permanent salts of the larger pans and in a similar layer about 3 feet thick below the pans. Through these layers an auger can be pushed with ease. The upper layer and probably also the lower one does not extend beyond the perimeter of the pans, so these fluid zones constitute the only source of easily or commercially extractable brine. Some brine, however, is present throughout the lake bed mud to a depth of about 7 feet from the surface, as indicated by the change from black mud to gray compact clay or silt; but percolation probably would be slow through much of the mud to wells or pits sunk for purposes of recovery. The brine underground is dense, about 1.24 in specific gravity, but its composition is known only from a surface sample (table 16).

Crystal.—The crystalline salts of the deposit are in pans whose arrangement, unlike that of B-J Lake, consists of a relatively large central portion of 6 or 8 large pans 70 to 100 feet across, and a portion

Table 16.—Analysis of brine from Virginia Lake

Sample No. 33				
Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	2.6
Mg (magnesium)	266	0.2	Na_2CO_3 (sodium carbonate)	0.1
Al (aluminum)	None	None	$MgSO_4$ (magnesium sulfate)	0.6
Fe (iron)	None	None	Na_2SO_4 (sodium sulfate)	96.0
Na (sodium)	43,300	32.2		
K (potassium)	----	----		
HCO_3 (bicarbonate)	None	None		
CO_3 (carbonate)	100	0.07		
SO_4 (sulfate)	87,900	65.4		
Cl (chloride)	2,620	1.9		
	134,186	99.8		99.3
Specific gravity at 26° C. (78.8° F.)		1.121		

Table 17.—Analysis of salt from Virginia Lake

Sample No. 34			
Constituents in percentage of total weight		Combinations in percentage of total weight	
Insoluble residue	28.4	Insoluble residue	28.4
Ca (calcium)	1.9	NaCl (sodium chloride)	0.4
Mg (magnesium)	0.2	Na_2CO_3 (sodium carbonate)	None
Al (aluminum)	None	$NaHCO_3$ (sodium bicarbonate)	None
Fe (iron)	None	R_2O_3 (iron and aluminum oxides)	None
Na (sodium)	20.5	$CaSO_4$ (calcium sulfate)	6.3
K (potassium)	----	$MgSO_4$ (magnesium sulfate)	1.0
SiO_2 (silica)	----	Na_2SO_4 (sodium sulfate)	62.7
HCO_3 (bicarbonate)	None	K_2SO_4 (potassium sulfate)	----
CO_3 (carbonate)	None	SiO_2 (silica)	----
SO_4 (sulfate)	47.6	Ignition loss	----
Cl (chloride)	0.2		
Ignition loss	----		
	98.8		98.8

near shore in the form of a ring, 30 to 75 feet wide, of much smaller pans. The area of mud relative to that of the pans is less in the central zone and much greater in the outer zone.

The deposit was tested by five auger holes (fig. 17). In hole 1 was found, top to bottom, the following: intermittent crust, 1 inch; black fluid mud that contains crystals $\frac{1}{4}$- to $\frac{1}{2}$-inch across and that makes up about 50 percent of the mass, 9 inches; permanent salt layer, easily drilled and that probably consists of a compact coarsely granular mass, 4 feet; black fluid mud that contains crystals and that grades downward into a sticky zone with few crystals, 3 feet; and gray compact mud or silty clay, difficult to drill, 1 foot. The same sequence was found in hole 2. Hole 3 showed: intermittent crust, 1 inch; crystal-bearing fluid mud, 10 inches; permanent crystal, $2\frac{1}{2}$ feet; and sticky mud, very difficult to drill, 4 feet. Hole 4 showed: intermittent crust, 1 inch; fluid mud and crystals, 8 inches; permanent crystal, 3 feet; and sticky mud, 4 feet. Hole 5 showed: brine, 8 inches; permanent crystal, 3 feet; and mud, 4 feet. Sample No. 34, table 17, represents crystal salts from the fluid layer above the permanent crystal.

Tonnage Estimate

The brine, which is predominantly sodium sulfate, is assumed to occupy a pore space of 30 percent to an average depth of 5 feet. It is estimated to contain about 2,000 tons of sodium sulfate, but perhaps no more than 1,000 to 1,500 tons could be obtained from the more easily recoverable brine. The solid salts are estimated at about 4,000 tons.

Lake 32

Location, Size, and Access

Lake 32, which is named for sec. 32, T. 32 N., R. 26 E., covers an area of about 7 acres and is 9 miles due south of Okanogan (fig. 18). A road, which probably was used by the operators of the deposit, leads to the lake from Monse on the south; but the lake may also be reached from the north (fig. 11) via a farm road that turns southwest from the Okanogan-Timentwa county road near Cameron Lake. This road, however, for 3 or 4 miles north from the lake is very infrequently traveled, and, like most roads to other lakes in the area, leads through numerous gates and often through farm yards.

Topography and Geology

The lake is in a depression formed at the western end of a ravine that heads on the west side of a granitic knob called Salt Hill, whose altitude is 2,936 feet above sea level, and approximately 700 feet above the lake. The lake lies partly on a bedrock of granite, which is capped by an outlying mass of basalt just to the west, and partly on glacial deposits that include large erratics of basalt boulders. Following the retreat of the Okanogan lobe of the Cordilleran ice sheet the lake probably stood about 90 feet above its present surface and overflowed southward over the narrow divide through which the road passes.

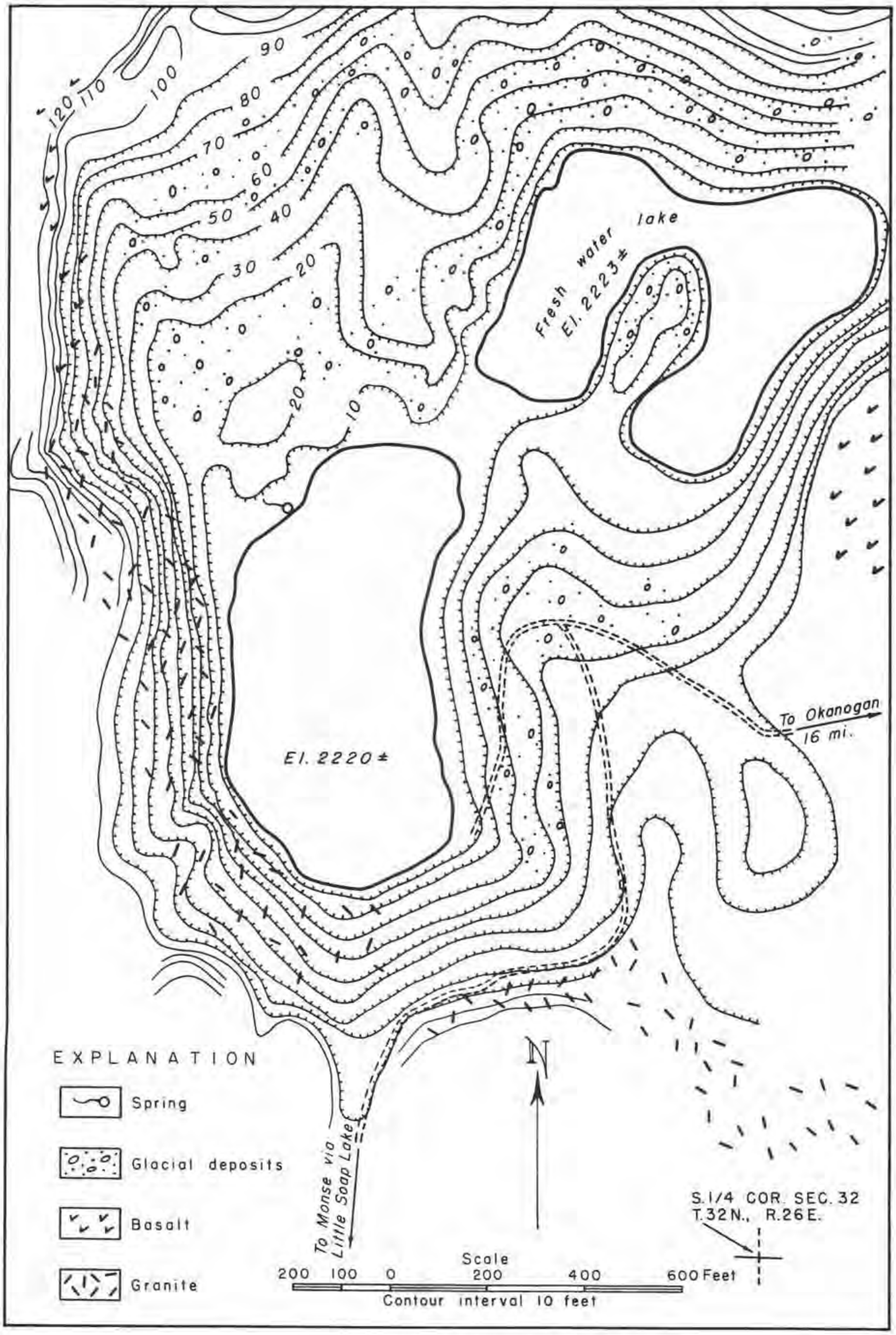


Figure 18.—Map of Lake 32.

History and Production

The deposit was worked by the Naso Chemical Co. of Wenatchee in the early thirties. A considerable amount of sodium sulfate was scraped from the lake and piled on the shore. The amount sold is not known. Several buildings were erected at the south and east sides of the lake but these are no longer standing.

The Salts

In July 1945 the lake consisted of a weak brine whose maximum depth was 6 feet. It was not possible to determine from a boat whether or not solid salts were forming or had formed on the bottom since the mining operations of the Naso Chemical Co. The specific gravity of the brine ranged from 1.014 on the surface to 1.036 on the bottom. In October there was still considerable brine, but its specific gravity had increased to 1.18, so it is possible that salts were again forming on the bottom. An analysis of the brine, collected in July, is shown in table 18.

Table 18.—Analysis of brine from Lake 32

Sample No. 36				
Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	5.6
Mg (magnesium)	23	0.05	Na_2CO_3 (sodium carbonate)	4.3
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	2.9
Fe (iron)	None	None	$MgSO_4$ (magnesium sulfate)	0.2
Na (sodium)	14,800	33.0	Na_2SO_4 (sodium sulfate)	86.1
K (potassium)	----	----		
HCO_3 (bicarbonate)	970	----		
CO_3 (carbonate)	1,100	4.5(1)		
SO_4 (sulfate)	26,400	58.9		
Cl (chloride)	1,540	3.4		
	44,833	99.8		99.1

Specific gravity at 26° C. (78.8° F.) ----- 1.037

(1) Includes bicarbonate reduced to normal carbonate.

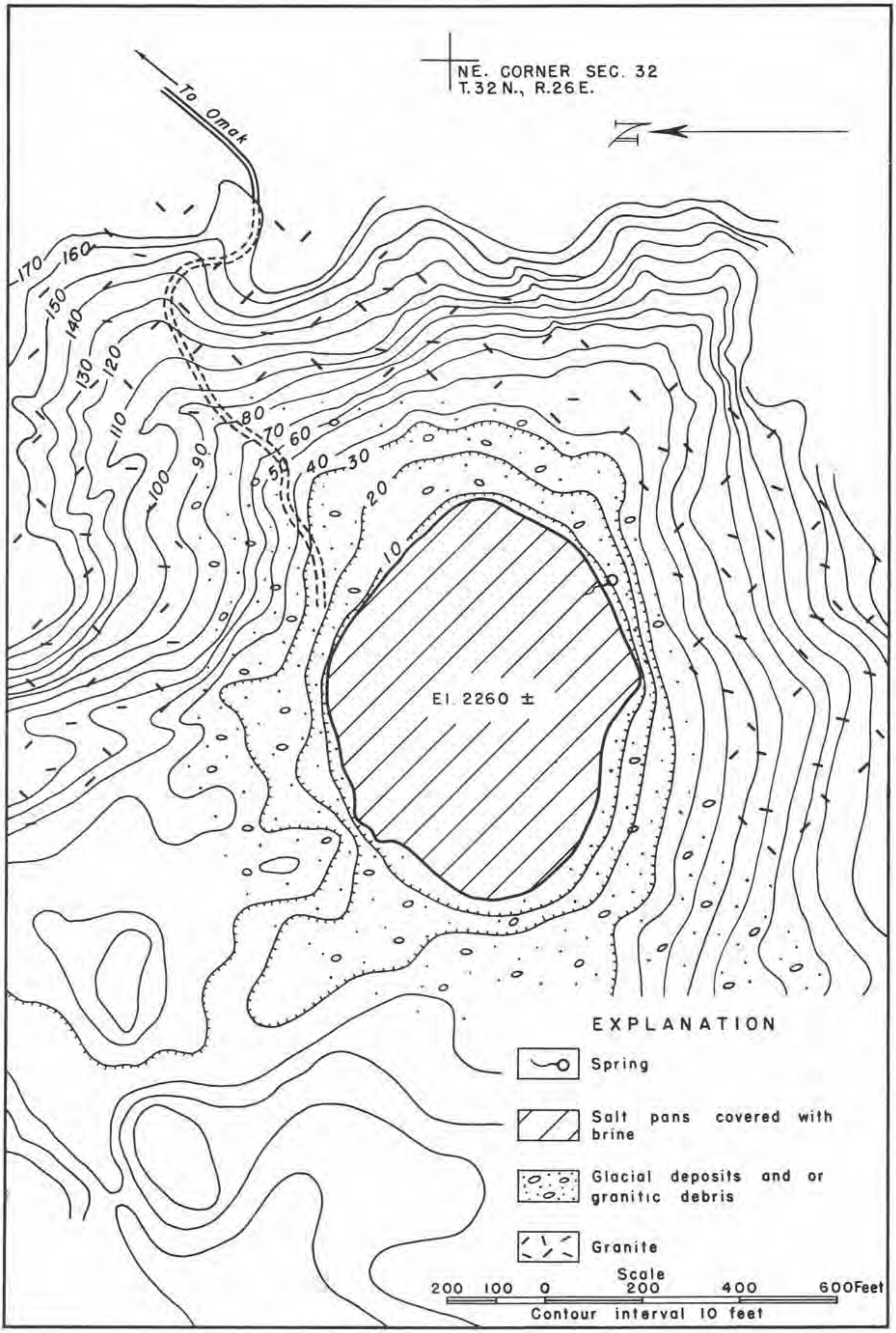


Figure 19.—Map of Stevens Lake.

The brine is estimated to contain about 1,900 tons of sodium sulfate and about 400 tons of chloride and carbonates.

A sample of the solids salts, presumably collected during the period of mining operations, has been analyzed by R. C. Wells (1937, p. 123-124) as follows:

Analysis of mirabilite from Lake 32

Insoluble	0.08
H_2O (water)	50.90
$NaHCO_3$ (sodium bicarbonate)	0.33
NaCl (sodium chloride)	0.23
$MgSO_4$ (magnesium sulfate)	0.18
Fe, Ca, B (iron, calcium, boron)	None
Na_2SO_4 (sodium sulfate)	48.28
	100.00

Stevens Lake

Stevens Lake is about half a mile northeast of Lake 32, on the north line of sec. 32, T. 32 N., R. 26 E. and close to the northeast corner of the section (fig. 19). It includes an area of about 8 acres and is reached most easily from the north over the same road as that which leads to Lake 32.

The lake is in a basin-like amphitheater that opens westward and that is surrounded mostly by granite on three sides. The basin is blocked by glacial deposits that hold back the runoff from draining into the Salt Lake basin (fig. 20).

Figure 20.—Stevens Lake. View from northeast, July 1945. A turbid brine obliterates the outline of pans. A white salt crust has formed on the mud at the shore line. Dark objects at the skyline are remnants of basalt flows that lie on granite.

The deposit consists of brine, which was present throughout the summer of 1945, and of solid salts in pans. In July the brine was 26 inches deep over the solid surfaces of the pans, and gradually shallowed toward the shore. Its specific gravity was 1.046 at 25° C., and a sample had the composition shown in table 19.

The salt pans, partly obscured by turbidity of the brine and probably in part by a covering of mud, appear to be about 15 feet in diameter. The pans are confined to the central part of the lake, no closer than 75 feet from the shore, unless the existence of pans near shore is obscured by a covering of mud.

The brine contains about 1,7000 tons of sodium sulfate, 500 tons of sodium carbonate, and less than 100 tons of sodium chloride. If half of the lake surface were underlain by salt pans there would be about 4,000 tons of salts per foot of depth.

Table 19.—Analysis of brine from Stevens Lake

Sample No. 35

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	3.2
Mg (magnesium)	None	None	Na_2CO_3 (sodium carbonate)	15.9
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	6.7
Fe (iron)	None	None	$MgSO_4$ (magnesium sulfate)	----
Na (sodium)	18,700	34.0	Na_2SO_4 (sodium sulfate)	74.4
K (potassium)	----	----		
HCO_3 (bicarbonate)	2,700	----		
CO_3 (carbonate)	4,950	13.8(1)		
SO_4 (sulfate)	27,600	50.2		
Cl (chloride)	1,080	1.7		
	55,030	99.7		100.2

Specific gravity at 26° C. (78.8° F.) ----- 1.047

(1) Includes bicarbonate reduced to normal carbonate.

Lawson Lake

Location, Size, and Access

Lawson Lake (fig. 21), which includes an area of about 20 acres, is in the SW¼NE¼ sec. 10, T. 31 N., R. 26 E. It is about 20 miles, mostly by graveled road, from Okanogan, 22 miles by dirt road from Monse, and 11 miles by a mine-to-market road, which was never completely finished, also from Monse (fig. 11).

Topography and Geology

The lake, at an altitude of about 2,350 feet, is in one of a series of depressions that lie between a granitic knob known as Salt Hill (altitude 2,936 feet) on the west and basalt flows of the plateau on the east. It lies partly on granitic bedrock but mostly on glacial drift. Ground water, which issues from a spring at the southeast end of the lake and from several places along the north shore, seems to have supplied most of the saline material to the lake. This is indicated by the relatively small catchment area, and the fact that the salt deposits are of considerable volume.

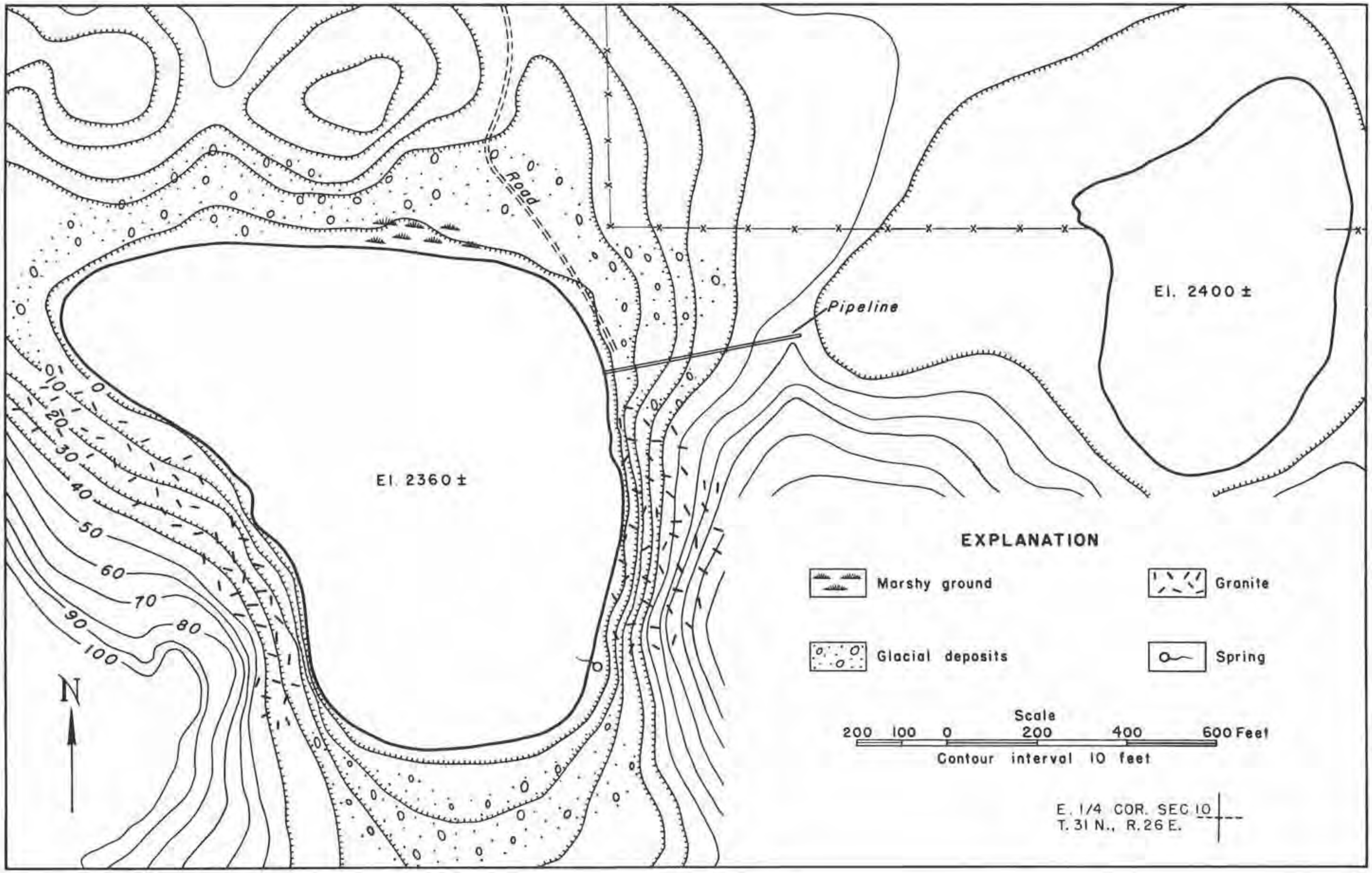


Figure 21.—Map of Lawson Lake.

Figure 22.—Lawson Lake. Larger irregularly rounded pans in the center beneath a clear brine, are surrounded by smaller, nearly circular ones next to the shore. View from the southeast. Glacial deposits near shore on the right; granite on the left and along the horizon. July 1945.

Development

The deposit is owned by John Isenhart of Chelan. It was leased to the Washington Chemical and Salt Co., of Seattle, which in 1942-43 had pumped the brine from the lake in preparation for mining salts and had erected a refining plant at Monse at a cost exceeding $100,000. A mine-to-market road was partly constructed but not surfaced. The plant was said to have a capacity of 100 tons per day; it was equipped with 3 boilers rated at 900 horse power, 4 evaporators, 3 centrifuges, a rotary dryer, melting and laundering tanks, pumps, and conveyors. It is reported that the plant was partly dismantled and some of the equipment sold to Industrial Enterprise Incorporated or its successor the Okanogan Salt Co., of Seattle. In 1961 the lake was reported to be owned by C. A. Kearney, of Seattle.

The Salts

The deposit consists of both brine and solid salts. In the late fall of 1944 there was only a few inches of brine over the pans, the rather soft mud ridges between them being mostly above the brine level. Apparently all the brine on the surface of the lake bed had been pumped by the Washington Salt and

Chemical Co. into a small lake that lies just to the east, probably in 1942 or 1943. Throughout 1945-46 the brine level stood about 2 feet above the salt pans and nearly a foot above most of the mud ridges (fig. 22). The specific gravity of the brine was 1.044 at 19° C. on the bottom and 1.042 at 20° C. on the surface. In the late fall of 1945 the brine was still too deep and the mud too soft to risk wading about in attempts to drill through the pans. A sample of the brine has the composition shown in table 20.

Table 20.—Analysis of brine from Lawson Lake

Sample No. 39				
Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) -----------	140	0.2	NaCl (sodium chloride) --------	3.4
Mg (magnesium) ---------	392	0.7	Na_2CO_3 (sodium carbonate) ----	0.2
Al (aluminum) ----------	None	None	$NaHCO_3$ (sodium bicarbonate) --	0.9
Fe (iron) ---------------	None	None	$CaSO_4$ (calcium sulfate) -------	0.9
Na (sodium) ------------	16,100	31.0	$MgSO_4$ (magnesium sulfate) -----	3.7
K (potassium) -----------	----	----	Na_2SO_4 (sodium sulfate) -------	90.8
HCO_3 (bicarbonate) -----	360	----		
CO_3 (carbonate) --------	60	0.8(1)		
SO_4 (sulfate) -----------	33,700	65.0		
Cl (chloride) -----------	1,070	2.0		
	51,822	99.7		99.9
Specific gravity at 26° C. (78.8° F.) ----- 1.043				

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 39. Bottom sample at 26 inches in center of lake. Collected in July 1945.

The salt pans, which may be distinguished in figure 21 beneath the cover of brine, are abundant and of rather large size except near the shore. Most of them are irregularly rounded or oval, rather than nearly perfect circles as in B-J and Morris Lakes. In some pans, either at the center or to one side, there is a hole that tapers, funnel-like, to a depth of 3 to 4 feet, yet appears to have a solid bottom of salts. Such features, which suggest the presence of springs or places where the brine is in constant circulation, have been observed elsewhere only in Hauan Lake; but they can be seen only in lakes covered with a clear brine.

The pans, although their thickness has not been determined by the writer, have been reported to reach a depth of 6 feet. Assuming, as in the deposits previously described, that half the surface of the lake is underlain by salts, there is approximately 8,000 short tons of anhydrous salts per foot of depth;

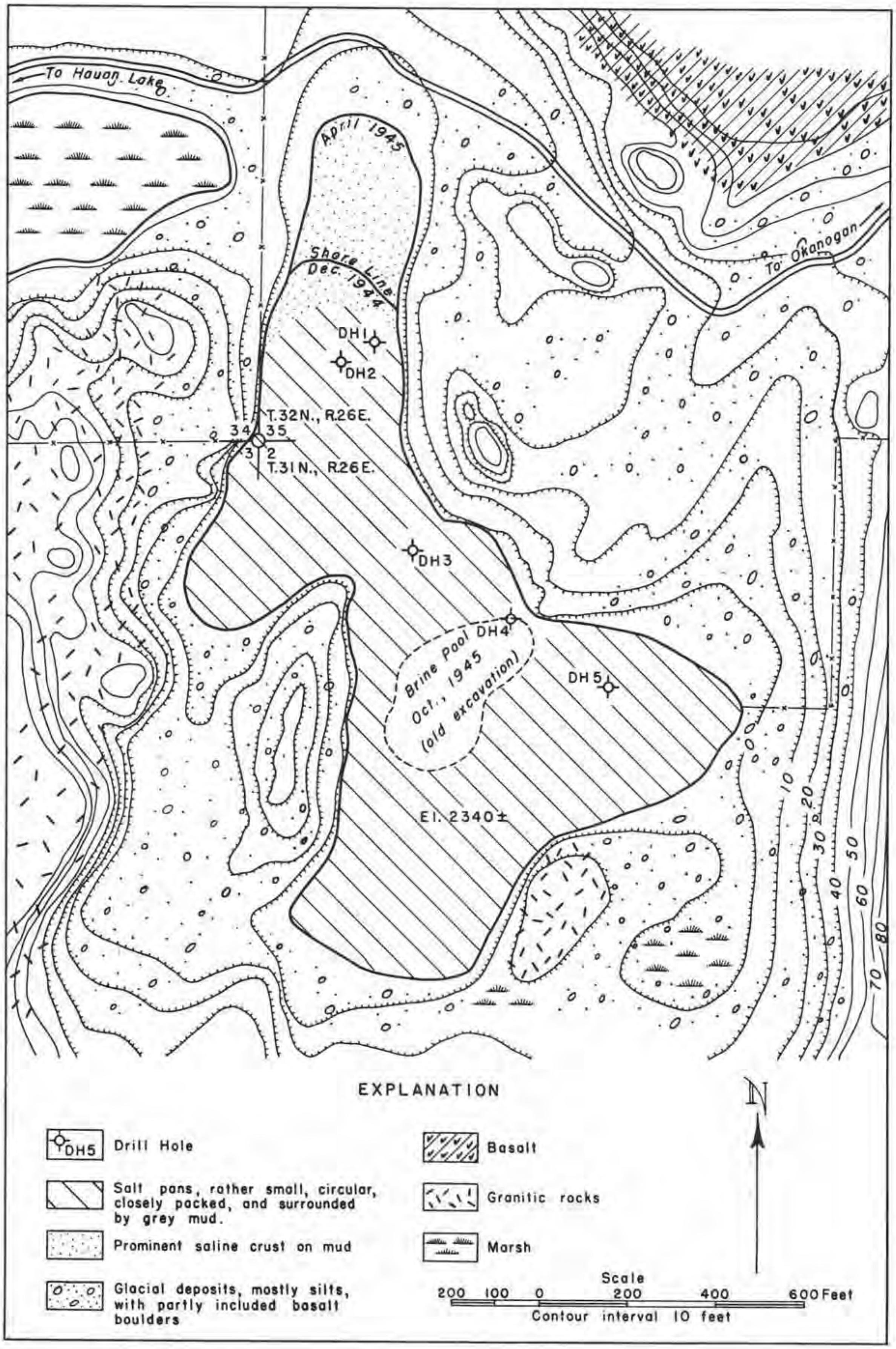


Figure 23.—Map of Morris Lake.

most of this amount, as indicated by the composition of the brine, is sodium sulfate. At least 2,000 tons of sodium sulfate is present in the brine, assuming a depth of 3 feet below the surface of the lake bed, and using a salinity factor of 5 percent.

Morris Lake

Location, Size, and Access

Morris Lake, (fig. 23) is another of the larger saline lakes on the Okanogan Plateau that contain crystallized salts. It covers 19 acres, is about the same size as Hauan and Lawson Lakes, which lie to the north and south respectively, and is located in the NW$\frac{1}{4}$ sec. 2, T. 31 N., R. 26 E. It is most easily reached from Okanogan over the county road to Timentwa, most of which is graveled; the last 3 miles, however, of the approximate 16-mile distance to Okanogan, is a farm road, and this is usually difficult to travel in the winter and early spring (fig. 11).

Topography and Geology

The lake, at an altitude of about 2,340 feet, about 600 feet below the summit of Salt Hill nearby to the west, is in an undrained depression, one of the many formed on the Okanogan Plateau by glaciation. Like many other such lakes in glaciated regions, it lies partly on bedrock (granite) and partly on glacial deposits that here consist mostly of a gray water-laid silt and large eratic boulders of basalt. A ledge of the basalt, which forms most of the plateau surface to the east and south, crops out about 1,000 feet northeast of the lake, more than half a mile further west than the margin as shown by Pardee's map (1918).

Development

The deposit is owned by C. A. Kearney, who in 1945 had granted a lease to the Okanogan Salt Co., of Seattle. Apparently during the early or middle thirties an effort was made to mine the salts from the center of the lake bed by using as a scraper a 15- to 20-foot 3- by 12-inch plank held edgewise and pulled from on shore. A considerable amount of salt was excavated in this manner, but there is no record of sales.

Thé Salts

The brine, which usually covers the lake until late fall, is turbid during the spring and summer. In July (1945) it was 17 inches deep in the center and its specific gravity was 1.040 at 22° C., having increased from 1.010 at 5° C. in April. By late October it had disappeared from the surface except in a pool near the center, where sodium sulfate had been removed in old operations. An analysis of the brine is shown in table 21.

The crystalline salts, as in all other lakes that contain permanent crystal, occur in pans marked by uniformity in size, circularity, and compactness — in this respect resembling the pattern of pans in B-J Lake. Most of the pans are between 5 and 10 feet in diameter, but at the southeast end of the lake they gradually decrease in size toward the shore as the depth of brine decreases. Although most of the salt crust was too soft to walk on at the time of examination, the depth of pans was tested in 5 places along the east side and was found to range from a few inches to about 1½ feet. The average thickness of salts for the lake probably is low in comparison with others examined; for the 5 tests the average depth is about 9 inches.

The tonnage of anhydrous salts per foot of depth is estimated at 11,000 tons. The brine contains 1,700 tons of sodium sulfate and minor amounts of other salts.

Table 21.—Analysis of brine from Morris Lake

Sample No. 40

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) ----------	None	None	NaCl (sodium chloride) --------	3.4
Mg (magnesium) --------	286	0.6	Na_2CO_3 (sodium carbonate) ----	0.9
Al (aluminum) ----------	None	None	$NaHCO_3$ (sodium bicarbonate) --	0.8
Fe (iron) --------------	None	None	$MgSO_4$ (magnesium sulfate) -----	3.0
Na (sodium) -----------	15,300	31.7	Na_2SO_4 (sodium sulfate) -------	91.0
K (potassium) ----------	----	----		
HCO_3 (bicarbonate) ----	300	----		
CO_3 (carbonate) -------	270	1.1(1)		
SO_4 (sulfate) ----------	31,100	64.4		
Cl (chloride) ----------	1,020	2.1		
	48,276	98.9		99.1

Specific gravity at 26° C. (78.8° F.) ----- 1.040

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 40. Collected in July 1945, when the brine was about 17 inches deep in the center of the lake.

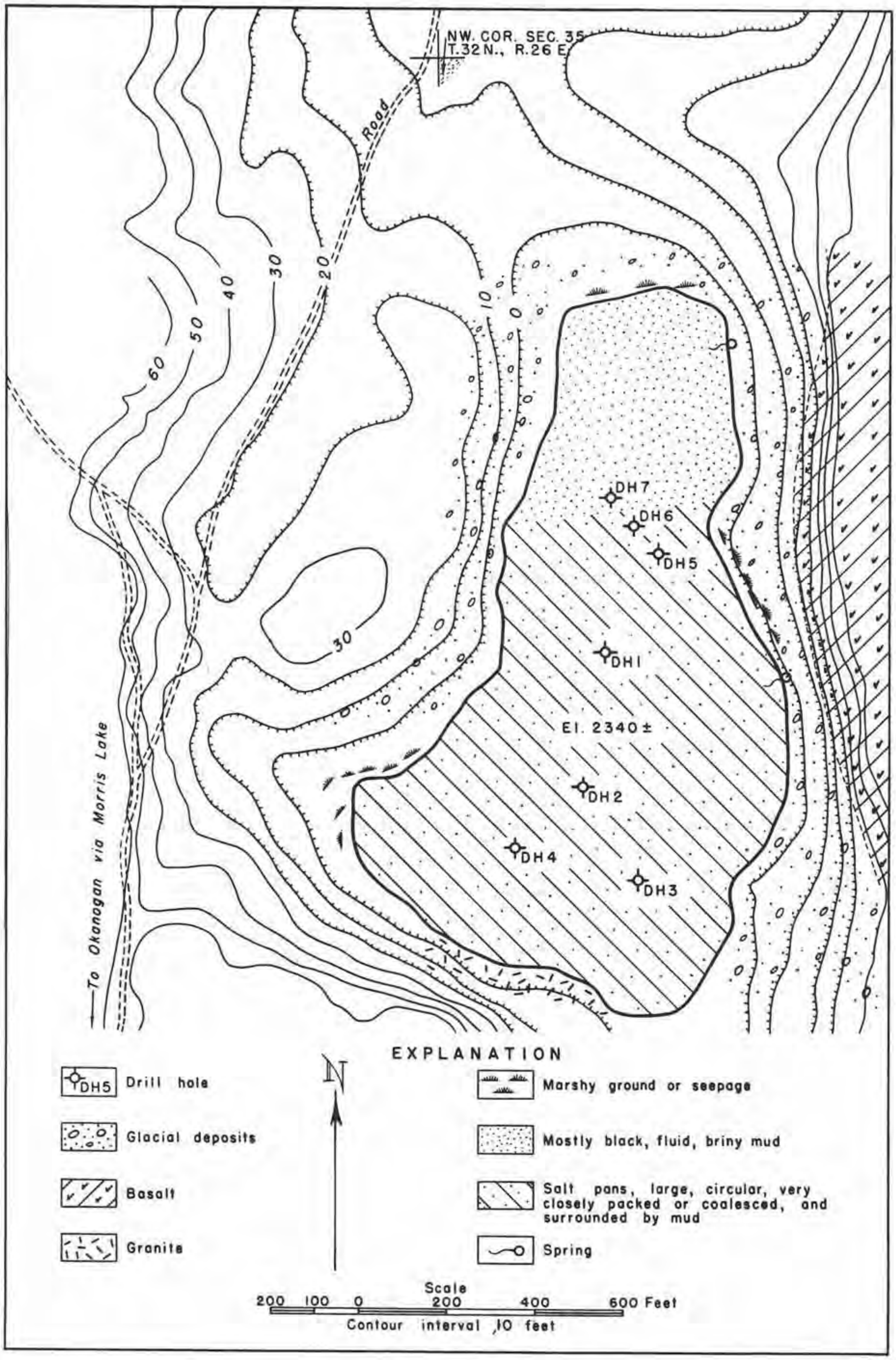


Figure 24.—Map of Hauan Lake.

Hauan Lake

Location, Size, and Access

Hauan Lake (fig. 24) lies mostly in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 35, T. 32 N., R. 26 E. It has an area of 21 acres, and is reached by an extension of the same farm road that leads to Morris and other lakes on the south (fig. 11).

Topography and Geology

The lake is at the south end of a long depression which, like Morris and Lawson Lakes, lies between the basalt of the plateau on the east and the granite of Salt Hill on the west. The Okanogan lobe of the Cordilleran ice sheet seems to have selectively eroded the basalt, cutting it back from over the granite in great blocks (fig. 25), which were transported southward and scattered over the Okanogan Plateau as "haystack" rocks. Thus, depressions were formed, which seem to be the result in part of irregularities of the granite bedrock and in part of irregular distribution of glacial till or drift. In these, light-gray water-laid silts accumulated from the melting ice. Mineral matter in the original lake, which

Figure 25.—Hauan Lake. View from the southwest, July 1945, showing the outlines of pans beneath a shallow brine. Basalt, some of which has slumped forward from the dark line of cliffs, forms the east wall of the basin opposite the granite of Salt Hill.

may have been larger than at present, was gradually concentrated, together with contributions from run-off and in particular from the leaching of glacial deposits by ground water.

History and Development

Most of the lake in 1945 was owned by Julius Hauan, of Gold Bar, Washington. In the early thirties the old Weltha Process Corporation of Okanogan had control of the north half and certain land adjoining. In 1945 the Okanogan Salt Co. had a lease on the deposit. In 1961 the lake was reported to be owned by C. A. Kearney, of Seattle.

The Salts

Brine.—In July 1945 the brine covered the salt pans to a depth of about 12 inches, its level having dropped 1.2 feet in 70 days, or at the rate of an inch in 5 days. Its specific gravity at that time was 1.120 at 21° C., but in October, in hole 1, it was 1.20. The brine, which in October had disappeared from the surface, filled the porous bottoms and external parts of the salt pans. A part of the brine fills the pores of the lake mud to a depth of between 10 and 15 feet which seems to be the limit of the black mud beneath the pans. This mud contains disseminated mirabilite crystals. The brine-mud mixture is perhaps made more fluid in places by springs. One of these springs was found unexpectedly under a thin crust where an iron rod dropped of its own weight to a depth of 10 feet. The analysis of a sample collected in July 1945 is reported in table 22.

Crystal.—Sodium sulfate together with minor amounts of other salts occur in the salt pans, as in many other lakes, and these pans are concentrated in the southern two-thirds of the lake basin. Many of them seem to be coalesced; that is, the mud which originally surrounded them has been squeezed out by growth of the bodies around their perimeters, leaving the mud in triangular areas. In the late fall the appearance is that of a uniform salt crust over the entire area underlain by pans. In places, seen only from a boat before the brine evaporates, the pans show funnel-like crystal-lined holes that extend to a depth of at least 4 feet; such features have been observed elsewhere in Washington only in Lawson Lake, but have been noted in sodium carbonate lakes in Canada (Goudge, 1926, p. 89). Although, as observed by Goudge, these holes show no currents in the brine, they probably are brine springs.

The lake was tested by seven auger holes the logs of which are as follows: hole 1—hard crystal at surface, 6 inches; crystal mixed with mud, 6 inches; hard crystal with apparently no mud layers, 7½ feet; black mud containing small disseminated crystals, 2 feet; and light-gray clayey mud, 27½+ feet. Hole 2 shows 10½ feet of salts above the black mud below; hole 3 shows a thickness of 10½ feet of salts; and hole 4 shows 9 feet of salts. Analyses of the salts from hole 4 are shown in table 23.

Tonnage Estimate.

The brine is considered to contain the following tonnages: sodium sulfate, 19,800; sodium chloride, 1,700; potassium sulfate, 940; magnesium sulfate, 875; and sodium carbonate, 20 tons. The solids (in short tons) are: sodium sulfate, 53,900; magnesium sulfate, 530; potassium sulfate, 530; sodium chloride, 400; and sodium bicarbonate, 400.

Table 22.—Analysis of brine from Hauan Lake

Sample No. 41

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) ----------	250	0.1	NaCl (sodium chloride) --------	7.2
Mg (magnesium) --------	988	0.7	Na_2CO_3 (sodium carbonate) ----	0.1
Al (aluminum) ---------	None	None	$NaHCO_3$ (sodium bicarbonate) --	None
Fe (iron) --------------	None	None	$CaSO_4$ (calcium sulfate) -------	0.6
Na (sodium) -----------	39,500	30.1	$MgSO_4$ (magnesium sulfate) -----	3.7
K (potassium) ----------	2,400	1.8	Na_2SO_4 (sodium sulfate) -------	84.2
HCO_3 (bicarbonate) ----	None	None	K_2SO_4 (potassium sulfate) ------	4.0
CO_3 (carbonate) -------	110	0.1		
SO_4 (sulfate) ----------	82,000	62.6		
Cl (chloride) ----------	5,740	4.3		
	130,988	99.7		99.8

Specific gravity at 26° C. (78.8° F.) ----- 1.119

Sample No. 41. From the center of the lake and on the bottom at a depth of 12 inches. Specific gravity, 1.120 at 21° C. Collected in July 1945.

Table 23.—Analyses of salts from Hauan Lake

Constituents in percentage of total weight

Sample no.	62	63	64
Insoluble residue	11.4	18.7	3.1
Ca (calcium)	0.1	0.1	None
Mg (magnesium)	0.1	0.1	0.1
Al (aluminum)	None	None	None
Fe (iron)	None	None	None
Na (sodium)	28.2	25.4	31.1
K (potassium)	0.3	0.5	0.3
HCO_3 (bicarbonate)	0.5	0.5	0.4
CO_3 (carbonate)	None	None	None
SO_4 (sulfate)	59.0	53.2	64.8
Cl (chloride)	0.2	0.5	0.3
	99.8	99.0	100.1

Conventional combinations in percentage of total weight

Sample no.	62	63	64
Insoluble residue	11.4	18.7	3.1
NaCl (sodium chloride)	0.4	0.8	0.5
Na_2CO_3 (sodium carbonate)	Trace	Trace	Trace
$NaHCO_3$ (sodium bicarbonate)	0.7	0.7	0.5
R_2O_3 (iron and aluminum oxides)	None	None	None
$CaSO_4$ (calcium sulfate)	0.5	0.5	None
$MgSO_4$ (magnesium sulfate)	0.4	0.5	0.5
Na_2SO_4 (sodium sulfate)	85.9	76.9	94.9
K_2SO_4 (potassium sulfate)	0.6	1.0	0.6
	99.9	99.1	100.1

Sample No. 62. Hole 4, from 0 to 3 feet.
Sample No. 63. Hole 4, from 3 to 6 feet.
Sample No. 64. Hole 4, from 6 to 9 feet.

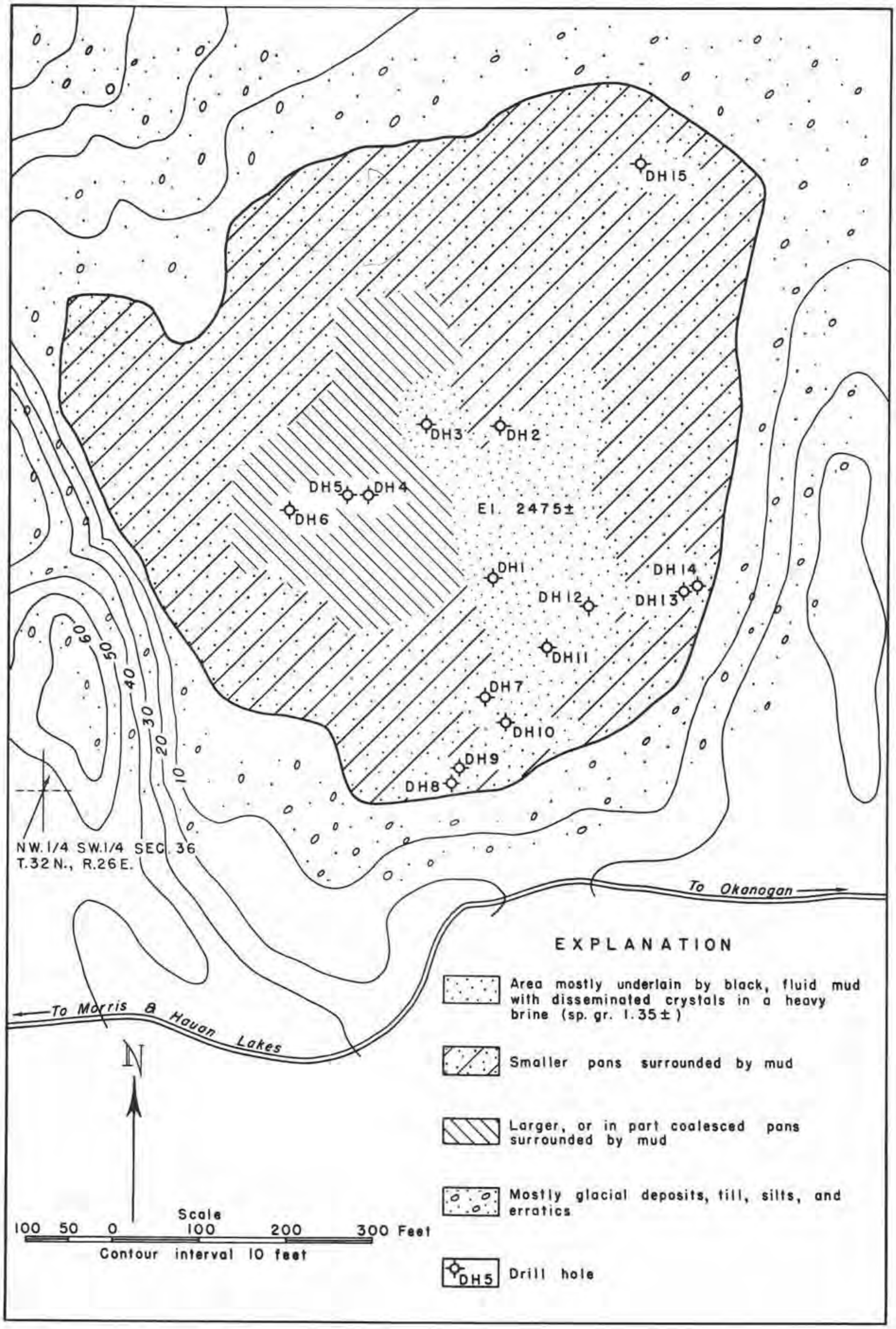


Figure 26.—Map of Deposit No. 13.

Deposit No. 13

Location, Size, and Access

Deposit No. 13 (fig. 26) which has an area of $10\frac{1}{2}$ acres, is in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 36, T. 32 N., R. 26 E. It is most easily reached by the county road from Okanogan to Timentwa (fig. 11).

Topography and Geology

The lake, an undrained, rather shallow depression of glacial origin, is on a bedrock of basalt. It is surrounded by deposits of glacial till and silts. A basalt knob, which seems to be a remnant of the dissected surface of the basalt flows that make up the plateau, lies about 700 feet to the south and 100 feet above the lake bed.

The Salts

Brine.—In March 1945 the brine, which appeared to be about 1 foot deep, was relatively clear and its concentration was considerably above that of other nearby lakes at that time of the year. By mid July it had nearly disappeared from the surface, and by the end of the month a crust had formed over most of the lake bed; the rate of evaporation of the brine was about a foot in 105 days. A sample of the brine was taken from a small pool near the south shore. Its specific gravity was 1.269. In early October the brine beneath the firm salt crust was found to be confined mainly to an area of fluid black mud that is outlined in figure 26. Samples of the brine, from the surface when the lake was about to dry up in July, and from the black fluid mud area, have been analyzed, and the results are given in table 24.

The analyses show (3d column from the left, table 24) an increase in the percentage of magnesium in the brine below the lake-bed surface as well as a marked decrease in sodium and potassium. The extent to which the composition of brine varies at different places in other lakes has not been determined except in Carbonate Lake and Poison Lake. The brine from Carbonate Lake showed a change in the proportions of the negative radicals (non metals) and that in Poison Lake, like Deposit No. 13, a change in the proportions of positive radicals (metals). Deposit No. 13 is the only important lake among those studied on the plateau in which magnesium is a major constituent of the brine.

Crystal.—Sodium sulfate is the principal constituent of the solid salt bodies that make up most of the lake bed. As in other lakes, it occurs in rather large irregular pans, especially in the central part of the deposit. Small pans occur near the shore. The composition of the salts is shown in table 25.

In view of the high concentration of the salts in the brine underground and of its comparative richness in magnesium, the composition of the solid salts in the lake bed is surprising. In most lakes there is a correspondence between the composition of the brines and the crystallized salts, but that rule does not appear to hold in this deposit.

The sodium sulfate and other minor salts form alternately hard and soft layers in the larger pans of the central area, but some of the pans of the border area show a coarsely granular phase, a compact

Table 24.—Analyses of brine from Deposit 13

Sample No. 43

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	480	0.1	NaCl (sodium chloride)	6.7
Mg (magnesium)	16,100	6.0	Na_2CO_3 (sodium carbonate)	0.3
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	0.5
Fe (iron)	None	None	$CaSO_4$ (calcium sulfate)	0.6
Na (sodium)	54,900	20.5	$MgSO_4$ (magnesium sulfate)	29.9
K (potassium)	9,030	3.3	Na_2SO_4 (sodium sulfate)	53.9
HCO_3 (bicarbonate)	1,000	----	K_2SO_4 (potassium sulfate)	7.5
CO_3 (carbonate)	580	0.5(1)		
SO_4 (sulfate)	174,000	64.8		
Cl (chloride)	10,900	4.0		
	266,990	99.2		99.4

Specific gravity at 26° C. (78.8° F.) ----- 1.272

Sample No. 44

Ca (calcium)	None	None	NaCl (sodium chloride)	11.0
Mg (magnesium)	34,200	11.1	Na_2CO_3 (sodium carbonate)	0.5
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	0.4
Fe (iron)	None	None	$MgSO_4$ (magnesium sulfate)	51.7
Na (sodium)	46,700	15.1	Na_2SO_4 (sodium sulfate)	32.2
K (potassium)	1,060	0.3	K_2SO_4 (potassium sulfate)	0.7
HCO_3 (bicarbonate)	940	----		
CO_3 (carbonate)	920	0.5(1)		
SO_4 (sulfate)	204,000	66.1		
Cl (chloride)	20,700	6.7		
	308,520	99.8		96.5

Specific gravity at 26° C. (78.8° F.) ----- 1.336

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 43. Collected in July 1945, when the brine, which during the wet season covers the entire lake bed to a depth of a foot or more, had mostly evaporated, leaving local pools that were mushy with crystals of salts.

Sample No. 44. Collected in October 1945, from hole 11, in an area of the lake bed that is underlain by black fluid mud with disseminated crystals.

Table 25. —Analyses of salts from Deposit No. 13

Constituents in percentage of total weight			
Sample no.	65	66	67
Insoluble residue	5.8	23.7	1.5
Ca (calcium)	0.4	None	0.2
Mg (magnesium)	0.4	0.2	0.1
Al (aluminum)	None	None	None
Fe (iron)	None	None	None
Na (sodium)	29.4	24.3	31.4
HCO_3 (bicarbonate)	None	None	None
CO_3 (carbonate)	None	None	None
SO_4 (sulfate)	63.4	51.6	66.6
Cl (chloride)	0.2	None	None
	99.6	99.8	99.8

Compounds in percentage of total weight			
Sample no.	65	66	67
Insoluble residue	5.8	23.7	1.5
NaCl (sodium chloride)	0.3	None	None
Na_2CO_3 (sodium carbonate)	None	None	None
$NaHCO_3$ (sodium bicarbonate)	Trace	Trace	None
R_2O_3 (iron and aluminum oxides)	None	None	None
$CaSO_4$ (calcium sulfate)	1.2	None	0.8
$MgSO_4$ (magnesium sulfate)	1.8	1.0	0.7
Na_2SO_4 (sodium sulfate)	90.3	75.1	96.8
	99.4	99.8	99.8

Sample No. 65. From hole 7, at 0 to 7 feet, to the bottom of the salt pan.

Sample No. 66. From hole 15, typical sample of the coarsely granular aggregate of mirabilite crystals, dark from mud or sand inclusions, that form the pan.

Sample No. 67. White, relatively pure, powdery thenardite layer that forms on the surface of the pans, this sample being taken from near hole 15.

aggregate of crystals as much as half an inch across. These granular salt pans, as much as 15 feet across, in one place are made up of an unlayered aggregate of crystals about 3 feet thick in the center, but at the top they have tapered curved-down (convex) rims that extend under the surrounding mud.

The lake bed was tested by 15 auger holes, the logs of which are as follows — Hole 1 (fig. 26): white rather firm salt crust, 4 inches; fluid mud with disseminated mirabilite crystals, 3+ feet (depth not fully determined). Hole 2: firm salt crust, 2 inches; black mud with disseminated crystals, 8 inches; salt layers, alternately hard and soft, 5 feet 8 inches; mud, becoming compact at bottom next to bedrock, 3 feet. Hole 3: firm salt crust, 2 inches; black mud on bedrock, 7 feet 10 inches. Hole 3a (on black mud surface at edge of pan penetrated by hole 3): mud, entirely free of salt crystals to bedrock, 8 feet. Hole 4: firm salt bed, 6 feet 6 inches; compact mud on bedrock, 2 feet. Hole 5: black mud on gravel and sand, 8 feet 6 inches. Hole 6: black mud on sand, 8 feet 6 inches. Hole 7: salts, 8 feet 6 inches. Hole 8 (center of small pan 5 feet in diameter): salts, 3 feet; mud, thickness undetermined. Hole 9 (center of 10-foot pan): salts, 5 feet; mud, depth not determined. Hole 10: black soft mud with disseminated crystals presumably of mirabilite, 2 feet; mud, depth not determined. Hole 11: firm salt crust, 2 inches; black mud, depth not determined. Hole 12: salt crust, 2 inches; black mud that contains a dense brine, specific gravity, 1.350, depth not determined. Hole 13: salts, 3 feet 6 inches; mud, depth not determined. Hole 14 (near shore): salts, 1 foot. Hole 15 (center of 15-foot pan): coarsely granular mirabilite crystals, 3 feet 3 inches; black mud, depth not determined; this pan was tested in several places with the chisel bit as well as explored by trenching to determine its shape.

Tonnage Estimate

The brine is estimated to contain the following salts (in short tons): magnesium sulfate, 5,000; sodium sulfate, 3,000; sodium chloride, 1,000; and potassium sulfate, 70. The crystallized salts, calculated to an anhydrous basis, amount to: sodium sulfate, 14,000 tons; magnesium sulfate, 330; calcium sulfate, 200; and sodium chloride, 40.

Murray Lake

Location, Size, and Access

Murray Lake (fig. 27), which includes an area of 13½ acres, is just south of the center of sec. 20, T. 32 N., R. 27 E. In 1945 no easily recognizable farm roads appeared to lead to the lake, but stock trails could be followed by car along ravines, preferably from the west (fig. 11).

Topography and Geology

The lake is at least 200 feet lower than the surface of the plateau and is one in a group of three lakes in depressions formed by glacial erosion of basalt from around a mass of granite and metamorphic rocks in a manner similar to that of Lawson, Morris, and Hauan Lakes. In these depressions, the receding

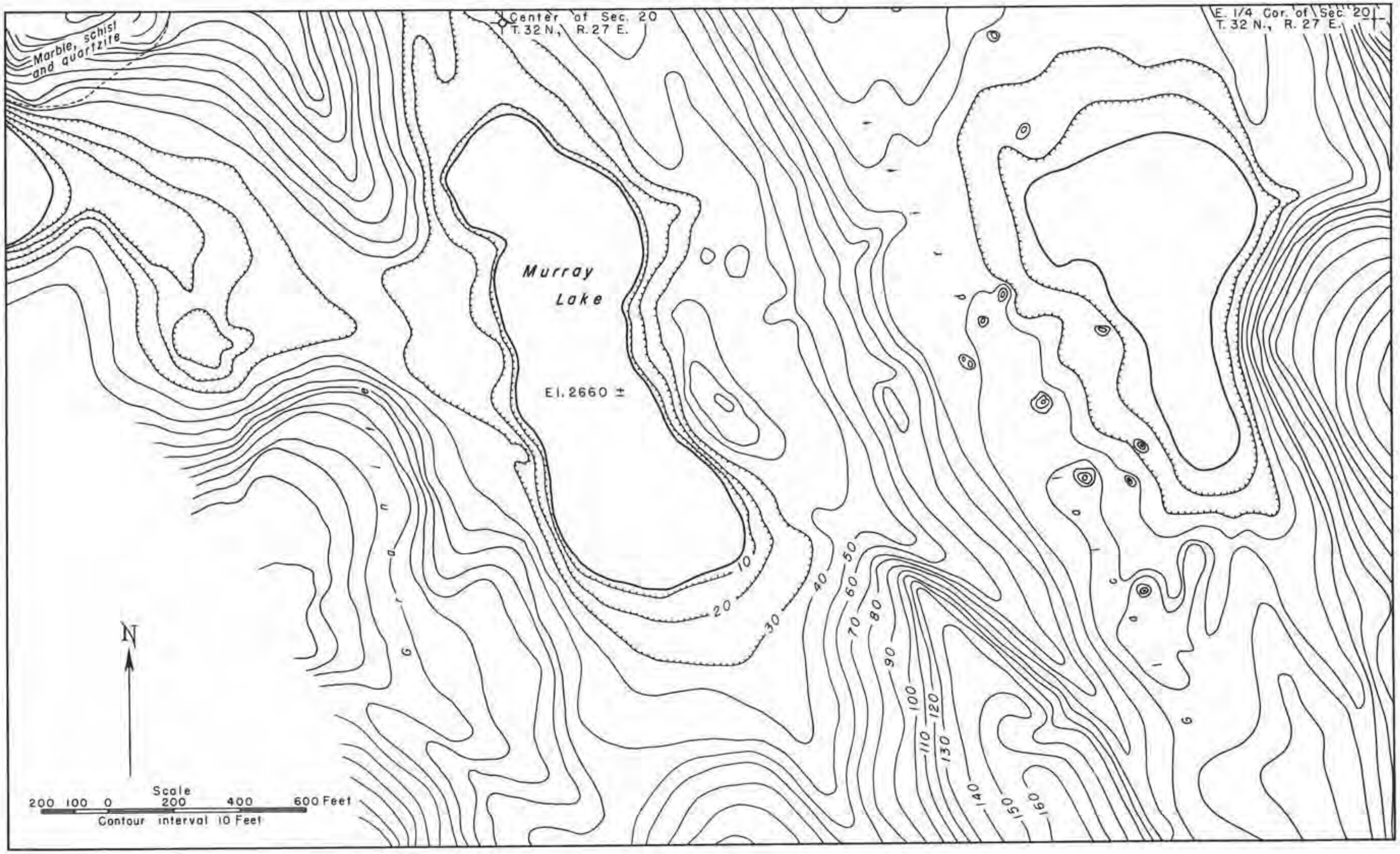


Figure 27.—Map of Murray Lake.

ice laid down deposits of till, followed by silts, probably in standing water and around blocks of ice that lay for a time in the basins. Numerous erratic boulders, a further example that basalt is relatively easily rended into great blocks by glacial ice, occur on the low ridge of drift or till that lies between Murray Lake and the smaller lake to the east.

The small outcrop of metamorphic rocks, although apparently overlooked by Pardee (1918, pl. 1), is worthy of note not only as the second occurrence of such rocks on the Okanogan Plateau but as a suggestion that they have a wider extent than has been realized under the basalt of the plateau, giving a clue to the origin of noteworthy amounts of magnesium in the brines of the several lakes in this vicinity.

Development

According to the owner, T. J. Murray, of Okanogan, the deposit of crystallized salts, which was once operated by a Spokane company, has a thickness greater than 8 feet (Glover, 1936, p. 99).

The Salts

At the time of examination the brine, which had a maximum depth of 40 inches in the center of the lake, had a specific gravity of 1.122 at 23° C. on the bottom. A sample of this brine, collected in July, has been analyzed with the results shown in table 26.

Table 26. — Analysis of brine from Murray Lake

Sample No. 42

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) ------------	450	0.3	NaCl (sodium chloride) --------	1.3
Mg (magnesium) ---------	2,120	1.6	Na_2CO_3 (sodium carbonate) ----	0.4
Al (aluminum) -----------	None	None	$NaHCO_3$ (sodium bicarbonate) --	0.3
Fe (iron) ----------------	None	None	$CaSO_4$ (calcium sulfate) -------	0.1
Na (sodium) -------------	38,700	29.4	$MgSO_4$ (magnesium sulfate) -----	8.0
HCO_3 (bicarbonate) ------	330	----	Na_2SO_4 (sodium sulfate) -------	89.0
CO_3 (carbonate) ---------	160	0.3(1)		
SO_4 (sulfate)	88,500	67.4		
Cl (chloride)	1,040	0.7		
	131,300	98.7		98.9

Specific gravity at 26° C. (78.8° F.) ----- 1.123

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 42. Collected in July 1945, when the specific gravity was 1.124 at 23° C. (72.8° F.), having increased from 1.078 at 21° C. in May.

Although the presence of salt pans could not be determined, the exceptional density and considerable volume of the brine so early in the summer is an indication of their existence. The lakes with dense brines usually evaporate at a slightly faster rate than those of weak concentration. The surface of this lake had dropped about 1.2 feet in 35 days, or at the rate of about 2 inches in 5 days. A thin crust had formed on the mud at the shore line.

Two other lakes, as indicated on figure 27, were mapped in May; but in July the water in the lake to the east of Murray was found to be of low concentration (specific gravity, 1.016 at 26° C.) and only 15 inches deep, and that of the lake on the northwest was essentially fresh.

Tonnage Estimate

The brine is estimated to contain the following salts (in short tons): sodium sulfate, 7,000; magnesium sulfate, 640; sodium chloride, 100; and sodium carbonate, 40. Assuming that crystallized salts are present and are of the usual type of occurrence, there would be roughly 5,000 tons of salts (anhydrous basis) per foot of depth in Murray Lake.

Deposit No. 16

Location, Size, and Access

An unnamed lake with an area of 19 acres, referred to here as Deposit No. 16, is located in the SW$\frac{1}{4}$ sec. 31, T. 32 N., R. 28 E. It is easily reached from Okanogan by the road to Omak Lake and Goose Lake (figs. 28 and 11).

The deposit is on the east side of the valley that extends southward from Omak Lake to the Columbia River and is near Boot Mountain but between it and the Okanogan Plateau on the west. The lake is entirely surrounded by glacial till or drift which is sufficiently impervious to prevent outflow and thus make the lake saline in contrast to other lakes nearby on the south.

The lake was first examined in mid-December 1944 when, frozen over with three-fourths of an inch of ice, its specific gravity was 1.031 at 0° C. Minute tufts of salts here and there on the mud near shore gave a qualitative test for carbonates. In March 1945 the specific gravity of the brine was 1.021 at 11° C., and clusters of salts were forming offshore in the deeper water. In July the water again had a specific gravity of 1.030 at 22° C., its level having dropped 24 inches in 120 days or at the average rate of 1 inch in 5 days. The maximum depth of water was 30 inches. As there is little evidence of ground water seepage, it would appear that the lake receives most of its water and mineral matter from surface runoff.

A conspicuous spring, which issues from near the contact of terrace sediments and an outcrop of granite, is about 50 feet above and 200 feet east of the south end of the lake. The water from the spring, however, disappears within a short distance into the porous materials on the side of the basin. Its water was sampled for comparison with the lake brine. The lake obviously received most, if not all, of its

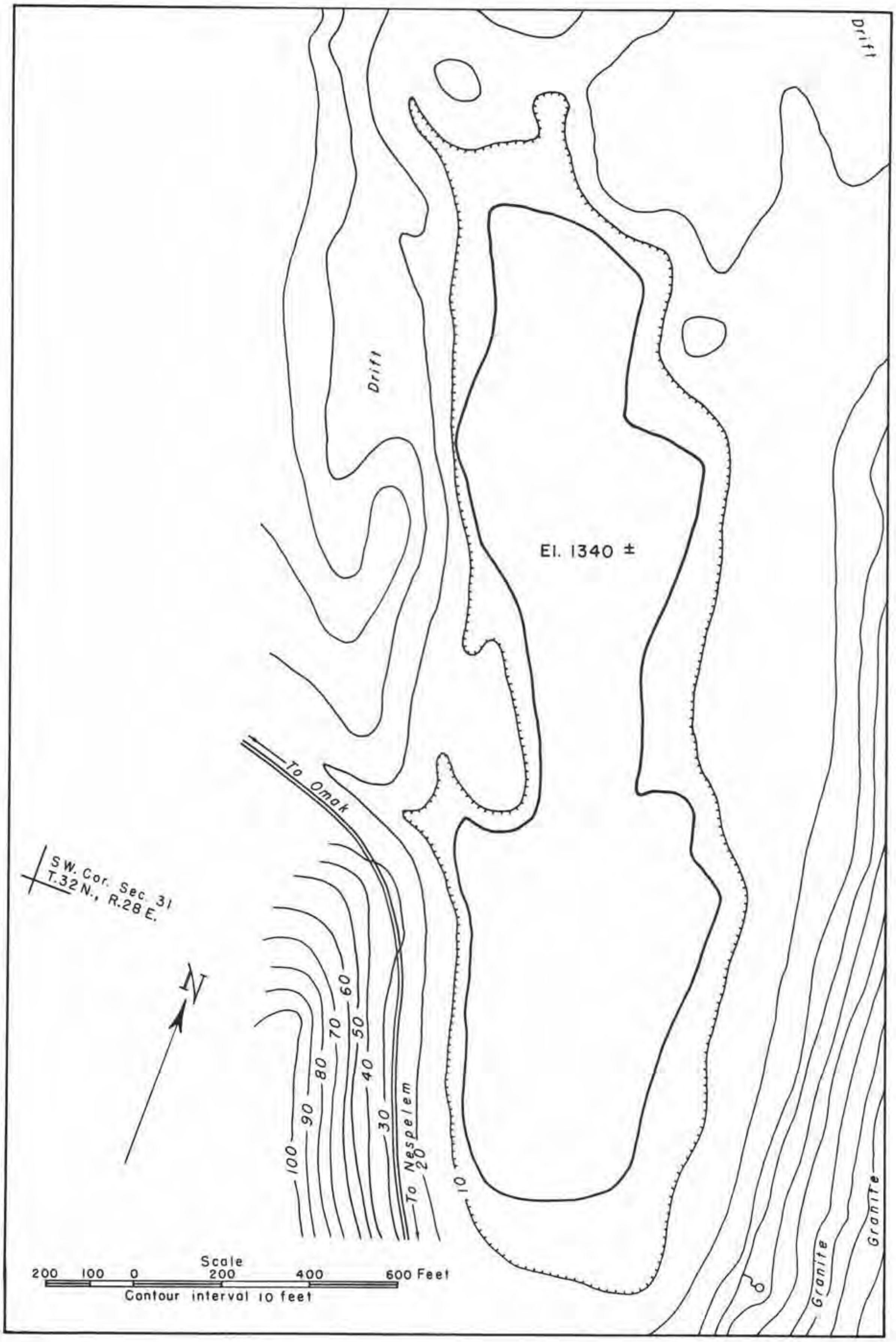


Figure 28.—Map of Deposit No. 16.

Table 27.—Analyses of brine and spring water from Deposit No. 16.

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Sample No. 50				
Ca (calcium) ----------	None	None	NaCl (sodium chloride) --------	11.3
Mg (magnesium) --------	13	0.06	Na_2CO_3 (sodium carbonate) ----	24.6
Al (aluminum) ---------	None	None	$NaHCO_3$ (sodium bicarbonate) --	15.7
Fe (iron) --------------	None	None	$MgSO_4$ (magnesium sulfate) -----	0.3
Na (sodium) -----------	7,030	34.9	Na_2SO_4 (sodium sulfate) -------	48.0
HCO_3 (bicarbonate) ----	2,300	----		
CO_3 (carbonate) -------	2,800	24.5(1)		
SO_4 (sulfate) ----------	6,580	32.7		
Cl (chloride) ----------	1,380	6.8		
	20,103	99.16		99.9
Specific gravity at 26° C. (78.8° F.) ------ 1.014				
Sample No. 51				
Ca (calcium) ----------	36	18.4	$Ca(HCO_3)_2$ (calcium bicarbonate)	71.0
Mg (magnesium) --------	9	4.6	$Mg(HCO_3)_2$ (magnesium bicarbonate)	22.3
Al (aluminum) ---------	None	None	$CaSO_4$ (calcium sulfate)--------	2.1
Fe (iron) --------------	None	None		
Na (sodium) -----------	None	None		
HCO_3 (bicarbonate) ----	150	----		
CO_3 (carbonate) -------	Trace	75.4(1)		
SO_4 (sulfate) ----------	3	1.5		
Cl (chloride) ----------	None	None		
	198	99.9		95.4
Specific gravity at 26° C. (78.8° F.) ------ 0.997				

(1) Bicarbonate expressed as normal carbonate.

Sample No. 50. Brine, collected in March 1945. Specific gravity at that time, 1.021 at 11° C.

Sample No. 51. Water from a spring near south end of lake. Specific gravity 1.002 at 14° C. (56.7° F.).

mineral matter from some source other than the spring, unless it is assumed that the calcium is precipitated out as carbonate and sulfate. The analysis of the brine and spring water is shown in table 27.

Tonnage Estimate

The following tonnages of salts have been calculated: sodium sulfate, 600; sodium carbonate, 300; sodium bicarbonate, 200; and sodium chloride, 100.

Patterson Lake

Patterson Lake, the size of which is greatly exaggerated on most maps, includes an area of 17 acres in the NE¼ sec. 1, T. 32 N., R. 26 E. It is reached over the county road that turns west from the Omak Lake road south of St. Mary's farm (figs. 29 and 11).

As shown by Pardee (1918, pl. 1), the lake is at the north end of a patch of drift, adjacent to granite and basalt on the west and east respectively.

The deposit is only a weak brine and of relatively small volume. Its maximum depth in July 1945 was 7 feet, and the specific gravity ranged from 1.026 to 1.015 at 25° C. to 21° C. respectively. The water shallows very gradually toward the north shore, where there is a wide mud flat that is widely crusted over with salts, but the water deepens rapidly elsewhere around the shore line. Analyses of the brine and of the salt crust are as shown in table 28.

The composition of the salt crust compares closely with that of the brine; it is surprisingly rich in magnesium sulfate, which suggests the presence of metamorphic rocks in the drainage basin.

The brine contains approximately 300 tons each of magnesium sulfate and sodium sulfate, and about 50 tons of other salts.

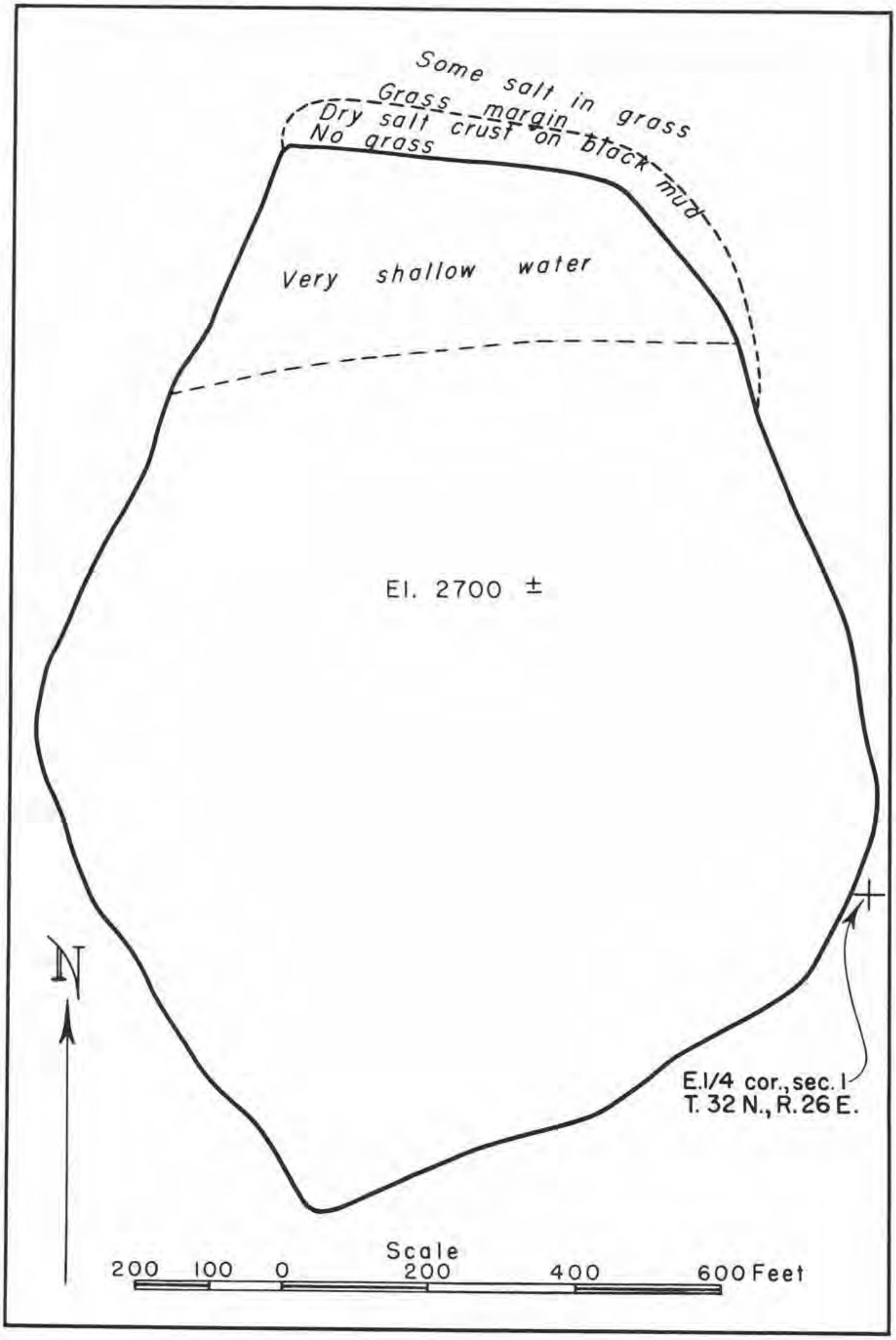


Figure 29.—Map of Patterson Lake.

Table 28. —Analyses of brine and of salt crust from Patterson Lake.

Sample No. 48

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	160	0.8	NaCl (sodium chloride)	2.5
Mg (magnesium)	1,640	9.1	Na_2CO_3 (sodium carbonate)	1.1
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	1.1
Fe (iron)	None	None	$CaSO_4$ (calcium sulfate)	3.0
Na (sodium)	3,070	17.0	$MgSO_4$ (magnesium sulfate)	45.1
HCO_3 (bicarbonate)	150	----	Na_2SO_4 (sodium sulfate)	47.0
CO_3 (carbonate)	120	1.4(1)		
SO_4 (sulfate)	12,600	69.9		
Cl (chloride)	280	1.5		
	18,020	99.7		99.8

Specific gravity at 26° C. (78.8° F.) ------ 1.013

Sample No. 75

Insoluble residue	4.1	Insoluble residue	4.1
Ca (calcium)	0.5	NaCl (sodium chloride)	0.4
Mg (magnesium)	9.5	Na_2CO_3 (sodium carbonate)	1.2
Al (aluminum)	None	$NaHCO_3$ (sodium bicarbonate)	None
Fe (iron)	None	R_2O_3 (iron and aluminum oxides)	None
Na (sodium)	11.8	$CaSO_4$ (calcium sulfate)	1.8
SiO_2 (silica)	0.1	$MgSO_4$ (magnesium sulfate)	47.2
HCO_3 (bicarbonate)	None	Na_2SO_4 (sodium sulfate)	34.3
CO_3 (carbonate)	0.7	SiO_2 (silica)	0.1
SO_4 (sulfate)	62.2	Ignition loss	10.1
Cl (chloride)	0.2		
Ignition loss	10.1		
	99.2		99.2

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 48. Brine, collected in late July 1945, from the bottom at 7 feet.

Sample No. 75. Salt crust on mud at north end of the lake, about 1 inch thick.

Cook Lake

Cook Lake, which has an area of between 10 and 15 acres, is in the NW¼ sec. 11, T. 32 N., R. 26 E., about 10 miles by county road from Okanogan (fig. 11).

The lake occupies a depression in granite near the west edge of the basalt of the Okanogan Plateau. Its west shore is an outcrop of granite in which the highway has been cut, but most of the lake bed rests on glacial deposits.

The maximum depth of the water is 6½ feet, and its specific gravity ranges from 1.020 to 1.050 at 32° C. The deposit appears to consist solely of brine, the analysis of which is shown in table 29.

The brine contains 3,700 short tons of sodium sulfate, 1,200 tons of magnesium sulfate, and about 300 tons of other salts.

Table 29.—Analysis of brine from Cook Lake.

Sample No. 49

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	340	0.5	NaCl (sodium chloride)	3.0
Mg (magnesium)	2,820	4.8	Na_2CO_3 (sodium carbonate)	0.5
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	1.0
Fe (iron)	None	None	$CaSO_4$ (calcium sulfate)	1.9
Na (sodium)	14,300	24.3	$MgSO_4$ (magnesium sulfate)	23.7
HCO_3 (bicarbonate)	450	----	Na_2SO_4 (sodium sulfate)	68.1
CO_3 (carbonate)	180	1.1(1)		
SO_4 (sulfate)	39,400	67.0		
Cl (chloride)	1,320	2.2		
	58,810	98.9		98.2

Specific gravity at 26° C. (78.8° F.) ----- 1.050

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 49. Brine collected at a depth of 4 feet near the west bank, the specific gravity being 1.050 at 32° C.

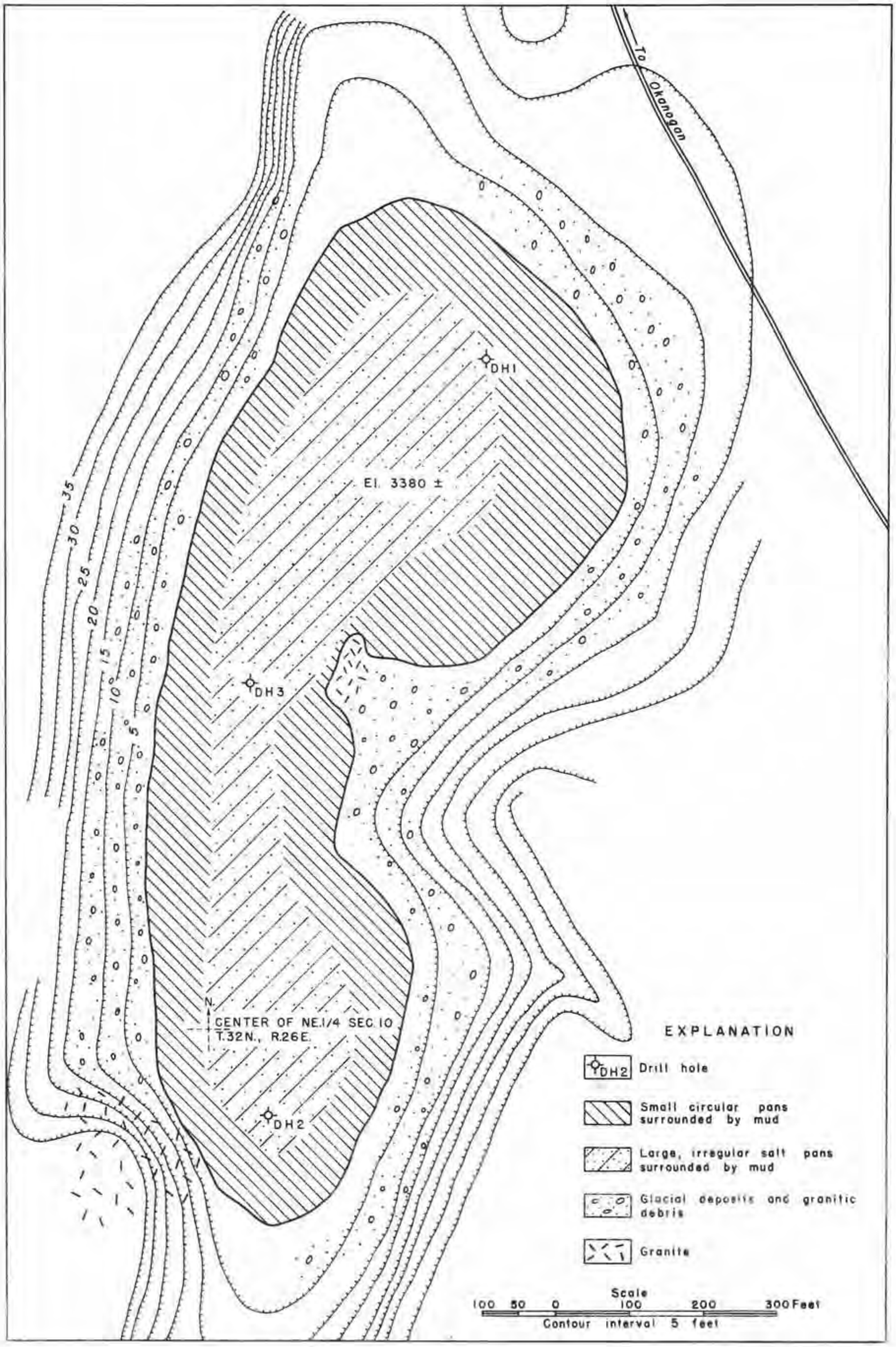


Figure 30.—Map of Penley Lake.

Penley Lake

Location, Size, and Access

Penley Lake covers an area of 11 acres in the NE$\frac{1}{4}$ sec. 10, T. 32 N., R. 26 E. (fig. 30). It is about 8 miles from Okanogan on the county road to Timentwa (fig. 11).

Topography and Geology

The lake, like many others nearby, is in an area of granite; it is in an undrained depression, at an altitude of between 2,360 and 2,400 feet, that appears to be mostly the result of the blocking of a preexisting drainage by glacial deposits. Except for two small outcrops at the shore line, the lake is surrounded by glacial drift.

History and Development

The deposit in 1945 was owned by John Isenhart of Chelan, but in 1950 was under lease to the Okanogan Salt Company. Efforts have been made at various times to mine the salts on a small scale. In 1940 it was tested by the Washington Chemical and Salt Corporation, which erected a plant at Monse. In 1961 the lake was reported to be owned by C. A. Kearney, of Seattle.

The Salts

Brine.—The brine, which usually disappears from the surface at the end of a dry summer, ranges in specific gravity from 1.008 in the early spring to 1.030 in the late fall. Its greatest density was below the surface of the lake bed, where, in hole 2, its specific gravity was 1.220, and in hole 3 it was 1.234.

The brine is present in the voids of the salt pans and in places exists as a fluid mixture with the lake mud as much as 10 feet from the surface, or 2 feet below some of the salt pans. The composition of the brine is shown in table 30.

Crystal.—Sodium sulfate and other salts occur in circular to irregularly circular or oval pans that range in size from a few feet to as much as 60 feet or more across, and which are surrounded by mud that rises as rings a few inches above their surface (fig. 31). The larger pans seem to "freeze" over with a fairly firm crust, strong enough in most places to stand on, leaving a mixture of brine and loose aggregates of large mirabilite crystals as much as a foot deep beneath the crust. An analysis of the salts is as shown in table 30.

The deposit has been tested in three places by hand auger; the logs of the holes are as follows: Hole 1, salts, 7 feet; gray mud (on bedrock) containing in its upper part small gypsum crystals, 14 feet. Hole 2 (in center of 50-foot pan) salt crust, 1 inch; brine, 3 inches; firm or solid crystal, 2 inches; disseminated crystals in mud, 7 feet 6 inches; light-gray mud with disseminated crystals 1/8 to 1/4 inch across, 3 feet; depth to bedrock not determined. Hole 3 (in center of large pan 50 to 60 feet in diameter) brine, partly crusted over but containing 1-inch mirabilite crystals in rather large ball-like poorly

Table 30.—Analyses of brine and of salts from Penley Lake.

Sample No. 47				
Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	400	0.2	NaCl (sodium chloride)	3.8
Mg (magnesium)	1,710	0.9	Na_2CO_3 (sodium carbonate)	0.1
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	0.2
Fe (iron)	None	None	$CaSO_4$ (calcium sulfate)	0.7
Na (sodium)	56,800	30.9	$MgSO_4$ (magnesium sulfate)	4.0
HCO_3 (bicarbonate)	370	----	Na_2SO_4 (sodium sulfate)	90.4
CO_3 (carbonate)	160	0.3(1)		
SO_4 (sulfate)	120,000	65.3		
Cl (chloride)	4,270	2.3		
	183,710	99.9		99.2

Specific gravity at 26° C. (78.8° F.) ------ 1.171

(1) Includes bicarbonate reduced to normal carbonate.

Sample no.	68	69
Constituents (radicals) in percentage of total weight	Percentage of total weight	Percentage of total wieght
Insoluble residue	11.3	86.9
Ca (calcium)	0.4	2.5
Mg (magnesium)	0.2	0.3
Al (aluminum)	None	None
Fe (iron)	None	None
Na (sodium)	28.2	0.9
HCO_3 (bicarbonate)	0.4	None
CO_3 (carbonate)	None	None
SO_4 (sulfate)	59.8	8.6
Cl (chloride)	0.2	0.4
	100.5	99.6

	68	69
Conventional combinations	Percentage of total weight	Percentage of total weight
Insoluble residue	11.3	86.9
NaCl (sodium chloride)	0.4	0.6
Na_2CO_3 (sodium carbonate)	None	None
$NaHCO_3$ (sodium bicarbonate)	None	None
R_2O_3 (iron and aluminum oxides)	0.5	None
$CaSO_4$ (calcium sulfate)	1.3	8.6
$MgSO_4$ (magnesium sulfate)	0.8	1.4
Na_2SO_4 (sodium sulfate)	86.2	2.1
	100.5	99.6

Sample No. 47. Brine, collected in July 1945.

Sample No. 68. Salts from hole 1, 0 to 7 feet.

Sample No. 69. Gray mud from hole 1, 7 to 21 feet.

Figure 31.—The north end of Penley Lake from the south, showing larger, somewhat irregular pans in the center, some with open brine marked by a black streak, and smaller, circular ones near the shore. October 1945.

consolidated growths, 10 inches; very hard salt layer (too hard to penetrate with a sharp coal auger; required chopping with a chisel bit), 2 inches; firm salts, 3 feet; granular crystal (coal auger could be easily pushed through without turning), 6 inches; firm salts, 2 feet 6 inches; softer salt layer, 1 foot; alternately hard and soft salt layers, 1 foot 6 inches; brine or fluid mud (auger could be easily pushed without turning), 1 foot; compact, brownish-gray mud, apparently not containing disseminated crystals, thickness not determined.

Tonnage Estimate

The brine is estimated to contain the following short tons of dissolved solids: sodium sulfate, 14,600; magnesium sulfate, 650; sodium chloride, 600; calcium sulfate, 100; and sodium carbonate, 50. The pans are estimated to contain the following short tons of salts, anhydrous basis: sodium sulfate, 23,700; calcium sulfate, 350; magnesium sulfate, 200; and sodium chloride, 100.

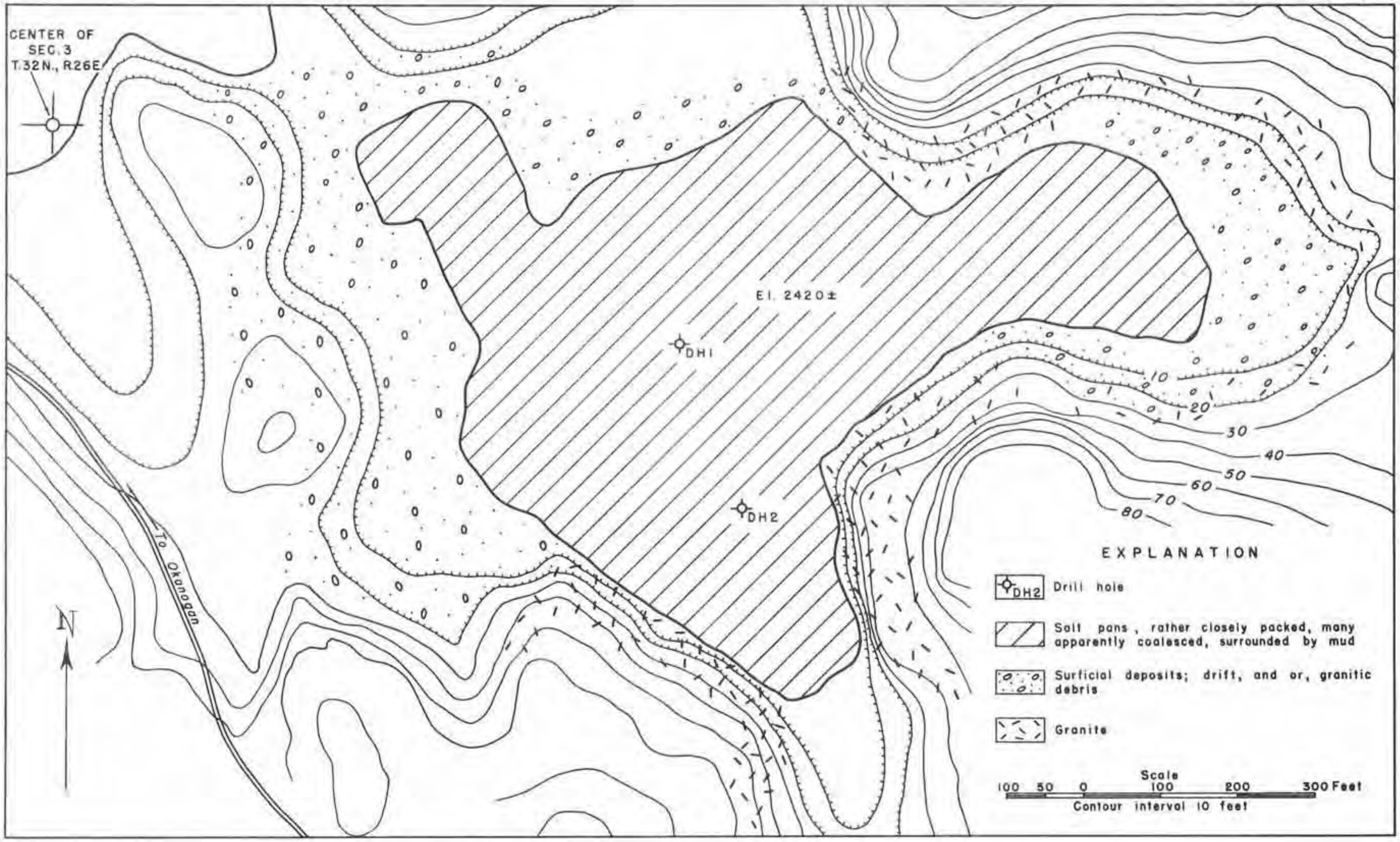


Figure 32.—Map of Cameron Lake.

Cameron Lake

Location, Size, and Access

Cameron Lake is in the N½SE¼ sec. 3, T. 32 N., R. 26 E., has an area of 9 acres, and, like Penley Lake lying just to the south, is reached by the county road from Okanogan to Timentwa and other parts of the Okanogan Plateau (figs. 32 and 11).

Topography and Geology

This lake is in a basin similar to that of Penley Lake and is at a slightly higher altitude of 2,420± feet above sea level. Knobs of granite rise abruptly more than 100 feet above the shore line at the north and south ends. The lake surface was probably at a higher level at one time and extended westward into a smaller basin near the road. If its present level were raised about 20 feet it would flow into the Penley basin on the south as well as into other basins on the northwest and north, and if raised about 50 feet it would flow eastward over a divide. The surface that is drained into the lake, exclusive of the barren outcrops of granite, is roughly equivalent to the area of the lake itself; but an equally large area to the west may be drained underground to the lake, though there is no indication of ground water seepage around the shore line. The surprising fact about this deposit, in comparison to all the others examined, is that a relatively large volume of salts has accumulated as related to a comparatively small drainage area, even though this is a lake that is underlain in part by rocks (drift and granitic debris) that may be unusually permeable and easily leached.

History and Development

The deposit, long owned by John Isenhart, of Chelan, in 1950 was leased to the Okanogan Salt Company, which, according to plans, was to build a refining plant in Okanogan and begin operations by using these salts and those from Penley Lake. In 1941 this lake together with several others was drilled and sampled by the Washington Chemical and Salt Corporation, which was preparing to excavate the salts of Lawson Lake and refine them in the plant at Monse. Salts presumably have never been mined from this deposit. In 1961 the lake was reported to be owned by C. A. Kearney, of Seattle.

The Salts

Brine.—In July 1945, the brine, which was 1½ feet deep over the center of the pans and 6 inches deep over the surrounding mud ridges, had a specific gravity of 1.120 at 17° C. It had disappeared from the surface in October, being confined to the mushy crystal layers between the harder surface crust and the permanent upper surface of the pans as well as to the more porous parts at greater depth and in the lake-bed mud. Its specific gravity in hole 2 was 1.20. A sample, collected from the bottom in the center of the lake in July, was analyzed and the results are shown in table 31.

Table 31.—Analysis of brine from Cameron Lake.

Sample No. 46.

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	4.9
Mg (magnesium)	210	0.1	Na_2CO_3 (sodium carbonate)	1.7
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	0.4
Fe (iron)	None	None	$CaSO_4$ (calcium sulfate)	----
Na (sodium)	42,500	32.6	$MgSO_4$ (magnesium sulfate)	0.8
HCO_3 (bicarbonate)	450	----	Na_2SO_4 (sodium sulfate)	92.1
CO_3 (carbonate)	1,300	1.3(1)		
SO_4 (sulfate)	81,800	62.8		
Cl (chloride)	3,960	3.0		
	130,220	98.8		99.9

Specific gravity at 26° C. (78.8° F.) ------ 1.118

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 46. Bottom sample from center of lake at depth of 18 inches.

Crystal.—The permanent crystallized salts are present in pans that commonly range in size from 10 to 15 feet and to as much as 25 feet in diameter. A few, which may be the result of coalescence by continued growth around their perimeters, are 35 to 40 feet across. Whereas the smaller pans are covered by 1 to 2 inches of mud, the larger have little, if any, mud on their upper surfaces. The larger pans have thicknesses of as much as 10½ feet, the maximum for all deposits so far explored, and extend essentially to bedrock in two places. The salts were not analyzed, but the predominance of sodium sulfate in the brine is a strong indication of its predominance in the pans.

The logs of two auger holes are as follows: Hole 1 (in center of lake) (fig. 32), intermittent crust, 7 inches; crystals disseminated in mud, 1½ feet; firm salt layer, 5 feet; softer crystal, 5 feet 6 inches; light-gray mud interbedded with brownish streaks that contain minute crystals apparently of gypsum. Hole 2 (in center of 35-foot pan), salt crust, 7 inches; crystal disseminated in mud, some brine, 10 inches; firm crystal, 3 feet 6 inches; very hard layer, difficult to drill with the coal auger, 4 feet 6 inches; softer crystal, on bedrock, 6 inches.

Tonnage Estimate

The brine contains approximately 8,000 tons of sodium sulfate; 400 tons of sodium chloride; and 180 tons of sodium carbonate. The pans, estimated as hydrous salts, contain roughly 27,000 tons of anhydrous salts. If a considerable part of the salts consists of naturally anhydrous sodium sulfate (thenardite), as the hard layers may very well be, then, because of the greater density of thenardite, the total tonnage of crystallized salts would be much greater than that stated.

Other Lakes

Many other saline lakes occur on the Okanogan Plateau, as mentioned by Pardee (1918, p. 179-180), as well as northward along the Okanogan Valley. A sample taken apparently from McDonald Lake is described by Pardee as follows:

> A sample of a saline crust taken from a pond in sec. 14, T. 31 N., R. 26 E., 2½ miles northwest of Duly Lake, was analyzed by W. B. Hicks in the laboratory of the United States Geological Survey. The total salts (ignited residue), which formed 72.16 percent of the original sample, contained 6.28 percent of potassium (K), which is equivalent to 7.57 percent of potassium oxide (K_2O), or 11.98 percent of potassium chloride (KCl). A qualitative examination of the sample showed the presence of considerable quantities of chlorides, sulphates, and carbonates, and the potassium therefore probably occurs as chloride or as both chloride and sulphate.

The following observations have been made at various lakes in the plateau area:

SW¼ sec. 1, T. 31 N., R. 25 E.,	specific gravity,	1.005	(Little Soap Lake)
S½ sec. 1, T. 31 N., R. 26E.,	" " ,	1.008	
SE¼NE¼ sec. 10, T. 31 N., R. 26 E.,	" " ,	1.046	
N½SE¼ sec. 10, T. 32 N., R. 26 E.,	" " ,	1.002	
Common corner secs. 10, 11, 14, and 15, T. 32 N., R. 26 E.,	" " ,	1.005	
SE¼ sec. 13, T. 32 N., R. 26 E.,	" " ,	1.002	
SW¼ sec. 14, T. 32 N., R. 26 E.,	" " ,	1.006	
SW¼NW¼ sec. 14, T. 32 N., R. 26 E.,	" " ,	1.005	
NE¼ sec. 22, T. 35 N., R. 26 E.,	" " ,	1.011	
SW¼NW¼ sec. 25, T. 32 N., R. 26 E.,	" " ,	1.002	
SE¼NW¼ sec. 25, T. 32 N., R. 26 E.,	" " ,	1.001	
NW¼NE¼ sec. 26, T. 32 N., R. 26 E.,	" " ,	1.004	
SE¼ sec. 36, T. 32 N., R. 26 E.,	" " ,	1.001	

MAGNESIUM SULFATE AND GYPSITE LAKES

OKANOGAN COUNTY

Poison Lake

Location, Size, and Access

Poison Lake, known also as Epso and Bitter Lake, is in the NE¼SE¼ sec. 5 and the NW¼SW¼ sec. 4, T. 38 N., R. 27 E., and is 12 miles by road north of Tonasket, the nearest town on a branch of

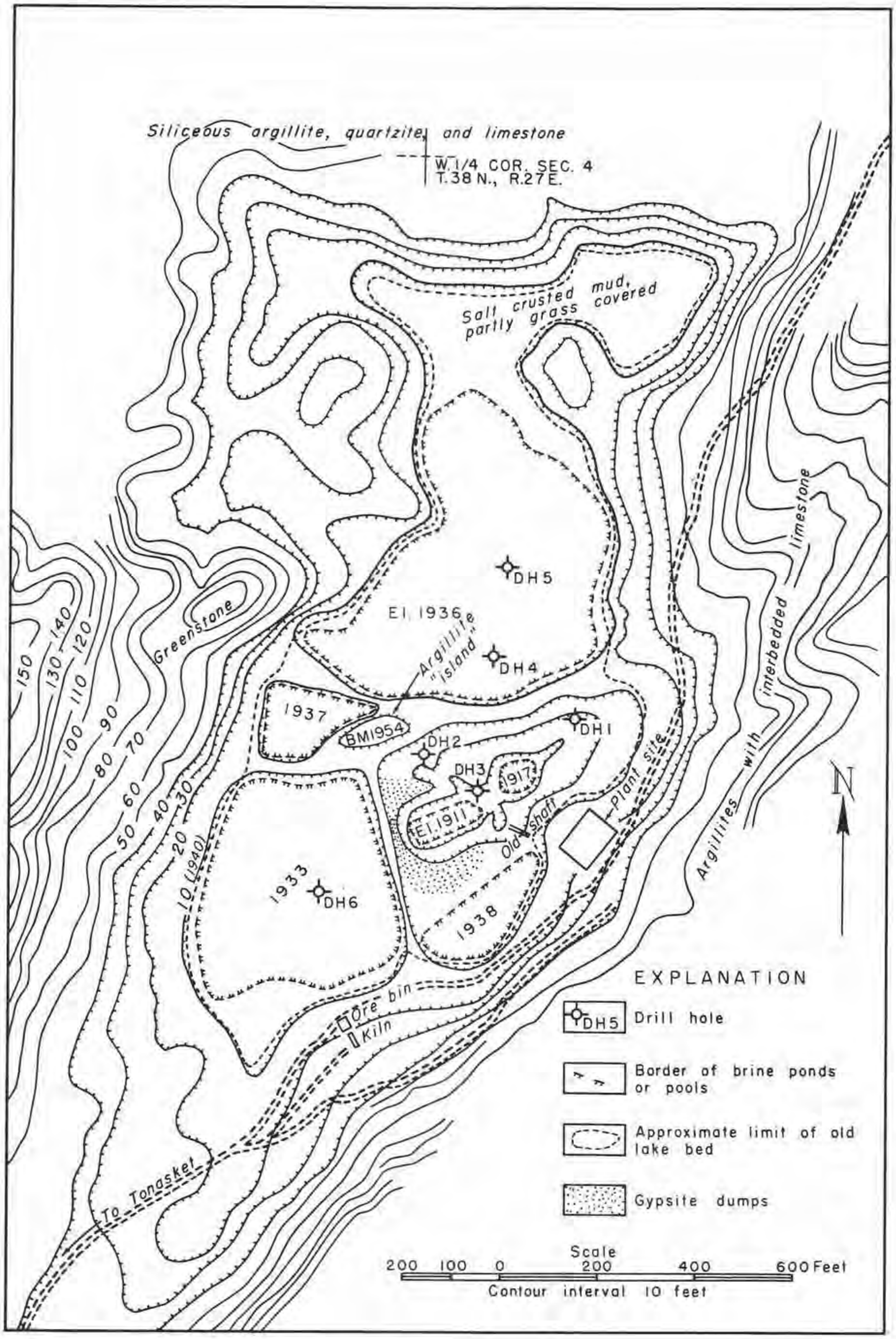


Figure 33.—Map of Poison Lake.

the Great Northern Railway. It includes about 19 acres, although less than 14 acres are covered by the larger brine ponds that have been included in tracts held by recent operators of the deposit (fig. 33). The lake is most easily reached from the south over a dirt road that connects with the Loomis road near the northwest end of Whitestone Lake. The road northward from the deposit is little traveled, is badly washed in places, and crosses farm land through several gates. It joins U.S. Highway 97 about 7 miles south of Oroville.

Topography and Geology

The lake occupies a small basin on a broad ridge that lies west of the Okanogan River and north of the depression or abandoned river valley in which are located Whitestone and Spectacle Lakes. Its altitude, which has been interpolated from the map of the Oroville quadrangle of the U.S. Geological Survey, is 1,720 feet, roughly 200 to 300 feet below hill tops on the east and west and 1,100 feet below Whiskey Mountain on the northwest. The basin is at the convergence of several small ravines that have been dammed by glacial deposits in the narrow channel followed by the road on the south.

The rocks that immediately surround the lake are part of the middle Anarchist Series of Waters and Kraskopf (1941, p. 1355-1417), which includes quartzite, schist, limestone, and old volcanic rocks. These rocks dip at moderate angles to the southeast.

History and Production

Epsomite was first mined at Poison Lake and processed in a plant at Oroville, together with brine from Bitter Lake, by the Epso Products Co., successors of the Stewart-Calvert Co. which had operated Bitter Lake from 1915-20 (Shedd, 1924, p. 137-138 and Glover, 1936, p. 42-43). The Epso Products Co., which continued to operate through the early twenties, sold Poison Lake to the Magnesium Products Co. of Portland, Oregon in 1927 (Hill, 1930, p. 178). Although some sales of epsomite had been made in western Washington in 1928, the Magnesium Products Co. produced small amounts from 1930-34, then leased through 1935-37 to C. A. Kearney. Later, Kearney acquired the deposit and continued to operate it as well as a refining plant at Tonasket (Anon., 1941). Still later, Kearney, in association with with J. S. Ramstead, built a refining plant at the lake and operated for a time, but this plant was destroyed by fire in July 1945.

The production from the lake always was relatively small, but in the late twenties or early thirties there was a period of 16 months during which 40 tons of crude epsomite per day was mined and shipped to Seattle, where it was sold at a price of $2.50 to $3.00 a ton (Krusoff, oral communication). The Bureau of Mines has concealed production figures (either because of small production or because of small number of producers) for all years except 1943, during which 358,000 pounds, valued at $10,000 was produced. The Bureau indicates no production for 1944-45 although one or two carloads had been shipped in the spring of 1945, and at least a carload was damaged in the plant at the time of the fire. The production from the lake enabled the State to hold fourth place among the four leading states in

1933-35, third in 1936-37, then back to fourth, which it held only through 1938-40. The total tonnage of epsomite removed from the lake can only be roughly estimated from the reported size of the deposit which, according to Mr. Krusoff (oral communication), of Oroville, was about 300 feet long by 200 feet wide and between 8 and 25 feet thick. It probably contained 50,000 short tons, of which probably only a small amount remains.

The deposit was said to have an irregular upper surface; it was directly overlain by 8 to 16 feet of gypsite, which in turn was overlain by 3 feet of mud. A layer of black fetid mud lay between the bottom of the epsomite and bedrock. A notable feature was the discovery, during the early period of development by underground mining, of a cavern that crossed a block of ground 50 by 75 feet.

The underground work consisted of a gently inclined shaft that leveled off as a crosscut about 175 feet long by 12 feet high, from which two parallel side drifts 50 feet apart, were driven southward one for 75 feet and the other 40 feet. The ground between the drifts was mined by a room and pillar method, a 3-foot roof being left to support the gypsite and mud overburden. Twenty five tons was reported broken per round in blasting with black powder, and 6,000 gallons per day of brine that contained 30 percent or more of salts was pumped from the main shaft. The underground methods were abandoned in the course of change of ownership, and for a time during later operations epsomite was taken from the brine. In part, concentration was effected in a vat at the lake by solar concentration and crystallization, but mostly the brine was hauled to the plant in Tonasket where crystallization was effected through the use of artificial heat. Sometime after 1941, when the plant was built at the lake, epsomite was mined from an open pit after being stripped of its gypsite overburden and it was used together with brine in a refining process to produce standard epsom salts for industrial use and for the drug trade. The details of the process have been published (Anon., 1941).

The Salts

Epsomite and gypsite were produced from Poison Lake from 1950 through 1952 by Laucks Chemical Co., of Seattle, and from 1953 to the present (1962) by Agro Minerals, Inc., of Tonasket.

Brine.—At the time of examination (July 1945) brine was standing in the main pit and in pools just to the north, in a pond to the south, in an old evaporating vat to the east, and in small pools at the extreme north end of the basin. Its specific gravity was 1.12 to 1.16 in the main pit and in the pools nearby, and 1.38 to 1.40 in the pond and old evaporating vat, where, presumably for several years, it had concentrated in the sun. Although none was found in holes 1, 2, and 3, the brine filled holes 4 and 5, where it had a density of 1.20. An ice-like film, presumably of epsom salt, was observed over much of the surface of the denser brine pools. On hot days a considerable part of this film dissolved, but it reappeared as the temperature dropped in the late afternoon and night.

The analyses of the brine are shown in table 32.

Table 32.—Analyses of brine from Poison Lake

I

Sample No. 54

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	None	None	NaCl (sodium chloride)	1.0
Mg (magnesium)	30,100	16.2	Na_2CO_3 (sodium carbonate)	0.1
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	0.4
Fe (iron)	None	None	$MgSO_4$ (magnesium sulfate)	80.5
Na (sodium)	11,000	5.9	Na_2SO_4 (sodium sulfate)	16.2
K (potassium)	1,230	0.6	K_2SO_4 (potassium sulfate)	1.4
HCO_3 (bicarbonate)	550	----		
CO_3 (carbonate)	100	0.3(1)		
SO_4 (sulfate)	141,000	76.1		
Cl (chloride)	1,230	0.6		
	185,210	99.7		99.6

Specific gravity at 26° C. (78.8° F.) ------ 1.200

(1) Includes bicarbonate reduced to normal carbonate.

II

Sample No. 53

Constituents (radicals) in percentage of total weight			Combinations in percentage of total weight	
	A	B		
Insoluble residue	0.4	----	Insoluble residue	0.4
Ca (calcium)	None	----	NaCl (sodium chloride)	0.7
Mg (magnesium)	11.8	13.8	Na_2CO_3 (sodium carbonate)	1.2
Al (aluminum)	None	----	$NaHCO_3$ (sodium bicarbonate)	None
Fe (iron)	None	----	R_2O_3 (iron and aluminum oxides)	None
Na (sodium)	8.7	10.2	$CaSO_4$ (calcium sulfate)	None
HCO_3 (bicarbonate)	None	----	$MgSO_4$ (magnesium sulfate)	58.5
CO_3 (carbonate	0.7	0.8	Na_2SO_4 (sodium sulfate)	24.3
SO_4 (sulfate)	63.1	74.1	Ignition loss	14.4
Cl (chloride)	0.4	0.5		
Ignition loss	14.4	----		
	99.5	99.4		99.5

Table 32.—Analyses of brine from Poison Lake.—Continued

III					
Sample A					
Qualitative tests		Analysis of separated salts		Analysis, basis of sample as received	
Potassium	None	Loss on heating at 105° C.	0.33	pH	6.55$^{(1)}$
Lithium	None	Ignition loss	15.53		
Boron	None			Free water (loss at 105° C.)	27.28
Barium	None				
Phosphoric anhydride	None	Hydrochloric, insoluble matter, iron and aluminum oxides	Trace	Combined water (ignition loss)	11.09
Iodine	None	Sulfur trioxide	54.84	Sulfur trioxide	40.01
Calcium	None	Magnesium oxide	26.78	Magnesium oxide	19.54
Strontium	None	Sodium oxide	0.70	Sodium oxide	0.51
Chlorine	Present	Chloride	0.84	Chlorine	0.61
Sulfur trioxide	Present				
Sodium	Present				
Magnesium oxide	Present	Bicarbonate alkalinity, calculated as sodium bicarbonate	0.11	Alkalinity, calculated as sodium bicarbonate	0.08
Bicarbonate alkalinity	Present				
			99.13		99.62

(1) Not a percentage.

Sample No. 54. From hole 5, brine that seeped in as the hole was drilled through gypsite to bedrock at 18 feet.

Sample No. 53. Brine taken from the vat that lies south of the old plant, on the east side of the lake basin. Collected in July 1945. Specific gravity, 1.40, which is unusually high and is probably the result of solar concentration. The sample was analyzed as solid salts, the constituents not being stated as parts per million. However, by comparison, on the basis of specific gravity, with the analysis of Sample No. 54, the concentration of magnesium sulfate is about 25 grams per 100 grams H_2O, sodium sulfate about 11 grams, and sodium chloride 0.3 grams. The brine is, thus, too weak for crystallization of epsomite (about 37 grams per 100 grams H_2O at 25° C.), and it would need about 19 grams of sodium chloride per 100 grams H_2O for blöedite ($Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$) to crystallize.

Sample A. A sample of brine submitted by C. A. Kearney to Laucks Laboratories, Inc., Seattle, the report being submitted by L. L. Heffuline February 6, 1940. From information in the files of the Division of Mines and Geology.

The ratio of sodium to magnesium or of sodium sulfate to magnesium sulfate, in the results of analyses in part I, table 32, is less than in part II, and potassium, which is reported in part I, probably is included with sodium in part II. For comparison on the same basis with part I the percentage of total solids in part II, A, has been recalculated in B, excluding the ignition loss and insoluble residue.

Epsomite. —The epsomite, which formed a single large lens in contrast to crystalline deposits of other saline lakes in the State by 1945 had been reduced by mining to a small remnant, about 10 feet thick (Ramstead, oral communication), which was mostly under the brine pool of the main pit. None was found in six auger test holes (see fig. 33 and the following logs) that penetrated the gypsite and encountered bedrock. The deposit is said to have been harder and less pure at the north end than at the south. A sample from the south has been analyzed with the results shown in table 33.

Table 33. —Analysis of epsomite from Poison Lake

Sample No. 81

Constituents	Percentage of total weight	Calculated compounds	Percentage of total weight
SO_3 (sulfur trioxide) ------------	34.3	$MgSO_4 \cdot 7H_2O$ (epsomite) --------	88.3
MgO (magnesia) ---------------	18.1	$MgSO_4 \cdot H_2O$ (kieserite ?) -------	11.1
Cl (chloride) ------------------	None	Insoluble residue ---------------	0.9
CO_3 (carbonate) --------------	None		
HCO_3 (bicarbonate) ------------	None		
R_2O_3 (iron and aluminum oxides) -	None		
Ignition loss at 1000° C. --------	47.0		
Insoluble residue ---------------	0.9		
	100.3		100.3
Sample dried at 26° C. Loss at 150° C.	38.7		

Sample No. 81. A colorless fragment but dark from included mud, found in the gypsite piles stripped from the main pit. The material analyzed presumably was partially dehydrated as indicated by compounds that have been calculated by the analyists. The analysis may be also calculated to show the hexahydrate of magnesium sulfate rather than epsomite and kieserite.

Epsomite, when exposed to warm dry air, forms a white porcelain-like efflorescent alteration product (Hill and Loughlin, 1925, p. 52), which resembles mirabilite ($Na_2SO_4 \cdot 10H_2O$) and natron ($Na_2CO_3 \cdot 10H_2O$) but forms less rapidly and represents only a partial loss of water of crystallization. Walker and Parsons (1927, p. 21-23) conclude, on evidence from chemical analyses presented in table 34, that this change represents alteration of epsomite to hexahydrite ($MgSO_4 \cdot 6H_2O$).

Further tests made on efflorescent material, which has lain for 3 years on a display table in the Division office and which was used for the analysis of Sample No. 81 (table 33), showed that it has absorbed 53 percent of moisture in an atmosphere of 65 percent humidity or more and at a temperature of less than 70° F. Under the microscope its index of refraction on beta is 1.480, 2E is about 43°, and the

Table 34.—Analyses of epsomite and its alteration products from Oroville and from adjacent areas in British Columbia (1)

	A	B	C	D	E	F
SO_3 (sulfur trioxide)	34.64	34.30	32.41	35.00	32.34	34.52
MgO (magnesia)	17.88	17.44	16.26	17.98	16.40	17.15
R_2O_3 (iron and aluminum oxides)	0.10	0.02	0.05	0.01	0.04	-----
Na_2O (soda) K_2O (potash)	-----	-----	0.055	-----	-----	-----
Cl (chloride)	-----	-----	0.003	-----	-----	-----
H_2O (water)	47.32	48.17	51.32	46.99	51.30	46.42
Insoluble	0.03	0.03	0.005	0.02	0.02	1.78
	99.97	99.96	100.103	100.00	100.10	99.87
Specific gravity (Pyc)	1.71					1.757

(1) Walker, T. L., and Parsons, A. L., Notes on Canadian minerals, tremolite, clinohumite, stromeyerite, natron, and hexahydrite: Toronto Univ., Studies, Geol. ser. no. 24, p. 21-23, 1927.

A. The white efflorescent crust, hexahydrite according to Walker and Parsons, that forms on epsomite when exposed to dry air. The sample, as inferred from their description, came from an open pit at Poison Lake. Analysis by H. C. Rickaby.

B. From a prospecting trench, about 200 feet from the inclined shaft at Poison Lake. Hexahydrite mixed with epsomite. Analysis by H. C. Rickaby.

C. Epsomite from Basque, near Ashcroft, B. C. Analysis by E. W. Todd.

D. Same sample as C, but after it had been exposed to the dry air of a steam heated laboratory for several months during the winter of 1925-26. Analyzed in May 1926 by H. C. Rickaby.

E. Same material as D but analyzed in October 1926, Walker and Parsons stating: "it would appear that, with the humid conditions which prevailed in Toronto in the summer of 1926, the material again took on the extra molecule of water." Analysis by H. C. Rickaby.

F. Hexahydrite from Bonaparte River, B. C. Analysis by R. A. A. Johnston, who described and named the mineral in Geol. Survey Canada Summary Rept. 1910, p. 256-257, 1911.

sign is negative. Most of the material consists of aggregates of minute plates, the maximum and minimum indices of refraction of which lie between those given for epsomite and kieserite (Winchell, 1933, p. 103-104, 106).

Although the atmospheric condition under which epsomite starts to effloresce has not been determined, it seems to be stable when the humidity is 55 percent and the temperature 75° F.; but efflorescence probably begins very slowly in somewhat dryer and warmer air, becoming rapid when the humidity is 20 percent and the temperature more than 100° F.

Drying tests of epsomite, which, however, failed to consider its apparently strong hygroscopic nature, show that 90 percent of its water of crystallization can be removed in a specially equipped gas-fired rotary dryer (Carnochan, 1928, p. 129-130).

Gypsite.—Gypsum, except as thin layers or as clusters of relatively large crystals, was not recognized at first in the development of the epsomite deposits, especially at Bitter Lake, but it had been noticed in the mud of the epsomite lakes in Canada (Goudge, 1926, p. 65-66). It occurs as the earthy or granular form known as gypsite and is the most abundant constituent of the lake-bed material that encloses the epsomite. It becomes less pure at depth, especially below 10 feet, as may be seen from the following logs and analyses:

Hole 1

	Ft	in
Gray gypsite	4	
Brown to dark-gray gypsite	2	
Gray gypsite	4	
Gray, changing to darker gypsite	3	
Light-gray gypsite	1	
Dark-gray gypsite	10	6
Gravel, some pebbles of coarse-grained marble that contains pyrite		6

Hole 2

(near "island" of schist)

	Ft	in
Nearly pure gypsite	3	
Gray gypsite	7	
Gravel and mud, near bedrock	1	

Hole 3

(near north end of main pit)

	Ft	in
Gray to dark-gray gypsite intermixed with mud	30	

Hole 4

	Ft	in
Epsomite		1
Black mud	1	
Light-gray gypsite	10	
Dark-gray or muddy gypsite on bedrock	5	

Hole 5	Ft	in
Light-gray, rather pure gypsite	3	
Gypsite with little mud	7	
Gray, muddy gypsite	7	
Gravel, on bedrock	1	

Hole 6	Ft	in
Epsomite		1
Black mud		10
Light-gray, rather pure gypsite	9	
Gray, or muddy gypsite	5	
Mud and gravel, on bedrock	3	

Table 35. —Analyses of salts from Poison Lake

I. Constituents in percentage of total weight

Sample no.	57	58	59	60
Insoluble residue	78.5	77.4	77.8	78.4
Ca (calcium)	5.1	5.1	4.6	4.5
Mg (magnesium)	0.8	1.0	1.0	0.9
Al (aluminum)	None	None	None	None
Fe (iron)	None	None	None	None
Na (sodium)	0.2	0.3	0.3	0.4
HCO_3 (bicarbonate)	None	None	None	None
CO_3 (carbonate)	None	None	None	None
SO_4 (sulfate)	15.8	16.6	15.3	14.8
Cl (chloride)	None	None	None	None
	100.4	100.4	99.0	99.0

II. Combinations in percentage of total weight

Sample no.	57	58	59	60
Insoluble residue	78.5	77.4	77.8	78.4
NaCl (sodium chloride)	None	None	None	None
Na_2CO_3 (sodium carbonate)	None	None	None	None
$NaHCO_3$ (sodium bicarbonate)	None	None	None	None
R_2O_3 (iron and aluminum oxides)	None	None	None	None
$CaSO_4$ (calcium sulfate)	17.5	17.3	15.7	15.2
$MgSO_4$ (magnesium sulfate)	3.8	4.9	4.7	4.3
Na_2SO_4 (sodium sulfate)	0.6	0.8	0.8	1.1
	100.4	100.4	99.0	99.0

Table 35.—*Analyses of salts from Poison Lake*.—Continued

III. Constituents in percentage of total weight

Sample no.	57A	58A	59A	60A	70	71	72	A
CaO (lime)	32.5	26.8	20.9	17.5	28.1	29.0	15.3	12.61
MgO (magnesia)	6.7	6.3	4.2	5.1	4.4	6.9	6.4	-----
Al_2O_3 (alumina)	1.7	4.3	6.7	8.0	4.4	3.2	8.0	-----
Fe_2O_3 (iron oxide)	0.4	0.4	1.5	1.5	0.4	0.7	2.3	-----
Na_2O (soda)	0.2	0.8	1.4	1.7	----	----	1.6	-----
SiO_2 (silica)	5.6	14.6	28.9	32.7	15.4	8.5	32.6	-----
CO_2 (carbon dioxide)	5.9	5.7	4.2	5.2	3.8	5.3	4.8	-----
SO_3 (sulfur trioxide)	45.6	39.4	26.2	24.0	40.4	42.9	23.8	25.19
Sulfide	----	----	----	----	Trace	----	----	-----
Cl (chloride)	None	None	None	0.4	0.1	None	None	-----
Ignition loss	8.0	8.0	7.3	7.4	7.1	8.3	9.9	11.43
	100.7	100.6	97.1	97.9	100.3	99.5	99.9	

IV. Combinations in percentage of total weight

Sample no.	57A	58A	59A	60A	70	71	72
$CaSO_4$ (calcium sulfate)	72.7	60.0	38.4	33.2	68.2	70.4	37.1
$MgSO_4$ (magnesium sulfate)	3.9	4.7	4.7	4.4	0.4	2.2	2.1
Na_2SO_4 (sodium sulfate)	0.4	1.8	0.9	2.7	----	----	1.1
NaCl (sodium chloride)	----	----	----	0.6	----	----	----
$MgCl_2$ (magnesium chloride)	----	----	----	----	0.1	----	----
$CaCO_3$ (calcium carbonate)	4.6	3.7	9.1	6.9	----	----	----
$MgCO_3$ (magnesium carbonate)	6.3	1.8	0.3	----	2.6	1.5	1.4
$3MgCO_3 \cdot Mg(OH)_2$ (magnesium carbonate-magnesium hydroxide)	3.8	7.4	0.4	4.9	5.8	10.6	9.6
$Mg(OH)_2$ (magnesium hydroxide)	----	----	3.5	1.5	----	----	----
Na_2O (soda)	----	----	1.0	----	----	----	1.1
SiO_2 (silica)	5.6	14.6	28.9	32.7	15.4	8.5	32.6
Al_2O_3 (alumina)	1.7	4.3	6.7	8.0	4.4	3.2	8.0
Fe_2O_3 (iron oxide)	0.4	0.4	1.5	1.5	0.4	0.7	2.3
H_2O (water)	1.3	1.9	2.0	1.5	3.0	2.4	4.6
	100.7	100.6	97.1	97.9	100.3	99.5	99.9

Table 35.—Analyses of salts from Poison Lake.—Continued

Sample No. 57. From hole 5, from 0 to 3 feet.

Sample No. 58. From hole 5, from 3 to 10 feet.

Sample No. 59. From hole 5, from 10 to 17 feet.

Sample No. 60. From hole 5, from 17 to bedrock at 18 feet.

The analyses of samples 57 to 60 represent the material leached by 150 milliliters of hot water applied in several portions. Complete analyses of these same samples (including items soluble in hot water leaches) are shown in part III of the table as samples 57A to 60A.

Sample No. 70. From hole 1, from 0 to 6 feet. A 5-gram portion of this sample, after being washed with water and the mud decanted but unavoidably including some fine gypsum crystals, was found to contain 64 percent of gypsum by weight.

Sample No. 71. From hole 1, from 6 to 11.7 feet.

Sample No. 72. From hole 1, from 11.7 to bedrock at 25 feet.

Sample A, part III. A sample of the gypsite submitted by C. A. Kearney to Laucks Laboratories, Inc., Seattle, the incomplete or partial analysis being reported by L. L. Heffuline on February 6, 1940. From information in the files of the Division of Mines and Geology. A calculation of this analysis gives 54.15 percent of gypsum ($CaSO_4 \cdot 2H_2O$).

Part IV. In calculating the combinations in part IV from the oxides stated in part III, it is obvious that the predominant items, lime and sulfur trioxide, are combined as gypsum, especially when gypsum can be identified mineralogically as making up a large part of the samples. But most of the other minor combinations have been computed in the usual manner by assigning, rather arbitrarily, certain elements or compounds to combine with others, none of the combinations being conclusively identified mineralogically. However, in part III it will be noticed that the percentages of MgO and CO_2 increases or decreases concurrently, from one analysis to another, suggesting that these compounds are tied together as magnesium carbonate in the samples, and that the MgO is not a component of the clay in the mud of the lake bed. Similarily, it is believed that the Al_2O_3 and the Na_2O that remains after NaCl and Na_2SO_4 have been computed are combined as clay. For $MgSO_4$, only enough of the MgO was used to equal the $MgSO_4$ calculated from the analyses of samples 57 to 60 (parts I and II), the remaining MgO being assigned to CO_2 for $MgCO_3$, and $3MgCO_3 \cdot Mg(OH)_2$ (hydromagnesite? minus three molecules of water). Samples 57A to 60A and 70 to 72, before analysis, were dried in an oven at a temperature of 150° C., 22° above that at which gypsum loses three-fourths of its water and 13° below that at which all of its water is expelled. The percentage of residual water, assumed to be that of the ignition loss minus CO_2, is insufficient to compute gypsum ($CaSO_4 \cdot 2H_2O$) and hydromagnesite ($3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$). A computation of hydrous salts, which includes the theoretical amount of water needed in addition to that stated as remaining in the sample, has been made for the analysis of Sample No. 76, table 38.

Other constituents.—As may be seen from the analyses and as explained in the key to table 35, other constituents regarded as present in the material of the lake bed include magnesium sulfate; sodium sulfate in minor amounts; basic magnesium carbonate (hydromagnesite?), which probably includes free magnesite; and clay. All components are minute and have not been identified with certainty under the microscope. The sulfates of magnesium and sodium are probably present in the dried sample as precipitates from the brine, and these may be leached and recovered separately. The presence of magnesium carbonate is indicated by solubility tests in hot hydrochloric acid. Under the microscope considerable volcanic glass and a few diatoms were observed.

As indicated in part IV of table 35 certain minor components, as well as calcium carbonate, appear to be irregularly distributed in the lake bed. This condition may actually exist, but is seems more likely, on the other hand, to be the result of errors, partly in the analyses and partly in assumptions of simple rather than more complex combinations in the computations that involve balancing of acidic and basic radicals. An analysis presumably of lake bed material made in 1951 by Laucks Laboratories, Inc., of Seattle showed 85 percent gypsum, 5 percent epsomite, 6 percent insoluble, 5 parts per million (ppm) copper, 10,000 ppm iron, 900 ppm manganese, 300 ppm titanium, 30 ppm nickel, 4,000 ppm strontium, 400 ppm lead, 5,000 ppm aluminum, 200 ppm vanadium, 0.8 ppm silver, 3,000 ppm sodium, and 8,000 ppm potassium.

Tonnage Estimate

The proportions in tons of salts present in the lake bed are based on compounds calculated from analyses, on the assumption that the brine is present throughout in a pore space of 30 percent, and on an average depth of 10 feet.

The brine (Sample No. 54, table 32) which has a specific gravity of 1.2 (75 pounds per cubic foot) and a salinity of 18.5 percent, contains 15,000 tons of solids to a depth of 10 feet. Of this, 12,000 tons is magnesium sulfate, 2,400 is sodium sulfate, 210 is potassium sulfate, and about 200 is sodium chloride and sodium carbonates.

The solids to an average depth of 10 feet throughout the 19-acre area, exlusive of the lenticular body of epsomite (Sample Nos. 57A and 58A, table 35), comprise 537,000 tons, of which 355,000 is calcium sulfate, 23,000 is magnesium sulfate, 6,000 is sodium sulfate, 22,000 is calcium carbonate, and 26,000 is combined magnesium salts (hydromagnesite and (or) magnesite). The amount of epsomite (in the original lenticular body) in 1945 was probably less than 10,000 tons.

Wannacut Lake

Location, Size, and Access

Wannacut Lake, which includes nearly 334 acres, lies in parts of secs. 11, 12, 13, 14, and 24, T. 39 N., R. 26 E., and is between 5 and 6 miles southwest of Oroville. It is reached by a graveled road that connects with U.S. Highway 97 (fig. 34).

Topography and Geology

The lake lies in a southwardly widening valley at an altitude of 1,847 feet (as shown on the map of the Chopaka quadrangle of the U.S. Geological Survey), and is for the most part 1,000 to 1,500 feet below ridges and summits on the west, north, and east. A low narrow divide crossed by the road to Oroville is just east of the north end of the lake, and there are other low divides toward the southeast a few hundred feet above the lake.

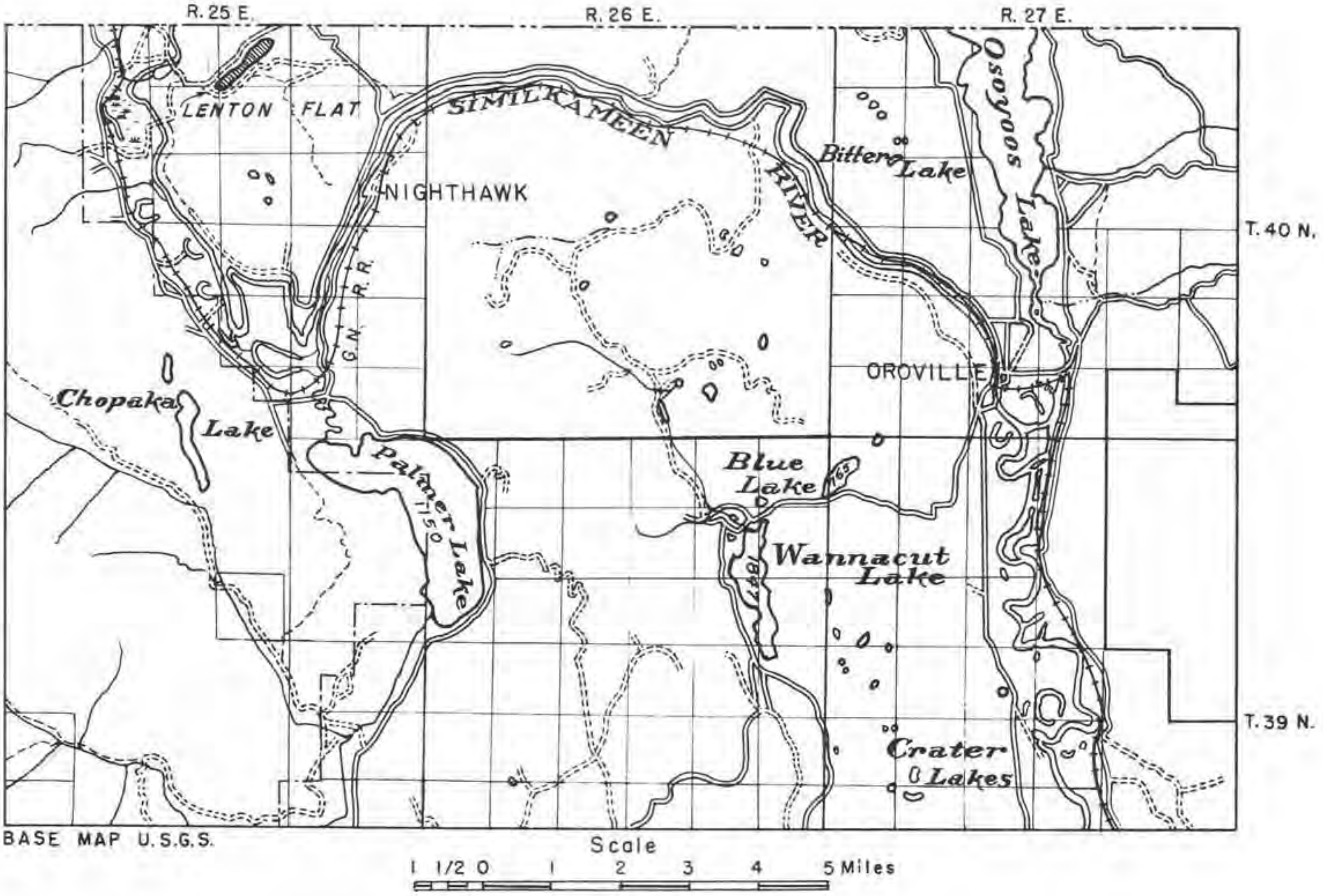
The drainage basin is underlain in part by granite but mostly by metasedimentary rocks, which include quartzose rocks, argillites, schists, and lenses of limestone. In places the metasedimentary rocks contain sulfides of iron, copper, lead, silver, arsenic, and antimony.

The lake has formed behind a dam of apparently impermeable glacial deposits in an old drainage channel, causing the water to be contained and concentrated through evaporation.

The Salts

The Wannacut Lake water is a weak brine, about one-third the concentration of sea water; and its composition, shown in table 36, is very similar to that of Poison Lake (table 32) and of epsomite lakes in British Columbia (Goudge, 1926, p. 73-78), which are mentioned by Clarke (1924, p. 152-180, 243), as being very unusual saline deposits.

A few determinations of depth are as follows: 17 feet at point about 200 feet from the west shore in the widest part of the lake, 37 and 67 feet near the center, and 80 feet midway between the center and the east shore.



BASE MAP U.S.G.S.

Figure 34.—Map of Oroville-Nighthawk district showing lakes.

The following tonnage estimate has been made on the basis of the percentage of conventional compounds that have been calculated from the analysis, and on an assumed average depth of 50 feet:

	Short tons
Magnesium sulfate	155,000
Sodium sulfate	47,900
Calcium sulfate	15,900
Sodium carbonate	4,500
Sodium chloride	2,200

Table 36.—Analysis of brine from Wannacut Lake

Sample No. 55

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium)	220	2.2	NaCl (sodium chloride)	1.1
Mg (magnesium)	1,370	13.7	Na_2CO_3 (sodium carbonate)	0.5
Al (aluminum)	None	None	$NaHCO_3$ (sodium bicarbonate)	1.6
Fe (iron)	None	None	$CaSO_4$ (calcium sulfate)	7.4
Na (sodium)	795	7.9	$MgSO_4$ (magnesium sulfate)	68.0
HCO_3 (bicarbonate)	120	----	Na_2SO_4 (sodium sulfate)	21.0
CO_3 (carbonate)	30	1.4(1)		
SO_4 (sulfate)	7,370	73.8		
Cl (chloride)	70	0.7		
	9,975	99.2		99.6

Specific gravity at 26° C. (78.8° F.) ------ 1.006

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 55. From the bottom at 37 feet, near the center of the lake; specific gravity, 1.020 at 17° C. and 1.015 at 22.5° C. The specific gravity of the surface water was 1.010, and as solutions of sodium and magnesium salts change in density between 0.003 and 0.005 per 5° change in temperature, the lake water at depth is more concentrated than it is on the surface. Calcium sulfate, which crystallizes from solution at a temperature of 25° C. and at a concentration of 0.17 grams per 100 grams H_2O, is found here at a concentration of about 0.07 grams per 100 grams of H_2O.

Blue Lake

Blue Lake is just northeast of Wannacut Lake, in the $W\frac{1}{2}$ sec. 6, T. 39 N., R. 27 E., along the road to Oroville (fig. 34). The lake was not examined in detail. As its specific gravity was low (1.006) in the middle of the summer, it seems not to have commercial possibilities. However, certain seasonal changes, which have attracted the attention of people living in the vicinity, may be mentioned here in connection with the general problem of biochemical processes in saline lakes. It is said that during the fall the lake turns from a bluish to reddish color with pronounced bubbling and evolution of a fetid gas, which may be hydrogen sulfide that results from the action of sulfate-reducing bacteria (Wells, 1923, p. 31-32; Twenhofel, 1939, p. 77, 109, 118, 304). A sample of the water collected by Dell Hart of Oroville and sent to the State College of Washington was analyzed (semiquantitatively) by Paul Vlasoff as follows:

K (potassium)	greater than 30 ppm
Na (sodium)	greater than 20 ppm
P (phosphorus)	None
Ca (calcium)	None
Mg (magnesium)	None
Cl (chloride)	200 ppm
SO_4 (sulfate)	greater than 1,000 ppm
Fe (iron)	None
Al (aluminum)	15 ppm
Mn (manganese)	None
pH (hydrogen ion concentration)	8.8

Bitter Lake

Location, Size, and Access

Bitter Lake, which covers 3 acres and is known also as Epso, Salts, Poison, Hot, and Spotted Lake, lies at the NE. cor. sec. 18, and the SE. cor. sec. 7, T. 40 N., R. 27 E., about 4 miles north-northwest of Oroville (figs. 34 and 35). An old road to the deposit, which needs repair to be easily passable by car, joins the road to Nighthawk at a point about 2 miles northwest of Oroville.

Topography and Geology

The small basin, in which the lake lies at an altitude of about 2,000 feet, is on a broad rather rugged sparsely timbered ridge that projects southeastward from Kruger Mountain, between Osoyoos Lake (altitude 913 feet) on the northeast and the Similkameen River on the southwest.

The underlying rocks of the basin, comprising mostly argillites and interbedded lenses of limestone, are considered to be of late Paleozoic age, and are rather extensively mineralized, particularly with sulfides of iron. Solutions that carried sulfate and acid oxidation products of these sulfides are believed to have leached magnesium and calcium from the bedrock to form the salts of the lake bed (Handy, 1916, p. 25; Jenkins, 1918, p. 638-644; Patty and Glover, 1921, p. 105-107)[1]. The

---

[1] See also Reinecke, L., Mineral deposits between Lillooet and Prince George, British Columbia: Canada Geol. Survey Mem. 118, p. 54-55, 1920.

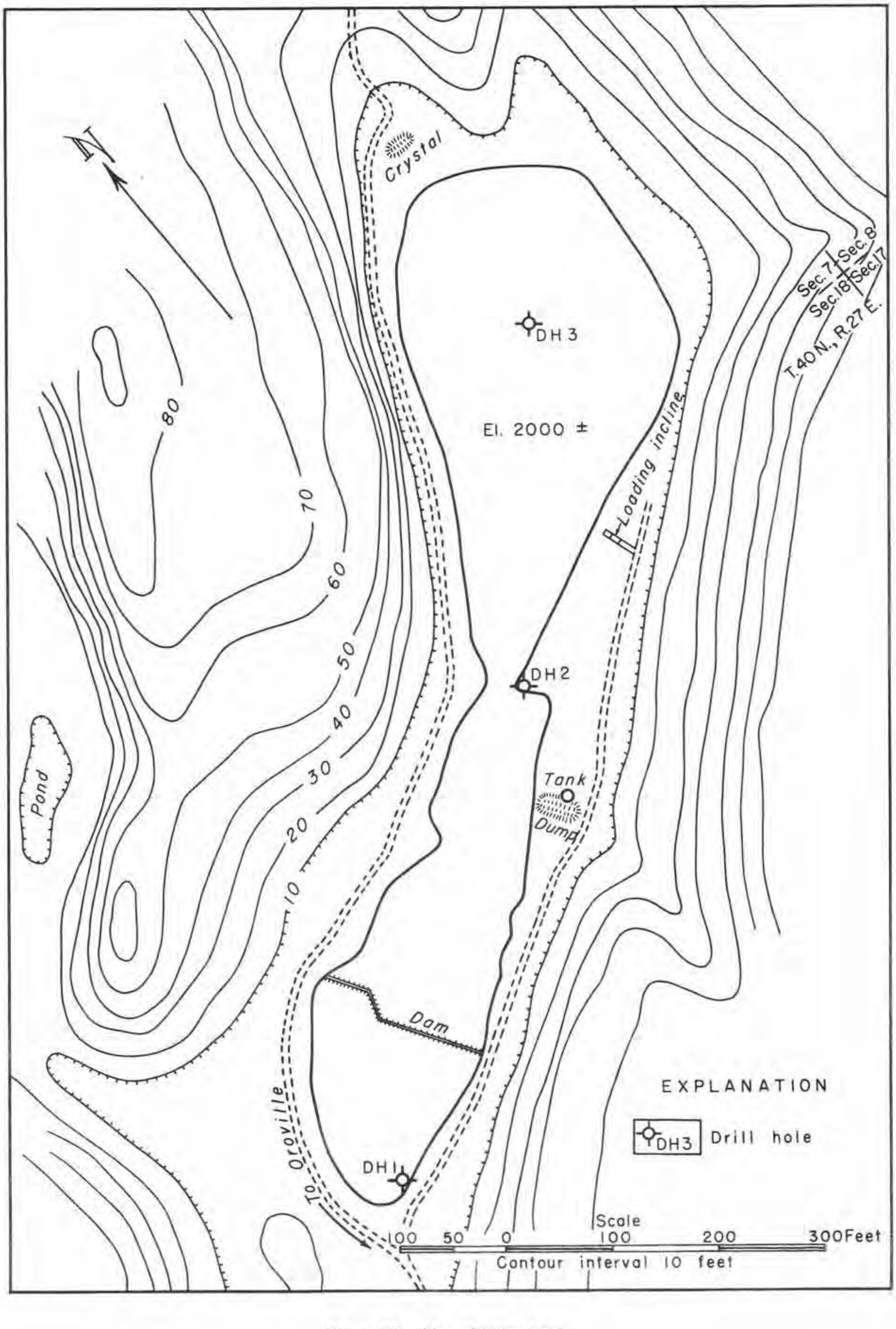


Figure 35.—Map of Bitter Lake.

basin, like many others in this region, very probably is the result of glacial scouring and damming of a pre-existing drainage channel, in contrast to the recurrent local view that it, as well as Poison Lake, is a volcanic crater.

History and Production

Pardee, presumably in conjunction with his mapping of the Colville Indian Reservation for the U.S. Geological Survey, visited the lake in 1913, and again in 1917 (Hill and Loughlin, 1925, p. 52). Production did not start in this State or in British Columbia until 1915 (Handy, 1916, p. 25; Cummings, 1940, p. 60-61), when 250 tons per day of 98 percent-pure epsom salt was reported shipped from Oroville by the Stewart-Calvert Co. of Seattle, to Chicago, New York, and Pittsburg via the Great Northern Railway at rates of $10 and $15 per ton (Anon., 1915, p. 870). Production continued to be large through 1916 (Patty and Glover, 1921, p. 105). According to Jenkins (1918, p. 638-644) much of the salt was pure enough to be readily pulverized, graded, and sacked as it came from the lake bed. The total production by the Stewart-Calvert Co., to the end of its operations in 1920, is not known, although the company sold 1,500 tons from Spotted Lake and 1,000 tons from Clinton Lake, which are respectively 12 miles and 160 miles northwest of Oroville in British Columbia. The material from Spotted Lake, because of its high content of sodium sulfate, was sold to the tanning industry.

A refining plant, later destroyed by fire, was located along the Similkameen River just west of Oroville, and has been described in the British Columbia Minister of Mines report for 1918, cited by Cummings (1940, p. 60-61), as follows:

> First the raw product, a crystalline salts dug from the lake, is dissolved in tanks by means of steam; from thence the liquid salts pass through launders into the evaporating-tanks, where it is brought to a certain density; then run into other tanks lined with cement (magnesite), where it is cooled and recrystallized; the liquid remaining being drawn off and pumped back into the boiling tank for further treatment. The crystals are then put through a Watson Laidlaw dryer with a 2-inch basket having a capacity of 15 tons every ten hours. After this preliminary drying the crystals pass through a chute into a rotary circular dryer, 25 feet long by 4 feet in width, which revolves from eight to ten times a minute. The screens at the discharge end have meshes varying from 1/2 by 1/16 to 3/32 by 1/2 inch. Directly outside the discharge end of the screen are a set of steam-coils so placed that the fan draws the hot air over the revolving salts. The temperature is kept below 80 degrees, so that the salts will not melt.
>
> Two grades of these salts are shipped, the finer crystals being used for medicinal purposes, whilst the coarser ones are used for tanning leather.

The epsomite was mined (Jenkins, 1918, p. 640; Hill and Loughlin, 1925, p. 52) by digging in the circular salt pans or "spots"; later, solutions were used, obtained by pumping water or weak brine into a series of holes that were drilled through the surficial mud of the lake bed, the stronger brine, resulting therefrom, then being pumped through a pipeline to the refining plant; still later, underground methods were employed.

The Salts

Brine.—In 1945 most of the lake was covered with brine, which had a maximum depth of a few feet in pools near its center, apparently where a considerable part of the epsomite was mined. Its composition, as shown in table 37, is marked by a preponderance of sodium sulfate, unlike the brine of Poison and Wannacut Lakes (tables 32 and 36) and of the magnesium sulfate lakes of British Columbia (Goudge, 1926, p. 62-80).

Table 37.—Analysis of brine from Bitter Lake

Sample No. 56

Constituents	Parts per million	Percentage of total solids	Conventional combinations	Percentage of total solids
Ca (calcium) ----------	190	0.1	NaCl (sodium chloride) ---------	1.3
Mg (magnesium) --------	1,790	1.4	Na_2CO_3 (sodium carbonate) -----	0.4
Al (aluminum) ---------	None	None	$NaHCO_3$ (sodium bicarbonate) ---	0.2
Fe (iron) --------------	None	None	$CaSO_4$ (calcium sulfate) --------	0.5
Na (sodium) -----------	36,000	29.9	$MgSO_4$ (magnesium sulfate) ------	7.3
HCO_3 (bicarbonate) ----	250	----	Na_2SO_4 (sodium sulfate) --------	90.0
CO_3 (carbonate) -------	330	0.4 (1)		
SO_4 (sulfate) ----------	80,700	67.1		
Cl (chloride) ----------	960	0.7		
	120,220	99.2		99.7

Specific gravity at 26° C. (78.8° F.) ------ 1.105

(1) Includes bicarbonate reduced to normal carbonate.

Sample No. 56. From the bottom of a rather shallow pool near old workings. Collected in July 1945.

Epsomite.—The original surface of the lake, like many others in this region, and as described by Jenkins (1918, p. 638-644), showed many more-or-less circular salt pans, particularly in the center and along the east shore, which were individually surrounded by mud. Jenkins believed that these pans were connected underground to a continuous bed of epsomite. None, however, could be seen at the time of examination, and no crystalline epsomite was found in auger test holes. It seems that no substantial amount of it remains in the lake bed, although Mr. Krusoff (Oral communication) of Oroville is of the opinion that only about half of it was mined. Pardee's description (Hill and Loughlin, 1925, p. 52) of the deposit, which may be an aid in further exploration, is as follows:

> Excavations made in the bed of the lake, which had been pumped virtually dry at the time of the examination, show many lenslike bodies of epsomite, the largest 15 feet thick, which was embedded in clay, both the clay and epsomite being covered by the persistent layer of clay that forms the present lake bed. The surface of this layer bears only thin crusts of epsomite, and the presence of the massive lenslike bodies beneath would hardly be suspected from a casual examination. These bodies are very coarsely crystalline and when freshly exposed are as clear as ice, but after exposure to the air for a short time the crystals lose water by evaporation and become white and opaque, showing an almost porcelainlike luster. The material is fairly pure, though most of the crystals inclose grains and masses of clay, and toward their margins and the bodies become more or less split into layers that are interbedded with the clay.

About 5 tons of partially dehydrated epsomite (hexahydrite ?) remained in a pile at the north end of the lake in 1945.

Gypsite.—The lake-bed material, which both Pardee and Jenkins regarded as mud or clay enclosing the epsomite, is mostly gypsite, and has been analyzed with the results shown in table 38. Its composition is comparable to that of Poison Lake and Lenton Flat and of magnesium sulfate lakes in British Columbia (Goudge, 1926, p. 65-66), although its content of gypsum is about 15 percent below the average of certain gypsite deposits of the Western States (Stone and others, 1920, p. 60-97). Three auger test holes were bored (fig. 26), and the results of analysis of material in two of them are given in table 33. Their logs are as follows:

Hole 1

(at edge of soft mud)

	Ft
Black mud	
Mud and gypsite	1
Gypsite	2
Gravel and mud, on bedrock	2

Hole 2

(at edge of brine)

Black mud	1
Light greenish-gray gypsite	2
Gypsite, slightly coarser	3
Gypsite, coarser still	2
Black smelly mud with minute shiny crystals of gypsum	5
Black compact mud, very difficult to drill, bottom not reached	7

Hole 3 (on top of dike, 1½ to 2 feet above brine level)	Ft	in
Gypsite	13	
Black mud with shiny gypsum crystals	2	6
Black and green mud in narrow alternating bands containing minute gypsum crystals	3	
Gray mud with tabular gypsum crystals up to 1/32 by 3/8 by 1/2 inch	1	6
Gravel, too difficult to drill		3

Other constituents.—Calculation of the analyses of the lake-bed material into compounds (table 38, Sample No. 76, A, B) shows that gypsum, basic magnesium carbonate, normal magnesium carbonate, magnesium sulfate, clay, and possibly magnesium chloride are present, although none, with the exception of gypsum, have been conclusively identified mineralogically under the microscope. As a further check on the validity of the calculations, it was found that a hot-water leach of the material gave strong tests for both magnesium and sulfate radicals and that the residue, which effervesced only in hot concentrated hydrochloric acid, gave a strong magnesium test, indicating the presence of magnesium carbonate. These materials are fine grained and are believed to be intermixed with the gypsite.

Tonnage Estimate

The proportions of salts, in terms of tons, based on calculations of the analyses, are as follows:

Brine	Tons
Sodium carbonate	10
Sodium bicarbonate	5
Sodium sulfate	2,800
Magnesium sulfate	220
Calcium sulfate	15
Sodium chloride	400

Intermixed solids of the lake bed	
Gypsum	86,000
Basic magnesium carbonate	16,000
Magnesite	11,000
Epsomite	8,900

Table 38.—Analyses of salts from Bitter Lake.

Constituents in percentage of total weight

Sample no.	76	79	80
CaO (lime)	25.1	25.6	18.6
MgO (magnesia)	12.8	11.4	7.0
Al_2O_3 (alumina)	1.2	1.9	7.4
Fe_2O_3 (iron oxide)	0.5	0.6	1.5
SiO_2 (silica)	5.2	7.7	25.4
CO_2 (carbon dioxide)	10.5	10.1	5.5
SO_3 (sulfur trioxide)	38.4	37.9	27.6
Sulfide	Trace	Trace	Trace
Cl (chloride)	0.9	1.0	1.3
Ignition loss	16.4	15.3	12.1
	100.5	101.4	100.9

Combinations in percentage of total weight

Sample No.	76		79	80
	A	B		
$CaSO_4$ (calcium sulfate)	60.9	65.75(1)	62.1	45.1
$MgSO_4$ (magnesium sulfate)	3.9	6.83(2)	2.1	1.6
$MgCl_2$ (magnesium chloride)	1.2	1.02	1.3	1.7
$MgCO_3$ (magnesium carbonate)	9.9	8.45	12.0	3.6
$3MgCO_3 \cdot Mg(OH)_2$ (magnesium carbonate-magnesium hydroxide)	12.5	12.46(3)	9.0	8.5
SiO_2 (silica)	5.2	4.44	7.7	25.4
Fe_2O_3 (iron oxide)	0.5	0.42	0.6	1.2
Al_2O_3 (alumina)	1.2	1.02	1.9	7.4
H_2O (water)	5.2	-----	4.7	6.1
	100.5	100.39	101.4	100.9

(1) Stated as gypsum. (2) Stated as epsomite. (3) Stated as hydromagnesite.

Sample No. 76. From hole 2, from 0 to 20 feet.
Sample No. 79. From hole 3, from 0 to 13 feet.
Sample No. 80. From hole 3, from 13 to bedrock at 20 feet.

Lenton Flat

Location, Size, and Access

Lenton Flat, with an area of about 80 acres in sec. 3, T. 40 N., R. 25 E., lies about 2½ miles northwest of Nighthawk, the nearest station of a branch of the Great Northern Railway. The distance by road from Nighthawk is between 3 and 4 miles (fig. 34).

Topography and Geology

The deposit, an old lake bed that lies in the southwest corner of a larger depression, is bounded by the Similkameen Valley on the southwest and by Kruger and Richter Mountains in British Columbia on the northeast. It drains westward through a low gap into the Similkameen River, which, at an altitude of about 1,200 feet, is some 150 feet lower than Lenton Flat.

The bedrock of the depression is mainly Similkameen Granite but may include small areas of alkaline syenite and metamorphic rocks (Campbell, 1939, p. 527-549).

The Salts

The lake bed is about a mile long and ranges in width from 400 feet on the southwest to 1,000 feet on the northeast. Most of it is covered by a sparse growth of grass or weeds, except on the southwest where, during the summer months, a powdery salt crust forms. An auger test hole drilled in the salt crust showed, in its upper 6 feet, a gray silty mud, and in its lower 10 feet black to gray mud and 1 foot of water or brine. The analyses in table 39 show that, in the upper part, the lake-bed material is mainly calcium sulfate (gypsite), basic magnesium carbonate (hydromagnesite?), and calcium carbonate, in order of abundance. The composition of this deposit is much like that of Poison Lake and Bitter Lake, although here the best grade of gypsite seems to be in a shallower zone near the surface. Assuming that similar material extends throughout the lake bed to a depth of at least 5 feet, there are available approximately 1,000,000 tons of intermixed gypsite, basic magnesium carbonate, calcium carbonate, and other constituents including clay.

Table 39.—Analyses of salts from Lenton Flat.

Constituents in percentage of total weight		
Sample no.	77	78
CaO (lime)	29.7	21.6
MgO (magnesia)	8.8	3.8
Al_2O_3 (alumina)	1.0	8.4
Fe_2O_3 (iron oxide)	0.5	1.7
Na_2O (soda)	----	1.4
SiO_2 (silica)	6.4	29.0
CO_2 (carbon dioxide)	10.3	6.6
SO_3 (sulfur trioxide)	37.4	22.8
Sulfide	Trace	Trace
Cl (chloride)	0.2	1.3
Ignition loss	16.3	9.1
	100.3	99.1

Conventional combinations in percentage of total weight		
Sample no.	77	78
$CaSO_4$ (calcium sulfate)	63.5	37.4
$MgSO_4$ (magnesium sulfate)	----	----
Na_2SO_4 (sodium sulfate)	----	1.4
$MgCl_2$ (magnesium chloride)	0.2	----
NaCl (sodium chloride)	----	2.1
$CaCO_3$ (calcium carbonate)	6.6	11.0
$MgCO_3$ (magnesium carbonate)	1.5	----
$3MgCO_3 \cdot Mg(OH)_2$ (magnesium carbonate-magnesium hydroxide)	15.4	4.2
$Mg(OH)_2$ (magnesium hydroxide)	----	2.4
SiO_2 (silica)	6.4	29.0
Fe_2O_3 (iron oxide)	0.5	1.7
Al_2O_3 (alumina)	1.0	8.4
H_2O (water)	5.1	1.5
Sulfide	tr	tr
	100.2	99.1

Sample No. 77. From drill hole at west end of lake bed, from 0 to 6 feet.
Sample No. 78. Same drill hole, from 6 to 16 feet.

REFERENCES CITED

Allison, I. S., 1947, Sodium salts of Lake County, Oregon: Oregon Dept. Geology and Mineral Industries GMI Short Paper 17, 12 p.

Bateman, A. M., 1942, Economic mineral deposits. New York, John Wiley and Sons, 898 p.

Bennett, W. A. G., 1950, Salines at Carbonate Lake, Grant County, Washington [abs.]: Geol. Soc. America Bull., v. 61, no. 12, pt. 2, p. 1520.

Bretz, J H., 1932, The channeled scabland: 16th Internat. Geol. Cong. United States 1933, Guidebook 22, Excursion C-2, 16 p.

——————1959, Washington's channeled scabland: Washington Div. Mines and Geology Bull. 45, 57 p.

Bretz, J H., Smith, H. T. U., and Neff, G. E., 1956, Channeled scabland of Washington—new data and interpretations: Geol. Soc. America Bull., v. 67, no. 8, p. 957-1049.

Byers, H. G., 1902, Potable and mineral water: Washington Geol. Survey Ann. Rept. 1901, pt. 5, p. 1-11

Campbell, C. D., 1939, The Kruger alkaline syenites of southern British Columbia: Am. Jour. Science, v. 237, no. 8, p. 527-549.

Carnochan, R. K., 1928, The drying of epsom salts. In Investigations in ore dressing and metallurgy, 1927, pt. 3: Canada Dept. Mines, Mines Branch Rept. 695, p. 129-130.

Chatard, T. M., 1890, Natural soda—its occurrence and utilization: U.S. Geol. Survey Bull. 60, p. 27-101.

Clarke, F. W., 1924, The data of geochemistry, 5th ed.: U.S. Geol. Survey Bull. 770, 841 p.

Collins, W. D., 1924, Mineral waters: U.S. Geol. Survey Mineral Resources U.S. 1921, pt. 2—Nonmetals, p. 229-236.

Cummings, J. M., 1940, Saline and hydromagnesite deposits of British Columbia: British Columbia Dept. Mines Bull. 4, 160 p.

Dub, G. D., 1947, Owens Lake, source of sodium minerals: Am. Inst. Mining and Metall. Engineers Tech. Pub. 2235, Mining Technology, v. 11, no. 5, 13 p.; Trans., v. 173, p. 66-78.

Fisher, L. C., 1941, Climate in Washington. In Climate and man: U.S. Dept. Agriculture Yearbook 1941, p. 1170-1181.

Foshag, W. F., 1935, Burkeite, a new mineral species from Searles Lake, Calif.: Am. Mineralogist, v. 20, no. 1, p. 50-56.

Gale, H. S., 1915, Salines in the Owens, Searles, and Panamint basins, southeastern California: U.S. Geol. Survey Bull. 580, p. 251-323.

Glover, S. L., 1936, Nonmetallic mineral resources of Washington, with statistics for 1933: Washington Div. Geology Bull. 33, 135 p.

Goudge, M. F., 1926, Sodium carbonate in British Columbia. In Investigations of mineral resources and the mining industry, 1924: Canada Dept. Mines, Mines Branch Rept. 642, pt. 5, p. 81-102.

Handy, F. M., [1916?], An investigation of the mineral deposits in northern Okanogan County: Washington State Coll. Dept. Geology Bull. 100, 27 p.

Harding, S. T., 1942, Lakes. In Meinzer, O. E., ed. Physics of the earth, pt. 9—Hydrology. New York, McGraw-Hill, p. 220-243.

Hill, J. M., 1930, Magnesium and its compounds: U.S. Bur. Mines Mineral Resources 1927, pt. 2—Nonmetals, p. 167-179.

Hill, J. M., and Loughlin, G. F., 1925, Magnesium and its compounds: U.S. Geol. Survey Mineral Resources U.S. 1922, pt. 2—Nonmetals, p. 41-57.

Jenkins, O. P., 1918, Spotted lakes of epsomite in Washington and British Columbia: Am. Jour. Science, 4th series, v. 46, p. 638-644.

Larsen, E. S., and Berman, Harry, 1934, The microscopic determination of the nonopaque minerals, 2d ed.: U.S. Geol. Survey Bull. 848, 266 p.

Nichols, H. G., 1930, Central mineral survey district (No. 3): British Columbia Dept. Mines Ann. Rept. 1929, p. C207-C249.

Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation, Wash.: U.S. Geol. Survey Bull. 677, 186 p.

Patty, E. N., and Glover, S. L., 1921, The mineral resources of Washington, with statistics for 1919: Washington Geol. Survey Bull. 21, 155 p.

Peale, A. C., 1886, Mineral waters. In U.S. Geol. Survey Mineral Resources 1885, p. 536-543.

Pettijohn, F. J., 1949, Sedimentary rocks. New York, Harper and Brothers, 526 p.

Phalen, W. C., 1919, Salt resources of the United States: U.S. Geol. Survey Bull. 669, 284 p.

Shedd, Solon, 1924, The mineral resources of Washington, with statistics for 1922: Washington Div. Geology Bull. 30, 224 p.

Sneed, M. C., and Maynard, J. L., 1942, General inorganic chemistry. New York, D. Van Nostrand, 1166 p.

Stone, R. W., and others, 1920, Gypsum deposits of the United States: U.S. Geol. Survey Bull. 697, 326 p.

Teeple, J. E., and others, 1929, The industrial development of Searles Lake brines: Am. Chem. Soc. Mon. 49, 182 p.

Twenhofel, W. H., 1939, Principles of sedimentation. New York, McGraw-Hill, 610 p.

Walker, T. L., and Parsons, A. L., 1927, Notes on Canadian minerals, tremolite, clinohumite, stromeyerite, natron, and hexahydrite: Toronto Univ. Studies, Geol. Series 24, p. 15-23.

Waters, A. C., and Krauskopf, K. B., 1941, Protoclastic border of the Colville batholith: Geol. Soc. America Bull., v. 52, no. 9, p. 1355-1417.

Wells, R. C., 1923, Sodium sulphate, its sources and uses: U.S. Geol. Survey Bull. 717, 43 p.

———— 1937, Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1914-36. . .: U.S. Geol. Survey Bull 878, 134 p.

Winchell, A. N., 1933, Elements of optical mineralogy, pt. 2, 3d ed. New York, John Wiley and Sons, 459 p.

Anonymous, 1915, Mining and Scientific Press, p. 870, Dec. 4, 1915.

———— 1941, Epsom salt production at Tonasket, Washington: Mining World, v. 3, no. 7, p. 29-31.

BERYLLIUM ANALYSES

Samples of salts from several **Washington** deposits were analysed in 1959 by The Beryllium Corporation, Reading, Pennsylvania, with the following results:

Sample	BeO (percent)
Penley Lake, hole 1, 0-7 feet	.03
Hauan Lake, hole 4, 0-9 feet	.02
Lenton Flat, hole 1, surface	.01
Lenton Flat, hole 1, at 1½ feet	.01
Lenton Flat, hole 1, at 4 feet	.02
Lenton Flat, hole 1, at 6 feet	.02
Lenton Flat, hole 1, at 6-16 feet	.02
Carbonate Lake, salt from brine pool, north end	.01
Carbonate Lake, mixed salts	.036
Poison Lake, epsomite crystal	.013