UNITED STATES DEPARTMENT OF THE INTERIOR
Ray Lyman Wilbur, Secretary

GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 820

NITRATE DEPOSITS IN SOUTHEASTERN CALIFORNIA

WITH NOTES ON DEPOSITS IN SOUTHEASTERN ARIZONA AND SOUTHWESTERN NEW MEXICO

BY

L. F. NOBLE

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1931

For sale by the Superintendent of Documents, Washington, D. C. - - - - - Price 45 cents

CONTENTS

ILLUSTRATIONS

NITRATE DEPOSITS IN SOUTHEASTERN CALIFORNIA

WITH NOTES ON DEPOSITS IN SOUTHEASTERN ARIZONA AND SOUTHWESTERN NEW MEXICO

By L. F. Noble

INTRODUCTION

EXPLORATIONS

The occurrence of nitrates in the desert region of southeastern California has been known for many years, but reports about the character and extent of the deposits have been so conflicting that there has been no substantial basis for an opinion as to whether the deposits are commercially workable. When the United States entered the World War interest in nitrate became very active, and many favorable reports concerning the California deposits were received by the Interior and War Departments. Some deposits were said to be large enough and rich enough to relieve the United States of the necessity of importing from Chile the sodium nitrate required for making munitions and fertilizers, and as the need of using all available shipping for other war work was urgent, the Geological Survey was at once called upon to examine the deposits and to make a systematic search for nitrate in the entire region. These explorations were begun in December, 1917, and were continued until November, 1918. Since that date occasional additional examinations have been made, the latest being early in 1928.

Practically every area in southern California known or reported to contain nitrate was examined, and other areas where the ground, either from its general resemblance to ground known to be niter-bearing or for other reasons, seemed likely to contain nitrate were tested or prospected.

The deposits in the Amargosa region were the first to be investigated by the Geological Survey.[1] The others in California are described in the present report, together with some deposits in Nevada, Arizona, and New Mexico, which were examined at about the same time.

---

[1] Noble, L. F., Mansfield, G. R., and others, Nitrate deposits in the Amargosa region, southeastern California: U. S. Geol. Survey Bull. 724, 1922.

GENERAL CHARACTER OF THE DEPOSITS

The nitrate deposits of southern California are generally associated with clay beds of Tertiary age. Most of these were laid down in nearly flat layers in lakes, but since deposition they have commonly been much deformed by faulting, folding, and igneous intrusion. The nitrate deposits under consideration are therefore chiefly of the "clay hill" type rather than of the "cave" or "disseminated" types found in other parts of the United States. The general character of the clay-hill nitrates and of their associated features is fully described in the publication cited.[2]

A typical section across a clay hill in a nitrate field is shown in Figure 1. The caliche layer, which consists largely of common salt and the sulphates of sodium, calcium, and magnesium, contains most of the nitrate, though some traces of nitrate may be found in other layers.

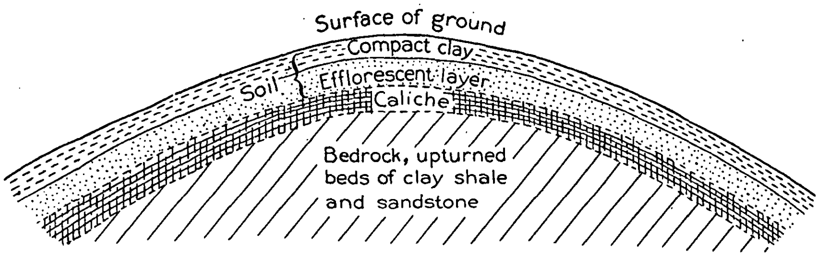


FIGURE 1.—Sketch showing arrangement of soil, caliche, and bedrock of the clay hills of the Amargosa region, California

Some of the areas of Tertiary beds have been reported to contain vertebrate fossil remains, but only one area, the Barstow syncline, has been searched systematically for them. (See p. 6.)

GENERAL CONCLUSIONS AS TO VALUE

As the findings of the Geological Survey with regard to the commercial possibilities of the nitrates in the Amargosa region[3] are applicable with even greater force to the districts herein described, they are repeated here:

> The ground in all the nitrate fields is rugged and broken, making transportation and mining somewhat difficult. The areas containing the higher-grade portions of nitrate-bearing caliche are small, only a few acres each at best, and these portions of the deposits are very irregular, pockety, or patchy. The caliche layer itself is rarely more than 4 or 5 inches thick, even in the best parts of the more favorable areas, and thus a large area would have to be worked over to obtain any great quantity of nitrate. The caliche underlies soil which would have to be removed in mining, and these two layers are in places exceedingly difficult to separate, the one grading almost imperceptibly

---

[2] Noble, L. F., and others, op. cit., pp. 6–10.

[3] Idem, p. 10.

into the other. A similar difficulty is involved in that [much of] the caliche has no distinct line of separation from the bedrock below.

The average nitrate value of the best material in the richer areas is low, few of the carefully taken samples * * * carrying more than 5.25 per cent of sodium nitrate. The total quantity of nitrate in the best of the areas studied is too small to justify the outlay of capital necessary for its commercial recovery.

In the present investigation eleven areas that had been reported to contain nitrate were examined, and six other areas that seemed likely to contain nitrate were prospected. Nitrate was found in every area but one of those reported to contain it. Danby Lake was barren. Most of the deposits were of the clay-hill type but much poorer in nitrate than the better deposits of the Amargosa region. Nitrate was present in the clay surfaces of two playas, or "dry lakes." In three areas it occurred as incrustations in protected situations in volcanic rocks. At another place it was found in cavities in a peculiar deposit of gypsiferous travertine or gypsite. None of these deposits are commercially valuable. The evidence for this conclusion is stated in the body of this report.

PRESENT INVESTIGATION

In spite of the unfavorable findings of the Amargosa investigation it was recommended [4] that "scouting should be continued until all reported deposits in similar districts and the unexamined parts of some of the Amargosa fields have been tested sufficiently to disclose their character." So far as southern California is concerned this recommendation has been carried out. Soon after the Amargosa field parties disbanded—in May, 1918—Hoyt S. Gale, who had been in general charge of the previous work, and the writer began the scouting mentioned. After June, 1918, the writer continued the work with one assistant.

The same general methods of exploration were employed in this work as in the earlier investigation.[5] Long experience with the delicate "brown ring" reaction in the Amargosa region and frequent comparison with quantitative chemical determinations of samples of the same material sent to the chemical laboratory of the Geological Survey had made it possible to judge by the strength of the reaction whether more or less than 3 per cent of nitrate (as sodium nitrate) was present in the material tested. For example, a reaction rated "negative" indicated the absence of nitrate or at most only a trace; "weak," less than 1 per cent and more than 0.1 per cent; "fair," less than 2 per cent and more than 0.5 per cent; "good," less than 3 per cent and more than 1 per cent; and "strong," more than 3 per cent. These ratings are used throughout the present report. If more

[4] Noble, L. F., and others, op. cit., p. 93. [5] Idem, pp. 15–17.

than 3 per cent of nitrate was present little idea could be formed of the actual percentage, because the reaction usually became too violent to preserve the brown ring. In general a reaction strong enough to turn the solution black caused the liquid to boil violently, throw off brown fumes, and immediately thereafter become transparent, thereby indicating the presence of 5 per cent or more. It was never possible to get a black boiling reaction from material containing less than 3 per cent of nitrate.

The checking by chemical analysis never showed a higher percentage of nitrate in a sample than the upper limit indicated by the rating of the field test, and in a few samples the percentage shown by analysis was much lower than the lower limit indicated by the rating. (See p. 70.) So far as the ratings err, therefore, they err in overestimating the amount of nitrate present.

It is doubtful whether nitrate can be extracted profitably even from large continuous areas of caliche containing 5 per cent of nitrate. Therefore ground containing less than 3 per cent is certainly not commercially valuable. These quantitative field tests, if carried out systematically and checked occasionally by quantitative chemical determinations in the laboratory, thus offer a practical, economical, and rapid method both for eliminating unpromising areas and for locating promising areas for more extensive sampling.

It was planned that if the field tests suggested that any areas were as promising as the better tracts of the Amargosa district, these areas would be recommended at once for detailed investigation. No such areas were found. Because of the low percentage of nitrate indicated by most of the field tests, few samples were saved for quantitative chemical determination in the laboratory, except enough in each area to check the field tests and to complete the record.

In the following table the areas examined in 1918 and described in this report are listed in the order of examination, together with a few localities subsequently tested. The locations of all areas but three (see figs. 5, 6, and 7), are given on Plate 1, which also shows the location of areas in the Amargosa region described in the previous report.

Areas examined

No. on Plate 1	Region and name	Character of deposit
	Middle Mohave Desert, Calif.:	
1	Barstow syncline	Clay-hill caliche.
2	Coolgardie Lakes	Clay surface of dry lake.
	Northern Mohave Desert, Calif.:	
3	Pilot nitrate field	Clay-hill caliche.
4	Leach Lake	Clay surface of dry lake.
5	Owl Spring nitrate field	Clay-hill caliche.
	Fish Lake Valley, Nev.: Tertiary beds (see fig. 7)	Do.
7	Southern Mohave Desert, Calif.: Twenty-nine Palms	Do.
	Valley of Colorado River below Needles, Calif.:	
8	West Well tract	Clay-hill caliche; incrustations on volcanic rocks.
9	Beal tract	Clay-hill caliche.
10	Vivet Eye tract	Cavities in gypsite deposit overlying schist.
11	Vidal tract	Clay-hill caliche.
12	Eastern Mohave Desert, Calif.: Danby Lake	Beds of rock salt and playa clay.
13	Amargosa Valley, Calif.: Ratliff nitrate claims, near Shoshone.	Clay-hill caliche.
	Peloncillo Mountains, Ariz.: Eberenz-Beach nitrate claims near San Simon (see fig. 5).	Incrustations on volcanic rocks.
	Animas Valley, N. Mex.: Hungerford nitrate claims (see fig. 6).	Do.
16	Death Valley, Calif.: Tertiary beds on Furnace Creek	Clay-hill caliche.
17	Valley of Virgin River, Nev.: Tertiary beds on Muddy Creek.	Do.

These areas are irregularly distributed over a wide region where water is scarce. At the time of investigation most of them were a considerable distance from places where supplies could be had and were reached by roads that for the most part were poor and were little traveled. In recent years, however, travel in the desert has greatly increased, the main roads have become good, places where gasoline and supplies may be obtained are much more numerous, and in consequence most of the areas are now easily accessible.

MIDDLE AND NORTHERN MOHAVE DESERT

BARSTOW SYNCLINE

Mr. Gale and the writer discovered niter-bearing ground in the so-called Strontium Hills of the Barstow syncline (see pl. 1) while examining an area that was being prospected for strontianite by Mr. E. T. Hillis, of Barstow. Mr. Hillis joined in the examination.

The geologic features of the Strontium Hills have been described as follows:[6]

> The Strontium Hills are underlain by a series of lake and terrestrial deposits which have been folded into a syncline. These beds have been partly described by Baker[7] under the name "Rosamond series" and later more fully by Pack.[8]

[6] Knopf, Adolph, Strontianite deposits near Barstow, Calif.: U. S. Geol. Survey Bull. 660, pp. 257–259, 1918.

[7] Baker, C. A., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 342–347, 1911.

[8] Pack, R. W., Reconnaissance of the Barstow-Kramer region, Calif.: U. S. Geol. Survey Bull. 541, pp. 141–151, 1913.

The syncline into which the beds have been bent is referred to by Baker and Pack as the Barstow syncline. A monograph on the fauna of the beds is in preparation [now published[9]] by Prof. J. C. Merriam, who discusses also the age and correlation of the beds. The term "Barstow formation" is used by Merriam for the deposits containing the upper Miocene fauna and comprising the uppermost beds of the Barstow syncline, but it is recognized that this fauna may occur in all of the strata of the syncline. * * *

A threefold subdivision of the beds in the Strontium Hills may easily be recognized, as Pack has pointed out. The lowest member consists largely of granitic detritus, remarkably fresh in composition and consisting of angular boulders, some of which are as much as 5 feet in diameter. It is without more than a trace of bedding and is clearly an ancient alluvial deposit, a "fanglomerate." Some rhyolite tuff occurs with it.

The middle subdivision, which contains the strontium, is made up chiefly of grayish-green clay in thick beds. The erosion of the clay beds has produced a badland topography which is highly characteristic of the middle member of the Barstow syncline. At the surface the clay is loosely coherent, but in places it grades into shale, which is fairly well bedded. Crystals of gypsum half an inch or so in diameter are common throughout the clay beds. Moreover, the clay yields calcium sulphate on extraction with water, and it effervesces freely in hydrochloric acid; it is therefore a gypsiferous, calcareous clay. Calcareous concretions of odd and peculiar patterns are of widespread occurrence in the clay beds; they are locally called "fossils."

Above the clays come more highly indurated beds, consisting of calcareous tuffs, white rhyolite tuff, sandstone, and limestone in persistent beds 4 to 6 feet thick. Many of these limestones are clearly of algal origin, as shown by the concentric circular patterns on their weathered surfaces. * * *

The section described in the preceding paragraphs is that near the east end of the Barstow syncline, * * * where only the north limb of the syncline is exposed. Farther west the strontium deposits occur in the south limb of the syncline. The beds here resemble those of the middle subdivision, already described, but the interbedded algal limestones are especially conspicuous.

The borate-bearing beds of the near-by Calico district are probably equivalent to a part of the middle subdivision just described.

The area which was then being prospected by Mr. Hillis for strontium is about 9 miles north of Barstow and is reached by a road that turns north from the Barstow-Death Valley road at a point about 6 miles out of Barstow. It lies between altitudes of 3,000 and 3,500 feet on the south limb of the Barstow syncline, nearly midway between the east and west ends of the syncline.

The strata that crop out in this area are evidently those of the "middle subdivision" described by Knopf. They consist of greenish shale, brown salty shale, fresh-water limestone, and some white ash or tuff. All the beds are steeply inclined. The shales resemble certain shales in the Saratoga and Confidence nitrate fields[10] (see pl. 1), 50 to 60 miles northeast of the Barstow syncline, which contain

[9] Merriam, J. C., Tertiary mammalian faunas of the Mohave Desert: California Univ. Dept. Geology Bull., vol. 11, pp. 437a–437e, 438–585, 1919.

[10] Noble, L. F., and others, op. cit., pp. 31 et seq., 52 et seq.

salt, gypsum, and celestite, but in general they contain less saline material than the Saratoga and Confidence strata. Here, as in the Saratoga and Confidence fields, they are covered in many places by a saline clay soil that is practically barren of vegetation. Because of the general resemblance of the ground to that in the areas in the Amargosa district known to contain deposits of niter-bearing caliche, a number of tracts of the greenish and brown shales were prospected by shallow pits.

The soil at the surface of the ground here consists of compact clay, in most places about 6 inches thick. The material in this layer gives no reaction for nitrate. Underneath the compact clay the soil is loose for a depth of 2 to 6 inches and contains large amounts of white efflorescent salts which appear to be chiefly sulphates of sodium and calcium. In places the material in this layer gives "weak" reactions for nitrate.

In the tracts underlain by greenish shale the shale just beneath the soil layers described is weathered and cracked, so that it crumbles into innumerable small flakes. These flakes are coated with films of transparent salt, largely sodium chloride. The zone of cracked shale, which is from 4 to 6 inches thick, occupies the position which the caliche layer occupies in the nitrate fields of the Amargosa district and grades downward into compact unaltered shale. Most of the material in the cracked zone gives "weak" to "fair" reactions for nitrate, but some of it gives "good" reactions. The unaltered shale beneath this zone gives "weak" reactions in some places but in general appears to be practically barren of nitrate.

In the tracts underlain by brown salty shale a hard, compact caliche is present in some places instead of the zone of cracked shale. This caliche is very similar to the hard caliche on the salty shales of the Saratoga and Confidence fields and consists largely of sodium chloride. It is about 4 inches thick and gives a weak reaction for nitrate.

To check the field tests, three samples of material from the cracked zone on the greenish shale and one sample of the compact caliche on the brown salty shale were saved for chemical determination. Two of the samples from the cracked zone, which gave "good" reactions for nitrate in the field tests, contained 1.44 and 1.92 per cent of sodium nitrate; the other sample from this zone, which gave a "weak" reaction, contained 0.27 per cent. The sample of compact caliche from the brown salty shale, which gave a "weak" reaction, contained 0.40 per cent.

The amounts of nitrate indicated by these tests in the ground examined are so low that the deposits are obviously of no commercial value, but the occurrence itself is interesting because it shows that nitrate deposits of the clay-hill type are widely distributed in the desert region and are to be expected wherever any considerable areas of clay or shale formation crop out.

COOLGARDIE LAKES

The Barstow syncline is on the south side of a long flat ridge whose crest is formed largely of granitic rocks. North of this ridge the land slopes into a wide basin known as Superior Valley, the lower part of which is filled with alluvial waste swept from the surrounding hills. Its central floor ranges in altitude from 2,980 to 3,100 feet and is a gently sloping alluvial plain about 100 square miles in extent, which contains three small playas or "dry lakes" known locally as the Coolgardie Lakes. (See pl. 1.) These dry lakes, which are shown on the Searles Lake topographic map, lie about a mile apart along an east-west line. Their surfaces are smooth, compact clay, not markedly saline but barren of vegetation, and do not differ in appearance from the surfaces of hundreds of similar playas in the desert region. The middle lake is crossed by the road from Barstow to Granite Wells. (See pl. 2, *C*.) It is the smallest of the three and is about a mile wide.

The rocks in the hills about Superior Valley are practically all pre-Tertiary granite or Tertiary volcanic rocks. The hills around the northern border of the valley, from Pilot Knob to the Eagle Crags, are carved from a thick series of lavas, breccias, and stratified tuffs which rest upon granite. Elsewhere about the valley granite appears to be the prevailing rock, though many hills consist of pink rhyolite or black lava. No clay strata like those with which the clay-hill nitrate deposits are commonly associated are exposed in the basin. Shore markings or other deposits on the slopes about the valley floor to indicate that a lake of greater extent than the present playas ever existed in the valley are lacking.

Because of the absence in the basin of any niter-bearing ground of the clay-hill type from which nitrate might be washed into the playas by erosion it seemed worth while to test the clay surface of one of the playas to get further evidence regarding the origin and distribution of nitrate in the region. Accordingly a point near the center of the middle Coolgardie Lake was selected at random and a hole 3 feet deep was dug. All the material taken from this hole was rather moist, fine clay which tasted salty but did not contain much visible saline matter. The material from the surface gave no reaction for nitrate; that a foot beneath the surface gave a "weak" reaction; and that 2 to 3 feet beneath the surface gave a "very weak" reaction. Evidently, therefore, none of the material contains as much as 1 per cent of sodium nitrate; indeed, probably all of it contains very much less than 1 per cent, but the fact that the locality tested was selected at random suggests that a small amount of nitrate is rather widely distributed in the playa clay. The occurrence has no commercial value, but it is interesting as evidence that nitrate is accumulating in some playa clays in the desert at the present time. Possibly the nitrate is being formed in the clay by the action of bacteria; but it is also conceivable that the nitrate is being washed into the playa by erosion. If it is being washed into the playa, the volcanic rocks in and around the basin would appear to be a possible source, although it is not known whether these rocks contain nitrate. Nitrate formed by bacterial action in soil supporting the sparse vegetation on slopes surrounding the playa might also be washed into it.

LEACH POINT VALLEY

Pilot Knob and the Eagle Crags, north of Superior Valley, are parts of an irregular east-west range of low, broken mountains that extends from the vicinity of Pilot Knob eastward to the Avawatz Mountains, on the border of South Death Valley. Different parts of this range have local names. The western portion, which includes Pilot Knob and the Eagle Crags, consists largely of lavas, tuffs, and breccias of Tertiary age. The eastern portion, called the Granite Mountains, consists almost wholly of granitic rocks.

North of and parallel with the range just described lies an east-west trough which is part of a chain of long irregular depressions separated by low divides. This trough has been described briefly in a previous report [11] and named the Leach Trough.

The part of the Leach Trough that lies just north of Pilot Knob is known as Leach Point Valley.[12] It is a long alluvium-filled depression which extends eastward from a point opposite Pilot Knob to the divide in the trough at Leach Point. The Slate Range lies north of the western part of the valley, and mountains that may be considered a southern extension of the Panamint Range lie north of the eastern part. West of the Slate Range Leach Point Valley is separated from the basin containing Searles Lake by a very low divide across which a great lake that formerly occupied the Searles Basin overflowed southward into Leach Point Valley and thence eastward and northward into Panamint Valley.[13] The middle portion of Leach Point Valley opens northward into Panamint Valley through a narrow rocky gap between the Slate and Panamint

[11] Noble, L. F., The San Andreas rift and some other active faults in the desert region of southeastern California: Carnegie Inst. Washington Year Book 25, pp. 423, 424, 1926.

[12] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 205, 1903.

[13] Gale, H. S., Salines in the Owens, Searles, and Panamint Basins, southeastern California: U. S. Geol. Survey Bull. 580, p. 312, 1914.

Ranges, and the entire valley drains northward into Panamint Valley through this gap.[14]

PILOT NITRATE FIELD

LOCATION AND EXTENT

The Slate Range is terminated abruptly on the south by a fault along the northern border of Leach Point Valley that is believed to be a prolongation of the Garlock fault.[15] North of the fault lie pre-Tertiary crystalline rocks—schist, gneiss, and granite—forming the southern part of the Slate Range. South of the fault, in a strip along the southern base of the range, is an area of light-colored bare hills which are rendered especially conspicuous by the pale, creamy tint of the barren clay soil that covers them. These clay hills mark the outcrops of upturned strata of Tertiary age and constitute the so-called Pilot nitrate field. (See pl. 1; also pl. 3, *A*.) The west end of the area is 6 miles south of the southeast end of Searles Lake and 15 miles southeast of Trona. From this point the outcrops of the strata extend eastward about 10 miles along the base of the Slate Range and disappear under the alluvium of the floor of Leach Point Valley at a point a mile southeast of the entrance to Panamint Valley. The width of the area does not exceed half a mile at most places, and the altitude ranges from 2,100 feet at the extreme east end to 3,500 feet or more in the middle portion along the flank of the Slate Range. The topography of the area is shown on the Searles Lake topographic map published by the Geological Survey.

PREVIOUS WORK

The Pilot nitrate field is described by Bailey[16] as follows:

The Pilot niter district is located on the old beach line east of Searles Lake, at the south end of the Slate Range. It takes its name from Pilot Peak [Pilot Knob], a famous landmark of the desert that is about 20 miles south of this district. [See pl. 2, *A*, *B*.] The locations are similar in general detail to those already described in Death Valley.

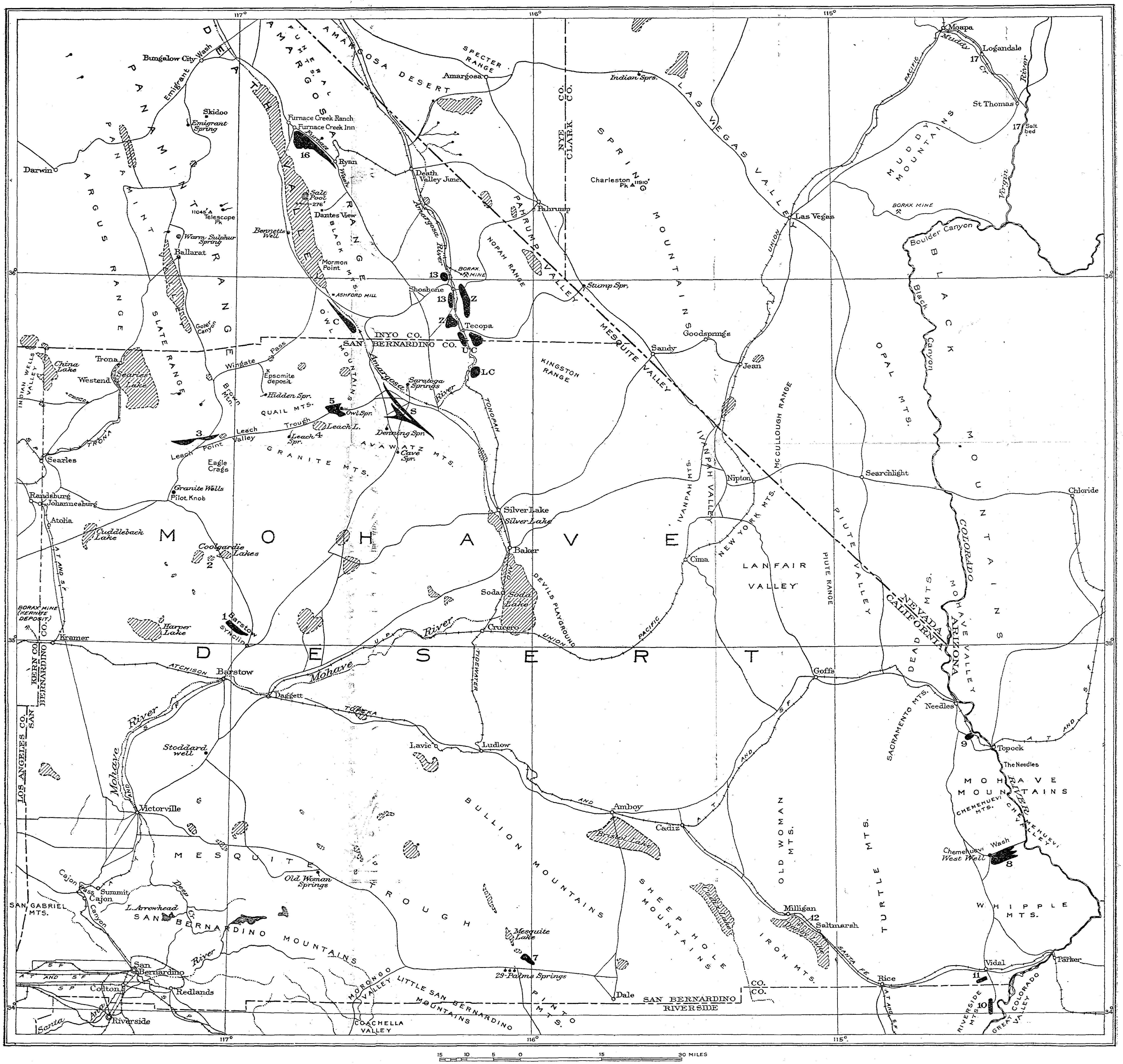
Searles Lake is the main depression, or sink, left by the evaporation of the ancient lake that once filled what is now known as the Panamint and Salt Wells Valleys, and whose terraces may be found 600 feet or more above the well-known borax lake. The local conditions were such that the beach lines of this great lake suffered more from erosion than did Death Valley, or more of the soft clay niter hills would be found around its margins.

---

[14] For logs of roads see Thompson, D. G., Routes to desert watering places in the Mohave desert region, Calif.: U. S. Geol. Survey Water-Supply Paper 490–B, pp. 172, 173, 183, 1921.

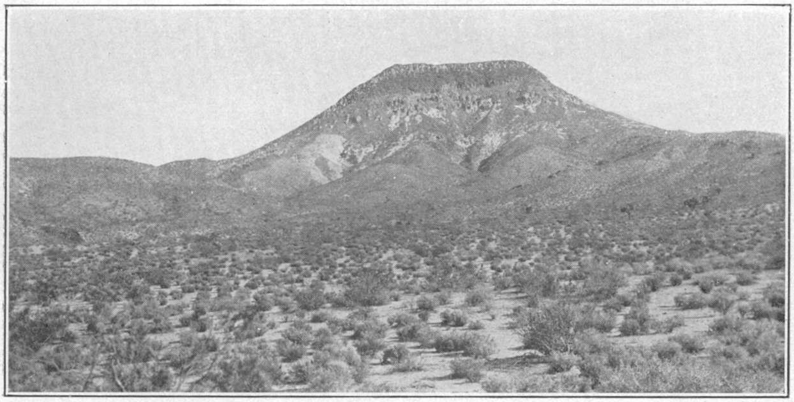
[15] Noble, L. F., op. cit., pp. 423, 424.

[16] Bailey, G. E., The saline deposits of California: California State Min. Bur. Bull. 24, pp. 178, 179, 1902.

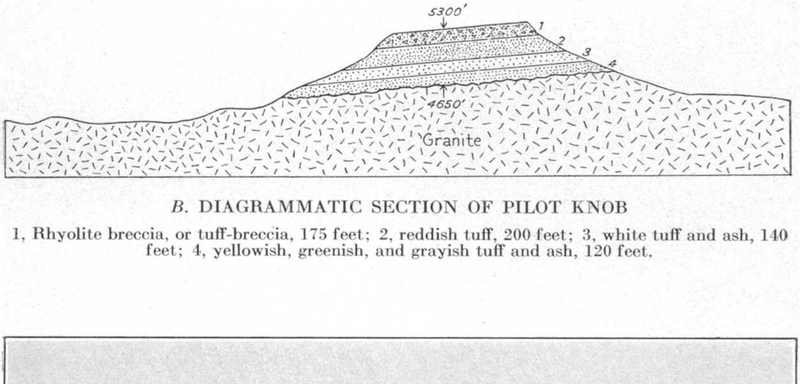


INDEX MAP OF NITRATE FIELDS IN SOUTHEASTERN CALIFORNIA, SHOWING AREAS EXAMINED

C, Confidence; LC; Lower Canyon; S, Saratoga; UC, Upper Canyon; Z, Zabriskie; 1, Barstow syncline; 2, Coolgardie Lake; 3, Pilot; 4, Leach Lake; 5, Owl Spring; 7, Twenty-nine Palms; 8, West Well; 9, Beal; 10, Vivet Eye; 11, Vidal; 12, Danby Lake; 13, Ratliff claims; 16, Furnace Creek; 17, Muddy Creek and Virgin River.



A. PILOT KNOB FROM NORTHWEST

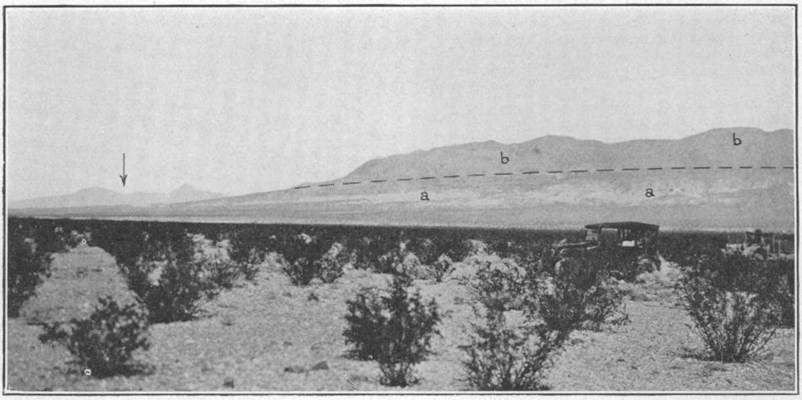


B. DIAGRAMMATIC SECTION OF PILOT KNOB

1, Rhyolite breccia, or tuff-breccia, 175 feet; 2, reddish tuff, 200 feet; 3, white tuff and ash, 140 feet; 4, yellowish, greenish, and grayish tuff and ash, 120 feet.

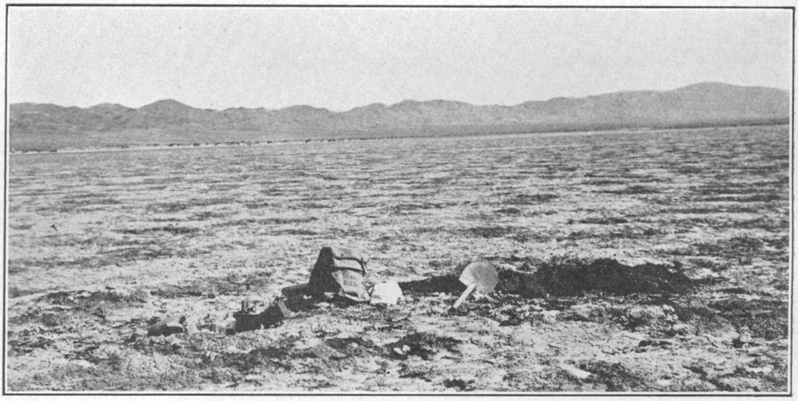
C. COOLGARDIE LAKE

View north from middle of lake. Eagle Crags in background.



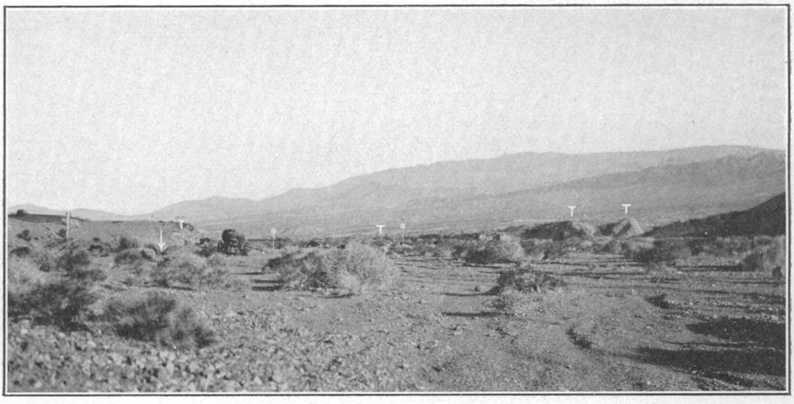
A. WEST END OF PILOT NITRATE FIELD

View north across Leach Point Valley. a, Outcrop of Tertiary strata ("niter hills"); b, Slate Range. Arrow indicates Searles Lake Basin.



B. LEACH LAKE

View east from point near middle, showing puffy character of ground. Avawatz Mountains in background.



C. OWL SPRING

View southeast across embayment and down Owl Spring Wash. Arrow indicates the spring; T, Tertiary beds with nitrate. Avawatz Mountains in background.

Bailey's description gives the impression that the niter-bearing ground of the Pilot field is associated with the beach lines of the lake that formerly occupied the Searles Basin or with deposits laid down in that lake; but in fact the niter-bearing ground is associated with upturned strata of Tertiary age which are very much older than any beds that were deposited in the lake. Gale[17] has shown that the altitude of the maximum water line of the former Searles Lake could never have exceeded 2,264 feet, which is the altitude of the highest point in the old outlet channel through which the waters of the lake overflowed into Leach Point Valley and thence into Panamint Valley. All but a very small part of the Pilot field lies above this altitude.

Claims covering an area of about 20,000 acres are said to have been located in the Pilot field in 1909 by Walter Duisenberg, W. R. Lawton, and others, of San Francisco, and samples taken from the surface of the ground by the locators are said to have contained from 3 to 14 per cent of sodium nitrate.

EXPLORATION

The clay hills 3 miles north of the 2,270-foot bench mark on the Randsburg-Death Valley road are characterized by specially large tracts of barren clay soil. The rocks underlying these hills strike east and are complexly folded along an axis parallel with Leach Point Valley and the fault along the Slate Range. The prevailing dips are nearly vertical. The hills are intricately dissected and are cut by deep canyons that cross the strike of the beds from north to south and open upon alluvial fans along the north margin of Leach Point Valley. In ascending one of these canyons to an altitude of about 3,300 feet the entire belt of clay hills was crossed. It was then recrossed by descending another canyon half a mile farther east. During this traverse the more promising-looking ground in the slopes and ridges of the clay hills on both sides of the canyons was examined and tested. The area thus covered lies 2 miles east of the west end of the Pilot field and is believed to be fairly representative of the middle and western portions of the field. (See pl. 3, *A*.)

The strata nearest the valley, which here form the typical clay hills, are loosely consolidated cream-colored sandstones or very sandy clays which contain little saline material. Some of the beds contain a small amount of gypsum. The slopes of the hills are covered with a thick, loose soil whose surface is a crust of compact clay, but

[17] Gale, H. S., op. cit., p. 266.

no caliche was found beneath the soil. In places "weak" or "fair" reactions for nitrate were obtained in the loose soil just above the bedrock. No reactions indicated the presence of as much as 2 per cent of sodium nitrate.

The strata farther back from the valley, above most of the clay-hill belt, are coarse sandy fanglomerates that contain a few beds of white volcanic ash. The relation of these fanglomerates to the sandstones and sandy clays of the clay hills was not determined. In the area examined the fanglomerates dip north, are less steeply inclined than the sandstones, and appear to be unconformable upon and younger than the sandstones, although they may be a part of the same series. They are certainly much older than the alluvial fans of the region. No reactions for nitrate were obtained in the ground underlain by the fanglomerates.

East of the area examined the sandstones and sandy clays with which the niter-bearing clay soil is associated disappear under high detrital slopes and dissected fanglomerate along the northern border of Leach Point Valley, but they reappear several miles farther on and continue eastward to the east end of the field, southeast of the mouth of Panamint Valley.

An area near the east end of the field, where the beds are crossed by the Ballarat road, was next explored. In this area the sandstones and sandy clays crop out in a strike valley north of a low ridge of fanglomerate. They contain more clay and more saline material than the beds in the area examined in the western part of the field. Many beds are creamy or greenish salty clay shales. In places a hard salty caliche was found on these shales just under the surface clay soil. All the caliche observed within a distance of 1,000 feet east and west of the road was tested, but no reactions for nitrate stronger than "fair" were obtained. In some places the shale just under the caliche gave "weak" reactions for nitrate. No caliche appears to be associated with the more sandy beds or with the fanglomerates.

A number of prospect trenches, some of them several feet deep, have been dug in the ground just described, presumably by the men who located claims in the Pilot field in 1909. A layer of hard salty caliche 4 inches thick was seen in one trench, dug in moist greenish salty clay shale about 1,000 feet east of the road. This caliche had evidently formed since the trench was dug. No caliche could be found on the same shale bed in the undisturbed ground near the trench. Apparently the formation of this caliche is due to the exposure of moister bedrock by the trench. It gave no reaction for nitrate. A sample of it, saved for qualitative determination in the chemical laboratory of the Geological Survey, was reported to contain no nitrate and to consist largely of sodium chloride, together with considerable sodium sulphate and calcium sulphate.

CONCLUSIONS

Although but a small part of the Pilot field was explored the ground examined is believed to be fairly representative of the whole. In general, the strata in the western and middle parts of the field contain little saline material, and the conditions there are thus unfavorable to the formation of caliche. The strata in the eastern part of the field are more saline, and caliche has formed on them in places, but the best of this caliche thus far observed is poor in nitrate. None of the material tested in the Pilot field contained as much as 2 per cent of sodium nitrate. The possibility of finding areas of rich nitrate caliche in this field is therefore apparently remote. As the steep dip of the strata limits their outcrops to a narrow belt, and the saline shales with which the caliche is associated constitute only a part of these strata, the existence of large areas of caliche in the Pilot field is exceedingly improbable.

LEACH LAKE

Leach Lake, at an altitude of about 1,500 feet (barometric) lies about 8 miles east of the Leach Point divide, in an irregular alluvium-filled basin that measures about 15 miles from east to west and about 10 miles from north to south. The Leach Point divide forms a pass between the Quail Mountains and the Granite Mountains and constitutes the narrowest part of the Leach Trough. After crossing this divide the Randsburg-Death Valley road descends eastward in a dry wash nearly to Leach Lake, turns northeastward and skirts the north shore of the lake, then ascends a long, gentle detrital slope to the low divide between the Leach Lake Basin and the Owl Spring embayment, reaches Owl Spring Wash near Owl Spring, and descends the wash to South Death Valley. (See pl. 1.) Leach Lake may be easily reached from the road, a log of which is given by Thompson.[18]

The basin of Leach Lake is typical of the smaller depressions in the desert region, whose drainage has no outlet to the sea. It is surrounded by ranges of bare, rocky mountains from which long, gentle alluvial slopes sweep down everywhere toward the central floor. These alluvial slopes consist of sand, clay, gravel, and disintegrated rock—detrital materials washed from the mountains and spread out by intermittent floods. The materials become finer toward the base of the alluvial slopes until, near the central floor,

[18] Thompson, D. G., op. cit., pp. 173, 203.

they consist chiefly of sand and clay. At places upon the slopes low rocky hills not yet buried by the alluvium project like islands. The lake is roughly circular in outline and about a mile wide. The surface consists of clay but differs somewhat from that of the Coolgardie Lakes, already described, in that it is rather uneven at places and has a curious rough, "puffy" appearance (see pl. 3, *B*), a feature which indicates that the clay contains more saline material than that of the Coolgardie Lakes. The alluvial slopes and parts of the sandy area bordering the lake support a scanty growth of desert shrubs, chiefly "creosote" (*Covillea tridentata*), which grow far apart after the fashion of desert plants, but the surface of the lake is bare.

The rocks in the mountain slopes from which the alluvial filling of the basin is derived are mostly igneous—chiefly pre-Tertiary granites. Tertiary volcanic rocks crop out at a few places. Metamorphosed sediments form a part of the Owl and Avawatz Ranges. Apparently no sedimentary rocks of Tertiary age crop out in the basin. A small area of the Tertiary strata that constitute the Owl Spring nitrate field is exposed on the low divide northeast of Leach Lake, but as most of the outcrops lie east of the divide it is unlikely that any appreciable quantity of material from this source has ever been washed into Leach Lake.

EXPLORATION

Leach Lake is said to have been sampled for nitrate by a Los Angeles mining engineer, who reported that the ground at a depth of a foot beneath the surface of the lake showed an average content of over 3 per cent nitrate, calculated as sodium nitrate. Three pits were dug by the Geological Survey party near the middle of the lake 100 yards apart and a little over 3 feet deep. At the surface at each pit is a layer of caked clay, one-half to 1 inch thick, which gave no reaction for nitrate. Beneath this is a layer of loose, granular puffy soil, 5 to 6 inches thick, filled with tiny elongated transparent crystals which are soluble and have a sharp, bitter, salty taste. This soil gave "fair" reactions for nitrate. Underneath the puffy soil is moist tough clay, which at a depth of 1½ feet gave "weak" to "fair" reactions for nitrate and at a depth of 2½ feet gave "weak" reactions.

Samples of the puffy soil and the moist clay were saved from the pit in which the puffy soil gave the strongest reactions for nitrate and sent to the chemical laboratory of the Geological Survey for determination of the nitrate content and for general qualitative tests to determine the character of other salts present. The results of these determinations follow:

Tests of samples from Leach Lake

No. of sample	Material	Depth below surface	Nitrate as $NaNO_3$ (per cent)	Other salts
1008	Puffy soil	1 to 6 inches	0.96	Largely NaCl, $CaCl_2$, and small amounts of K and $MgCl_2$.
1009	Moist clay	1 to 2 feet	.44	Largely NaCl, $CaCl_2$, and small amounts of K and $CaSO_4$.
1010	do	2 to 3 feet	.41	

It is of interest to compare these determinations with a similar qualitative determination of a sample of caliche from the Upper Canyon nitrate field of the Amargosa district, which was made at the same time in the chemical laboratory. This sample, collected by Mr. Gale and the writer, consisted of 50 pounds of caliche representing a strip 10 feet long between the 135 and 145 foot marks in trench T-12 on Bully Hill.[19] The results of the determination follow: Sample 1025, 6 to 12 inches below surface; nitrate as $NaNO_3$, 6.88 per cent; total salts, 15.27 per cent; very little K; other salts largely NaCl, $CaCl_2$, $CaSO_4$, and small amount of Mg. From this it appears that the salts associated with nitrate in the playa clay at Leach Lake are practically the same as those associated with nitrate in the caliche at the typical clay-hill nitrate deposit of Bully Hill.

Leach Lake was revisited in October, 1918, to collect a sample of soil from the niter-bearing ground for bacterial examination. (See p. 93.) Four pits 2 to 3 feet deep were dug in the surface of the lake in an area between the middle and the northwest shore, at intervals of 100 yards. The surface of the lake had been wet deeply by a heavy rain three weeks before. The material was moist and did not show so distinctly the layers noted in the former tests, when the ground was dry, but the layers were still recognizable. The material in all the pits gave "weak" to "fair" reactions for nitrate to a depth of about 1½ feet and "weak" to "negative" reactions below that depth. A sample for bacterial examination was selected from material that gave the strongest field test for nitrate. This material was moist clay at a depth of a foot below the surface of the lake in one of the pits. (See pl. 3, *B*.) Another sample of the same material saved for determination of its nitrate content was reported by the chemical laboratory to contain 0.29 per cent of sodium nitrate.

CONCLUSIONS

The tests made at Leach Lake indicate that nitrate is widely distributed in the clay just under the surface of the lake but that the

[19] See U. S. Geol. Survey Bull. 724, pl. 30, 1922.

amount is small, averaging less than 1 per cent. Evidently the amount diminishes below a depth of 1 to 1½ feet, but the tests did not go deeper than 3 feet. The deposit has no commercial value, but the occurrence, like that in the Coolgardie Lakes, is interesting because it shows that nitrate is accumulating in some playas at the present time.

OWL SPRING NITRATE FIELD

LOCATION AND GENERAL GEOLOGIC FEATURES

From the low divide 2½ miles northeast of Leach Lake a broad valley descends eastward to South Death Valley and is followed by the Randsburg-Death Valley road. This valley, here called the Owl Spring embayment, is a wide alluvium-filled arm of the South Death Valley trough, similar in character to the embayments of Wingate Wash and Emigrant Wash, which enter Death Valley farther north. It is occupied by the shifting channels of Owl Spring Wash, a dry stream course that rises in the Owl Mountains north of the divide and enters South Death Valley at a point about 5 miles below Saratoga Springs. The Owl Spring embayment forms a rudely wedge-shaped depression pointing westward. The apex of the wedge is at the divide; the north side of the wedge is the Owl Mountains; the south side, the Avawatz Mountains; and the base, South Death Valley. The length of the embayment from its apex at the divide, where the altitude is about 1,900 feet, to the floor of South Death Valley, where the altitude is about 150 feet, is 12 miles. The embayment is about 10 miles wide where it opens into South Death Valley but narrows westward to about 2 miles near the apex. The Owl Spring nitrate field lies along the channels of Owl Spring Wash and some of its small tributaries in the region about Owl Spring, at the west end of the embayment. (See pl. 1.)

Owl Spring (pl. 3, *C*) emerges along the north side of Owl Spring Wash at an altitude of about 1,750 feet. It is 10 miles west of the Saratoga nitrate field[20] (see pl. 1) and 15 miles south of the Confidence field.[21] It is about 45 miles by road from both Shoshone and Silver Lake, stations on the Tonopah & Tidewater Railroad, and about 65 miles from Randsburg.[22]

The floor of the Owl Spring embayment is a sloping plain built of deposits of alluvial material washed into the embayment from the bordering hills. Along the sides of the embayment the numerous coalescing alluvial fans form a continuous slope. In the axis of the embayment, along the channels of Owl Spring Wash, the deposits

[20] Noble, L. F., and others, op. cit., pp. 31–51.
[21] Idem, pp. 51–59.
[22] For logs of these roads see Thompson, D. G., op. cit., pp. 198, 199, 202, 203.

washed from the hills mingle with vast quantities of coarse gravel, boulders, and sand brought down the wash by intermittent floods. In most of the wide lower part of the embayment these alluvial deposits conceal the rocks that underlie its floor, but toward the head of the embayment, in the vicinity of Owl Spring, the main wash and its tributaries have cut down their channels beneath the alluvial mantle, so that they expose narrow outcrops of the underlying rocks along their banks. In this dissected area, which extends eastward from the divide at the head of the embayment to a point about 2 miles east of Owl Spring and covers perhaps 5 square miles, the underlying rocks thus exposed are upturned sedimentary beds of Tertiary age. The outcrops of some of these Tertiary beds which constitute the Owl Spring nitrate field are shown in Plate 3, *C*.

The Tertiary sediments of the Owl Spring nitrate field are separated from the older limestone and granite of the Owl Mountains by a fault. This fault apparently continues eastward and forms the border of the Owl Spring embayment northeast of the nitrate field. Between Denning Spring Wash and Cave Spring Wash, at the east end of the southern border of the embayment, a magnificently exposed fault separates Tertiary beds lying in the embayment from the older rocks of the Avawatz Mountains. Apparently this fault continues westward and borders the embayment on the south. The existence of outcrops of Tertiary beds projecting through the alluvial floor of the embayment at Round Mountain and in the hills 4 miles southwest of Round Mountain, coupled with the existence of outcrops of similar beds in the Owl Spring nitrate field, suggests very strongly that the entire embayment is underlain by Tertiary rocks. The embayment, therefore, would appear to be a structural depression underlain by Tertiary rocks and bounded by faults. Inasmuch as the Owl Spring embayment is nearly in line with the chain of depressions which includes the Leach Trough and which, farther to the west, is associated with the Garlock fault, it is possible that the embayment represents a prolongation of that structural feature.

The Tertiary beds that constitute the Owl Spring nitrate field are complexly folded and are cut by numerous faults, so that they dip in various directions. In some places the dips are very steep. A well-marked anticline whose axis trends northwest is exposed at one place, but in general the details of structure are difficult to determine, because the beds are so largely concealed by the alluvial mantle that overlies them. It is evident, however, that the structure is very similar to that of the near-by Saratoga and Confidence fields.

The beds comprise saline and gypsiferous shales, sandstones, and limestones. The stratigraphic succession of the beds, like their structure, is difficult to determine, owing to the intense disturbance that they have suffered and the fact that they are so largely concealed by the mantle of alluvium. In the banks of Owl Spring Wash just below Owl Spring are beds of curious gnarly or lumpy limestone, some of which are as much as 8 feet thick. Associated with the limestones are arkose conglomeratic sandstones similar to those exposed in the Amphitheater Canyon area of the Saratoga field.[23] Southeast of the limestones and sandstones lies a belt of very salty brown shales containing stringers of gypsum. These shales do not differ in any respect from the salty shales that form a large part of the Saratoga Hills area of the Saratoga field and there contain a bed of rock salt.[24] Beyond the salty shales and apparently underlying them are clayey and sandy strata which contain large amounts of gypsum in thick beds and in stringers. Similar strata crop out northwest of Owl Spring for a mile or more along the banks of the main wash that passes near the camp of the manganese mine operated at that locality for a short time during the war. These strata contain bed after bed of gypsum and, in some places, small crystals of celestite. They closely resemble strata in the Salt Basin area of the Saratoga field that contain large deposits of gypsum and celestite.[25]

North of the Randsburg road and west of Owl Spring, in an area southwest of the wash that leads past the manganese camp, a number of washes afford more exposures of the Tertiary beds. Here also the beds comprise saline shales, sandstones, conglomerates, and limestones and contain large amounts of gypsum. They are succeeded on the northwest by a thick bed of greenish breccia composed largely of fragments of metadiabase. The relations of this bed were not determined, but it appears to overlie the other beds. All these beds are overlain by coarse, poorly consolidated fanglomerate which makes high, grayish gravel hills northwest of the nitrate field and also appears to cover much of the ridge that extends southeastward to the Avawatz Mountains from the divide at the head of the Owl Spring embayment. This fanglomerate is only moderately tilted. It is apparently unconformable with the beds of the nitrate field and is therefore younger, but it is older than the alluvial material that fills the Owl Spring embayment and is probably of late Tertiary or early Quaternary age. Similar deposits of fanglomerate overlie the Tertiary beds of the Saratoga, Confidence, and Upper Canyon nitrate fields.[26]

The occurrence of limestone, although not at all unusual in the Tertiary formations of the desert region, is perhaps the most interesting feature of the Owl Spring nitrate field. In places the limestone forms beds as much as 10 feet thick. Some beds are full of

[23] Noble, L. F., and others, op. cit., p. 38.
[24] Idem, p. 33.
[25] Idem, p. 32.
[26] Idem, p. 35.

hollow tubes, which probably represent plant stems. Many beds exhibit the characteristic structure of travertine. Some beds contain much siliceous material. In places beds of yellowish and buff shale are interstratified with the limestone. Limestones of this type, which are obviously of fresh-water origin, constitute a large part of the Horse Spring formation of southern Nevada, where they are associated with deposits of boron minerals (colemanite and ulexite) and magnesite.[27] Similar limestones in the Mohave Desert near Bissell, Calif., are associated with strata containing deposits of magnesite.[28] They also occur in Tertiary strata that contain borate deposits in the Furnace Creek, Shoshone, Kramer, and Calico districts. A large exposure of them was noted in a series of Tertiary beds that crops out near Tecopa Pass, on the western edge of Pahrump Valley. Another area of them has been observed in Wingate Wash, at the edge of Death Valley about 18 miles north of Owl Spring. Still another occurrence is in the Barstow syncline, where they are associated with beds containing deposits of strontianite.[29] In that locality the limestones appear to have been deposited through the agency of algae.

Aside from the limestones just described, which do not appear to be represented in the Saratoga nitrate field, the upturned Tertiary strata of the Owl Spring field are so much like those of the Saratoga field in lithology that they are indistinguishable from them in appearance. Moreover, as already shown, there is good reason for believing that they are continuous with the strata of the Saratoga field beneath the alluvium that fills the Owl Spring embayment; even if they are not continuous, the nearest outcrops of the strata of the Saratoga field are only 6 miles away. It is practically certain, therefore, that the strata of the Owl Spring and Saratoga fields are the same series of rocks. It is not known what epoch of the Tertiary they represent, but it is probable that they are late Miocene or Pliocene.[30]

PREVIOUS WORK

The Owl Spring nitrate field was first explored in 1901 by Gilbert Bailey, who describes it as follows:[31]

The Owl Spring nitrate field occupies the head of the valley between the west end of the Avawatz Range and the east flank of the Owl Mountains. The district takes its name from the well-known "Owl Holes," or Owl

[27] Noble, L. F., Colemanite in Clark County, Nev.: U. S. Geol. Survey Bull. 735, p. 28, 1922.

[28] Gale, H. S., Magnesite deposits in California and Nevada: U. S. Geol. Survey Bull. 540, pp. 512–516, 1912.

[29] Knopf, Adolph, op. cit., pp. 258, 259.

[30] Noble, L. F., and others, op. cit., p. 35.

[31] Bailey, G. E., op. cit., pp. 177, 178.

Springs, that are located in about the center of the district. The locations selected here cover 6,080 acres.

The niter hills of this field are still partially covered by the Quaternary gravels, the top of the clay hills showing from 25 to 100 feet above the gravels in many places. As the field lies near the top of the divide, it has been more protected from erosion than the other fields. The southwestern or higher portion of the district is especially rich in colemanite and other borates, while the northeastern or lower portion is rich in large deposits of rock salt and heavy salt crusts. The caliche of this field, in general, is not so soft and friable as that of the other fields but carries sufficient salt to make the surface difficult to penetrate with a pick. In other respects the hills resemble the other districts.

In a summary of analyses of caliche from all the nitrate fields of the Amargosa district[32] Bailey gives the results of his sampling in the Owl Spring field as follows: "Highest per cent of niter, 67; lowest, 0.38; average of 18 analyses, 17.2 per cent." Each analysis is stated to represent a sample from a separate claim of 160 acres. The average nitrate content of the caliche in the Owl Spring field thus reported is far greater than that in any other field explored by Bailey, being nearly double that of the next best fields, the Saratoga and Upper Canyon, in which he reports the average nitrate content as respectively 9.4 and 8.98 per cent.

A number of other parties have prospected the Owl Spring field. See particularly notes on the work of Olshausen, Chestnut, and Farrell, published in the report on the Amargosa region.[33]

The records given by the engineers cited are contradictory. The high analyses reported by Bailey and Olshausen indicate that the caliche in the Owl Spring field is the richest in California and suggest that the field is decidedly promising. On the other hand, the results obtained for the California Nitrate Development Co. by Chestnut do not indicate that the field is particularly promising, even if much of the better ground reported by Chestnut should lie in the field. Finally, the low analyses of the samples taken by Farrell indicate that the field is decidedly unpromising.

EXPLORATION

Seven days were spent by the writer at different times from 1918 to 1926 exploring and prospecting the Owl Spring field. In the course of this exploration, which amounted to a fairly thorough reconnaissance, a careful traverse was made of all parts of the field. First the representative types of ground were tested to learn what places contained nitrate. Then pits were dug in the more promising ground to a depth sufficient to penetrate into the underlying unweathered bedrock, and all the material taken out of each pit was

[32] Bailey, G. E., op. cit., p. 165.
[33] Noble, L. F., and others, op. cit., pp. 11–14.

tested. In addition each outcropping set of beds in the bedrock strata that seemed at all likely to contain boron minerals or concentrations of nitrate was opened and tested. Field tests for boron were made by powdering the material, mixing it with a small amount of strong sulphuric acid in an iron spoon, adding alcohol to the mixture, and igniting it. If boron were present the flame would burn green at the end of the test.

It was found that the nitrate in the Owl Spring field is associated only with the outcrops of Tertiary strata, exactly as it is in the Saratoga, Confidence, Upper Canyon, and Lower Canyon fields of the Amargosa region. As in these other fields, the outcrops of the strata on the gentler slopes are covered with a clay soil that is barren of vegetation. The layer of compact clay that forms the surface of the soil contains practically no nitrate. Beneath the compact surface layer at most places is a loose, powdery layer which contains a varying amount of white, efflorescent salts mixed with clay. These salts are largely sulphates and chlorides of sodium, lime, and magnesium. Only insignificant amounts of nitrate are present. Beneath this powdery layer and grading downward into the unaltered bedrock is a cemented layer, the caliche. This caliche is essentially the weathered upper portion of the bedrock (Tertiary strata) which has been recemented by various salts, chiefly sodium chloride. In other words, it represents a concentration of water-soluble salts in a zone below the leached soil at the surface and above the less pervious bedrock strata. The soluble salts appear to have been deposited in this situation by the evaporation of ground moisture, which brought them in solution to the surface, and the salts have been protected from being dissolved or washed away in surface water by the peculiarly impervious character assumed by the surface clay when it becomes wet.[34] At most places in the field the caliche gives reactions for nitrate. At many places reactions indicating the presence of 0.1 to 3 per cent of sodium nitrate were obtained, but in all the field only one reaction that suggested more than 3 per cent. The distribution of nitrate in the caliche, moreover, proved to be exceedingly irregular. A "fair" or "good" reaction in one place would commonly be followed by a "weak" or "negative" reaction a few feet away. As in the other nitrate fields, the only significant amounts of nitrate proved to be in the caliche. The Tertiary strata upon which the caliche lies contain insignificant amounts at some places near the surface, but at most places they contain none at all. The gravelly beds of the washes that traverse the area, the alluvium that mantles it and fills the Owl Spring embayment, the

[34] Noble, L. F., and others, op. cit., p. 70.

fanglomerates that overlie the upturned Tertiary beds, and the pre-Tertiary rocks of the region are entirely barren of nitrate.

The Owl Spring field differs little in essential character from the Saratoga, Confidence, Upper Canyon, and Lower Canyon fields, in all of which the nitrate occurs in a blanket deposit, the caliche, which is associated only with the outcrops of upturned Tertiary strata. In general it resembles the Saratoga field more than it does the others, owing to the similarity of the strata. It differs from all these fields, however, in one very important respect. In the other fields the Tertiary strata with which the niter-bearing caliche is associated form hills which project above most of the alluvium that mantles slopes and fills depressions in the desert. Consequently areas in which caliche can occur cover a considerable part of these fields. In the Owl Spring field, however, the Tertiary strata are buried nearly everywhere under a mantle of alluvium and are exposed only along the washes that have cut their channels beneath the alluvial cover. (See pl. 3, *C*.) Consequently areas in which caliche can occur form only a small part of the field. For example, although the Owl Spring field covers more ground than the Saratoga Hills area of the Saratoga field, the extent of the niter-bearing ground in the Owl Spring field is only a small fraction of the extent of the niter-bearing ground in the Saratoga Hills. This fact alone is sufficient to condemn the Owl Spring field as a commercial source of nitrate, for the 1,200 acres of niter-bearing ground in the Saratoga Hills was regarded as too small an area to be worth consideration as a source of nitrate even under war conditions, unless it could be shown to be covered by a fairly continuous deposit of caliche averaging more than 5 per cent in nitrate content;[35] whereas the tests of the caliche in the Owl Spring field show that an average nitrate content as high as 3 per cent is not even a remote possibility.

Altogether, 58 tests for nitrate were made in different parts of the Owl Spring field, 11 in pits dug entirely through the caliche and the rest in holes dug well into the caliche. Of these 19 were "negative," 22 "weak," 11 "fair," 5 "good," and 1 "strong."

As in the Saratoga field, the hardest and thickest caliche was in the ground underlain by brown salty shales. This hard caliche consists chiefly of sodium chloride and at some places is at least 12 inches thick, but it yields no reaction for nitrate. Apparently, like the similar caliche overlying the bed of rock salt in the Saratoga field,[36] it is practically barren. The resemblance of the salt caliche just described to that overlying the bed of rock salt in the Saratoga field suggests that the salty shales in the Owl Spring field may

[35] Noble, L. F., and others, op. cit., p. 50.
[36] Idem, p. 39.

also contain one or more beds of rock salt, for the salt in the Saratoga caliche overlying the salt bed there is unquestionably derived from the salt bed.

In the ground underlain by gypsiferous shales associated with the salty shales, a few small patches of caliche gave reactions for nitrate ranging from "fair" to "good."

In the ground underlain by the limestones and sandstones there was at some places a hard salty caliche ranging in thickness from 2 to 6 inches. A number of "fair" reactions were obtained from this caliche, a few "good" reactions, and one that could be rated "strong." This very strong black boiling reaction was obtained in a patch of cream-colored caliche about 100 yards below Owl Spring, in ground on the northwest bank of the main Owl Spring Wash. A few feet on each side of this place the caliche gave only a "fair" reaction.

In all the Owl Spring field, as in the Saratoga field, not only is the nitrate irregularly distributed in the caliche but the caliche itself is discontinuous and patchy, large areas of the outcropping Tertiary strata being practically free from it. Owing to the fact that the preliminary testing of the Owl Spring and Saratoga fields was done in a similar way, it is possible to estimate the relative richness of the niter-bearing ground in the two fields with a reasonable degree of assurance; the caliche in the Owl Spring field is very much poorer in nitrate than that in the Saratoga field.

The bedrock strata were tested for nitrate in all excavations dug through the caliche and at many places where no soil or caliche covers them. At most places beneath the caliche they gave no reaction for nitrate, but at some places they gave a "weak" reaction. The strata in the Owl Spring field dip steeply, and therefore the numerous washes that cut across their strike expose far thicker sections of them than would appear if the strata were horizontal. Many hundred feet of beds free from a cover of soil and caliche are thus displayed in low bluffs along the washes, where they afford excellent sections for testing and study. Many beds in these situations in all parts of the field were tested, but they yielded practically no nitrate. Very weak reactions were obtained at two or three places. In brief, here as in all the other nitrate fields, no evidence was found that the strata contain more than insignificant amounts of nitrate.

Exploration of the Owl Spring field by deep boring in the hope of encountering deeply buried concentrations of nitrate can not be recommended as practical, although, as stated in the report on the nitrate fields of the Amargosa region,[37] where the question is

[37] Noble, L. F., and others, op. cit., p. 20.

discussed further, boring in any of the fields would be of scientific interest and might yield results that could not be anticipated. But if such deep boring were contemplated it would seem wiser to undertake the work in a field where the existence of considerable tracts of ground relatively rich in nitrate had been proved conclusively, as, for example, in the Upper Canyon field of the Amargosa region.

In testing the strata for boron no reactions were obtained from the sandstones or from the salty shales. At a few places beds of limestone reacted to the test. Moreover, several samples of limestone sent to the chemical laboratory of the Geological Survey for analysis contained small percentages of boric acid, the maximum being about 0.25 per cent. From one sample made up of fragments chipped from shaly beds interstratified with the limestones both a reaction for boron and a "weak" reaction for nitrate were obtained. Other samples of similar material gave no reactions for boron. The best reaction for boron obtained in the Owl Spring field was in a lumpy calcareous bed about a foot thick consisting partly of shale and partly of nodules of calcareous material. This bed crops out in a wash south of the Randsburg-Death Valley road about half a mile south of Owl Spring. The calcareous nodules gave reactions for boron, which were also obtained from the caliche in the district at two or three places. The samples of caliche that reacted for boron also reacted for nitrate. Colemanite and other boron minerals were searched for at many places in the strata but not found. Evidently Bailey's statement[38] that beds of colemanite crop out in the Owl Spring field is unwarranted. Yet the fact that the strata in places yield reactions for boron suggests that boron minerals may occur in them, and it is possible that a more careful search may reveal their presence. At any rate, the field may be worth prospecting for boron minerals. At different times in the last 10 years a number of claims have been located for borax in the district, as is shown by notices posted on the claim monuments.

CONCLUSIONS

1. The nitrate in the Owl Spring field occurs in a layer of caliche averaging less than 5 inches thick that lies at most places less than a foot beneath the surface of the ground. The caliche is associated only with the outcrops of upturned strata of Tertiary age.

2. The nitrate is irregularly distributed in the caliche, large tracts of the caliche being practically barren of nitrate.

3. The richer tracts of caliche are of small extent, generally not over a few feet in length.

[38] Bailey, G. E., op. cit., pp. 177–178.

4. The aggregate extent of all tracts of nitrate-bearing caliche in the field is not more than a few hundred acres.

5. The average nitrate content of the caliche is low, probably less than 1.5 per cent.

6. There is no evidence near the surface that the Tertiary strata with which the caliche is associated contain more than insignificant amounts of nitrate. It is therefore highly improbable that they contain valuable concentrations of nitrate at depth.

7. For these reasons the Owl Spring field can not be regarded as of commercial importance as a source of nitrate.

8. Owing to the fact that some of the strata yield a reaction for boron it is conceivable that they contain deposits of colemanite or other boron minerals, although none have been found.

NITRATE NEAR TWENTY-NINE PALMS SPRINGS

REASON FOR INVESTIGATION

The occurrence of nitrate near Twenty-nine Palms Springs was brought to the attention of the War Department in 1917 by R. F. Kellam, of Los Angeles, in a letter to the Secretary of War announcing the discovery and asking for an investigation. The deposits were said to lie in Mud Hill (pl. 4, *B*, *C*), a bare silt-covered hill 2 miles north of the springs, and to be covered by a group of claims held by Mr. Kellam and others. Mr. Kellam stated that he had submitted to a chemist a 50-pound sample consisting of a mixture of samples of the ground in the claims, " obtained by gathering material at a number of places, taking it just as it came, without distinction as to layers," and that the chemist had reported the sample to contain " 2 per cent of sodium nitrate and 3 per cent of water-soluble potash." The Geological Survey was called upon to examine the deposits, and the writer spent three days in July, 1918, exploring them in company with John Waltenberg, assistant, and Mr. Kellam.

LOCATION AND GENERAL TOPOGRAPHIC FEATURES

Twenty-nine Palms Springs (see pl. 1) are in the southeastern part of a long, irregular depression in the southern Mohave Desert that has been named by Free[39] the Mesquite Trough. The Mesquite Trough lies just north of and parallel to the San Bernardino Range and extends from the valley of the Mohave River southeastward to Dale. Its length is over 100 miles, and its width at places is as much as 20 miles. It marks a part of the southern boundary of Mohave Desert, much as the Leach Trough marks a part of the northern

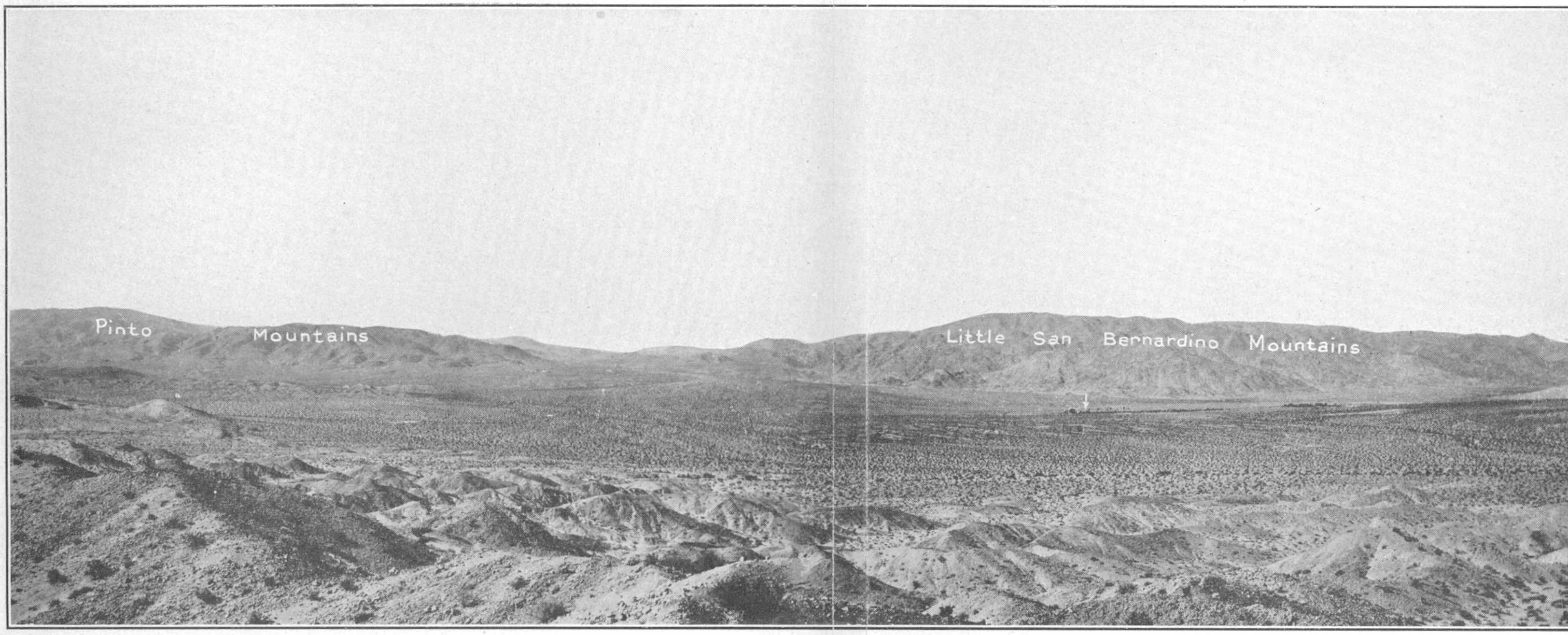
[39] Free, E. E., The topographic features of the desert basins of the United States, with reference to the possible occurrence of potash: U. S. Dept. Agr. Bull. 54, pp. 45, 46, 1916.

boundary. Like the Leach Trough, it is probably of structural origin. The Mesquite Trough consists of a number of local basins separated by low alluvial divides, each basin independent and inclosed and each containing its typical dry lake, or playa. The basin at the extreme east end of the trough contains Dale Dry Lake. The basin next west of the Dale Basin contains Mesquite Dry Lake and two other small playas; Twenty-nine Palms Springs lie in the southern part of this local basin, about 6 miles south of the lake. Twenty-nine Palms Springs are most easily reached by a road that branches from the Los Angeles-Imperial Valley highway at a point 15 miles east of Banning, a town on the Southern Pacific Railroad. (See pl. 1.) This road, which runs through Morongo Valley and crosses a low divide that separates the San Bernardino Mountains from their southeastern extension, the Little San Bernardino Mountains, is a good desert road. The distance over it to Twenty-nine Palms Springs from the point where it leaves the highway is 45 miles.[40]

The floor of the Mesquite Trough in the region about Twenty-nine Palms Springs is a nearly level to gently sloping plain composed of alluvial material washed from the bordering mountains and deposited in fans. Here and there in the plain a low hill projects above the alluvium. Plate 4, *A*, gives an idea of the character of the topography. Bordering this part of the Mesquite Trough on the north are the Bullion Mountains; on the south are the Little San Bernardino and Pinto Mountains, both forming a southeastward extension of the San Bernardino Mountains. The Little San Bernardino and Pinto Ranges are composed of pre-Tertiary crystalline rocks, chiefly granites and gneisses. Mesquite Dry Lake and two other playas on the floor of the trough lie in a chain along and parallel to the western base of a long, low spur of the Bullion Mountains that projects southeastward into the trough. On the south side of the trough, directly opposite this spur, a wide valley enters from the Pinto Mountains. At the mouth of the valley the alluvial material washed down is spread far out into the trough in a great fan. Across the nearly flat lower slopes of this fan, at a point about 2 miles out from the base of the mountains, a thin straight line of trees runs east and west for a distance of a mile or more at right angles to the general northerly slope of the fan. (See pl. 4, *A*.)

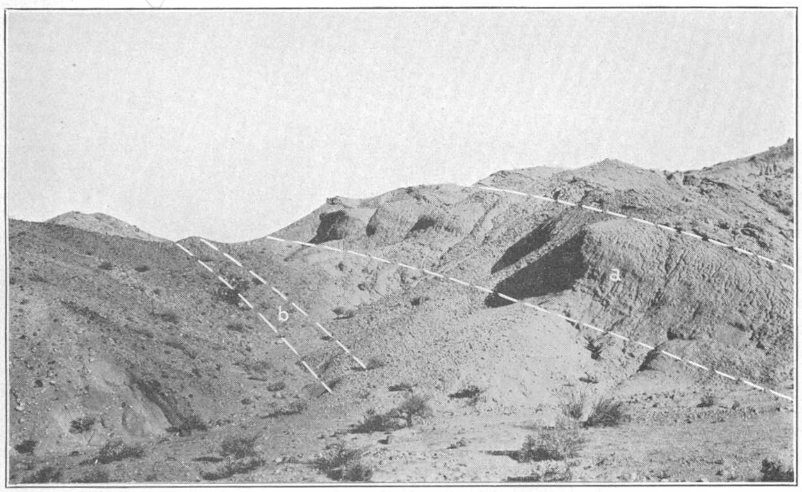
The Twenty-nine Palms Springs emerge at intervals along this straight line, which is marked at most places by moist ground and, near its east end, by a low northward-facing escarpment in the alluvium. The fact that the escarpment trends at right angles to the general slope of the alluvial fan suggests that the escarpment may

[40] For log of road and map see Brown, J. S., The Salton Sea region, California: U. S. Geol. Survey Water-Supply Paper 497, pp. 187–190, 1923.



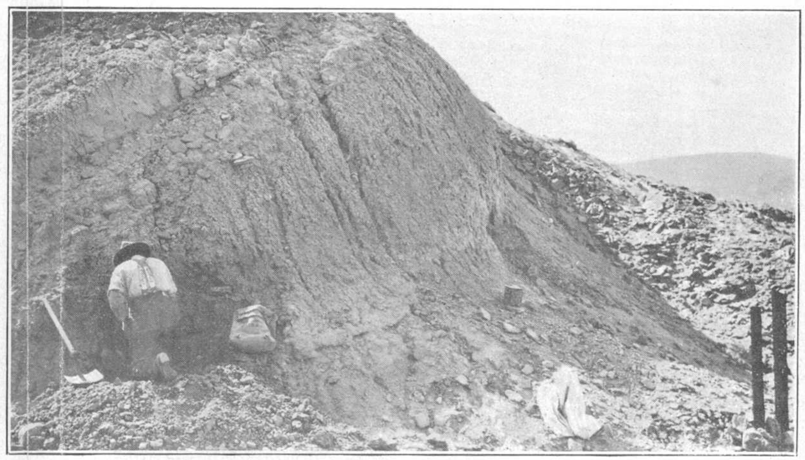
A. VIEW SOUTH ACROSS MESQUITE TROUGH FROM MUD HILL

Tertiary strata in foreground. Twenty-nine Palms Springs in right middle ground, indicated by arrow



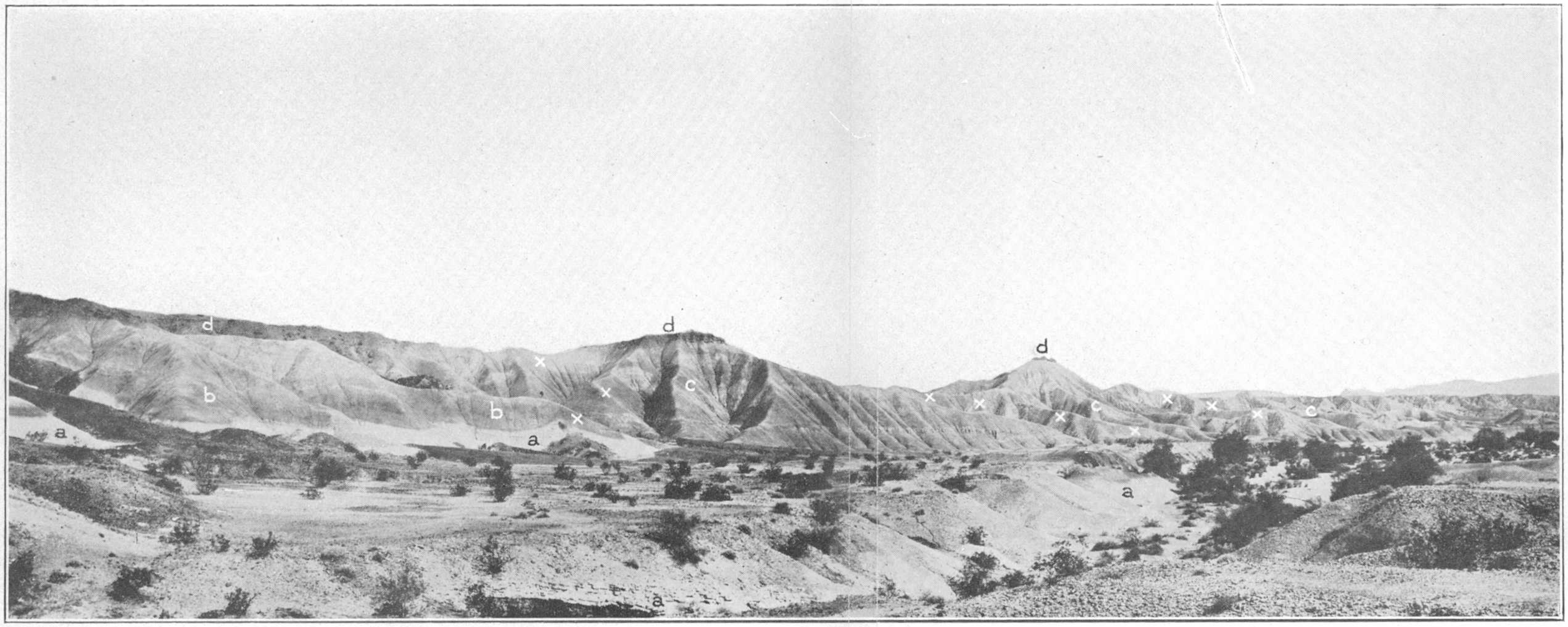
B. SOUTH SLOPE OF MUD HILL

View northwest along upper zone of greenish clay beds. a, Greenish clay bed 20 feet thick; b, greenish clay bed 4 feet thick at base of zone. The dips of beds a and b appear to be divergent, owing to perspective, but are not, as may be seen from Figure 2.



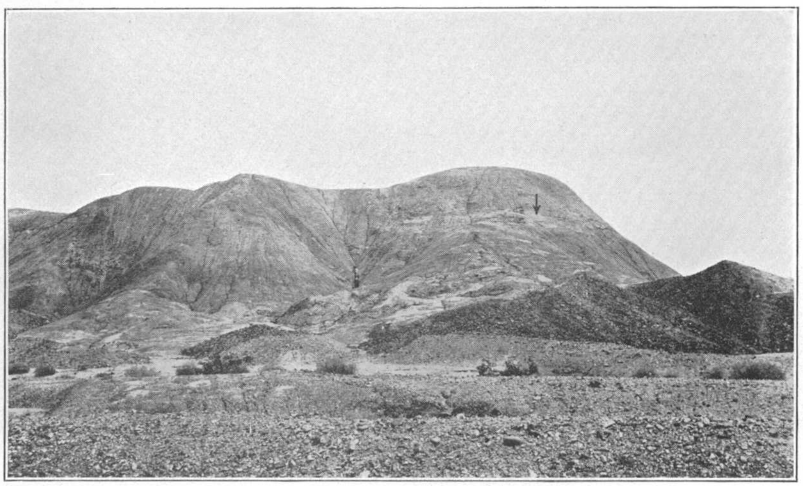
C. PROSPECTING 20-FOOT BED IN MUD HILL

The bed is in the upper clay zone. Samples 1 and 2 were taken here. Center monument Palms Claims No. 1 at right.



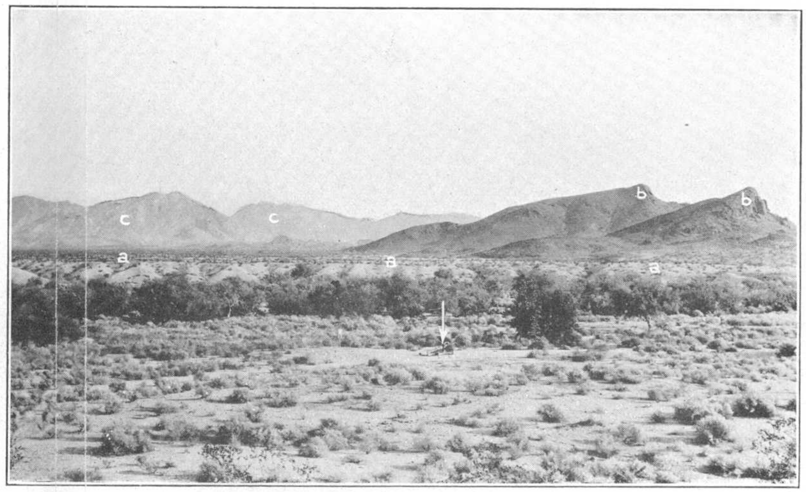
A. GENERAL VIEW OF 400-ACRE AREA 3 MILES WEST OF WEST WELL

a. Basal white chalky shale overlying eroded crystalline rocks; b ,greenish clay shale; c, buff and yellowish shale with lenses of sand; d, alluvial caps, unconformable; ×, locality where sample was taken for field test for nitrate.



B. UPPER BEDS OF BUFF SHALE IN 400-ACRE AREA

Arrow shows locality where sample West Well No. 4 was taken.



C. WEST WELL VIEWED NORTHEAST ACROSS CHEMEHUEVI WASH

Arrow indicates the well. a, Alluvium overlying lake-bed clays upon whose outcrop nitrate is found; b, Tertiary volcanic rocks containing "cave deposits" of nitrate; c, Chemehuevi Mountains.

not be an erosional feature but rather the topographic expression of a fault that has displaced the alluvium. The linear arrangement of the springs and their alinement with the escarpment also suggest the existence of a fault. A number of houses and a small stamp mill stood near the springs at the time of visit, and several tracts of land in the vicinity were being cultivated. Most of the trees along the line of springs are cottonwoods and mesquites; a few are figs. All afford grateful shade. A group of tall native palms (*Washingtonia;* see pl. 7, *C*) stands above the low escarpment just south of the easternmost springs. These palms and the long line of green trees rising from the barren plain make Twenty-nine Palms Springs one of the most picturesque oases in the desert. Palms like these are an unfailing indication of ground water near the surface. Mesquite, shown at the right of the illustration, is another such indicator. According to a barometric reading checked against a bench mark in Morongo Valley a few hours before reaching Twenty-nine Palms, the altitude at the springs is approximately 2,000 feet.

GENERAL GEOLOGY

The observer looking across the Mesquite Trough at Twenty-nine Palms Springs sees few features that break the monotony of the nearly level alluvial floor. The only features that are at all conspicuous are a low hill that projects above the alluvium a mile northwest of the springs and a group of low hummocky hills (pl. 4, *A*) that project here and there above the alluvium 2 miles northeast of the springs and continue southeastward several miles toward the base of the Pinto Mountains. All these hills are composed of beds whose age is probably late Tertiary. Since the beds were laid down they have been tilted, faulted, and perhaps folded, and their upturned edges have been eroded into hills which are now all but buried by the alluvium washed into the trough from the bordering mountains. Altogether the hills cover an area of perhaps 3 or 4 square miles, and the outcrops of the Tertiary beds in them cover probably less than 2 square miles. The structural relations between these strata and the pre-Tertiary rocks bordering the Mesquite Trough are unknown, because the contacts between the two series of rocks are concealed beneath the alluvium that fills the trough. Conceivably, however, the supposed fault in the alluvium at Twenty-nine Palms Springs marks a recent movement on the line of a concealed fault between these Tertiary strata and the pre-Tertiary granitic rocks of the mountains bordering the trough on the south.

The Kellam nitrate claims are in Mud Hill, one of the hills of upturned Tertiary strata just described. This hill lies 2 miles N.

15° E. of Twenty-nine Palms Springs and is the northernmost hill in the group that extends southeastward toward the Pinto Mountains. Mud Hill is about a mile long and half a mile wide. The summit is 2,225 feet above sea level (barometric reading), or 225 feet higher than Twenty-nine Palms Springs. The strata in the hill dip 25°–45° NE. and strike southeast. The axis of the hill is parallel with the strike of the strata.

Most of the strata exposed in Mud Hill are beds of loosely consolidated buff sandstone which here and there contain a lens of gravel, but at two horizons beds of greenish clay or shale are interstratified with the sandstones. The sandstones weather into a loose sandy or gravelly soil that covers all the lower slopes of the hill. In places the soil contains numerous fragments of gypsum, although very little gypsum was observed in the underlying strata. Some of the clay beds taste salty, but the sandstones are remarkably free from saline material.

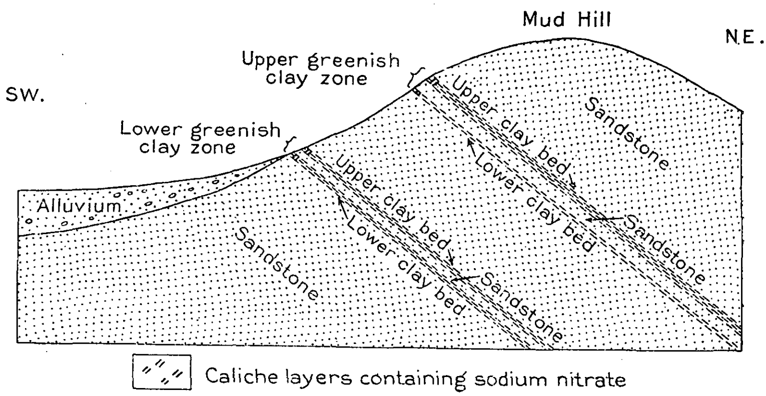


FIGURE 2.—Diagrammatic cross section through Mud Hill, showing position of upper and lower greenish clay zones and relation of nitrate-bearing caliche to their outcrop

The upper set of greenish clay beds may be called the upper clay zone and the lower set the lower clay zone. Figure 2 shows the position and relation of these two zones in Mud Hill. The upper clay zone crops out in a belt three-quarters of a mile long and not much over 100 feet wide along the south slope of the hill about midway up the slope. (See pl. 4, *B*.) Near the center monument of Palms claim No. 1 a clay bed at the top of the zone is 20 feet thick; below the clay bed lies 30 feet of sandstone, and below the sandstone a 4-foot clay bed from which sample No. 4 (see p. 31) was taken. Northwest of this locality other beds of clay appear in the zone and are separated by beds of sandstone, but none of them attain a thickness of more than 6 feet. Nowhere does the thickness of the entire upper clay zone exceed 100 feet. A few fragments of bone embedded in clay were found in digging a prospect pit in the uppermost clay bed near the center monument of the Palms claim No. 1. (See pl. 4, *C*.) These fragments are too poor for paleontologic determination, but they appear to be pieces of a limb bone of a small camel or horse. Although they afford no evidence concerning the exact age of the beds, they show conclusively that the beds are not pre-Tertiary and are not of marine origin. Probably the beds are of late Tertiary age. The amount of disturbance and erosion that they have suffered makes it improbable that they are younger than Tertiary. At any rate, the occurrence shows that the beds contain fossils and suggests that a systematic search in them for fossils would be worth while.

The lower clay zone is separated from the upper by about 300 feet of sandstone. This lower zone crops out in a belt half a mile long and about 100 feet wide along the base of the south slope of the hill. The beds are not so well exposed as those of the upper zone, because they are covered at most places by soil and débris washed down the slopes of the hill. They resemble the beds of the upper zone but individually are thinner. The largest bed exposed is about 12 feet thick.

In general the strata in Mud Hill and in the other low hills near by resemble those of the Pilot nitrate field more than they do those of any other nitrate field described in the present report. In appearance and in degree of disturbance they are like the Tertiary beds that form the Indio Hills, in the Salton Sea region, 30 miles southwest of Twenty-nine Palms, and it is not unlikely that they are roughly equivalent to those beds in age.

EXPLORATION

From preliminary testing it was learned that reactions for nitrate could be obtained only in ground upon the outcrops of the beds of greenish clay in the upper and lower clay zones already described. If the nitrate were concentrated in a caliche layer, it could not possibly be commercially valuable unless the caliche were much thicker and richer than any previously found in California, because the total area of outcrop of the clay beds is too small, owing to the steep dip of the beds, to furnish any considerable tonnage of caliche. If, however, the clay beds themselves should contain significant amounts of nitrate, there was a remote chance of finding concentrations of nitrate in them that would be commercially valuable.

The clay beds were therefore prospected systematically by digging pits in the more promising ground along their outcrops, making the pits deep enough to penetrate the bedrock clay to depths of 2 feet or more. The results of this work showed that the deposits are not essentially different from those in the Barstow syncline, Pilot, and Owl Spring fields, already described. The only significant amounts of nitrate occur in a caliche layer just beneath the surface soil.

Characteristically, the outcrop of each clay bed is marked by a layer of compact clay soil, barren of vegetation and from 1 to 3 inches thick. The surface of the clay soil, as in all the other nitrate fields, is furrowed by innumerable small knobby corrugations, which give it a "cauliflowerlike" appearance. This surface clay gives no reactions for nitrate. At places the clay is underlain by a loose powdery layer consisting of clay mixed with a varying amount of efflorescent saline material. This layer is from 4 to 6 inches thick and gives negative or only weak reactions for nitrate. Underneath the soil layers just described the bedrock clay is cracked and weathered to a depth of several inches and contains films of salt along the cracks. In places the cracked and weathered material is cemented into a compact hardpan, or caliche, by various salts, chiefly sodium chloride. The patches of caliche are very irregular, appearing or disappearing within distances of a few feet, and are thin, averaging perhaps 4 inches in thickness, although some patches reach 8 inches. At some places the caliche or the cracked layer corresponding to it give "good" reactions for nitrate, but at most places the reactions range from "weak" to "fair." Reactions differing greatly in strength were obtained within distances of a few inches, showing that the nitrate is irregularly distributed in the caliche. The bedrock clay strata beneath the caliche everywhere gave much weaker reactions than the caliche. At most places they gave no reaction at depths of 2 to 3 feet but at some places gave "weak" reactions. In general, therefore, they are either practically barren of nitrate or contain only insignificant amounts. Plate 4, *B*, *C*, shows the general character of the nitrate-bearing ground.

The best reactions for nitrate were obtained in caliche overlying the 20-foot clay bed at the top of the upper clay zone, and the next best in caliche overlying the 4-foot clay bed at the base of the zone. None of the reactions were stronger than "good," and nearly all the better ones were only "fair," but in order to check the rating of the field tests a few samples were taken at places on the 20-foot bed and one sample on the 4-foot bed. These were sent to the laboratory of the Geological Survey for chemical determination. From the lower clay zone mostly "weak" or "negative" reactions were obtained and no reaction stronger than "fair." Therefore no samples from that zone were saved for chemical determination. A summary of the results of the sampling follows. By systematic mixing and division the original samples were reduced to half a pound each.

Tests of samples from Mud Hill

[Chemical determinations by E. T. Erickson]

No.	Thickness of layer represented	Depth below surface	Weight of original sample	Reaction in field test of ground from which sample was taken	Nitrate as $NaNO_3$	Soluble K
	Inches	*Inches*	*Pounds*		*Per cent*	*Per cent*
1	18	12-30	35	Negative	0	Trace.
2	6	6-12	5	Weak	.54	Trace.
3	8	8-16	3	Good	2.18	Trace.
4	6	5-11	5	Fair	1.19	0.15
5	6	5-11	3	do	.60	1.42
6	24	12-36	5	Negative	.31	Trace.

1. Greenish clay shale at center monument of Palms claim No. 1. (See pl. 4, *C*.)
2. Cracked and weathered clay containing films of salt, overlying material represented by No. 1; corresponds to caliche layer.
3. Caliche 150 feet northwest of center monument of Palms claim No. 1.
4. Caliche 150 feet southeast of center monument of Palms claim No. 1.
5. Cracked and weathered clay containing films of salt, 600 feet southeast of center monument of Palms claim No. 1; corresponds to caliche layer.
6. Greenish clay shale underlying material represented by No. 5.

Samples 2, 3, 4, and 5 represent caliche and 1 and 6 represent the underlying unaltered bedrock. Samples 2, 3, and 5 are from the outcrop of the 20-foot clay bed. Sample 3, the most promising material found, represents the compact, thoroughly cemented type of caliche, and samples 2 and 5 the loose or flaky type, consisting of cracked fragments of clay separated by films of salt. Sample 4 represents caliche of the flaky type from the outcrop of the 4-foot clay bed. The caliche represented by samples 3, 4, and 5 is overlain by a layer of loose powdery clay soil containing white efflorescent salts and small transparent crystals which have a bitter taste. The caliche represented by samples 4 and 5 grades imperceptibly into this overlying layer, a part of which is thus necessarily included in the samples, but the caliche represented by sample 3 is distinct from the overlying layer, and the sample consists of compact caliche alone. At the locality where sample 2 was taken the overlying loose layer is absent, and the caliche lies directly under the compact surface clay. According to Mr. Kellam, a large part of the material which made up his 50-pound composite sample of the ground in his claims was obtained at the locality of samples 1 and 2.

From the results just given, it appears that the best caliche in Mud Hill contains considerably less than 3 per cent of sodium nitrate, that the caliche in general contains less than 1 per cent, and that the bedrock clay beneath the caliche contains only insignificant amounts.

Mud Hill constitutes perhaps one-sixth of the total area in which upturned Tertiary strata crop out in the Twenty-nine Palms region. Other outcrops appear in a hill a mile northwest of Twenty-nine Palms springs and in the tract of low hummocky hills that extend from Mud Hill southeastward to the base of the Pinto Mountains.

In all these areas the prevailing beds are nonsaline, loosely consolidated sandstones which neither contain nitrate nor are overlain by nitrate-bearing caliche. The clay beds, with which the nitrate deposits are associated, are much less abundant than the beds of sandstone.

CONCLUSIONS

1. The nitrate in the Twenty-nine Palms district occurs in a blanket deposit of so-called caliche less than 8 inches thick which lies 4 to 16 inches below the surface of the ground.
2. The caliche is sharply restricted to outcrops of upturned beds of greenish clay.
3. The greenish clay below the caliche and the soil above the caliche contain insignificant amounts of nitrate.
4. The total area of outcrop of the greenish clay beds on which the nitrate-bearing caliche occurs does not exceed 12 acres in Mud Hill, the only locality where nitrate has been discovered in the district.
5. The distribution of the caliche is spotty.
6. The richest caliche obtainable contains less than 3 per cent of sodium nitrate, and the average probably contains less than 1 per cent.
7. Although other beds of clay similar to those in Mud Hill occur in the district their outcrops obviously can not cover a large area, owing to the steep dip of the beds.
8. For all these reasons the deposits of nitrate in the Twenty-nine Palms district afford no hope of commercial utilization.
9. The amounts of soluble potash found in the samples are not unusually high and are of no commercial importance. Like the nitrate, the potash occurs in significant amounts only in the caliche. The scarcity of saline material in the Tertiary beds renders it highly improbable that concentrations of potash salts occur in them.

NITRATE IN VALLEY OF THE COLORADO RIVER

OCCURRENCES

Nitrate has been found at the following localities in the valley of the Colorado River below Needles, Calif.: In California, near Beal, 6 miles southeast of Needles; near West Well, 33 miles southeast of Needles; near Vidal, 50 miles south of Needles; and near Vivet Eye Peak, 7 miles south of Vidal; in Arizona, 7 miles southeast of Parker.

The nitrate near Beal, Vidal, and Parker and most of that near West Well occurs a few inches beneath the surface of the ground in a salty layer at the base of clay soil underlain by strata composed largely of clay. These deposits resemble those in the Amargosa region[41] and those in the Barstow, Pilot, Owl Spring, and Twenty-nine Palms districts, described in the present report, and are of the "clay-hill" type.

Some of the nitrate near West Well, however, is associated with volcanic rocks, occurring mostly in crevices and on cliff faces protected by overhanging ledges. This deposit belongs to a class to which Gale[42] has applied the general term "cave deposits." Gale[43] and Mansfield[44] have described many "cave deposits" in the western United States similar to the one associated with volcanic rocks near West Well. The nitrate deposit in volcanic rocks near San Simon, Ariz., described elsewhere in the present report, is similar to the deposit near West Well. Other deposits of this type in Presidio and Brewster Counties, in western Texas, have been examined by the Geological Survey.

The nitrate near Vivet Eye Peak occurs in cavities in a deposit of gypsiferous material like travertine and appears to constitute a type of deposit somewhat different from either the "clay-hill deposits" or the "cave deposits."

The West Well, Beal, Vidal, and Vivet Eye deposits are described below. Their locations are shown in Plate 1.

PREVIOUS EXPLORATION

Bailey[45] states:

> Clay hills of considerable extent that carry niter in commercial quantities are reported as existing in the mountains on the west side of the Colorado River, about 30 miles south of the town of Needles. * * * Analyses of specimens brought in show from 14 to 40 per cent of niter in clay strata.

This locality is undoubtedly the clay-hill portion of the West Well tract.

In 1904 Turner[46] made a careful and systematic examination of the Beal, West Well, Parker, and Vivet Eye tracts, exploring the niter-bearing ground by digging or blasting pits and trenches in which he took samples at different depths for analysis. He outlines the general geologic sequence along Colorado River below Needles as follows:

> Soft lake beds (mostly horizontal).
> Unconformity.
> Volcanic rocks (chiefly tuff and breccia).
> Older rocks.

---

[41] Noble, L. F., and others, op. cit.

[42] Gale, H. S., Nitrate deposits: U. S. Geol. Survey Bull. 523, p. 9, 1912.

[43] Idem, pp. 16–25.

[44] Mansfield, G. R., Nitrate deposits in southern Idaho and eastern Oregon: U. S. Geol. Survey Bull. 620, pp. 19–44, 1915.

[45] Bailey, G. E., op. cit., p. 180.

[46] Turner, H. W., The sodium nitrate deposits of the Colorado: Min. and Sci. Press, vol. 94, pp. 634–635, 1907.

He then states:

> The nitrates were found in three forms:
>
> 1. Efflorescence, chiefly on porous volcanic breccias, West Well area. In protected places on volcanic rocks patches of white salts were found to contain sodium nitrate up to 1.5 per cent, with much sodium chloride. It required but a few blasts, however, to demonstrate that the deposits were a mere surface efflorescence, as a foot or two below the rock contained only traces.
>
> 2. In the shales of the lake beds. In the Beal area, near West Well, and south of Parker, as well as at many other points, there are extensive layers of greenish shale in the lake beds, and these shales nearly always give a reaction for sodium nitrate.
>
> The beds are much cut up by gulches, and the surface is usually crusted over with a mud formed by the slacking of the shale during rains. This crust (A) usually gives a reaction for nitrates and other salts, but immediately under it there is frequently a white layer (B) richer in soda and lime salts. Frequently layer (B) is wanting. Finally, resting on the undisturbed shale, is a third layer (C) from 3 to 12 inches thick, composed of broken bits of shale, and this lower layer usually shows a strong reaction for sodium nitrate.
>
> If now we cut through these surface deposits into the undisturbed underlying shale, we find usually a sudden decrease in the content of salts and conclude that the larger content of salts in the surface layers is due to leaching by the rain water from the shale, which breaks and slacks when wet. These salts are then redeposited immediately under the mud crust in layers (B) and (C).
>
> 3. Deposits on the hill slopes associated with other salts and travertine, Vivet Eye. * * * In ascending [the Riverside Mountains in the vicinity of Vivet Eye Peak] from Colorado River, one passes first over limestone and dolomite beds probably of Paleozoic age; next over a series of green schists; then comes the limestone that forms the summit of Vivet Eye. These three terranes have a general north-south strike and dip at a steep angle.
>
> The zone of green schist is largely obscured by fragments of schist that have been cemented by a porous deposit of carbonate of lime resembling travertine, mixed with varying amounts of white salts. This travertine material, evidently of recent origin, is 20 feet or more thick in some places.
>
> A number of cuts were made in the cement breccia of Vivet Eye, and here also the content of sodium nitrate was found rapidly to diminish with depth. At some points, however, nearly pure deposits of white salts, a foot or more thick, were observed, and subsequent analyses showed several salts were present. In one sample as high as 14.4 per cent sodium nitrate was found.

Only one of the many samples that Turner took from the clay-hill deposits—that is, the deposits "in the shales of the lake beds" was found to contain as much as 4 per cent of sodium nitrate, and only two other samples as much as 3 per cent.

Turner concluded that none of the three types of deposit are commercially valuable. His analyses of the samples from type 1 (the cave deposits), in which the nitrate occurs as "efflorescence chiefly on porous volcanic breccias," and from type 2 (the clay-hill deposits), in which the nitrate occurs "in the shales of the lake beds," indicate that the amount of nitrate in these deposits is prevailingly low; whereas the rapid decrease of nitrate with depth in every excavation indicates that the deposits are superficial. Some samples from the Vivet Eye deposit (type 3) are relatively rich in nitrate, but the excavations dug in this deposit indicate that it also is superficial. However, Turner regarded the Vivet Eye deposit as the most promising of all the deposits that he examined.

Turner's report, like a report by Frank Robbins on the nitrate deposits of the Upper and Lower Canyon fields in the Amargosa region,[47] which was made in the same year (1907), records a fair, thorough, and conscientious attempt to ascertain the extent and value of typical clay-hill nitrate deposits by systematic prospecting and sampling. Like Robbins's report, it gives a clear and accurate account of the mode of occurrence of the nitrate and is in close accord with the observations made later by the Geological Survey in the same ground.

In 1910 Graeff,[48] gave analyses of four samples which he took from the surface of clay beds that crop out in clay hills 100 to 300 feet high in Chemehuevi Valley, 32.6 miles south of Needles. This locality is undoubtedly within the West Well tract and in all probability lies within that part of the tract that is designated the 400-acre area in the present report. The analyses show 7.2, 8.2, 17.2, and 22.6 per cent of sodium nitrate. These remarkably high percentages of nitrate in the surface samples led Graeff to conclude that the interior of the clay hills contains large deposits of nitrate. As evidence in support of this conclusion he states that one surface sample taken near the top of a hill contains 8.2 per cent of sodium nitrate, whereas another surface sample taken 14 feet lower down on the same hill contains 22.6 per cent. However, as he states that he did not penetrate the interior of the hills nor obtain samples from strata under their base, it is evident that all his samples represent surface material.

REASON FOR INVESTIGATION

In 1917, after the United States had entered the World War, interest in nitrate revived, and many tracts of niter-bearing ground in the desert region were again actively prospected. In the Colorado River Valley interest centered in the deposits near West Well, and many claims were staked there. Some of the locators wrote to the War and Interior Departments stating that valuable deposits of nitrate had been discovered and asking for an investigation of the deposits. One deposit that was said to cover 15,000 to 20,000 acres in the vicinity of West Well was said to have yielded samples containing as high as 15 per cent of sodium nitrate. Another deposit near West Well was said to form a bed many hundred acres in extent

[47] Noble, L. F., and others, op. cit., p. 12.
[48] Graeff, F. W., Eng. and Min. Jour., vol. 90, p. 173, 1910.

containing 4.87 per cent of calcium nitrate. Clay strata at some places were said to have yielded samples containing as high as 20 per cent of sodium nitrate. Notwithstanding these optimistic reports concerning the discoveries, it is probable that in ordinary times the Geological Survey would not have undertaken an investigation of the deposits, for Turner's careful and systematic examination had demonstrated beyond a reasonable doubt the superficial character of the deposits and their prevailing low nitrate content. Indeed, the mode of occurrence alone, as outlined by Turner, would indicate that the deposits are valueless, even if some patches of ground contained a fairly high percentage of nitrate. However, the emergency created by the war made it imperative to overlook no clue to the existence of even possibly workable deposits.

PLAN AND RESULTS OF INVESTIGATION

In planning the investigation it was decided to examine one representative tract of each of the three types of deposit described by Turner, prospecting the ground by digging pits deep enough to penetrate the unweathered bedrock beneath the deposit and testing the material removed. If systematic field testing showed that any deposits in these representative tracts offered hope of commercial utilization all tracts of the sort in the region were to be prospected and sampled, but if the representative tracts proved unpromising a brief reconnaissance of the other tracts would suffice. The West Well and Vivet Eye tracts were selected for the more detailed exploration—the West Well tract because it contains all the promising discoveries reported to the War and Interior Departments, because it contains deposits of both the "cave" and the "clay-hill" type, and because it contains larger areas of clay-hill ground than the other tracts; the Vivet Eye tract because it contains the unusual type of deposit that Turner regarded the most promising of all the Colorado River deposits.

Beginning in August, 1918, seven days was spent exploring the West Well tract, part of a day was devoted to the Beal tract, five days to the Vivet Eye tract, and one day to a tract near Vidal.

In the West Well tract considerable areas of clay-hill ground contain nitrate concentrated in a layer less than 6 inches thick a few inches below the surface. The content of nitrate in the caliche layer is low, averaging certainly less than 2 per cent and probably less than 1 per cent, and the bedrock 6 inches below the caliche contains no nitrate or only traces. The nitrate is very irregularly distributed in the caliche, and the caliche itself is patchy in distribution, being present at some places and absent at others. In volcanic rocks near West Well some protected surfaces under cliffs and some cavities in the rock contain nitrate, but this nitrate is only a surface efflorescence. Field tests of the best material obtained from these deposits indicated a nitrate content of less than 2 per cent. Both the clay-hill deposits and the deposits in volcanic rocks are therefore of very low grade, superficial, and consequently of no commercial value. There is no tract of niter-bearing ground covering, as was reported, 15,000 to 20,000 acres anywhere in the region. The largest single tract of niter-bearing ground does not exceed a few hundred acres in extent, and the area of all the niter-bearing ground in the West Well tract is measurable in hundreds of acres, not thousands. The deposit said to form a bed containing 4.87 per cent of calcium nitrate proved to be a bed of calcareous marl containing no nitrate or only traces, although patches of caliche upon some outcrops of the bed contain small amounts of nitrate.

The nitrate-bearing ground of the Vivet Eye tract is a peculiar surface deposit of loose or partly consolidated material averaging 3 feet in thickness which overlies steeply inclined beds of schist. The character and origin of this surface deposit are not clear. It somewhat resembles travertine but appears to be composed chiefly of gypsum, not calcium carbonate. In general it suggests certain gypsum deposits of the efflorescent type to which Hess [49] has applied the term "gypsite." It is therefore called gypsite in the present report. The gypsite is perforated by numerous small cavities, most of which contain deposits of white powdery saline material, largely sulphates of sodium, calcium, potassium, and magnesium, and some of the saline material contains as much as 12.70 per cent of sodium nitrate. Most of the cavities are only a few feet in diameter, and their aggregate extent is small in comparison with the mass of the gypsite, which is nearly barren of nitrate; moreover, the nitrate content of the saline material in the cavities varies widely. Perhaps a few tons of nitrate could be produced from the Vivet Eye tract by collecting the saline material from all the more readily accessible cavities, but the distribution of the nitrate is so spotty and the amount contained in the gypsite as a whole is so small that the tract is of no commercial importance. The schist beneath the gypsite contains no nitrate.

The Beal and Vidal tracts proved to be clay-hill tracts like the West Well tract but smaller. Here also the nitrate occurs in a caliche layer a few inches below the surface. The caliche is patchy and spotty. No ground was observed better than that in the West Well tract, which is poor.

In brief, the results of the Geological Survey's investigation are practically the same as those obtained by Turner and confirm his

[49] Hess, F. L., A reconnaissance of the gypsum deposits of California: U. S. Geol. Survey Bull. 413, pp. 7–22, 1910.

conclusion that none of the Colorado River deposits are commercially valuable.

Detailed descriptions of the localities and of the deposits upon which the conclusions just stated are based follow.

WEST WELL TRACT

LOCATION AND EXTENT

Chemehuevi Basin, the broad irregular depression bordered by the Mohave, Sacramento, Turtle, and Whipple Mountains, is drained by a dry stream course known as Chemehuevi Wash, which enters the Colorado River in Chemehuevi Valley. (See pl. 1.) About 5 miles west of the river Chemehuevi Wash cuts through a group of low rocky hills that rise across its path on the floor of the basin. Just upstream from these hills a well, known as West Well, has been dug in a sandy flat bordering the wash. (See pl. 5, *C*.) To reach West Well from Needles the traveler must turn east from the Needles-Parker road at a point 27 miles from Needles and follow a road that leads to the well. The distance by road from Needles to West Well is a little over 33 miles.[50]

The niter-bearing ground that constitutes the West Well tract lies along Chemehuevi Wash between West Well and the Colorado River and is wholly within T. 4 N., Rs. 24 and 25 E. Nearly all of it is south of Chemehuevi Wash, and most of it is within the part of T. 4 N., R. 24 E., that lies east of a line drawn south through West Well. The area of the entire tract is about 36 square miles.

GENERAL GEOLOGIC FEATURES

Most of the surface of the tract is covered with a mantle of alluvium forming broad, gently sloping plains which rise from Chemehuevi Wash and the Colorado River to the bedrock slopes of the Mohave and Whipple Mountains. (See pl. 5, *C*.) Numerous stream courses, the largest of which is Chemehuevi Wash, have cut deep channels in the alluvium, so that most of the tract is a monotonous succession of gently sloping mesa-like surfaces and steep-sided gullies. As exposed in the sides of the gullies the alluvium ranges in thickness from 3 to 50 feet. Over some areas it has been worn entirely away.

Underneath the alluvial mantle lie strata of the lake-bed series and older rocks of Tertiary and pre-Tertiary age. In the higher parts of the tract the lake-bed strata are either covered entirely by the alluvium or crop out only in bluffs along the deeper gullies, but in the lower parts, where the gullies widen out and where much

---

[50] For log of road see Thompson, D. G., op. cit., p. 240.

of the alluvium has been removed by erosion, they are exposed over considerable areas and are carved into clay hills or badlands. (See pl. 5, *A*, *B*.) At some places in the tract low rocky hills of the older rocks project above the lake-bed series and the alluvium. (See pl. 5, *C*.) The largest of these hills form the group that rises across the path of Chemehuevi Wash just east of West Well. They consist chiefly of volcanic rocks of Tertiary age—rhyolite, breccia, and tuff—but partly of quartzite and gneiss that are much older than the Tertiary volcanic rocks.

By rough estimate, the alluvium covers 29 of the 36 square miles in the West Well tract, the outcrops of the lake-bed series cover 2 square miles, and the outcrops of the older rocks 5 square miles.

AREAS CONTAINING NITRATE

The clay-hill nitrate deposits are associated with the outcrops of the lake-bed series, and the "cave deposits" are associated with the outcrops of the Tertiary volcanic rocks. The alluvium contains no nitrate.

The largest continuous exposure of the lake-bed strata in the West Well tract lies about 3 miles east of West Well and occupies roughly the SE. ¼ sec. 11, the SW. ¼ sec. 12, and the E. ½ sec. 14, T. 4 N., R. 24 E., covering in all about 400 acres. (See pl. 5, *A*, *B*.) This exposure may be called the 400-acre area. Some fairly large exposures, none of which appear to be as large as the 400-acre area, occur in secs. 7, 17, and 18, T. 4 N., R. 25 E. All other exposures in the tract are narrow, disconnected outcrops in bluffs along the sides of gullies. Altogether the outcrops outside the 400-acre area cover perhaps 850 acres, but no single outcrop is more than a few acres in extent.

The low rocky hills that border Chemehuevi Wash just east of West Well occupy secs. 9 and 15, the S. ½ sec. 4, the SW. ¼ sec. 10, the N. ½ sec. 16, and the W. ½ sec. 14, T. 4 N., R. 24 E., and cover about 2,400 acres.

Secs. 1 to 4, 8 to 17, and 20 to 23, T. 4 N., R. 24 E., were traversed and explored. These sections include the 400-acre area and practically all the disconnected outcrops of the lake-bed strata, as well as most outcrops of the Tertiary volcanic rocks. They contain all the ground in the West Well tract in which discoveries of nitrate have been reported.

CLAY-HILL DEPOSITS

METHOD OF EXPLORATION

At first preliminary tests were made at many different places on the outcrops of the lake-bed strata to locate the more promising ground. Then the ground where the strongest reactions for nitrate had been obtained was prospected by pits dug 1 to 3 feet deep, and the different layers of material removed were sampled. The pits were deep enough to penetrate 6 inches to 2 feet into the unaltered bedrock below the surface soil. Each sample taken from the pits was obtained by systematically mixing and dividing not less than 5 pounds of material.

More than 100 preliminary tests were made, but only 37 were sufficiently promising to justify digging pits for systematic sampling. In all, 81 samples from the 37 pits were tested in the field, but no sample furnished a reaction indicating the presence of more than 3 per cent of sodium nitrate. Therefore it was not considered worth while to save many samples for analysis in the chemical laboratory of the Geological Survey. A few that gave "weak" reactions were, however, sent to the laboratory to check the first tests. Upon analysis they were found to contain only traces of nitrate.

The 400-acre area was more thoroughly explored than the other outcrops of the lake-bed strata, both because it is larger and because it exhibits a thicker section of the strata than any other area in the West Well tract. Of the 37 pits 19 were dug in this area, and more than half of all the samples were taken there.

THE 400-ACRE AREA

Areal geology.—The rocks consist chiefly of strata of the lake-bed series that crop out continuously in steep slopes along the sides of the valley and its tributary gullies. (See pl. 5, *A*, *B*.) At most places the strata are carved into badlands, but here and there they are worn into smooth rounded hills, some of which stand within the valley. These hills are mantled with a light-colored clay soil that supports no vegetation and are similar to the clay hills of other nitrate districts described in this report. Except where they are so steep as to form bluffs, the badland slopes are likewise covered with the characteristic barren clay soil. Along the rim of the valley the alluvium overlies the lake-bed strata in a continuous mantle, and within the valley isolated remnants of the alluvium cap some of the higher clay hills. (See pl. 5, *A*.) The floor of the valley is covered with gravel and sand washed down the stream courses by intermittent floods.

The base of the lake-bed series is well exposed in the southern part of the area. The strata lie upon an uneven surface composed partly of Tertiary lavas, largely rhyolite, and partly of pre-Tertiary metamorphic rocks, largely quartzite and gneiss. Here and there these older rocks project through the lowermost lake beds, and at places remnants of the basal lake beds fill small hollows in the older rocks.

The basal layer of the lake-bed series is a coarse sandy conglomerate made up of fragments of the underlying rocks. The fragments as a rule are derived from whatever type of rock immediately underlies the conglomerate. For example, where the conglomerate rests upon Tertiary lavas the fragments are composed of rhyolite and rhyolite breccia; where it rests upon pre-Tertiary metamorphic rocks the fragments are composed of quartzite, gneiss, and pegmatite. The conglomerate varies considerably in thickness, ranging from 15 feet to the vanishing point. Over considerable areas it is absent.

Overlying the conglomerate is a bed of brilliantly white loose-textured shale that ranges in thickness from 15 to 50 feet. (See pl. 5, *A*.) In the field this shale was thought to be very fine volcanic ash, but a specimen of it sent to the chemical laboratory of the Geological Survey for determination proved to consist largely of calcium carbonate and was classified as a calcareous marl, or chalk. This shale is the bed that was reported to contain 4.87 per cent of calcium nitrate (pp. 35–36).

Above the white shale is greenish shale 25 to 50 feet thick which is more or less gypsiferous and very thinly laminated, many laminae being as thin as cardboard. (See pls. 5, *A*, and 6, *A*.) This shale passes up into light yellowish-brown or buff shale which here and there contains lenses of sandy material. Both the greenish shale and the buff shale contain a considerable amount of sodium chloride. The greatest thickness of the buff shale as exposed in the area is 175 feet. It is overlain unconformably by the alluvium, so that its thickness as originally deposited is unknown.

The strata just described, which constitute the lake-bed series, dip very gently or are horizontal in the 400-acre area, but at some places near by they dip steeply in various directions and are cut by faults. One of these places is about a mile to the southwest, in the upper valley of the main wash that traverses the area.

Most of the alluvium overlying the lake-bed strata consists of poorly assorted sand, gravel, and clay that obviously have been washed from the mountains surrounding Chemehuevi Basin and spread out in alluvial fans. (See pl. 5, *C*.) In places, however, beds of sorted and well-rounded cobbles lie upon the lake-bed strata, and, although some of these cobble beds are 200 feet or more above the Colorado River, it is impossible to escape the conclusion that they have been deposited by the river, for many of the cobbles are identifiable with rocks that crop out along the river many miles above Chemehuevi Valley. One cobble bed, shown in Plate 7, *B*, contains fragments that appear to be lithologically identical with certain beds of Cambrian quartzite (Tapeats sandstone) and Carboniferous limestone (Redwall limestone) of the Grand Canyon region.

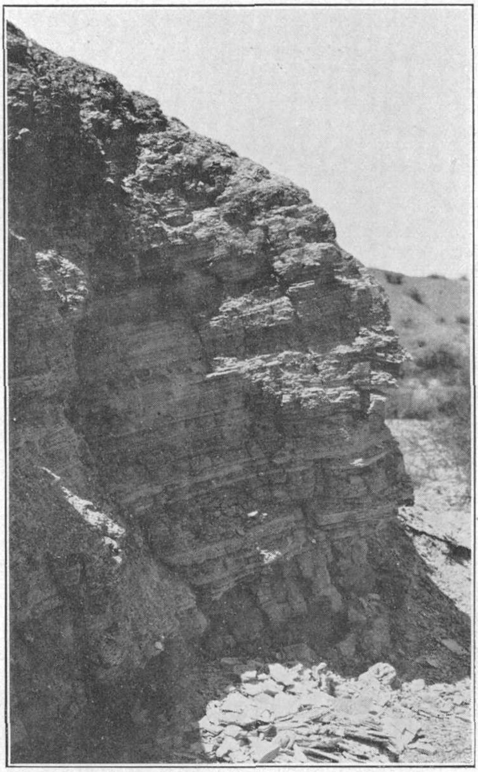
The stratigraphic sequence of the deposits just described is summarized in the following table:

Section of formations exposed in the 400-acre area

	Feet
Sand and gravel, filling beds of washes	(?)
Undifferentiated alluvium, consisting chiefly of mountain outwash deposited in alluvial fans, but partly of river deposits	0–50
Unconformity.	
Lake-bed series:	
4. Buff clay shale containing a few sandy beds	+175
3. Greenish clay shale	25–50
2. White chalky shale	15–50
1. Conglomerate	0–15
	+290
Unconformity.	
Volcanic rocks, largely rhyolite and rhyolite breccia	(?)
Unconformity.	
Quartzite, quartz schist, granitic gneiss, and pegmatite	(?)

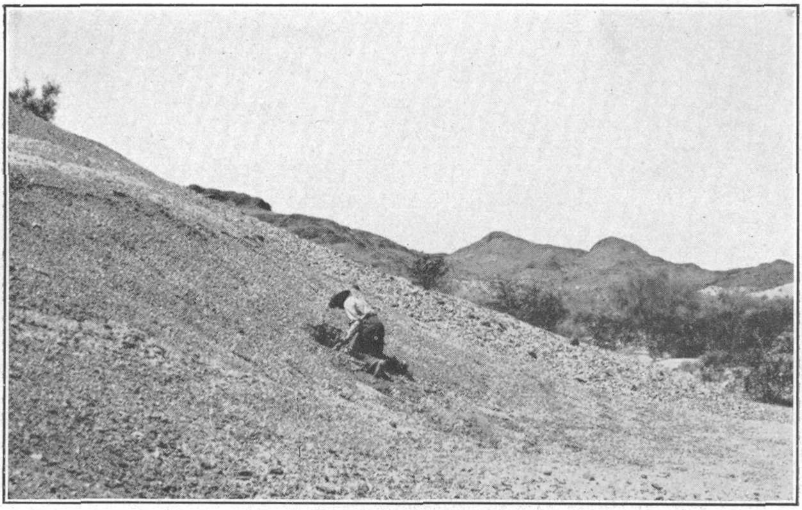
Mode of occurrence of nitrate.—The soil that mantles the outcrops of the shales of the lake-bed series commonly exhibits two distinct layers—an upper layer of compact material, which forms the surface of the ground, and an underlying layer of loose, powdery material. (See pl. 9, *C*.) At some places the powdery layer is absent. The upper layer consists of compact clay whose surface is corrugated by innumerable little knobs and cracks and is 1 to 3 inches thick. (See pls. 6, *B*, and 9, *C*.) At most places it gives no reaction for nitrate, but at some places it gives a very weak reaction. The underlying loose layer consists of powdery clay mixed with white efflorescent salts—chiefly sulphates and chlorides of sodium, potassium, calcium, and magnesium. This layer is commonly less than 12 inches thick. Generally it gives weak reactions for nitrate.

Ordinarily the shale beneath the soil mantle just described is cracked, weathered, and more or less cemented by saline material to a depth of 2 to 12 inches. The saline material occurs far more abundantly in this weathered zone than in the soil above it or in the unweathered shale below it, consists chiefly of sodium chloride, and at some places gives fair to good reactions for nitrate. As a rule the shale beneath the weathered zone gives no reaction for nitrate, but at some places it gives a weak reaction. Thus here, as in the other clay-hill tracts described in this report, the only significant amounts of nitrate occur in a weathered and more or less cemented zone cor-



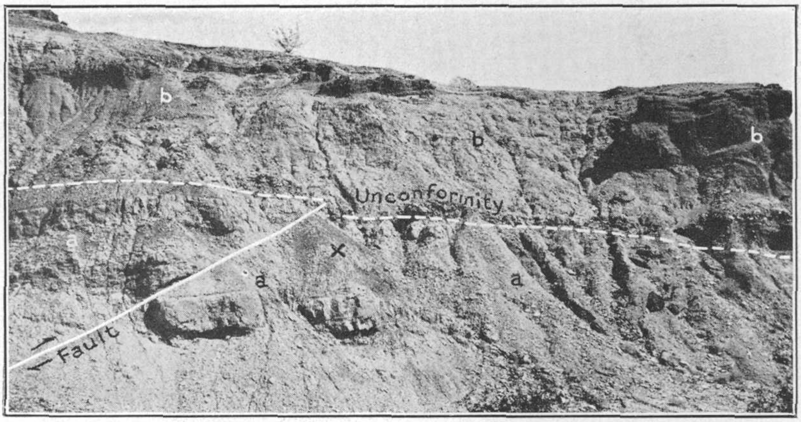
A. GREENISH LAKE-BED SHALE IN CHEMEHUEVI WASH

Shows thin lamination.



B. PROSPECTING GREENISH CLAY SHALE IN CHEMEHUEVI WASH, 1½ MILES NORTHEAST OF WEST WELL

Nitrate-bearing ground free from vegetation.



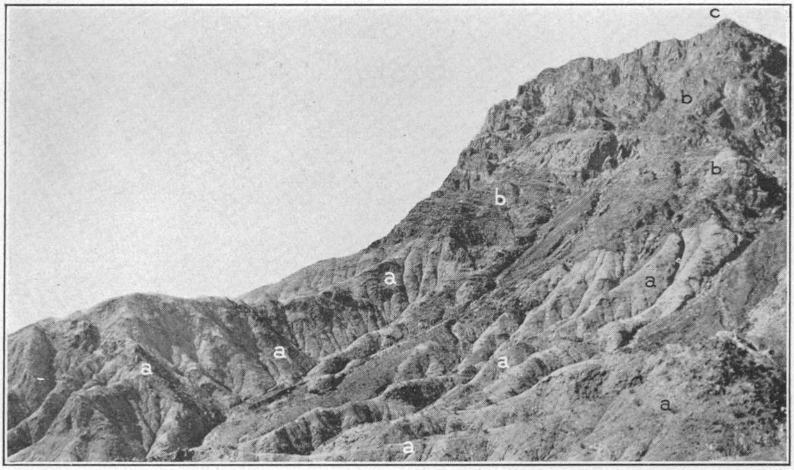
A. FAULTED AND ERODED STRATA OF LAKE-BED SERIES (a) OVERLAIN BY ALLUVIUM (b)

b, Typical exposure in bluffs along lower Chemehuevi Wash; ×, locality where sample that gave nitrate reaction was obtained at depth of 1 foot.

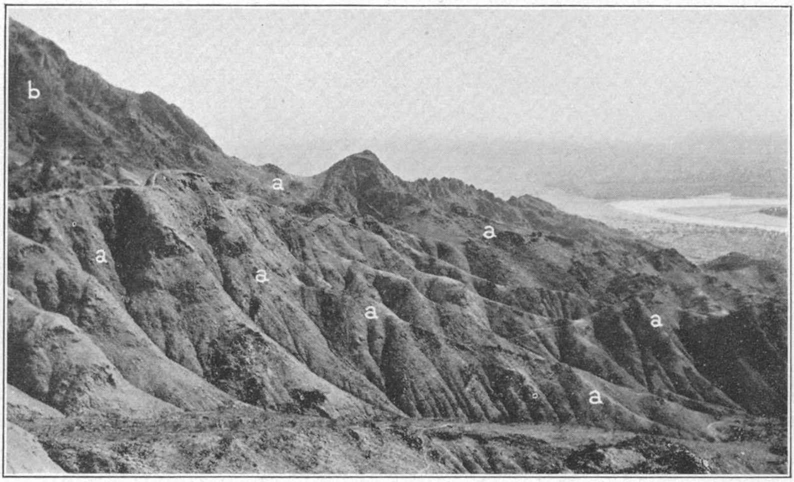
B. RIVER-WORN COBBLES LYING UPON LAKE-BED SERIES MORE THAN 200 FEET ABOVE COLORADO RIVER

C. TWENTY-NINE PALMS

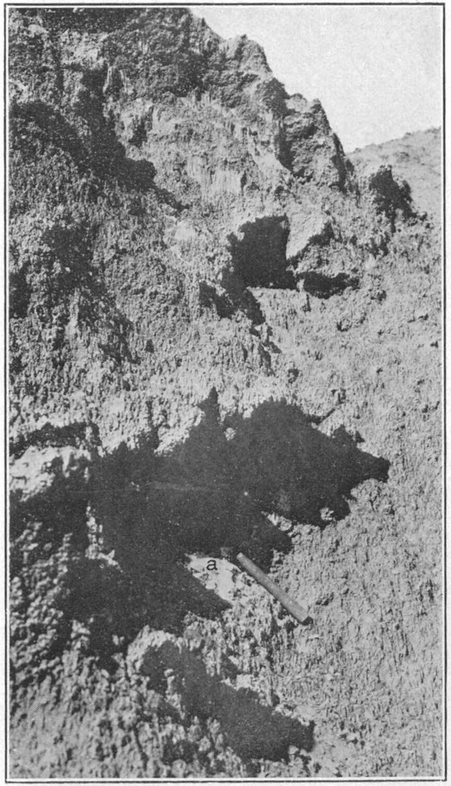
Note low escarpment. Palms like these are unfailing indicators of ground water near the surface.



A. GYPSITE DEPOSIT ON EAST SLOPE OF RIVERSIDE PEAK
a, Gypsite deposit lying on schist; b, limestone; c, Riverside Peak.

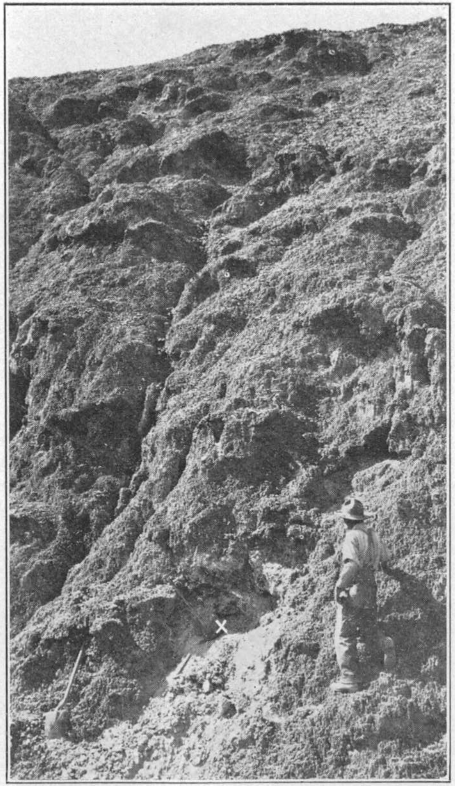


B. VIEW NORTHEAST ALONG GYPSITE BELT
Colorado River at right. a, Gypsite belt; b, limestone.



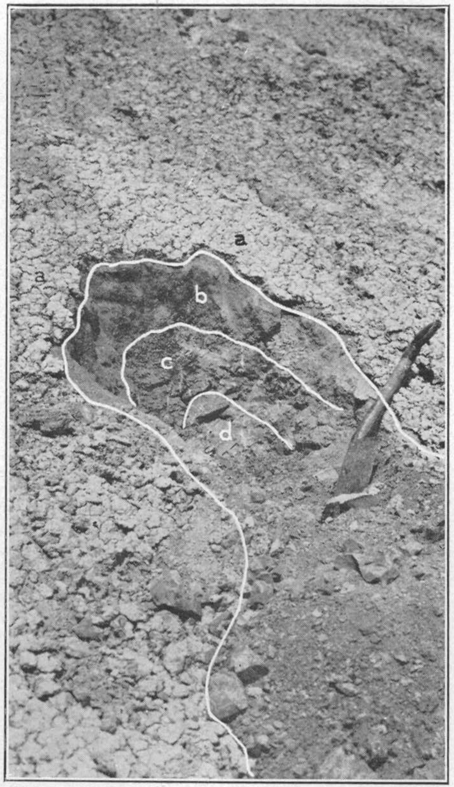
A. NEAR VIEW OF GYPSITE DEPOSIT

Shows cavernous surface and honeycomb structure. a, Nitrate-bearing cavity.



B. PROSPECT IN GYPSITE

×, Schist.



C. PROSPECT PIT IN BUFF SHALE

a, "Cauliflower" clay soil, 2 inches; b, efflorescent salty layer, 8 inches; c, caliche, 8 inches (sample West Well No. 1); d, bedrock clay (sample West Well No. 2).

responding to the caliche layer of the more promising clay-hill tracts of the Amargosa region.[51] As in the other clay-hill tracts described in the present report, only a small part of the material in this zone forms true caliche. Most of it is loose and flaky, crumbles into small fragments when dug, and resembles the "pie-crust" caliche[52] of the Amargosa fields, but at some places it is tightly cemented and resembles the harder, compact caliche[53] of those fields. In general, however, even the best material is much poorer in nitrate than the average material obtained in the Saratoga and Upper Canyon fields of the Amargosa region.

Exploration.—The outcrops of the four subdivisions of the lake-bed series in the 400-acre area were prospected, first by preliminary tests at many different places to determine what ground contained nitrate, then by digging pits and taking samples in the ground where the best reactions for nitrate were obtained. The tests were distributed vertically across the outcrops as well as horizontally along them, in order to cover the beds of each subdivision in vertical sequence as well as along the strike. The results of this exploration may be summarized as follows:

No nitrate is associated with the conglomerate at the base of the lake beds, and very little is associated with the white chalky shale that overlies the conglomerate. (See p. 41.) This white shale contains little soluble saline material and at most places gives no reaction for nitrate, but at some places near the surface it gives a very weak reaction. The clay soil that covers the shale is barren of nitrate, but here and there the cracked surface of the shale just under the soil contains a small amount of soluble salts and gives a "weak" reaction for nitrate. However, no reaction was obtained anywhere that indicated the presence of more than 1 per cent of nitrate, and it is therefore inconceivable that any considerable amount of calcium nitrate is associated with the bed, as reported.

Most of the nitrate in the 400-acre area is associated with the outcrops of the greenish shale and the buff shale. (See p. 41 and pls. 5, *A*, *B*, and 6, *A*.) "Good" reactions for nitrate were obtained from the greenish shale at some places in the cracked and more or less cemented caliche zone just under the soil layer, but generally the reactions were "weak" or only "fair." The unaltered shale beneath the caliche zone gave everywhere either "very weak" or "negative" reactions. Six pits were dug in the greenish shale at different places where the best reactions were obtained. Of the samples thus taken two from the caliche zone gave "good" reactions,

[51] Noble, L. F., and others, op. cit., p. 7.
[52] Idem, pp. 69, 70.
[53] Idem, p. 37.

two "fair," and two "weak." The best of the "good" reactions did not indicate the presence of as much as 3 per cent of sodium nitrate. Samples of unaltered shale from depths of 2 to 3 feet in four pits gave "negative" reactions, and samples in two pits gave "weak" reactions.

The buff shale, which overlies the greenish shale and constitutes the uppermost subdivision of the lake-bed series in the 400-acre area, is thicker than all the other subdivisions together and underlies at least three-fourths of the typical clay-hill ground in the area, all the larger clay hills being carved from it. The buff shale yielded "fair" reactions for nitrate in the caliche zone at most places and "good" reactions at some places. Bedrock at depths of a few inches to 2 feet below the caliche zone gave "very weak" or "negative" reactions. Thirteen pits were dug in ground where the best preliminary tests were obtained. Six of the pits were distributed over about an acre of ground on slopes bordering a low gap in clay hills between the main stream course traversing the 400-acre area and the largest tributary wash entering this stream course from the west. The pits were dug at different stratigraphic levels in the lower 100 feet of the buff shale. This locality, as nearly as could be determined, is in the NE. ¼ SE. ¼ sec. 11, T. 4 N., R. 24 E. The other seven pits were distributed over about 2 acres of ground on steep slopes just north of the tributary wash mentioned and were dug at different stratigraphic levels in the upper 75 feet of the buff shale. (See pl. 5, *B*.) This locality is a little over a quarter of a mile northwest of the first locality and is approximately in the center of sec. 11.

Of the samples taken in the six pits dug in the lower 100 feet of the buff shale, two from the caliche zone gave "good" reactions and four "fair"; one sample of the unaltered shale at a depth of 16 inches below the caliche zone gave a "weak" reaction, and five samples at depths between 1 and 3 feet gave "negative" reactions. Plate 9, *C*, shows one of the pits in which a "good" reaction was obtained in the caliche zone and illustrates the prevailing character of the niter-bearing ground in the clay-hill areas of the West Well tract.

Of the samples taken in the seven pits dug in the upper 75 feet of the buff shale, four gave "fair" reactions, two "negative," and one "good." The material that gave the "good" reaction is a compact caliche, 4 to 8 inches thick, in which the chief cementing salt is sodium chloride. The deposit is of small extent, however, covering less than half an acre. A few other small patches of this material occur in the vicinity, but at most places, as elsewhere in the 400-acre area, the caliche zone consists of loose fragments of cracked shale mixed with a small amount of saline material; the salts fill tiny cracks in the shale and coat the fragments in thin films but are not so abundant as to cement the shale into a compact mass. Samples of the unaltered shale at depths of 2 feet beneath the caliche zone in all pits gave " negative " reactions.

Both the buff shale and the underlying greenish shale contain some saline material, most of which is sodium chloride, and some beds contain more than others. At many places the soil that mantles the shale contains small pieces of gypsum. Probably the gypsum occurs in tiny stringers in the shale. The buff shale contains many lenses of sandy material. Curiously, the patches of hard salty caliche appear to be associated with these sandy beds rather than with the finer beds of saline clay shale.

OTHER AREAS

The clay-hill deposits in other parts of the West Well tract do not differ materially from those in the 400-acre area just described, the nitrate occurring in a cracked and more or less saline layer on outcrops of strata of the lake-bed series; but because the lake beds in these other parts of the tract are covered nearly everywhere with alluvium and crop out only along the sides of the deeper washes, the patches of niter-bearing ground are narrow, discontinuous, and individually of small extent, although in the aggregate their area greatly exceeds that of the niter-bearing ground in the 400-acre area. Accordingly the deposits could not be commercially valuable even if they were very much richer in nitrate than those in the 400-acre area proved to be. Nevertheless, it seemed worth while to explore them systematically in order to learn whether there was any basis for the statements that valuable amounts of nitrate occur beneath the caliche zone in the lake beds themselves.

At most places in these other parts of the West Well tract the strata with which the clay-hill deposits are associated are lithologically identical with the lake beds that crop out in the 400-acre area and are readily identifiable with one or more of the four subdivisions occurring in that area. At some places, however, they differ somewhat from the strata already described. For example, a series of beds exposed about half a mile south of the 400-acre area, in the N. ½ sec. 23, T. 4 N., R. 24 E., consists of layers of greenish clay shale averaging less than a foot in thickness alternating with layers of brown, loosely consolidated sandstone 1 to 5 feet thick. These beds are not identifiable with any of the four subdivisions in the 400-acre area, because they consist predominantly of sandy material. Moreover, unlike the beds in the 400-acre area, they dip steeply in different directions and are cut by faults. Their relations to the beds in the 400-acre area are difficult to determine, because they are not in contact with them, but it seems probable that they are a part of the same series. The shale interbedded with the sandstone is indistinguishable lithologically from much of that in the greenish shale and buff shale of the 400-acre area. Probably, therefore, the alternating beds of shale and sandstone overlie the buff shale and represent a transition from clayey to sandy deposits at the top of that subdivision. The fact that the upper part of the buff shale in the 400-acre area contains lenses of sandstone lends support to this inference.

Prospecting of the niter-bearing ground yielded practically the same results as in the 400-acre area. At most places the surface soil gave " negative " reactions and at some places " weak " reactions, but in general it proved to be barren of nitrate. Locally the material in the caliche zone gave " good " reactions, but as a rule the reactions were " fair " or " weak." As in all other clay-hill districts explored, this zone proved to be the only horizon at which significant amounts of nitrate occur. Everywhere below the caliche zone the unaltered strata at a depth of a few inches gave " negative " or only " very weak " reactions, and although many tests were made at different places no evidence was found that any stratum contains more than an insignificant amount of nitrate.

In all, 18 pits were dug at places where the best reactions were obtained during the preliminary testing. Only four of these pits yielded samples that gave " good " reactions, all taken from the caliche zone. No reaction indicated the presence of more than 3 per cent of sodium nitrate. The following table shows the approximate location of these four pits and the character of the ground at each locality.

Pits sampled in T. 4 N., R. 24 E., West Well tract

1. E. ½ NE. ¼ sec. 17	Greenish clay shale equivalent to subdivision 3 of the 400-acre area.
2. E. ½ SW. ¼ sec. 16	Beds of greenish and buff clay shale a few inches to a foot thick, alternating with beds of loose sandstone 1 to 5 feet thick.
3. SW. ¼ NE. ¼ sec. 10 (see pl. 6, *B*)	Greenish clay shale equivalent to subdivision 3 of the 400-acre area.
4. SE. ¼ NE. ¼ sec. 21	Buff clay shale.

The following record of pit 2 is typical of the other three pits and, indeed, represents fairly the character of the best clay-hill nitrate deposits in the West Well tract.

Results of sampling in pit 2

Material sampled	Depth below surface (inches)	Reaction for nitrate
Compact clay	0–2	"Negative."
Loose, powdery clay mixed with efflorescent salts	2–6	"Weak."
Cracked, flaky shale containing considerable saline material (caliche zone)	6–9	"Good."
Greenish shale	9–30	"Weak."

The pit was dug in one of the shale layers in a series of alternating beds of shale and sandstone. In a near-by pit dug in one of the sandstone layers the material in the caliche zone gave a "weak" reaction for nitrate and the sandstone under the caliche zone gave a "negative" reaction.

As in the 400-acre area, the nitrate in all the ground explored proved to be associated chiefly with outcrops of greenish or buff, more or less saline clay shale, for the most part equivalent to subdivisions 3 and 4 of that area. Comparatively little nitrate was found with the white chalky shale equivalent to subdivision 2.

About half a mile southeast of West Well, near the southern border of the hills of volcanic rock, prospectors have dug pits at several places in the white shale, some of them 6 feet wide and 4 to 5 feet deep. Several of the deeper pits were cleaned out and a number of other pits were dug in the vicinity during the present investigation, but no reactions for nitrate stronger than "weak" were obtained either in the shale itself or in the soil overlying it. Exploration of the white shale at other places in the West Well tract yielded no more promising results.

DEPOSITS ASSOCIATED WITH VOLCANIC ROCKS

A small amount of nitrate is associated with the outcrops of the volcanic rocks in the group of low hills just east of West Well, composed partly of volcanic rocks of Tertiary age and partly of older rocks. The volcanic rocks crop out in bold ledges, in places forming precipitous cliffs, and many of them exhibit the cavernous structure common in rhyolitic lava and breccia, so that small caves or shallow alcoves protected from the weather by overhanging ledges are abundant. Most of the nitrate occurs in these protected situations.

The hills cover about 3 square miles and rise several hundred feet above the general level of the alluvial deposits on the floor of Chemehuevi Basin, which entirely surround them. (See pl. 5, *C*.) At some places along the base of the hills, particularly along their southern margin, strata of the lake-bed series, chiefly the white chalky shale and the greenish shale, crop out beneath the alluvium.

Chemehuevi Wash crosses the hills in a canyon cut in the volcanic rocks. Probably at one time the hills were buried by the lake beds; otherwise it is difficult to explain why the stream has cut its channel directly through these hills, composed of resistant rocks, instead of around them through the much more easily eroded lake beds and alluvium. Apparently the stream established its present course before erosion had removed any considerable part of the lake beds and, remaining in this course down to the present time, cut through the hills as they were gradually exhumed.

An area in the southwestern part of the hills covering approximately the N. ½ sec. 16, T. 4 N., R. 24 E., appears to have been prospected more thoroughly than any other part of the West Well tract. In this area, which lies just east of West Well, beds of greenish tuff and breccia and flows of pinkish rhyolite are the most conspicuous members of the volcanic series. Much of the tuff is well stratified and resembles coarse sandstone. In one good exposure it dips at an angle of about 30° and is overlain by a flow of rhyolite. At some places a bed of whitish compact siliceous material, whose character was not determined but which appears to be either a fine-grained silicified rhyolitic ash or an altered rhyolite, is associated with the rhyolite and tuff. Common features of many of these rocks are cavernous structure and the presence of a considerable amount of opalescent silica, or chalcedony. Many outcrops of the greenish tuff and some outcrops of weathered rhyolite are covered with clay soil that resembles the soil on the niter-bearing ground in the clay-hill deposits. Pits 2 to 3 feet deep have been dug at many places in the soil on these outcrops and were still fairly fresh at the time of examination. In the present test several of these pits were deepened and others dug in the vicinity. The results were no more encouraging than those obtained in the niter-bearing ground associated with the lake beds. At most places the weathered tuff or rhyolite just under the surface soil contains considerable saline material, which corresponds to the caliche in the clay-hill deposits and, as in those deposits, is at the most only a few inches thick. It passes down into unaltered bedrock that appears to contain practically no soluble salts. Only "weak" or "negative" reactions for nitrate were obtained in the soil, "weak" or "fair" reactions in the saline zone, and "negative" reactions in the underlying bedrock. No reaction at any place was strong enough to justify systematic prospecting and sampling of the ground.

Many small caves and alcoves in rhyolite, breccia, and tuff were examined here and in other parts of the volcanic hills. The surface of the rock in some of these protected situations is covered with a whitish efflorescence, and for an inch or two beneath the surface the rock is more or less disintegrated and tastes salty. This surface material yielded reactions for nitrate ranging from "weak" to "fair," but no reaction strong enough to justify systematic sampling. Pieces of the fresh rock an inch or two under the surface everywhere gave "negative" reactions. The patches of niter-bearing material are not abundant and are of small extent, most of them being only a few feet wide and less than an inch thick. They are obviously superficial, because they do not extend into the mass of the rock. These "cave" deposits would be commercially valuable only if large masses of the rock were impregnated with nitrate, whereas the tests show that the surface material contains only insignificant amounts and indicate that the fresh rock either is practically barren or at best contains very little.

Many "cave" deposits in the western United States similar to those near West Well have been explored in the hope that the rock under or behind the deposits might prove to be impregnated with valuable amounts of nitrate. The results of this work have invariably been disappointing. The surface showings of nitrate at the West Well deposits do not compare favorably with those at the more promising "cave" deposits elsewhere, so that, unless one of the more promising deposits can be shown to be commercially valuable, it would seem to be a waste of time and money to make the excavations necessary to explore systematically the West Well deposits.

VIVET EYE TRACT

LOCATION AND GENERAL GEOLOGIC FEATURES

The Vivet Eye tract (see pl. 1) lies in the extreme northeast corner of Riverside County, Calif., and occupies the eastern slope of a small rugged desert range known as the East Riverside Mountains. These mountains begin at a point 4 miles due south of Vidal and extend southward about 7 miles parallel with the general course of the Colorado River. Their average width is about 2 miles. At most places they are 2 to 3 miles from the river, but at one point midway between their north and south ends a great meander in the river's course carries it within a mile of their base. Riverside Peak (pl. 8, *A*), the highest point in the range, lies opposite this meander, and Vivet Eye Peak, another high point, is about a mile north of Riverside Peak. At the time of Turner's visit Riverside Peak was called Vivet Eye; accordingly the Riverside Peak of the present report is the Vivet Eye Peak of Turner's report.

The mountains rise abruptly from a gently sloping plain that borders the Colorado River. (See pl. 8, *B*.) This plain is composed of alluvium—in part sand and gravel washed from the mountains and spread out in alluvial fans; in part sand, gravel, and clay deposited by the river. It is possible that strata of the lake-bed series underlie the alluvium along the eastern base of the mountains, because clay shales similar to those in the West Well tract crop out beneath the alluvium in several washes between Vidal and the north end of the range, where they form the clay-hill area here described as the Vidal tract.

In the vicinity of Vivet Eye and Riverside Peaks the steep eastern face of the range consists of parallel belts of rock that trend north. Along the base of the foothills nearest the river are outcrops of granitic gneiss and granite. West of the gneiss is a belt of schist and quartzite, followed by a belt of massive limestone. The quartzite and limestone form most of the lower slopes of the range. Above the quartzite and limestone is a belt of greenish and pinkish quartz-sericite schist occupying the middle slopes. (See pl. 8, *A*, *B*.) The higher slopes and the summit of the range consist chiefly of massive cherty magnesian limestone. (See pl. 8, *A*.) The structural and stratigraphic relations of the rocks just described were not determined. The prevailing dip of the beds is about 35° W., and the strike is not far from north, so that the structure, considered broadly, appears to be simple, the belts of rock succeeding one another in orderly stratigraphic succession. However, the structure may actually be complex, for the beds are cut by numerous faults.

The rocks are prevailingly dark colored, the limestone and quartzite weathering brown and the schist weathering rusty green or pink. Most of the limestone is crystalline. Much of it does not effervesce with dilute acid and is probably dolomite. Many limestone beds contain parallel bands of chert. The schist is cut by veins and stringers of quartz and contains a considerable amount of epidote. All the rocks are more or less metamorphosed, and any fossils that they may originally have contained appear to have been obliterated. Consequently their age is unknown. The quartzite, limestone and schist series is almost certainly not younger than Paleozoic. Whether the granitic gneiss and granite near the river are unconformable beneath this series or intrusive into it was not determined. If unconformable, they are probably pre-Cambrian.

The schist belt lies between 800 and 1,500 feet above sea level (barometric reading), or between 500 and 1,200 feet above the Colorado River. On this belt, practically coincident with it and covering it like a blanket, lies a curious deposit that is conspicuous from a considerable distance by its light buff color, which contrasts sharply with the darker hues of the quartzite, limestone, and schist. This deposit (see pl. 8, *A*, *B*) consists largely of finely granular gypsum. (See p. 51.) The most striking feature of the deposit is its porous and cavernous structure. (See pl. 9, *A*, *B*.) It contains numerous small cavities ranging in diameter from 1 to 6 feet, most of which open at the surface of the ground. Nearly everywhere the deposit sounds hollow under foot. The surface of the deposit is puffy, crusty, compact, and exceedingly rough. This compact material is difficult to penetrate with a pick, although it is porous and spongy, but a few inches under the surface the material is softer and can be worked rather easily. In texture much of the gypsite resembles granulated sugar. In most parts of the deposit, particularly at the surface, the gypsite contains considerable clay, which has probably been blown over the surface as dust. At many places it contains angular fragments of schist, which are locally so abundant that the material resembles breccia. The gypsite does not effervesce with acid and therefore probably does not contain much carbonate of lime. Thin lenses of powdery white salts readily soluble in water occur at many places in the gypsite. Most of this soluble material tastes alkaline or bitter rather than salty and probably consists largely of sulphates of sodium, potassium, and magnesium. Most of it gives reactions for nitrate ranging from "fair" to "very strong." A sample of the insoluble material tested in the chemical laboratory of the Geological Survey was reported to consist largely of calcium sulphate. Perhaps the cavities in the gypsite owe their existence to the lenses of loose, powdery, partly soluble material just described, the material breaking down and determining cavities because it is much more soluble than the mass of the gypsite.

The gypsite covers an area measuring about 4 miles from north to south and one-half to three-fourths of a mile from east to west. Isolated patches of the gypsite occur at intervals for a distance of a mile north of this area and a mile south of it. Practically all the gypsite overlies the schist, but at a few places it extends a short distance beyond the borders of the schist belt and overlies limestone or quartzite. Here and there within the schist belt small patches of schist are entirely bare of gypsite. The deposit lies upon an exceedingly rugged surface (see pl. 8, *A*, *B*) and covers this surface without regard to topographic form or direction of slope, occurring on all sides of hills, on the sides and crests of spurs, on hilltops, and in gulches. Likewise the bare patches of schist within the gypsite area are distributed without regard to the topography, occurring on slopes or in depressions as well as upon hilltops. The thickness of the deposit is variable, commonly ranging from 1 to 6 feet but averaging perhaps 3 feet for the area as a whole. Its thickness, like its areal distribution, appears to be unrelated to the topography.

A large gulch that heads between Riverside and Vivet Eye Peaks contains several gold mines, which were not being worked at the time of examination. Most of the workings are in the schist belt, and a great number of prospect pits and small tunnels have been dug through the gypsite into the underlying schist. These excavations afford an excellent opportunity to study the gypsite, and the trails that connect them give easy access to large parts of the gypsite area that would otherwise be difficult to explore because of the rough topography. With the Steese camp, near one of the mines, as a base five days was spent exploring the gypsite deposit.

EXPLORATION

Preliminary tests were made at many different places in the gypsite to as great a depth as material could be readily dislodged with a small pick. At most of these places the gypsite itself gave no reaction for nitrate or at best only a "weak" reaction, but the loose powdery salts in the cavities commonly gave "good" or "strong" reactions. Excavations in the gypsite were then made in and around the cavities containing the loose salts, to determine the extent and average nitrate content of the niter-bearing material and also in situations as far as possible from niter-bearing cavities, to determine whether the mass of the gypsite contains significant amounts of nitrate.

In all 28 excavations were made—18 in and around cavities and 10 in situations as far as possible from cavities. Most of them were dug in the part of the gypsite deposit that lies near the Steese mining camp, but some were dug in other parts of the deposit. All were deep enough to penetrate entirely through the gypsite and into the underlying schist. In each excavation a 5-pound sample of each distinct layer of material removed was taken and tested for nitrate. A summary of the results of this sampling follows:

Average conditions revealed by 18 excavations in and around cavities in the gypsite

Material removed	Range in thickness (inches)	Character of field tests
Loose, earthy, gypsiferous soil containing much clay, at surface of ground.	1–2	"Negative."
Porous, spongy, compact gypsite, in places containing fragments of schist.	12–36	"Negative" to "weak."
Lenticular layers of whitish soluble salts mixed with powdery gypsum and in places containing fragments of schist. The layers are usually more than 3 feet and less than 12 feet in horizontal extent.	4–18	"Fair" to "very strong"; for the most part "good" to "strong."
Transition from gypsite to bedrock; cracked and weathered schist fragments cemented by gypsum and cut by veins of gypsum. Here and there the deposit contains a small amount of soluble salts.	12–24	"Weak" to "fair."
Weathered bedrock; quartz-sericite schist traversed by veins of gypsum.	(?)	"Negative."

To check the field tests and to determine more accurately the nitrate content of the better material five selected samples were sent to the chemical laboratory of the Geological Survey for determination. Each sample was taken from a different excavation, and each represented the best material, as indicated by the field tests, encountered in the excavation—namely, the loose, powdery white material occurring in cavities in the gypsite. The 5 excavations were selected at random from 12 dug at different places in the gypsite deposit within a radius of a mile from the Steese camp. The average nitrate content of these five samples as determined in the laboratory may be considered an indication of the percentage of nitrate that the material in the cavities contains, although the estimate is subject to considerable error owing to the small number of samples taken. The determinations follow:

Nitrate determinations of samples of loose powdery salts from five excavations

No.	Location of excavation (all altitudes barometric)	Thickness of material (inches)	Depth below surface (inches)	Rating of field test	Percentage of nitrate as $NaNO_3$ as determined in laboratory
1	About 1 mile southwest of Steese camp, east slope of Riverside Peak, at 1,150 feet.	6	24	"Fair"	0.96
2	200 feet southwest of No. 1, at 1,200 feet	12	24	"Strong"	5.00
3	About ¾ mile southwest of Steese camp, on south bank of ravine, at 1,000 feet.	12	12	do	5.22
4	About ½ mile west of Steese camp, on trail leading west, at 900 feet.	6	16	"Very strong"	11.65
5	200 feet west of No. 4	8	12	do	12.70

Average percentage of $NaNO_3$ in 5 samples, 7.1.

The material represented by samples 2 and 3 contains fragments of schist and rests on quartz-sericite schist. Plate 9, *A*, *B*, shows the cavity in which sample 4 was taken and gives a good idea of the character of the ground in which the excavations in and around cavities were made.

Average conditions revealed by 10 excavations in the gypsite in situations as far as possible from niter-bearing cavities

Material removed	Range in thickness (inches)	Character of field tests
Loose, earthy, gypsiferous soil containing much clay; at surface of ground.	1–2	"Negative."
Porous, spongy, compact gypsite, in places containing fragments of schist.	12–36	"Negative" on level or gently sloping ground; "negative" to "weak" on steep slopes or in protected situations.
Transition from gypsite to bedrock; schist fragments cemented by gypsum.	12–24	"Negative" to "weak."
Weathered bedrock; quartz-sericite schist containing veins and stringers of gypsum, some of which, as exposed in prospect holes and tunnels, extend downward at least 4 feet into the schist.	(?)	"Negative."

These field tests indicate that the mass of the gypsite contains only insignificant amounts of nitrate and that the schist underlying the gypsite contains no nitrate. To check the field tests, five selected samples were sent to the chemical laboratory for determination.

These samples were taken from three different excavations selected at random from 10 dug at different places in the gypsite deposit within a radius of a mile from the Steese camp. Three of these samples represent material on gentle slopes and two material on steep slopes. The determinations follow:

Nitrate determinations of samples of gypsite from three excavations

No.	Location of excavation	Material represented by sample	Thickness of material (inches)	Depth below surface of ground (inches)	Rating of field test of sample	Percentage of $NaNO_3$ in sample as determined in laboratory
1	About 1 mile southwest of Steese camp, on gentle slope just south of summit of a divide between two gulches, at 1,100 feet.	Loose, earthy gypsiferous soil overlying gypsite.	2	0-2	"Negative"	None.
2	Same as No. 1	Hard, porous gypsite.	20	2-22	do	Do.
3	About 5/8 mile southwest of Steese camp, on steep slope at 900 feet.	do	18	2-20	"Weak"	Trace.
4	Same as No. 3	Transition from gypsite to bedrock; weathered schist fragments cemented by gypsum.	24	20-44	do	Do.
5	100 feet west of No. 3, on gentle slope.	do	12	12-24	"Negative"	None.

These determinations confirm the results of the field tests and strengthen the conclusion that the mass of the gypsite is practically barren of nitrate.

CONCLUSIONS

The nitrate of the Vivet Eye tract is associated with deposits of loose, powdery saline material occurring in small cavities in gypsite. The gypsite itself is practically barren of nitrate, containing only traces here and there. The deposits of loose saline material are small—for the most part less than 18 inches thick and less than 12 feet in horizontal extent—and are distributed irregularly through the gypsite. They consist chiefly of sulphates of calcium, sodium, potassium, and magnesium, but all of them contain some nitrate, and many contain a considerable percentage of nitrate. Chemical determinations of five representative samples show amounts of sodium nitrate ranging from 0.96 to 12.70 per cent of the total sample and averaging a little over 7 per cent. From these determinations and from numerous field tests in different parts of the tract it would seem that the sodium nitrate content of the niter-bearing material should average at least as high as 5 per cent and may average higher than 5 per cent. Although the pockets of niter-bearing material are fairly numerous they constitute a very small part of the total quantity of gypsite. If all the loose material that could be gathered from the cavities were taken out and treated it could probably yield only a few tons of sodium nitrate. More niter-bearing material could be obtained by excavating around the cavities, but the amount of nitrate that could be produced from the total quantity of material available would still be measurable in tens of tons, and the cost of removing the mass of compact gypsite to get at the material would be prohibitive. The deposits therefore can not be considered commercially valuable.

BEAL TRACT

Brief reconnaissance was made of the Beal or Topock tract of Turner, which lies along the west side of the Colorado River 6 to 8 miles southeast of Needles (see pl. 1) and extends a mile or more west of the river. The automobile highway from Needles to the Topock bridge and the Atchison, Topeka & Santa Fe Railway track pass through a part of it. The conditions in this tract are essentially the same as those in the West Well tract, described above. The clay beds with which the niter-bearing ground is associated crop out only along the sides of washes cut through the overlying alluvium. At most places they form bluffs or are carved into steep badland slopes that are unfavorable for the accumulation of large or continuous areas of caliche, but in a few places where the gravel cover has been eroded away they form gentle slopes and rounded clay hills. No single area of clay beds exposed in the tract is as large as the 400-acre area of the West Well tract, and the total area of clay beds is much smaller than in the West Well tract. The nitrate, as in the West Well tract, is concentrated in a thin saline layer of broken clay, in places cemented and calichelike, at the base of the surface soil. A number of tests were made in the niter-bearing ground at different places, but no material giving a reaction that would indicate the presence of as much as 3 per cent of sodium nitrate was found. It was obvious that if the West Well tract offered no hope of commercial exploitation the smaller Beal tract likewise offered none.

VIDAL TRACT

The Vidal tract is a clay-hill area like the West Well and Beal tracts and is one of many similar areas that occupy parts of the valley of the Colorado River above and below Needles. It is about 5 miles northwest of the Vivet Eye tract. (See pl. 1.) Attention had been called to the area by J. M. Wilson, of Vidal, who had been mining clay in it and shipping the clay to a plaster mill at Amboy, Calif. Mr. Wilson said that a number of samples taken from the clay outcrops had been analyzed and found to contain nitrate and that the clay was believed to be impregnated with nitrate. Accordingly, in company with Mr. Wilson the writer spent the greater part of a day there testing the ground for nitrate and taking a few samples for analysis. The area proved to be a tract of at least 200 acres of fairly continuous clay outcrops, in part forming barren clay hills. It lies in a large wash 2½ miles southwest of Vidal that drains eastward past the north end of the East Riverside Mountains to the Colorado River. As in all the other clay-hill nitrate tracts near the river, the clay beds are mantled by alluvium. The clays are paler in color and freer from sandy beds, but they do not otherwise differ in any important respect from those in the 400-acre area of the West Well tract. At many places a compact caliche a few inches to a foot thick was found on the clay beds. This caliche gave reactions for nitrate ranging from weak to good but evidently consists chiefly of sodium chloride. Recently made excavations dug in mining the plaster clay afforded a good opportunity to test the bedrock clay for nitrate at depths as great as 7 feet. At no place, however, was a reaction for nitrate obtained from the clay. In order to check field tests three samples of caliche and two samples of the bedrock clay were saved and sent to the chemical laboratory for determination of the nitrate content. The results of this sampling follow:

Tests of 2-pound nitrate samples from Vidal tract

No.	Locality	Material	Depth below surface (inches)	Character of field test	Nitrate as $NaNO_3$ (per cent)	Remarks
1	2½ miles south of Vidal, in small clay hill from which plaster clay had been mined by Mr. Wilson.	Caliche	14-20	Good	1.09	At the surface is a 2-inch layer of compact clay soil, barren of vegetation. Beneath this layer is a 12-inch layer of powdery salts mixed with clay, followed by the caliche, which is hard and compact and tastes strongly of sodium chloride. Beneath the caliche is nearly horizontal yellowish clay shale, the "plaster clay."
2	50 feet east of No. 1, in same hill. Fresh cut 6 feet deep from which plaster clay had been mined.	Bedrock	60-72	Negative	None.	Clay shale ("plaster clay") underlying the caliche represented by No. 1.
3	Near base of small hill 100 yards south of No. 1.	Caliche	7-13	Fair	0.86	At the surface the usual layer of knobby, compact clay soil 1 inch thick, underlain by 6 inches of powdery saline material mixed with clay, followed by 6 inches of compact salty caliche like No. 1 and horizontal beds of buff shale which give no reaction for nitrate. All material in excavation moist.
4	100 feet south of No. 3 shaft in bed of wash.	Bedrock	48-60	Negative	None.	Bluish-gray clay shale in nearly horizontal beds at bottom of a 5-foot shaft.
5	¼ mile northwest of No. 1.	Caliche	6-12	Weak	Trace.	Caliche of the loose, flaky type, overlying nearly horizontal beds of bluish-gray clay shale that give no reaction for nitrate.

These analyses indicate that the caliche in the Vidal tract is no richer in nitrate than that in the West Well tract and that the bedrock clay is practically barren of nitrate.

DANBY LAKE

REASON FOR EXAMINATION

Bailey[54] states:

The existence of niter has been reported as discovered in the playa deposits near the salt beds at Danby Lake, and locations were filed upon the land in 1901; but no development work has been done, and no analyses are at hand at the date of this bulletin.

LOCATION AND GENERAL GEOLOGIC FEATURES

Danby Lake lies in the eastern part of the Mohave Desert, in the extreme southeastern part of San Bernardino County, Calif. (See pl. 1.) The Parker cut-off of the Atchison, Topeka & Santa Fe Railway, which leaves the main line at Cadiz, Calif., and runs to Phoenix, Ariz., skirts the northeast shore of the lake about 25 miles southeast of Cadiz. Two stations on the railroad are near the lake. One, Milligan, is on a detrital slope about a mile north of the northwest end of the lake; the other, Salt Marsh, is only a few hundred feet from the lake, near the southeast end. A road that branches from the National Old Trails highway near Cadiz and leads to Parker and Phoenix crosses a part of the lake between Milligan and Salt Marsh. This road also is popularly known as the Parker cut-off.[55]

Danby Lake occupies the lowest part of an irregular inclosed basin which may be called the Danby Basin. The altitude of the lake is probably not far from 600 feet, for that of Salt Marsh, the station nearest the lake shore, is 626 feet. The Danby Basin is separated from the Bristol Basin, to the northwest, by a divide of low rocky hills. The Bristol Basin contains Cadiz and Bristol Lakes, two large playas very similar to Danby Lake. The lowest part of the divide is at least 500 feet (barometric reading) higher than the surface of Danby Lake. Although a few alluvial gaps extend through the hills in the divide the alluvium in them is evidently thin, because bedrock is exposed in the bottom of gullies cut in the gaps; the divide is therefore a rock divide. The Danby Basin is separated from the Blythe Junction Basin, to the southeast, by a low alluvial divide west of Rice (formerly Blythe Junction). The only large arm of the Danby Basin is a long, open detrital valley that extends far to the north, between the Old Woman Mountains and the Turtle

---

[54] Bailey, Gilbert, op. cit., p. 180.

[55] For log of road see Thompson, D. G., op. cit., pp. 222, 223.

Mountains. This valley, which drains directly into the lake between Milligan and Salt Marsh, is at least 40 miles long and averages perhaps 15 miles in width. Elsewhere the basin is bordered by ranges of mountains that lie near the lake. North of the lake are the Old Woman Mountains; south and west of the lake, the Iron Mountains. The lakeward face of the Iron Mountains is steep and probably represents a dissected fault scarp. As nearly as could be determined, most of the rocks in the ranges inclosing the basin are pre-Tertiary, chiefly granite. The rocks in the Old Woman Mountains are nearly all granites. Those in the low hills of the divide northwest of Danby Lake and those in the Iron Mountains are granites, gneisses, and partly metamorphosed sediments. Tertiary volcanic rocks, however, appear to form a considerable part of the Turtle Mountains.

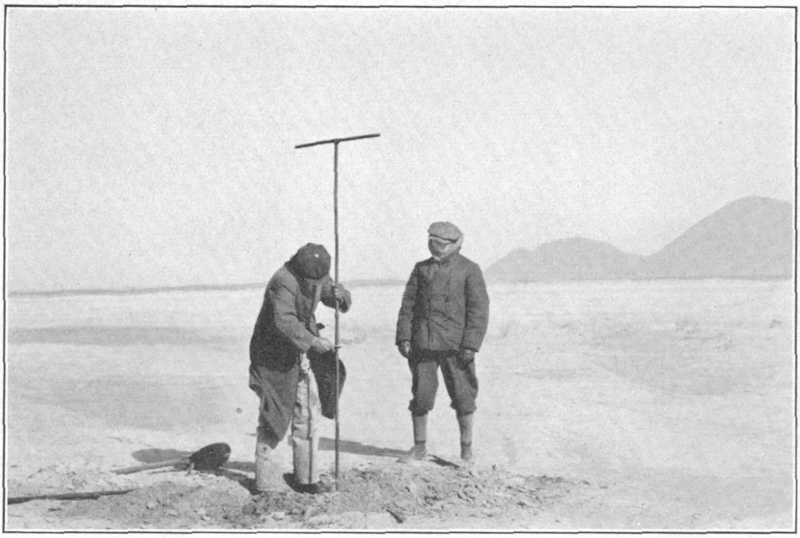
Danby Lake is about 14 miles long and 1 to 4 miles wide. The narrowest part of the lake is near the northwest end. Most of the surface of the lake consists of a hard, salty clay crust which breaks through when walked upon, and which has a curious rough, puffy appearance suggesting a muddy field that has been trampled by cattle. (See pl. 10, *A*.) This salty crust is about a quarter of an inch thick. Beneath it is a layer of dry powdery clay mixed with tiny transparent salty crystals, some of which have a bitter taste. This dry layer, which at most places is several inches thick, grades downward into moist salty clay containing small crystals of gypsum. At the southeast end of the lake much of the surface consists of unconsolidated deposits composed of beds of loose gypsum crystals mixed with varying amounts of clay. At places these gypsiferous beds are eroded into curious small mesalike forms. Ground in the neighboring Cadiz Lake is reported to contain deposits of celestite as well as gypsum and salt. Gypsum deposits in Bristol Lake have been worked for many years.

In the southeastern part of Danby Lake the surface deposits of saline clay are underlain by a body of rock salt which at some places is exposed practically at the surface. Numerous pits and quarries, some of them as much as 8 feet deep, have been dug in the salt body in this part of the lake, but none of them were being worked when visited. Some of these excavations afford good cross sections of a part of the salt body. They show that it consists of solid beds of rock salt a foot or more thick alternating with thin beds of clay. Mr. Bedell, the station master at Salt Marsh, stated that the salt body is said to reach a thickness of at least 10 feet in this part of the lake. He had no information as to what lies beneath that depth.

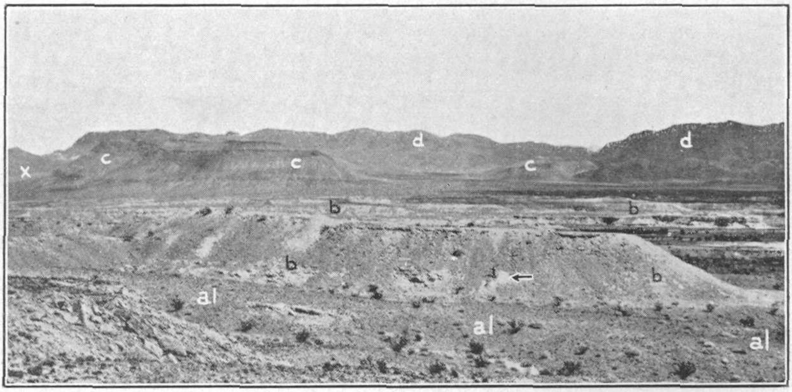
In the northwestern part of the lake the surface deposits are also underlain by a body of rock salt. A shaft (No. 1) dug by Mr. McIntosh, the section foreman at Milligan, at a point in the middle

A. SHAFT NO. 2, DANBY LAKE, 2 MILES SOUTHWEST OF MILLIGAN

Shaft is 9 feet deep.

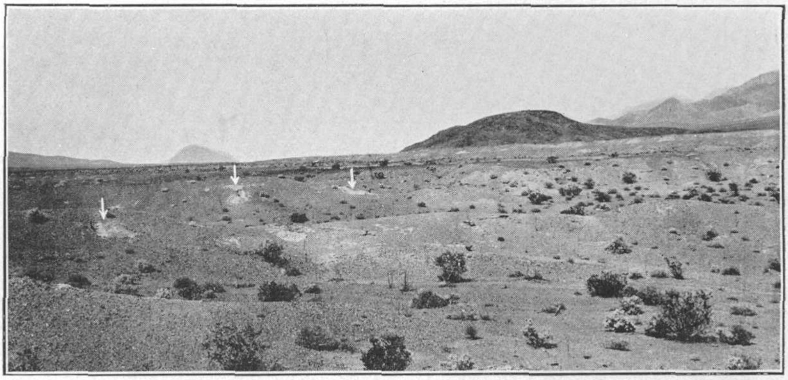


B. DRILLING WITH SOIL AUGER AT LOCALITY SHOWN IN *A*



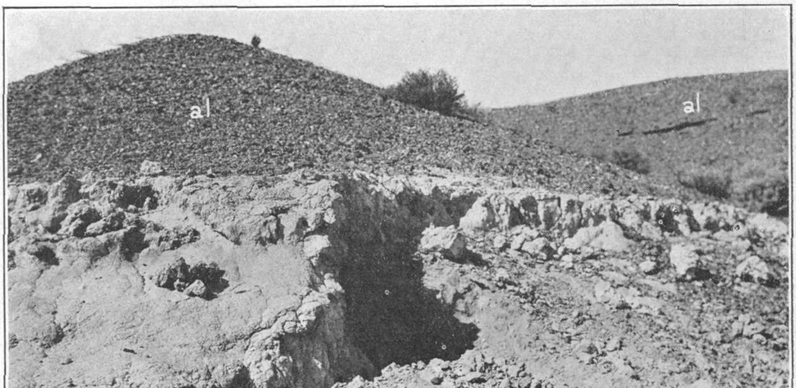
A. RATLIFF CLAIMS SOUTHWEST OF SHOSHONE

View looking east from locality $\times_5$ on Figure 3. b, Lake beds; c, Tertiary rocks; d, Paleozoic rocks; ×, borax mine; al, alluvium. Arrow indicates nitrate test pit.



B. RATLIFF CLAIMS NORTH OF SHOSHONE

Arrows indicate nitrate test pits dug through alluvium into lake beds that are practically concealed.



C. WHITE BED TESTED FOR NITRATE NEAR LOCALITY $\times_3$ ON FIGURE 4

al, Alluvium.

of the lake about 2 miles south of Milligan, reaches the salt body at a depth of 6 feet. A hole drilled in the bottom of the shaft penetrates the salt to a depth of a foot. This hole is filled with brine from the salt body. The shaft is 4 by 5 feet and is cased, so that the deposits penetrated are not exposed, but the log of the shaft contributed by Mr. McIntosh shows that the salt body is here overlain by 6 feet of alternating layers of sandy and salty clay and gypsiferous sand. This shaft is 2¼ miles east of the ruins of the "salt house"—a house built of blocks of rock salt many years ago on the lake near its northwest end. Another shaft (No. 2; see pl. 10, *A*) dug in the lake by Mr. McIntosh at a point half a mile northwest of the shaft just described is 4 by 5 feet and 9 feet deep. A hole drilled in the bottom of the shaft reaches the salt body, 2 feet deeper. Brine now fills the shaft up to a level 6 feet beneath the surface of the ground. The shaft is cased and tightly covered, so with Mr. McIntosh's aid a hole was drilled near by with a soil auger. (See pl. 10, *B*.) The first 3 feet below the surface was sand; next came 3 feet of moist plastic brown clay; then 5 feet of wet dark-blue clay containing numerous small crystals of gypsum, which increased in abundance with depth; and finally, at 11 feet beneath the surface, solid rock salt was struck. Immediately brine gushed into the hole and rose 4 feet above the surface of the salt. Northwest of the two localities just described, in the extreme northwestern part of the lake, the salt body is said to lie nearer the surface. That part of the lake was not visited. Along the north shore of the lake, about a mile from the salt house, were noted loose deposits of granular gypsum and clay similar to those at the southeast end of the lake.

The part of the lake midway between the northwest and southeast ends is built up higher than the two ends by recent playa wash, much of which is dissected by small gullies. Apparently most of this recent wash material is derived from the long valley already described that drains into the lake from the north between Milligan and Salt Marsh. As there are no excavations in this part of the lake, drilling would be necessary to determine whether the salt body underlies it. However, the fact that the salt underlies both ends of the lake suggests that it may be continuous under this middle portion.

EXPLORATION

The surface deposits of Danby Lake were tested for nitrate at five places in the northwestern part of the lake and at five places in the southeastern part by digging pits to a depth of 2 feet and testing in each pit the surface crust, the powdery clay layer beneath it, and the moist clay beneath the powdery clay. No reactions for nitrate were obtained.

The beds of rock salt and clay in all the excavations described were also tested, and near Mr. McIntosh's shaft No. 2 (see pl. 10, *A*, *B*) each layer of material removed was tested in drilling with the soil auger down to and including the surface of the salt body, 11 feet below the surface of the ground. The brine in each excavation and the salt crystals that formed a crust upon the brine were tested. No reaction for nitrate was obtained.

A number of samples of brine and of different types of surface deposits of the lake were sent to the chemical laboratory for partial analysis to check the results of field tests. None of them when analyzed contained nitrate. The details of this sampling follow:

Sample 01, brine from the bottom of an open shaft 2 miles south of Salt Marsh and about 3 miles northwest of the southwest end of the lake. This shaft was the deepest excavation then remaining open in that part of Danby Lake. It penetrated 7 feet into solid beds of rock salt alternating with thin layers of clay, and the brine stood 1 foot in the bottom and was covered with a crust of salt crystals (sample 1) which had to be broken to procure the brine sample. According to Mr. Bedell, brine enters the hole only after a heavy rain. A desert thunderstorm had occurred about a month before the sample was taken. The specific gravity of the brine was 1.203 at a temperature of 23° C. The percentage of total salts was 26.79 to 26.84 (two determinations). The percentage of potash (K_2O) in the total salts was 0.2. No nitrate in the form of sodium nitrate ($NaNO_3$) was present.

Sample 02, water from the Atchison, Topeka & Santa Fe Railway well at Salt Marsh, only a few hundred feet from the lake. The well is 600 feet deep, but the water was being pumped from a depth of 300 feet. It is soft, has a peculiar taste, and is not used for domestic purposes. The well is sunk at a point where the detrital wash entering Danby Lake from the north merges with the playa beds of the lake. The sample was taken to show whether potash or nitrate occurs in ground water that enters the lake depression. The specific gravity of the water at 23° C. was 0.997. The percentage of total salts was 0.047, and the potash content of the total salts was 2.02 per cent. No nitrate in the form of $NaNO_3$ was present.

Sample 03, brine from shaft No. 1, described above, obtained by breaking through the salty crust. The shaft was cased and tightly covered. Mr. McIntosh states that the level of the brine in this hole is entirely independent of rains and that before the rain of the preceding month the brine had stood for two years during which practically no rain fell. The specific gravity of the brine at 23° C. was 1.220. The percentage of total soluble salts was 27.95 to 28.02 (two determinations). The potash content of the total soluble salts was 0.23 per cent, but no nitrate in the form of $NaNO_3$ was present.

The composition of the salts was essentially $NaCl$, Na_2SO_4, and a little KCl.

Sample 04, brine from shaft No. 2, described above. The level of the brine is said to be independent of rains. According to Mr. McIntosh this brine has been analyzed at different times with contradictory results: one analysis showed as much as 3 per cent of K_2O; another showed only a trace. The bottle containing the sample sent to the Geological Survey was broken in transit so that it was impossible to check the analyses cited.

Sample 1, crust of salt crystals noted under sample 01. No nitrate was found.

Sample 2, porous, salty, calichelike layer about 1 foot thick taken from the surface of Danby Lake about 100 yards north of the shaft which furnished samples 01 and 1. This layer overlies beds of rock salt and clay and underlies curious loose, crusty deposits consisting of gypsum crystals mixed with clay, which range in thickness from 1 to 3 feet and are eroded into little mesalike forms. In the laboratory no nitrate was found in this material.

Sample 3, moist, saline clay about 1 foot below the surface of the ground at a point about 4 miles west of Salt Marsh. The surface here has a dirty whitish salty crust, which has a puffy appearance and looks everywhere as if cattle had trampled it. Under this crust is about 3 inches of dry, powdery clay full of transparent soluble crystals that have a bitter taste. Beneath lies the moist salty clay represented by the sample. These conditions are typical of the greater part of the surface of Danby Lake except where the salt body is very near the surface. In the laboratory this sample yielded no nitrate.

Sample 4, powdery clay, 4-inch layer, mixed with small transparent crystals just under the surface crust at the border of Danby Lake about 1 mile south of Milligan. In the laboratory no nitrate was obtained from this sample.

CONCLUSIONS

The absence of nitrate in the salt body that underlies Danby Lake is consistent with its absence in the much larger salt body that underlies Searles Lake,[56] in the salt deposit on the floor of Death Valley (see pl. 18, *A*), and in beds of rock salt in Tertiary strata. The bed of rock salt in the Tertiary strata of the Saratoga nitrate field, which was prospected and tested in great detail for nitrate, contained none,[57] and even the caliche over the salt bed was entirely barren. This Tertiary salt bed in the Saratoga Hills is identical in character and origin with the Quaternary salt bed at Danby Lake, differing

[56] Gale, H. S., op. cit., p. 297. [57] Noble, L. F., and others, op. cit., pp. 48, 49.

from it only in age and position. It has been upturned and eroded since it was deposited, whereas the salt deposit in Danby Lake lies in its original position. Similar gypsiferous clays are associated with the salt at both places. Tests in another Tertiary salt bed in the valley of the Virgin River, Nev., yielded no reaction for nitrate. (See p. 86.)

Tests of the clay deposits of the surface of Danby Lake were not sufficiently numerous to demonstrate that the deposits are everywhere barren of nitrate; possibly at places they contain a trace; but the results certainly warrant the statement that the deposits are practically barren.

RATLIFF NITRATE CLAIMS AND OTHER DEPOSITS NEAR SHOSHONE

LOCATION

The Ratliff claims include 2,280 acres of ground lying on the west side of the valley of the Amargosa River near Shoshone, Calif. (See pl. 1 and figs. 3 and 4.)

REASON FOR INVESTIGATION

A report on the property made by an engineer and submitted to Mr. Ratliff in May, 1918, contains the following statement:

> I believe it probable that a thorough examination will show this property very valuable for niter and possibly for two or three other salines. I made numerous field tests and a considerable number of analyses and in many cases found niter in paying quantities. I consider the prospects more than ample to justify a thorough and complete examination and a report on this property.

A list of over 100 analyses of samples from the property accompanies the report. These analyses show amounts of sodium nitrate ranging all the way from "traces" to over 20 per cent and averaging probably over 5 per cent for the samples as a whole.

The fact that the Geological Survey had just examined large parts of the Zabriskie field [58] (the nitrate field in which the Ratliff claims lie) and had found the conditions there entirely unfavorable to the existence of nitrate in commercial quantity established a strong presumption against the existence of valuable deposits in the Ratliff ground. Nevertheless, the analyses submitted to Mr. Ratliff by the engineer were so high that, in view of the emergency created by the war, no possibility, however remote, of the existence of valuable deposits could be overlooked. Accordingly in October, 1918, the writer, with John Waltenberg as assistant, spent 10 days prospecting and testing the ground.

[58] Noble, L. F., and others, op. cit., pp. 61–67.

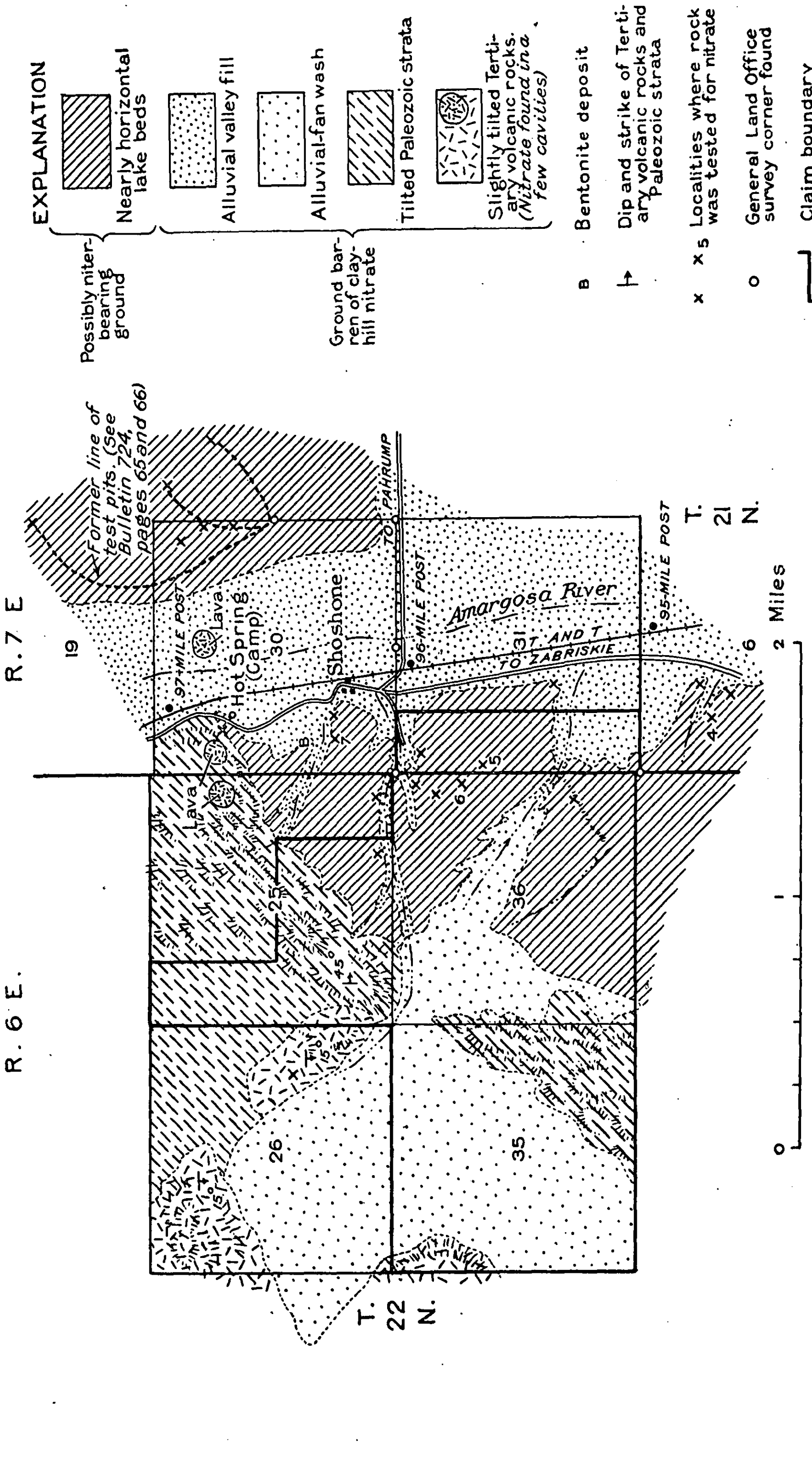


FIGURE 3.—Sketch map of claims of Messrs. Ratliff and others southwest of Shoshone, Calif.

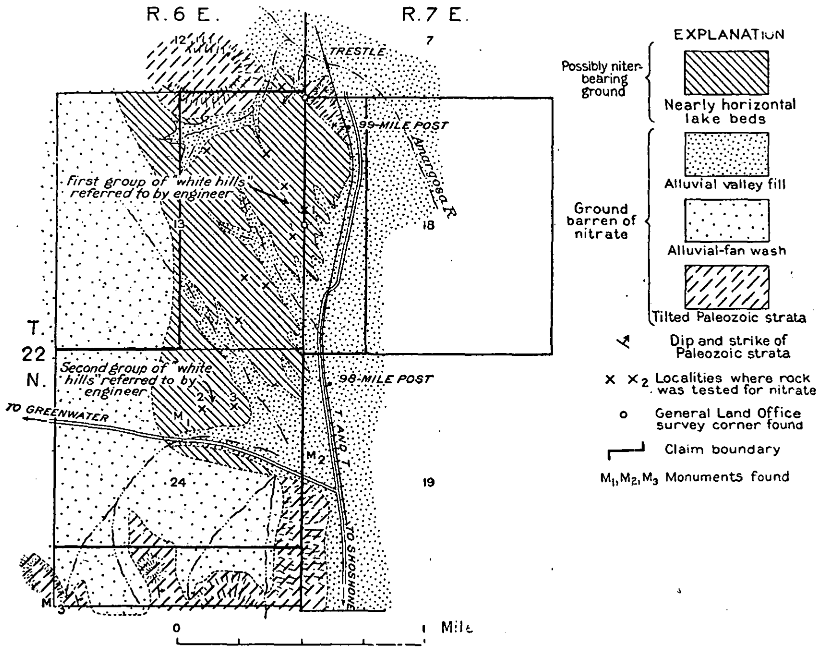


FIGURE 4.—Sketch map of claims of Messrs. Ratliff and others north of Shoshone, Calif.

GENERAL GEOLOGY

The Zabriskie nitrate field lies in the valley of the Amargosa River about Shoshone and Tecopa. The geology of this part of the valley has been described briefly in earlier reports.[59]

General geologic section of Zabriskie nitrate field, Amargosa Valley, Calif.

Recent alluvium: Valley fill and alluvial-fan wash; unconsolidated sand, gravel, and clay.

Unconformity.

Lake beds: Stratified sand, gravel, clay, and volcanic ash; very loosely consolidated; deeply dissected; nearly horizontal; age probably Quaternary; the nitrate deposits of the Zabriskie field are associated with these lake beds; near Shoshone the lake beds contain deposits of bentonite.

Unconformity.

Tertiary rocks: Volcanic and sedimentary rocks of very diverse character—tuff, breccia, lava, ash, clay shale, sandstone, and conglomerate; moderately consolidated; tilted, folded, and faulted; comprising at least two unconformable series of rocks, the older of which is probably Miocene, the younger probably Pliocene; the Miocene (?) beds contain a deposit of colemanite near Shoshone and deposits of gypsum near Acme; the nitrate deposits of the Upper and Lower Canyon fields are associated with the Miocene (?) beds.

[59] Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: U. S. Geol. Survey Bull. 200, pp. 14, 15, 1902. Noble, L. F., and others, op. cit., pp. 59–88. Noble, L. F., Note on a colemanite deposit near Shoshone, Calif., with a sketch of the geology of a part of Amargosa Valley: U. S. Geol. Survey Bull. 785, pp. 63–73, 1926.

Unconformity.

Pre-Tertiary rocks: Limestone, quartzite, slate, schist, granite, and gneiss; highly indurated; tilted and faulted; at some places contain deposits of metallic minerals and deposits of talc; sedimentary rocks partly metamorphosed; age of sedimentary rocks in part Cambrian; age of other rocks unknown.

The distribution of the pre-Tertiary and Tertiary rocks, the lake beds, and the recent alluvium on the Ratliff claims is shown in Figures 3 and 4.

Only the lake beds need be considered in the present report, as the clay-hill nitrate of the Zabriskie field is associated only with them. Their outcrops constitute the Zabriskie field.

LAKE BEDS

At some time after the end of the Tertiary period the waters of the Amargosa River were ponded, and a lake was formed in which beds of clay, sand, and gravel were deposited. These deposits cover most of the floor of the valley between Tecopa and a point several miles north of Shoshone and extend several hundred feet up the slopes on the sides of the valley. (See pl. 11, *A*.) The lowest exposures of the beds lie at an altitude of about 1,300 feet along the Amargosa River near Tecopa. The upper limit of the beds at most places around the sides of the valley is between 1,700 and 1,800 feet, but in some of the larger embayments formed by tributary valleys it appears to be higher. To the eye the beds appear horizontal; actually, however, they dip very gently toward the center of the valley from all sides. Their total thickness probably does not exceed 400 feet. The beds cover an area of at least 100 square miles.

The barrier behind which the waters were ponded to form the lake lies south of Tecopa and is composed partly of Pliocene (?) fanglomerates and partly of older rocks. After the basin of the lake was filled with sediments, possibly to the level of its outlet, the Amargosa River began to cut down through the barrier and to lower its bed. Since that time it has carved for itself below Tecopa a deep rocky canyon which is one of the striking scenic features of the region. As the river bed was progressively deepened the lake deposits were subjected to erosion. As a result they have been dissected almost to their base, so that over most of the area in which they are exposed they now form mesas and badlands.

The only exposures of older rocks within the lake-bed area are some low hills. One of these hills stands half a mile northeast of Shoshone, in the middle of the valley; it is composed of black basaltic lava, tilted eastward and probably of Tertiary age. Other hills that form a small group north of Tecopa are composed of pre-Tertiary rocks. A strong bench, or terrace, which encircles the highest hill near its summit and bevels the steeply dipping beds of quartzite of which the hill is composed, probably represents an ancient shore line of the lake. These hills once formed islands in the lake; later they were partly or wholly buried by sediments; and now they are exhumed by the erosion to which the lake beds have been subjected.

Below an altitude of about 1,600 feet in the lake-bed area nearly all the sediments are true lake beds, consisting of white, buff, yellowish, and greenish fine-textured saline clay. At many places the soil upon their outcrops contains a large amount of soluble salts, chiefly sulphate and chlorides of sodium, showing that the beds contain considerable saline material.

Above the 1,600-foot level the beds become predominantly sandy, contain lenses of gravel, and gradually pass upward into beds that are practically all fanglomerate and differ little from recent alluvial-fan wash. Compared with the beds below the 1,600-foot level they contain little soluble saline material. The uppermost sediments apparently represent detrital material washed into the basin from the surrounding hills, near or perhaps soon after the end of the period when the lake existed. Indeed, it seems highly improbable from their character that they are lake beds at all, but they are grouped with the lake beds for convenience of description. Except in a small part of sec. 36, T. 22 N., R. 6 E. (unsurveyed), south of Shoshone, all the beds on the Ratliff claims are above the 1,600-foot level. (See figs. 3 and 4.)

At about the 1,600-foot level, in the vicinity of Shoshone, a bed of white volcanic ash (see pl. 12, *B*) is interstratified with the sand and clay. Just west and north of Shoshone, in the vicinity of the Shoshone hot spring, this volcanic ash has been altered to material known locally as "soap," "fuller's earth," or "bentonite," which is mined at several places. The largest deposit is worked by the Associated Oil Co. These bentonite deposits were discovered by Mr. Fairbanks, of Shoshone. An interesting account of them has been written by John Melhase, geologist, of the Southern Pacific Co.,[60] who has proposed for the bentonites occurring along the Amargosa River the name "amargosite" as a means of distinguishing this particular material from bentonites occurring elsewhere. Melhase writes:

[60] Melhase, John, Mining bentonite in California: Eng. and Min. Jour. Press, vol. 121, pp. 837–842, May 22, 1926.

The bentonite deposits are nearly always found in areas where beds of incrustations of alkaline salts abound. Especially is this true of the Amargosa deposits, where the surrounding lowlands are covered with mixtures of sodium sulphate, sodium carbonate, common salt, borax, and gypsum. Efflorescences and sometimes thick crusts of these salts also cover and obscure the bentonite beds as well. This leads to the belief that waters charged with these salts are responsible for the alteration of the ash beds from which the Amargosa bentonite is clearly derived. This belief is further strengthened by the fact that the bentonite beds are always localized in the vicinity of extinct or living thermal springs the waters of which carry more or less of the alkaline salts in solution. The volcanic ash beds interstratified in the sedimentary deposits were porous enough to permit ready percolation of the alkaline waters for a considerable distance from their source, and the extent of percolation may be said to determine the area over which the ash beds were altered to bentonite.

According to Melhase,[61] a deposit of bentonite occurs in the Tertiary beds of the Upper Canyon nitrate field, as well as in the Quaternary lake beds already described. This Tertiary deposit lies 4 miles southeast of Tecopa, in a canyon draining into the Amargosa River.

RECENT ALLUVIUM

Part of the recent alluvium in the Amargosa Valley consists of alluvial-fan deposits—gravel, sand, and boulders swept down by streams over the lower slopes of the valley. In the higher parts of the lake-bed area these deposits cap the mesas into which the lake beds are carved; lower in the area they fill the beds of the innumerable washes that separate the mesas. (See pl. 11, *A*.) The rest of the alluvium is valley fill—clay and sand deposited by the Amargosa River. Most of it is clay, which forms marshy flats along the river.

GENERAL CONSIDERATIONS

Erosion and dissection of the lake beds has been going on ever since the barrier that formed the lake was cut away, and great aprons of alluvial waste from the bordering hills have crept down since that time, so that now the lake-bed area is a succession of flat-topped, gently sloping, gravel-capped mesas alternating with steep-sided, alluvium-filled washes. (See pl. 11, *A*.) Consequently, the lake beds crop out mostly in bluffs along the alluvium-filled washes. Their exposures on the Ratliff claims, then, amount to but a small fraction of their areal distribution shown on Figures 3 and 4. A still smaller fraction of the exposures consists of slopes gentle enough to be covered with soil and thus to form the type of ground which experience has shown to be favorable for the accumulation of caliche.

---

[61] Melhase, John, op. cit., p. 838.

By far the greater part of the ground consists of gravel-covered surfaces bordered by steep bluffs of lake beds. As a caliche nitrate field the ground is, therefore, from its very nature, hopeless. Even if patches of caliche rich in nitrate could be found, their area would be so limited by these natural factors that the caliche would be of no commercial value.

EXPLORATION

Ten days were spent traversing many well-exposed sections of the lake beds from top to bottom in all parts of the Ratliff claims. More than 265 field tests for nitrate were made in such a way as to cover some part of the outcrop of every bed in each section. No nitrate-bearing caliche was found anywhere on the claims. Wherever soil is present on the beds it appears to grade down into them without the intervention of any hard saline layer. At most places this soil is deep, loose, and very powdery, and at some places it is mixed with white powdery salts—chiefly sulphates of sodium and calcium. Here and there "fair" to "good" reactions for nitrate were obtained in the soil at a depth of about a foot. Below this depth the reactions were negative or very weak. In brief, the nitrate-bearing material on the claims is essentially a layer of soil that does not average over a foot in thickness and appears to be confined chiefly to outcrops of sandy clay beds. It is spotty in distribution even on the same bed. As may be seen from the results that follow, the nitrate content of this material must average only a small fraction of 1 per cent.

When it became evident that no nitrate caliche exists on the claims, the possibility was considered that concentrations of nitrate might exist in the bedrock strata—that is, in the lake beds themselves. The engineer who examined the claims had reported to Mr. Ratliff that he had found that "some of the rich nitrate ground on the claims goes down to depths of 10 feet underground." Pits and trenches were therefore dug in all the ground that was specifically designated by the engineer as the richest. Nowhere was more than the smallest trace of nitrate found in the bedrock itself. Supplementary tests of the bedrock by traverses all over the claims yielded similar results.

Results of tests for nitrate in pits and trenches dug on Ratliff claims

Areas north of Shoshone

[See fig. 4 and pl. 11, *B*]

Locality as marked on sketch maps	Character of underlying rock [a]	Character of excavation	Depth	Length of trenches	Number of tests made	Rating of tests: "Good"	Rating of tests: "Fair"	Rating of tests: "Weak"	Rating of tests: "Negative"	Remarks
			Ins.	*Ft.*						
X1	Sandy clay	Pit	24		3				3	This locality is the first area of "white hills" specifically designated by the engineer as a place where he procured rich samples.
	Conglomerate	do	18		2				2	
	White sandstone	do	30		2				2	
	do	Trench	24	4	3			1	2	
	Sandy clay	Pit	24		3	1	1		1	
	do	do	42		5			2	3	
	do	Trench (see pl. 12, *A*)	48	10	5	[b]1	2	1	1	
	do	do	36	6	4	[c]1	2	1	1	
	Conglomerate	Pit	30		3				3	
	Sandy clay	do	30		3		1	1	1	
X2	White sandstone	do	42		3				3	This locality is the second area of "white hills" specifically designated by the engineer as a place where he procured rich samples.
	do	do	36		3			2	1	
	do	do	48		3				3	
X3	do	do	40		3				3	
	do	do	42		3				3	
	do	do	42		3				3	
	do	do	42		3				3	
	do	do	36		2				2	
	do	do	36		2				2	
	do	do	36		2				2	

Areas southwest of Shoshone

[See fig. 3 and pl. 11, *A*]

Locality as marked on sketch maps	Character of underlying rock [a]	Character of excavation	Depth	Length of trenches	Number of tests made	Rating of tests: "Good"	Rating of tests: "Fair"	Rating of tests: "Weak"	Rating of tests: "Negative"	Remarks
X4	Greenish clay	Pit	36		3	1	1		1	This locality is just off the Ratliff claims, but the ground fairly represents a small portion of the extreme eastern and southeastern part of the Ratliff land.
	do	do	36		3	1		1	1	
	do	do	36		3		1	1	1	
	do	do	36		3	1	1		1	
X5	White sandstone (volcanic).	5 trenches	48	[d]6	15				15	The white-ash bed found barren of nitrate is probably the bed that is altered to bentonite near the Shoshone hot springs.
	Fine white sandstone (ash).	4 trenches	48	[d]6	12				12	
X6	White saline sandstone (ash).	Pit	24		3			1	2	
	Fine sandstone	do	24		3				3	
	Coarse sandstone	3 pits	24		9				9	

[a] Many of the beds designated white sandstone are largely volcanic ash.
[b] Sample saved for analysis (No. 1).
[c] Sample saved for analysis (No. 2).
[d] Length of each trench.

Total number of pits dug, 26; total number of trenches, 12; total length, 74 feet.
Tests made, 114—"good," 6; "fair," 9; "weak," 11; "negative," 88.
Every pit and trench was dug deep enough to penetrate into the bedrock (clay, sandstone, or conglomerate) under the loose surface soil. All reactions for nitrate were obtained in the loose soil layer, generally just above the upper surface of bedrock. In every excavation the bedrock itself gave "negative" or nearly negative tests for nitrate.

In addition to the intensive work tabulated above between 150 and 160 more field tests were made for nitrate in the course of reconnaissance traverses to and fro across the Ratliff claims. In this work the outcrop of every bed exposed in the lake-bed series was tested at one point or another, some beds at many points. For each test a small pit was dug deep enough to reach bedrock, and both the soil layer and the bedrock in each hole were tested. In this reconnaissance only six reactions for nitrate were obtained that could be rated as high as "fair," and only ten as high as "weak." The rest were negative or practically negative. No reaction better than "weak" was obtained in bedrock. Nearly every test in bedrock was "negative."

SUMMARY OF TESTS

In over 265 tests made in all parts of the Ratliff ground only three reactions were obtained that might be expected to indicate the presence of as much as 2 per cent of sodium nitrate in the material tested. These were rated "good." To check the field ratings samples of the material which had yielded two of the "good" reactions were saved and sent to the chemical laboratory. Samples of the same material were also saved for bacterial tests. Sample No. 1 (see table) was found to contain 0.32 per cent of sodium nitrate, and No. 2 0.36 per cent. These analyses show that the field ratings were too high. These two samples represent the best material found in any part of the Ratliff claims. The excavations from which the samples were taken are shown on Plate 12, *A*.

Most of the reactions for nitrate on the Ratliff claims were obtained in the lower part of the surface soil layer and can not represent material that averages over a foot in thickness. Although the bedrock was penetrated at every place where tests of the surface soil layer were made, only "negative" or nearly negative reactions were obtained from the bedrock at every place.

CONCLUSIONS

1. The Ratliff claims contain no deposits of commercial nitrate, either as caliche or in bedrock.

2. The relatively low saline content of the lake beds on the claims renders it exceedingly unlikely that they contain valuable amounts of potash or other soluble saline materials.

CAVE DEPOSITS

At a point about 100 feet northeast of the east quarter corner of sec. 13, T. 22 N., R. 6 E., there is a small cave in a bed of conglomerate. The locality is in the first group of "white hills" designated by the engineer, marked X_2 on Figure 4. The floor of the cave is covered with earthy material that gives a "strong" reaction for nitrate. The material is adjacent to a rat's nest and is full of rat manure. The nitrate is probably derived from this source. No trace of nitrate was found in the conglomerate. Although the material evidently contains a high percentage of nitrate, it is obviously a deposit of cave nitrate and of no commercial significance. It was therefore not included in the tabulation. Other similar cavities exist in the lake beds, and it is possible that some of the rich samples reported from the claims may have come from them.

In sec. 36, T. 22 N., R. 6 E., about 1½ miles west of Shoshone, there is an area covered by tuffs and interbedded lavas of Tertiary age. (See fig. 3.) At places under small overhanging ledges in the tuffs there are thin crusts of white saline material which gives "good" reactions for nitrate. A sample of this material was saved for analysis and was found to contain 1.72 per cent of sodium nitrate. The tuff itself a few inches beneath the saline crusts gave no reaction for nitrate. Evidently the nitrate is a superficial deposit and of no commercial importance. At some places the tuff is covered by a loose soil which contains a small amount of white saline material. This material, however, gave "negative" or only "weak" reactions for nitrate. Inasmuch as these occurrences of nitrate are outside the Ratliff claims and moreover are not commercially valuable, they were not included in the tabulation.

BED OF VOLCANIC ASH

At the time of examination the white ash bed (see pl. 12, *B*), which later was found to be altered to bentonite near the Shoshone hot spring, was being prospected by Mr. Fairbanks in numerous open cuts just west of Shoshone (locality X_7, fig. 3). The bed was tested for nitrate at many places in these excavations but yielded no reaction. These tests were not included in the tabulation, because the locality is outside the Ratliff claims.

EBERENZ-BEACH NITRATE CLAIMS, NORTHEAST OF SAN SIMON, ARIZ.

REASON FOR INVESTIGATION

At several times during 1917 and 1918 the occurrence of a deposit of sodium or potassium nitrate northeast of San Simon, Ariz., was reported to the Geological Survey. The last report was made in connection with an application for a permit to prospect for potash and nitrates filed in the names of George B. Eberenz and L. B. Beach.

LOCATION

The Eberenz-Beach nitrate claims lie in the foothills of the Peloncillo Mountains 7 to 10 miles northeast of San Simon, a station on the Southern Pacific Railroad. The altitude of San Simon is about

3,600 feet, and the claims lie at about 4,300 to 5,000 feet. Their location and extent is shown in Figure 5.

GENERAL GEOLOGY

The Peloncillo Mountains consist in this district chiefly of lavas, tuffs, and breccias of Tertiary age. In the vicinity of the claims acidic volcanic rocks—rhyolitic tuff, rhyolite, and obsidian—are the prevailing types. The structure appears to be rather simple. The

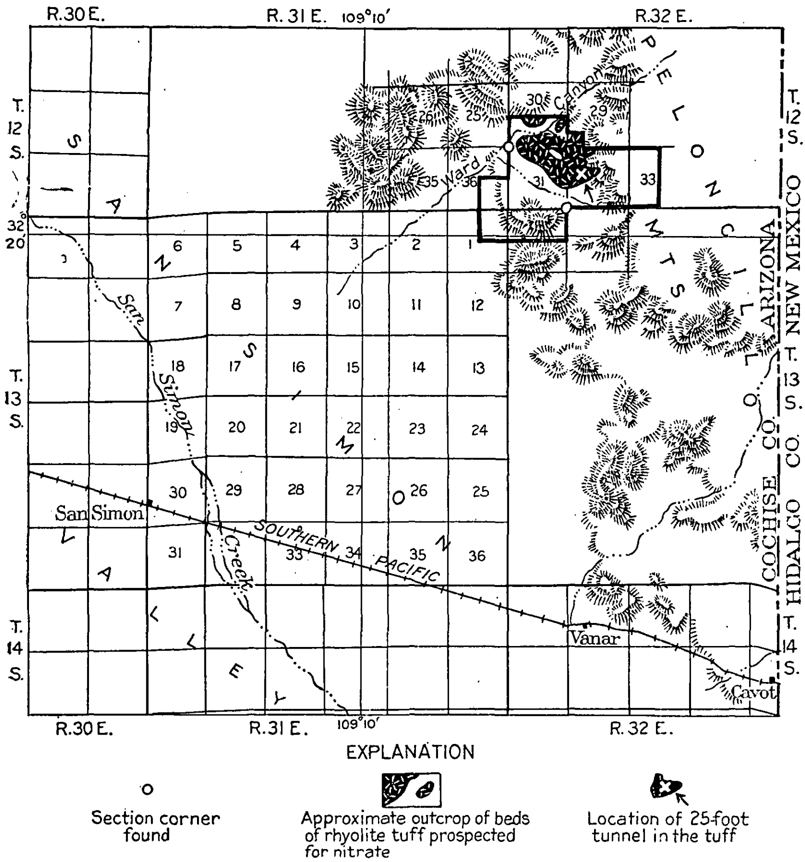


FIGURE 5.—Map showing location of Eberenz-Beach nitrate claims, near San Simon, Ariz.

rocks are cut by a few faults and have suffered a certain amount of disturbance, but as a rule the beds of tuff and flows of rhyolite dip gently or lie nearly horizontal. The geology of the San Simon Valley, which lies along the western base of the Peloncillo Mountains, has been described by Schwennesen,[62] but the area covered by his report does not extend into the mountains.

[62] Schwennesen, A. T., Ground water in San Simon Valley, Arizona and New Mexico: U. S. Geol. Survey Water-Supply Paper 425, pp. 6–9, 1917.

SUPPOSED MODE OF OCCURRENCE OF THE NITRATE

The nitrate deposit which Messrs. Eberenz and Beach proposed to develop is a great bed or, more exactly, a series of beds of tuff which underlie the greater part of the ground included in the claims. The tuff crops out over an area of considerably more than a square mile, its exposed thickness is more than 500 feet, and it dips 3°–15° W. (See pl. 15, *C*.) It comprises, therefore, a vast tonnage of material that could be mined or quarried at the surface. The tuff was believed by the men interested in the claims to be impregnated throughout with a small amount of sodium and potassium nitrate, averaging perhaps between 1½ and 2 per cent. Their belief that the tuff is impregnated with nitrate and that it thus constitutes a low-grade ore of nitrate was based on the following considerations:

1. Many samples rich in nitrate have been found in protected places on outcrops of the tuff, whereas no rich samples have been found in similar situations on outcrops of other types of rock in the vicinity. These rich surface showings were believed to represent surface concentrations derived from nitrate contained in the tuff, the nitrate having been leached from the body of the tuff by percolating ground waters or by capillary moisture and deposited at the surface by evaporation.

2. Analyses of samples of the tuff taken by Mr. Eberenz and his associates at depths as great as 25 feet showed small percentages of nitrate.

WORK DONE

The tuff beds have been prospected in many open cuts and in one tunnel driven 25 feet into the rock. Most of the open cuts were made by blasting great spalls off the face of the tuff in such a way as to expose the fresh rock to depths of 5 to 10 feet. The tuff in these open cuts was sampled at the time the cuts were made, and analyses of some samples were said to show amounts of nitrate ranging from 1 to 4 per cent. The tunnel was sampled by Mr. Eberenz in February, 1918. A 200-pound sample cut from the east wall and representing an average of the tuff from the portal of the tunnel to the far end was pounded up, quartered on canvas, and averaged down to a 1-pound sample. An analysis of this 1-pound sample showed a content of sodium and potassium nitrate together amounting to 1.77 per cent.

EXAMINATION

Three days in the fall of 1918 was spent in an examination of these claims, during which the writer was accompanied by George B. Eberenz, of Pueblo, Colo.; E. E. Lee, of Paradise, Ariz.; and H. Click, of Rodeo, N. Mex., who had done most of the exploratory work on the claims.

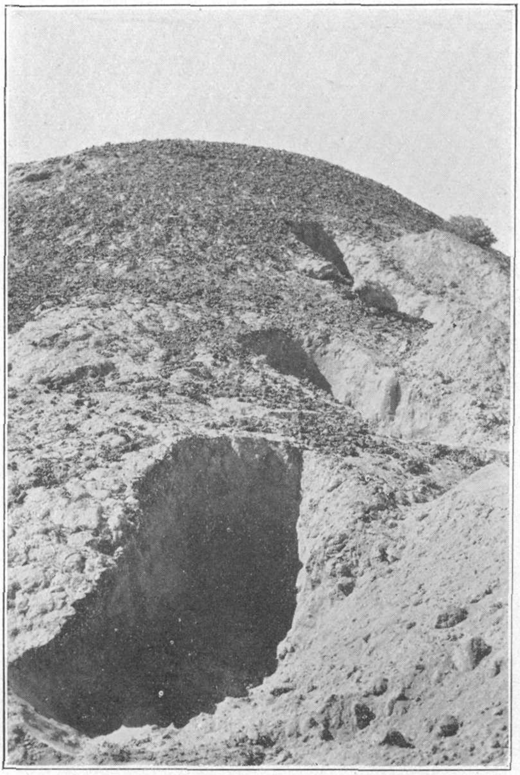
THE TUFF

A fair idea of the appearance of the outcrops of tuff at the localities where most of the prospecting and sampling has been done is given in Plate 15, *C*. The beds shown crop out in the steep south slope of a hill in secs. 31 and 32, T. 12 S., R. 32 E., and their exposures extend continuously for more than a mile in an easterly direction along the south face of the hill.

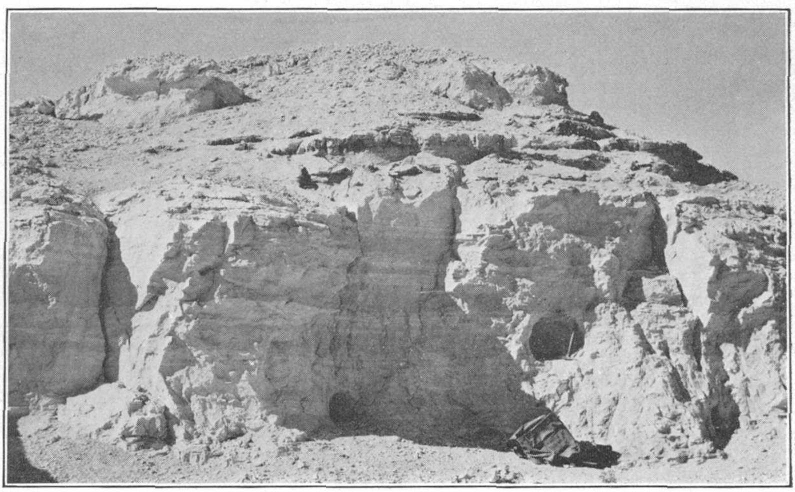
The tuff is characteristically fine-grained, and the fresh rock appears compact. Some beds are much more indurated than others, and these harder beds form cliffs. Most of the tuff contains a great deal of very fine-grained pinkish material which is almost clay-like in consistency and gives color to the fresh rock, but the tuff weathers brown on exposed surfaces. Much of this material is distributed through the tuff in little lenses that give the rock a blotched appearance and weather out readily, leaving innumerable little cavities. Some parts of the tuff contain numerous large fragments of volcanic rock, chiefly rhyolite, and are practically a volcanic breccia or agglomerate, but most of it is composed of fine material. None of the component material shows evidence of sorting or sizing, and the separate beds of tuff do not exhibit lamination. Notwithstanding the compact appearance and feel of the tuff it is said to drill easily. Fragments of the freshly dug rock soon disintegrate or slack when exposed to the weather and moistened by rain, and the pinkish color changes to white. On the whole the texture of the tuff appears to be uniformly and rather finely porous and might well favor impregnation by nitrates and other soluble salts. The beds of tuff weather into exceedingly cavernous forms and crop out in a succession of cliffs, steep slopes, and narrow ledges. Most of the ledges are overhung by cliffs in such a way as to protect them from the weather and form alcoves. (See pl. 13, *A*, *B*.) The huge scale of the shelves and caverns formed by these ledges and alcoves is not well realized from the photographs. A number of them contain small cliff dwellings.

SURFACE DEPOSITS OF NITRATE

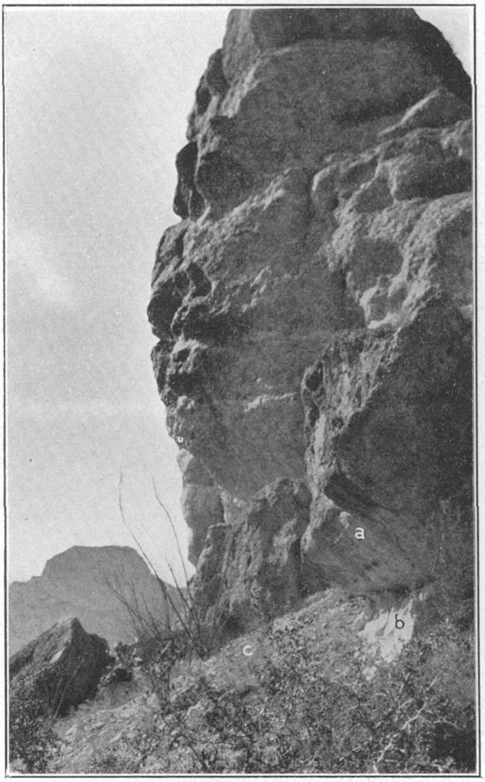
On roofs of alcoves.—The roofs of a number of alcoves contain saline deposits very rich in nitrate. The rock in such places is considerably weathered and spalls off readily in flakes. Between these flakes are crusts of milky crystalline salts. Nearly every sample of these salts yields " very strong " reactions for nitrate. This condition persists from 6 inches to a foot into the rock that forms the roofs of the alcoves; beyond that zone the rock is compact, appears fresh and unweathered, and gives " negative " or only " very weak " reactions for nitrate.



A. PROSPECT PITS AND TRENCH, RATLIFF CLAIMS

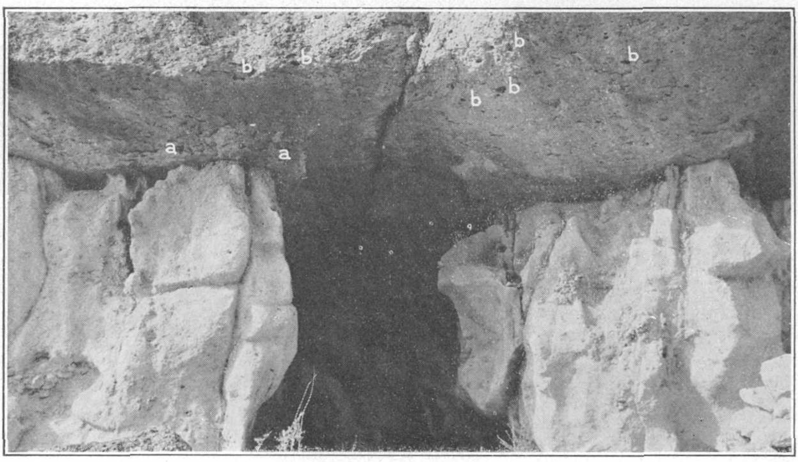


B. VOLCANIC ASH IN LAKE BEDS NEAR SHOSHONE



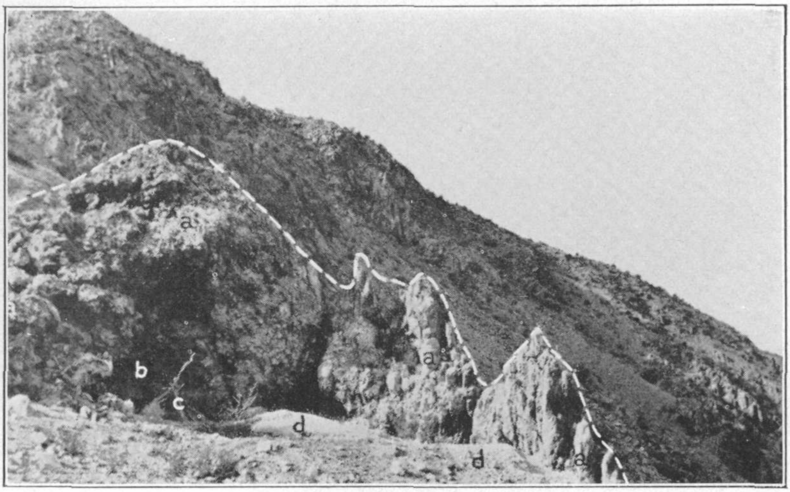
A. CLIFFS OF RHYOLITE TUFF ON EBERENZ-BEACH CLAIMS

a, Roof of alcove; b, back wall; c, loose material under overhanging ledge



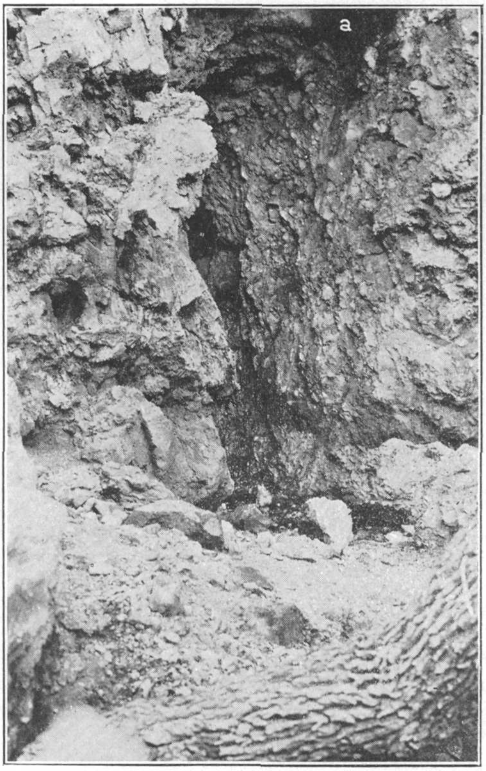
B. ALCOVE IN RHYOLITE TUFF

Harder materia over softer. Shows mode of occurrence of nitrate. a, Flaky areas; b, nitrate-bearing cavities.



A. HUNGERFORD-MOORE NITRATE CLAIMS

a, Breccia (so-called "blowout"); b, mouth of tunnel; c, mouth of shaft; d, dump from tunnel and shaft.



B. MOUTH OF TUNNEL SHOWN IN *A*

Shows cavernous nature of breccia. a, Cavity containing guano.

At places on the roofs of the alcoves small cavities in the tuff that range in diameter from half an inch to 3 inches are filled with milky crystalline salts so rich in nitrate that they will sputter when touched with a glowing match or lighted cigarette. (See pl. 13, *B.*) "Very strong" reactions were obtained from all of this material tested; probably most of it contains at least 30 per cent of nitrate. In these situations the rock might be likened in appearance to a porphyry in which the numerous little pockets of nitrate-bearing salts correspond to the phenocrysts. The salt-filled pockets, however, are superficial, for excavation shows that they do not extend more than a few inches into the mass of the rock.

On back walls of alcoves.—The back walls of alcoves here and there have coatings or crusts not over an inch thick of milky crystalline salts which do not differ in appearance from the salts in the pockets just described but which give only "weak" to "fair" reactions for nitrate. (See pl. 13, *A.*) At some places these penetrate the rock in veins. The filtrate from this material yields a dense white flocculent precipitate ($CaSO_4$?) in the test tube when ferrous sulphate is added.

On floors of alcoves.—The floors of many alcoves are covered to a depth of 1 to 2 feet with earthy material formed apparently by the disintegration of fragments of weathered rock that have shelled off and dropped from the roof. (See pl. 13, *A.*) At most places this earthy material gives "very strong" reactions for nitrate.

Analyses.—The material in all the rich surface showings just described is nowhere sufficiently abundant to be commercially valuable, and it is not so regarded by the men interested in the claims. However, for record and to get an idea of the nitrate content, one sample was saved of material from each of the three types of deposit described and sent to the chemical laboratory of the Geological Survey for analysis.

Analyses of samples of surface deposits on Eberenz-Beach claims

[R. K. Bailey, analyst]

Material	Nitrate as $NaNO_3$ (per cent)	Remarks
Incrustations of milky crystalline salts from roof of alcove to depth of about 6 inches. (See pl. 13, *B.*)	[a]34.84	Tuff weathered to a depth of about 6 inches; can be pried off in flat slabs or shells. Cracks filled with milky salts; "very strong" reaction for nitrate. Sample represents 3 pounds of saline incrustations divided down to 1 pound.
Incrustation of milky crystalline salts on back wall of an alcove. (See pl. 13, *A.*)	.65	Gives "fair" field test for nitrate.
Earthy material covering floor of an alcove. (See pl. 13, *A.*)	32.70	Gives "very strong" field test for nitrate.

[a] R=Na with some Ca.

No samples were taken of the milky crystalline salts in the little cavities or pockets in the tuff in the roofs of alcoves, because the material in all of them flared up so quickly when touched with a lighted cigarette that there could be no doubt concerning its richness in nitrate.

Origin.—Several hypotheses as to the origin of the accumulations of nitrate just described suggest themselves. All assume final concentration in protected situations by evaporation of percolating ground water or capillary moisture.

1. That the nitrate has been derived entirely by nitrification of guano deposited in caves in the rock by rodents.
2. That it has been formed in weathered rock and soil near the surface by the action of nitrifying bacteria.
3. That it has been formed near the surface by either or both of the two agencies just suggested, then carried down into the body of the tuff by percolating ground water (rainfall) and deposited there, leaving the tuff impregnated with small amounts of nitrate.
4. That the nitrate, like the tuff, is of volcanic origin and the tuff is impregnated with it; the impregnation may have taken place when the tuff was deposited or later; the rich surface accumulations of nitrate represent material leached from the tuff.

From examination of the nitrate deposits in the crusts and small cavities on the roofs of alcoves and the deposits on the walls of alcoves it seemed quite out of the question to ascribe the origin of the nitrate in these situations directly to accumulations of bat, rat, or other rodent guano, because the nitrate deposits are in places where the natural deposition of guano would be physically impossible. It was equally difficult to see how the nitrate could have reached its present position by leaching from any places where guano had decomposed. Moreover, the amount of guano in sight anywhere near the deposits is insignificant and seems utterly inadequate to account for the nitrate. Small accumulations of guano were noted in a very few caverns that could be readily reached by animals, but no more than may be found in caverns in rocks of all kinds anywhere in the desert region. Undoubtedly some of the niter-bearing earthy material on the floors of alcoves has been enriched from this source, but most of it has obviously derived its nitrate from nitrate-rich material that has fallen from the roofs of the alcoves.

Hypothesis No. 1 may therefore be ruled out as inadequate to explain the origin of the deposits. Hypothesis No. 4, which assumes that the body of the tuff is impregnated with nitrate, is the view held at that time by the men interested in the claims, and their expectations as to the value of the property were based upon it. They believed that the nitrate is of volcanic origin.

NITRATE IN THE TUFF

The tuff itself received most attention in the examination, because it was regarded as the principal body of nitrate ore and because the surface showings, though rich in nitrate, are clearly not in commercial quantity. The tuff was tested where exposed beneath the surface in the excavations already dug.

Tests in open cuts.—All the open cuts had been directly exposed to the weather for periods ranging from one to four years. Chips of the rock were cut at several depths beneath the original surface in each excavation and tested for nitrate after being pulverized. Most of the chips gave no reaction for nitrate, but some yielded "weak" reactions. These reactions were generally obtained from the chips cut at places near the original surface. None of those obtained were strong enough to indicate more than a small fraction of 1 per cent of nitrate in the material tested. Because the cuts are all exposed to the weather it would be impossible to say whether these poor results were due to the leaching of the rock or to the actual poverty of the rock in nitrate. Therefore no samples for analysis were taken from these open cuts.

Tests and samples in tunnel.—The 25-foot tunnel is in relatively soft tuff beneath a harder, cliff-forming bed near the base of the exposed section of the tuff series, which forms the roof. (See pl. 15, *C*, and fig. 5.) The deeper part of the tunnel had been dug about 18 months before this examination, and the first 10 feet from the portal had been dug several years earlier, but as all the rock of its walls is protected from the weather and is dry, the tunnel afforded as fair an opportunity to test the tuff as it did when dug. The results of Mr. Eberenz's sampling are given on page 75.

The Geological Survey party first made tests of the rock in the face of the tunnel, 25 feet from the portal. The tests were difficult to make because the rock when crushed, pulverized, and moistened forms a mud which is exceedingly difficult to filter. The scanty filtrate from these crushed and pulverized samples of the rock gave no reaction for nitrate. Filtrate from uncrushed chips of the rock likewise gave "negative" reactions. Chips of the rock at different places along the walls of the tunnel were tested with similar results. Two or three chips cut near the portal gave very faint, almost imperceptible reactions, which could not be rated better than "very weak." Thus no reaction was obtained anywhere in the tunnel that could be considered indicative of more than a trace of nitrate in the material tested.

Three samples of the rock in the tunnel were taken as a check and sent to the chemical laboratory of the Geological Survey for analysis. The first sample was taken to show roughly the average nitrate content of the tuff for the length of the tunnel. It consisted of small chips cut from the east wall in a strip extending from the end to a point about 2 feet from the portal. It represented roughly, but in very much smaller quantity, the material constituting Mr. Eberenz's 200-pound sample. As a further check Mr. Eberenz himself, on request, cut this sample. It was a fair average sample for its weight but was not nearly so representative of the rock as the original 200-pound sample. When analyzed in the chemical laboratory by R. K. Bailey it was reported by him to contain no nitrate.

Another sample, which weighed three-quarters of a pound, was taken to show roughly the nitrate content of the tuff at the greatest depth reached, at the end of the tunnel. It consisted of chips cut from the west wall of the tunnel between the 20 and 25 foot marks. Mr. Bailey's analysis showed no nitrate.

A third sample, weighing three-quarters of a pound, was intended to show roughly the nitrate content of the tuff a few feet beneath the surface, as contrasted with the tuff at a depth of 15 feet or more, represented by the second sample. It consisted of chips from the west wall of the tunnel between the portal and a point 5 feet within. Mr. Bailey found no nitrate in it.

As the analyses of these three samples agree with the results of the field tests in the tunnel, which were practically negative, doubt may fairly be expressed regarding the accuracy of the analysis of the 200-pound sample cut by Mr. Eberenz, and consequently regarding the impregnation of the tuff with as much as 1 to 2 per cent of nitrate. Certainly the negative character of the field tests and the absence of nitrate in the samples analyzed creates a strong presumption against the impregnation of the tuff with even a small percentage of nitrate in the part penetrated by the tunnel. On the other hand, the Geological Survey samples are so much smaller than the one taken by Mr. Eberenz that results obtained from them may not be conclusive. Moreover, the sampling of one tunnel does not constitute a fair test of the vast body of the tuff.

The apparent poverty in nitrate of the tuff in the tunnel is rendered more impressive by an occurrence of some very rich superficial deposits of nitrate at the mouth of the tunnel. The roof of the alcove overhung by a cliff-making tuff bed beneath which the tunnel is driven is coated with crusts of saline material that give so strong a reaction for nitrate that they must consist almost wholly of it. Yet the tuff a few feet underground, where exposed in the tunnel, gives no reaction.

CONCLUSIONS

1. The rich deposits of nitrate-bearing salts in protected places on the outcrops of the tuff do not extend more than a few inches into the body of the tuff and are therefore not sufficient in quantity to be of commercial importance.

2. The value of the property depends on whether the mass of the tuff is impregnated with nitrate.

3. The available tonnage of the tuff is unquestionably very large, and the material is exposed in such a way that it could readily be mined and quarried.

4. The texture of the tuff is porous and therefore favorable for impregnation by nitrate.

5. The rich surface deposits of nitrate in protected situations do not necessarily indicate that the tuff itself is impregnated with nitrate, because (*a*) rich surface deposits have been found in other regions in protected situations on types of rock other than volcanic tuff—on limestones, for example; (*b*) the nitrate may have been formed near the surface through the action of bacteria and then concentrated in protected situations by evaporation of percolating ground water or capillary moisture.

6. If the tuff is impregnated with nitrate, either as a whole or in places along cracks and zones, it is reasonable to suppose that the rich surface deposits represent niter-bearing saline material leached from the tuff and carried to the surface by percolating water or capillary moisture and concentrated in protected situations by evaporation. Given time, even traces of nitrate disseminated through the tuff would be sufficient to account for these rich surface concentrations.

7. Whether the tuff is impregnated with nitrate is not yet definitely known and can be determined only by systematic underground exploration and sampling.

8. This work had been begun by Mr. Eberenz and his associates but not carried to a conclusion. It represented a systematic and conscientious attempt to learn at considerable expense, and possibly loss, whether a deposit of this type has any promise as a low-grade ore of nitrate. Results obtained by Mr. Eberenz and his associates indicated that the tuff contains between 1½ and 2 per cent of nitrate.

9. The Geological Survey's results are adverse to the conclusion that the tuff is impregnated with nitrate; they indicate, indeed, that the parts of the tuff tested are practically barren of nitrate. They are not regarded as conclusive, for reasons already stated. Before final conclusions are reached other parts of the tuff should be tested in tunnels driven at least 15 feet into it.

10. If further prospecting is carried on it would be worth considerable effort and expense to get therefrom conclusive evidence as to the origin of the nitrate, because the deposit is a fair sample of hundreds of others of the same type in the western United States which have likewise been prospected with unsatisfactory results and abandoned before a definite conclusion as to origin and value could

be reached. Work on the deposit should therefore be watched with interest.

11. In view of the results already obtained, however, further work should be undertaken only with a full understanding of the expense and the highly speculative risk involved.

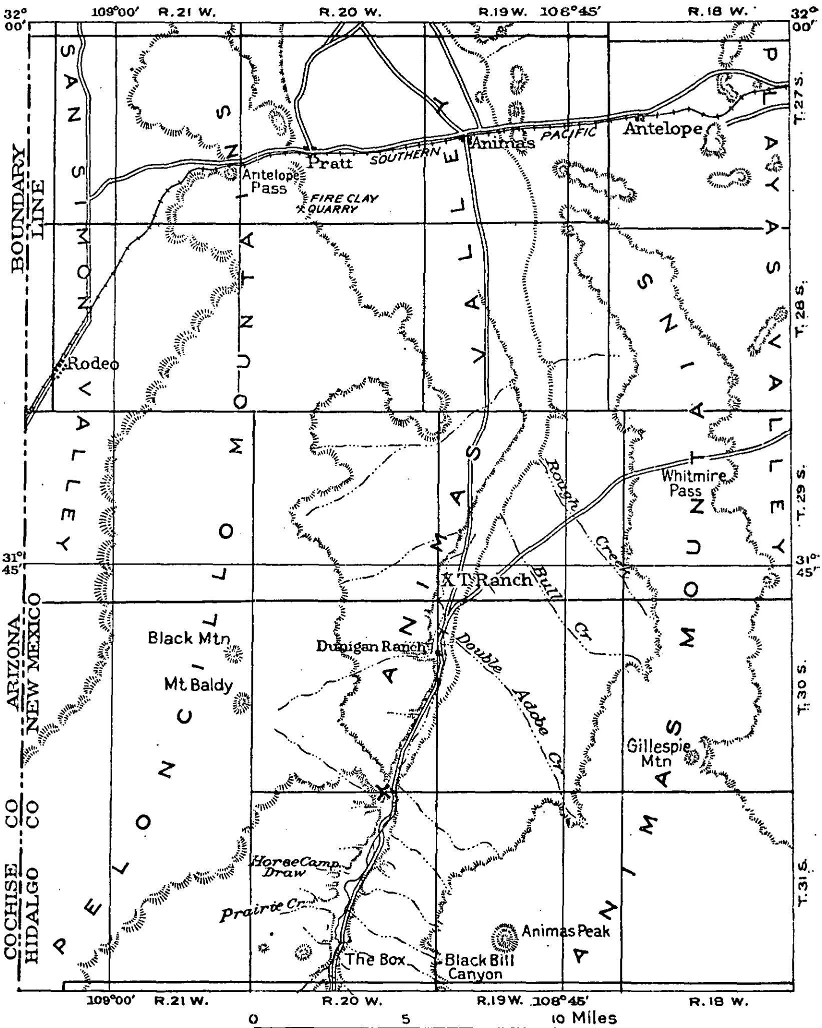


FIGURE 6.—Map showing approximate location of Hungerford-Moore nitrate claims (X), Animas Valley, N. Mex.

HUNGERFORD-MOORE NITRATE CLAIMS IN ANIMAS VALLEY, N. MEX.

LOCATION AND ACCESS

The Hungerford-Moore nitrate claims lie in Hidalgo County, N. Mex., about 20 miles south of Animas station on the Southern Pacific Railroad, as shown in Figure 6. The property was discovered by

John Moore, a miner and prospector well known in the Animas Valley. Moore brought it to the attention of D. H. Pemberton, under whom he was working in Searchlight, Nev., and through Pemberton to C. B. Hungerford, of Newmark, Calif. These three men are associated in the project, but Moore has done the locating and most of the prospecting and sampling.

In company with E. E. Lee, of Paradise, Ariz., the writer visited and examined the property on November 22, 1918.

The claims are 4 miles south of the Dunnigan ranch, a well-known place in the upper Animas Valley 16 miles south of Pratt, on the mail route south from Animas station to Cloverdale, near the Mexican border.

The altitude as indicated by a barometer reading checked against the altitude of the railroad station at Rodeo, is 5,100 feet.

GENERAL GEOLOGIC FEATURES

The geology of the Animas Valley has been described by Schwennesen.[63] The Animas Valley at the point where the claims are located is wide and open, with the dry bed of the river about in the center. Animas Peak rises several miles to the southeast, and the Peloncillo Mountains a corresponding distance to the west. The west bank of the river here is a steep rocky slope that rises perhaps 200 feet above the stream bed, but the east bank is simply a low bluff some 20 feet high, cut in the alluvial filling of the valley. No bedrock is exposed in the east bank or in the bed of the stream. The steep slope on the west side is practically all an outcrop of light gray, rather massive acidic volcanic rock, apparently rhyolite, dacite, or latite porphyry; it is probably an outlier of the volcanic rocks of the Peloncillo Mountains. The exposure extends half a mile or more along the stream.

About in the middle of this exposure, near the base of the rocky slope, is a curious mass of cavernous rock locally termed a "blowout." (See pl. 14, *A*.) Viewed from a distance it looks like a hot-spring or geyser deposit, but on examination it proves to be a coarse cavernous breccia. (See pl. 14, *B*.) The fragments in the breccia resemble the porphyry on the steep slope back of the "blowout," but they have a pinkish color and appear to be more or less silicified. The matrix in which the fragments lie is a fine whitish or pinkish material which forms perhaps somewhat less than half the mass of the breccia. The cavernous nature of the breccia is due to the weathering out of this powdery material from between the fragments.

The outcrop of the breccia is about 160 feet long and 120 feet wide. The depth of the mass and its probable form are unknown.

[63] Schwennesen, A. T., Ground water in the Animas, Playas, Hachita, and San Luis Basins, N. Mex.: U. S. Geol. Survey Water-Supply Paper 422, pp. 28–36, 1918.

Possibly it is a sort of vertical pipe in surrounding porphyry. The lowest part of the outcrop is perhaps 50 feet above the level of the stream bed.

REASON FOR THE EXAMINATION

Samples taken from the deposit were submitted to the Geological Survey by Mr. Hungerford in 1914, together with a letter containing the following description:

> It apparently has been a river or lake bed. We have six claims and have done some development work outside of location work. There is a range of hills and low mountains on either side. The vein or ore deposit seems to be about 200 feet wide, but of course this is so near the surface it is impossible to tell how wide it really is. The older diggings seem to have the most crystals in sight—that is, there seems to be a pressure from the inside of a fluid impregnated with potash that shows in the shafts that are the oldest, as the fresh moved rock and earth do not show the coating of potash that some of these samples show. The finer particles in the sack are from the recent workings, and although they do not show the white coating the analyses are very good. We wish to go on with our development work and verily believe with depth we have a large body of good grade of nitrate. We have had some very good analyses made by responsible firms. We would like to give this property a thorough testing, drilling holes to a depth of 200 feet and sampling the product every 10 feet or oftener.

The samples sent to the Geological Survey proved to be a little more than one-half soluble in water. Approximately two-thirds of this soluble material was potassium nitrate; no chloride and only a small amount of sulphate was present. The samples, then, were relatively rich in nitrate.

A personal call on Mr. Hungerford elicited the information that the nitrate was "in a pinkish conglomerate" and was found "in crystals on the conglomerate." He said that some samples showed a content of potassium nitrate at a depth of 16 feet in an excavation. According to his recollection, one sample ran 32.6 per cent of sodium nitrate and 36.4 per cent of potassium nitrate.

Apparently, then, from their statements the locators of the property considered the mass of pinkish cavernous breccia, or "blowout," above described, the "vein or ore deposit." (See pl. 14.) They believed that somewhere in the breccia there is a "large body of good-grade nitrate" and they based their expectations on the fact that they had found rich samples of sodium and potassium nitrate on the surface of the "older diggings" and some fair samples "in the recent workings."

EXAMINATION

There is a 30-foot shaft in the breccia in the lower part of the outcrop, about 50 feet above and perhaps 150 feet west of the creek bed. A great ledge of cavernous breccia overhangs the mouth of the shaft and almost entirely protects it from the weather. At the mouth of the shaft a tunnel has been driven westward about 30 feet directly into the breccia.

According to Mr. Dunnigan, the numerous cavities in the breccia once contained considerable cave niter, which has been practically all cleaned out and taken away. It is possible, therefore, that this material is the source of some if not most of the rich samples obtained by the locators. No attempt was made to sample it because, owing to its nature, its superficial character, and its small quantity it is obviously of no importance as a source of commercial nitrate.

The 30-foot tunnel afforded an excellent opportunity to examine the breccia underground. Accordingly the breccia was tested at many places in the tunnel and its exposures in the walls were carefully examined. No veins or shoots of nitrate were seen in the breccia, nor could any evidence of their existence be found. The fragments of siliceous porphyry that make up the greater part of the breccia furnished no reactions for nitrate. These porphyry fragments are so dense and solid that it is inconceivable that they could contain more than the smallest traces of soluble saline material. It was therefore evident that if the breccia contains any considerable amount of nitrate, the nitrate either impregnates the matrix of whitish or pinkish powdery material in which the porphyry fragments are embedded or lies in caverns or pockets in the breccia. The powdery material was next tested. From it "weak" reactions for nitrate were obtained at two places in the tunnel, but no reactions at other places. To check these field tests two samples of the material that gave reactions were sent to the chemical laboratory for analysis. Sample 1 represented about a pound of the powdery material that forms a matrix of the breccia, gathered from a strip 5 feet long at the far end of the tunnel. The powdery material is not continuous in this strip; it was picked out from between the fragments of solid porphyry that are embedded in it. Sample 2 represented a pound of similar material gathered in the same way from a strip 5 feet long midway between the portal and the end of the tunnel.

As analyzed by E. T. Erickson, sample 1 contained only traces of NO_3 and of soluble K, and sample 2 contained 0.5 per cent of NO_3 and a trace of soluble K.

These results may indicate that at some places the powdery matrix of the breccia contains a little nitrate, although the amount is evidently much too small to be of commercial significance. On the other hand, it is not at all unlikely that the material tested and sampled in the tunnel had been contaminated by cave nitrate or by nitrate derived from deposits of guano. Several large cavities in the breccia are cut by the tunnel; according to Mr. Dunnigan these cavities contained deposits of cave nitrate when the tunnel penetrated them. At the time of examination a pile of guano 2 feet high and 4 feet in diameter lay upon the floor of the tunnel under a bat roost on the ceiling near the end of the tunnel. Similar accumulations were noted in several natural caverns in the breccia. Some of the material had evidently nitrified in place.

It was not clear whether by "the older diggings" the locators meant the tunnel or the shaft, or both. It may well have been possible originally to obtain rich samples of cave nitrate in either one, because the breccia is cavernous in both, or to obtain rich samples in the numerous cavities in and about the great natural alcove where the tunnel and shaft are dug. It therefore seems probable that the rich samples referred to by Mr. Hungerford represented material of the cave-niter type like the material on roofs, walls, and floors of alcoves on the Eberenz-Beach nitrate claims, described on pages 74–75. Very little of this material remained in the cavities, however, at the time of this investigation. No evidence could be seen that the walls of the tunnel are being impregnated at the present time by a fluid containing potash or nitrate; the walls were dry; there was no coating or bloom of efflorescent salts upon them and no evidence of seepage through them.

The shaft was not accessible, but it could be seen that the walls were in the same sort of material as the tunnel and that there was no evidence of seepage into the shaft at that time from the sides or bottom, which were dry. The property was visited at the end of a two days' storm of snow and rain, which had thoroughly soaked the region. Although the mouth of the shaft was protected from the weather by an overhanging ledge of cavernous breccia the situation is such that a very heavy rain if driven by high wind from the east might leach cave nitrate from the overhanging ledge and wash it down over the walls of the shaft. Whether this had happened is not known, but it is possible, and if some rich samples came from the walls of the shaft, which, as Mr. Hungerford seems to state, did not show nitrate when the shaft was first dug, the nitrate may have been deposited later upon the walls in this way. No reaction for nitrate was obtained from material lying on the dump heap composed of material thrown out in digging the tunnel and shaft. However, this material had been exposed directly to the rains for a long time and was probably thoroughly leached of any soluble salts that it may have contained.

It is possible that the nitrate occurs in some form or situation that has been overlooked through some misinterpretation of the statements of the locators, but from conversation with Mr. Dunnigan, who lives near the property and is familiar with it, this does not seem to be true. According to Mr. Dunnigan, there are similar "blowouts" in the Peloncillo Mountains, west of the property, and deposits of cave nitrate occur in cavities in them.

CONCLUSIONS

The mass of breccia which, from statements of the men interested in the property, seems to constitute the "vein or ore" of nitrate is clearly not large enough to be of commercial importance unless it contains large bodies of nitrate in veins or shoots or is impregnated with a considerable percentage of nitrate. No indications could be found in a tunnel driven 30 feet into the breccia that veins or shoots of nitrate exist in the rock.

Tests and samples of the breccia exposed in the tunnel might be considered to indicate that the breccia is impregnated with a small percentage of nitrate, but it is at least as likely that the material sampled has been contaminated by nitrate derived from guano deposits in the tunnel. If the breccia is impregnated with nitrate, the average percentage must be very low, for the best sample showed a nitrate content of only 0.5 per cent. This amount is far too low to be of commercial importance. No other field test in the tunnel indicated as much as this amount; indeed, most tests in the tunnel were "negative." Moreover, nitrate if present as an impregnation in the breccia could be contained only in the powdery material that forms the matrix of the breccia, for the fragments of porphyry that are embedded in the matrix can contain no soluble saline material. Inasmuch as these porphyry fragments constitute at least half of the mass of the breccia the percentage of nitrate shown in samples taken must necessarily be reduced one-half if it is to represent the content of the mass of the breccia.

The only material relatively rich in nitrate seen on the property is of the "cave nitrate" type. It occurs in protected situations on roofs, walls, or floors of cavities in the breccia but is superficial and therefore of no commercial importance.

As the writer was not accompanied by any of the men interested in the property, it is possible that the nitrate occurs in some form or situation that was overlooked. If for example, it occurs in veins or as concentrations within the mass of the breccia the property would be worth further prospecting.

RANDOM TESTS IN AREAS OF TERTIARY STRATA

At several times since 1918, while traveling through areas of Tertiary strata that resemble the clay-hill areas described in this report, the writer has stopped for a few nitrate tests. Although these areas were not examined in detail it seems worth while to note briefly the results of the tests.

VALLEYS OF MUDDY CREEK AND VIRGIN RIVER, NEV.

The lower valley of Muddy Creek and the valley of the Virgin River below St. Thomas contain many exposures of a series of loosely consolidated beds of sandy clay, sand, and gravel, which at most places are horizontal or nearly so but at some places are moderately tilted and folded. This series of beds, named the Muddy Creek formation by Stock, has been described in detail by Longwell,[64] who assigns it tentatively to the Pliocene. Possibly it is equivalent in age to the beds with which nitrate is associated at West Well near the Colorado River below Needles, described on pages 38–39. Some beds contain much saline material. Many beds contain gypsum, and one bed exposed in the valley of the Virgin River consists of solid rock salt. Gypsiferous clay beds are associated with the salt bed. At some places the beds of clay or sandy clay are covered with a barren clay soil that resembles the soil in the clay-hill nitrate areas. At the surface of the ground is a thin layer of compact clay furrowed with tiny knobby corrugations. Beneath this clay is a layer of loose material consisting of powdery clay mixed with varying amounts of soluble salts. This loose soil, which passes downward into the underlying rock, was tested at a number of places near Logan, in the valley of Muddy Creek (see pl. 1), and a reaction for nitrate was obtained at each place.[65] None of the reactions, however, were better than " weak." At the places tested no caliche layer is present at the base of the soil, but in the vicinity of the salt bed exposed in the valley of the Virgin River about 7 miles below St. Thomas a hard salty caliche was found resembling that which overlies the more saline clays and the salt bed in the Saratoga nitrate field.[66] The hard, salty caliche is confined to the outcrop of the salt bed. Unquestionably, therefore, the salt in the caliche has been derived from the underlying salt bed. This caliche was tested at one place, but yielded no reaction for nitrate. Several pieces of the rock salt were also tested for nitrate, but no reaction occurred.

FURNACE CREEK, CALIF.

One of the largest and certainly the most spectacular area of Tertiary strata in the desert region lies along the valley of lower Furnace Creek between Ryan and the floor of Death Valley, the

---

[64] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 4th ser., vol. 50, pp. 39–62, 1920. See also U. S. Geol. Survey Bull. 798, 1928.

[65] Noble, L. F., Colemanite in Clark County, Nev.: U. S. Geol. Survey Bull. 735, p. 31, 1922.

[66] Noble, L. F., and others, op. cit., p. 39.

exposures extending continuously for at least 12 miles along the south side of Furnace Creek Wash. (See pl. 1.) The area is interesting not only for the odd colors of the strata and the weird badland scenery to which these beds give rise but because the strata contain many large deposits of boron minerals (colemanite and ulexite). The rocks comprise sandstones, conglomerates, clay shales, fresh-water limestones, tuffs, breccias, and sheets of lava. They are steeply tilted, folded, and faulted and include at least two unconformable series whose total thickness amounts to many thousands of feet. Many clay beds are very thinly laminated and were evidently deposited in lakes. Many sets of beds closely resemble the strata with which nitrate deposits are associated in the Amargosa region and were obviously deposited under similar conditions. Much of the Tertiary section on Furnace Creek and much of that in the Amargosa region is probably equivalent in age. In general the section on Furnace Creek contains more volcanic material than that in the Amargosa region. The beds in both sections, however, were deposited during a period of continuous and violent volcanic activity. Many clay beds on Furnace Creek, as in the Amargosa region, consist largely of fine volcanic ash.

Enormous tracts in the Furnace Creek region are intricately carved into badlands, and at some places the beds form rounded hills, covered with clay soil, which resemble the typical niter hills of the Amargosa region. (See pl. 15, *A*, *B*.) South of Furnace Creek, in the vicinity of Mount Blanco and extending to the edge of Death Valley, tracts of this typical clay-hill ground must cover many hundreds of acres. It seemed worth while, therefore, to test some of this ground for nitrate. Accordingly tests were made at two places selected at random along the road down Furnace Creek.

The first locality is on the north bank of Furnace Creek Wash, about half a mile below the tank shown on the Furnace Creek topographic map northwest of the 1,939-foot bench mark. At this locality steeply tilted beds of greenish-yellow sandy shale crop out in the bank of the wash. At places the outcrops of the shale are covered with a barren clay soil. Two pits in this soil disclosed compact clay at the surface, 2 inches; powdery clay mixed with white efflorescent salts, apparently chiefly sodium sulphate, 1 foot; cracked and weathered shale cemented by saline material (apparently chiefly sodium chloride) and resembling the typical caliche layer of the Amargosa nitrate fields, 6 inches; and unaltered shale. The caliche in both pits was tested. In one pit it gave a "weak" reaction for nitrate and in the other a "fair" reaction.

The second locality is on the south bank of Furnace Creek Wash about 1.8 miles below the tank already mentioned. Here a tract of ground many acres in extent is underlain by whitish or cream-colored shales that dip steeply and at some places stand nearly vertical. Two pits were dug in this ground. (See pl. 15, *A*.) Both revealed the same arrangement as in the first locality—compact clay at the surface, 3 inches; a powdery saline layer, 4 inches; caliche, 4 inches; and unaltered shale. The ground proved to be remarkably similar to that at Bully Hill, in the Upper Canyon nitrate field.[67] Samples of caliche from both pits yielded "fair" reactions for nitrate.

These random tests on Furnace Creek, all of which yielded a reaction for nitrate, suggest that much of the caliche in the Furnace Creek areas contains nitrate. Inasmuch as the clay-hill ground on Furnace Creek is of considerable extent and is similar to that in the more promising areas of the Amargosa region, it is possible that systematic prospecting in the Furnace Creek area would reveal tracts of caliche similarly rich in nitrate.

FISH LAKE VALLEY, NEV.

On the east side of Fish Lake Valley, at the mouth of the canyon through which a road descends from Emigrant Pass, are outcrops of tilted beds of Tertiary clay which in places are covered with barren clay soil like that in the clay-hill nitrate areas of the Amargosa region. The locality is about 3 miles northeast of the ruins of the borax mill near "The Crossing," in Fish Lake Valley. (See fig. 7.) The altitude is about 5,000 feet. One pit was dug in the typical clay-hill ground in this locality, and the arrangement of the ground proved to be similar to that in the numerous other clay-hill areas already described—a layer of compact clay at the surface, 2 inches; powdery clay containing much saline material, 1 foot; cemented caliche, 3 inches; and unaltered shale. A test of the caliche yielded a "fair" reaction for nitrate.

The results of these random tests in three widely separated areas of clay strata—Muddy Creek, Furnace Creek, and Fish Lake Valley—indicate that nitrate deposits of the clay-hill type are very widely distributed in the desert region and are probably to be found wherever there are any considerable areas of exposed clay strata.

PARTIAL ANALYSES OF CALICHE FROM THE NITRATE FIELDS OF THE AMARGOSA REGION

After the nitrate fields of the Amargosa region had been explored, one sample of nitrate-bearing caliche from each of the four fields

---

[67] Noble, L. F., and others, op. cit., p. 69.

most thoroughly prospected was analyzed in the chemical laboratory of the Geological Survey to determine the relative amounts of the chief salts present in the caliche. Through an oversight these analyses were not included in the Amargosa report, and accordingly they are given below.

The Saratoga and Confidence samples represent the hard, compact salty caliche characteristic of those two fields; the Upper Canyon sample represents the semicompact flaky caliche characteristic

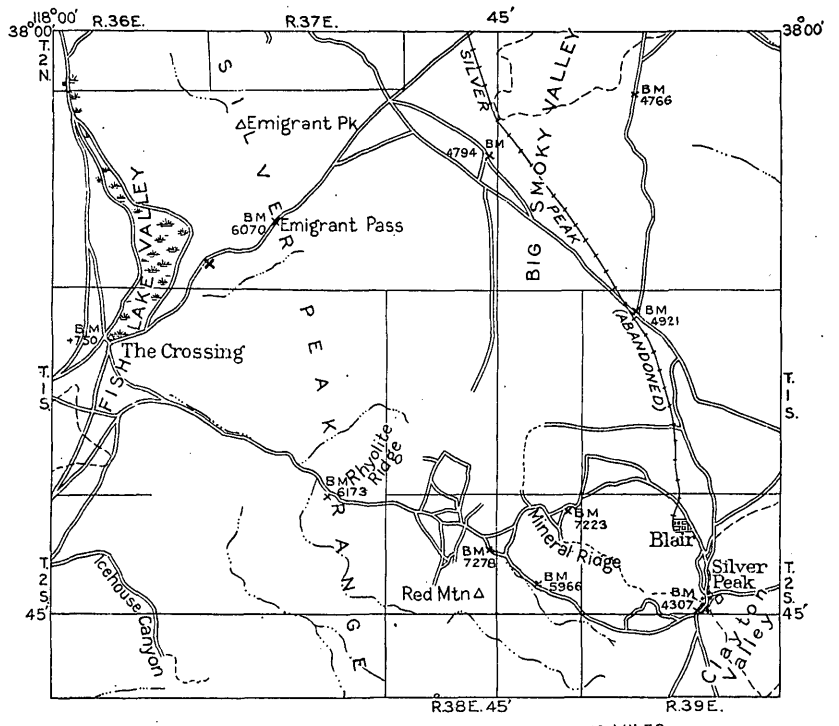


FIGURE 7.—Map of Fish Lake Valley and adjacent regions, Nev. X, approximate location of Tertiary beds tested for nitrate

of the better ground in that field; and the Zabriskie sample represents the crumbly and rather ill-defined layer that lies at the base of the soil at some places in that field and corresponds to the caliche layer of the other fields. None of the samples analyzed was selected with reference to its relative richness or poverty in nitrate. Accordingly none of them represents the best or the poorest material found in its field. Each represents, rather, the caliche which in physical character is most typical of the field in which it occurs.

Partial analyses of caliche from Amargosa region

Nitrate field	Reference in Bull. 724	No. of sample	Soluble salts at 180° C. (per cent)	Na	Ca	K	Cl	CO_3	SO_4	NO_3
Confidence	Pl. 15; pp. 54, 55	A-44	40.35	Much.	Trace.	Trace.	14.82	0.15	8.17	1.89
Saratoga	Pl. 8; p. 42	S-16	23.62	Much.	Little.	Trace.	9.60	.04	3.61	[a]1.57
Upper Canyon.	Pl. 30; pp. 70, 71	T-12(214)	13.68	Much.	Trace.	Trace.	3.46	.03	Little.	4.56
Zabriskie	Pl. 23	Z-3	8.17	Much.	None.	Trace.	2.16	1.19	Little.	.82

[a] Nitrate content of this sample erroneously tabulated in terms of $NaNO_3$ in Bulletin 724, instead of in terms of NO_3.

Calculated salts (per cent)

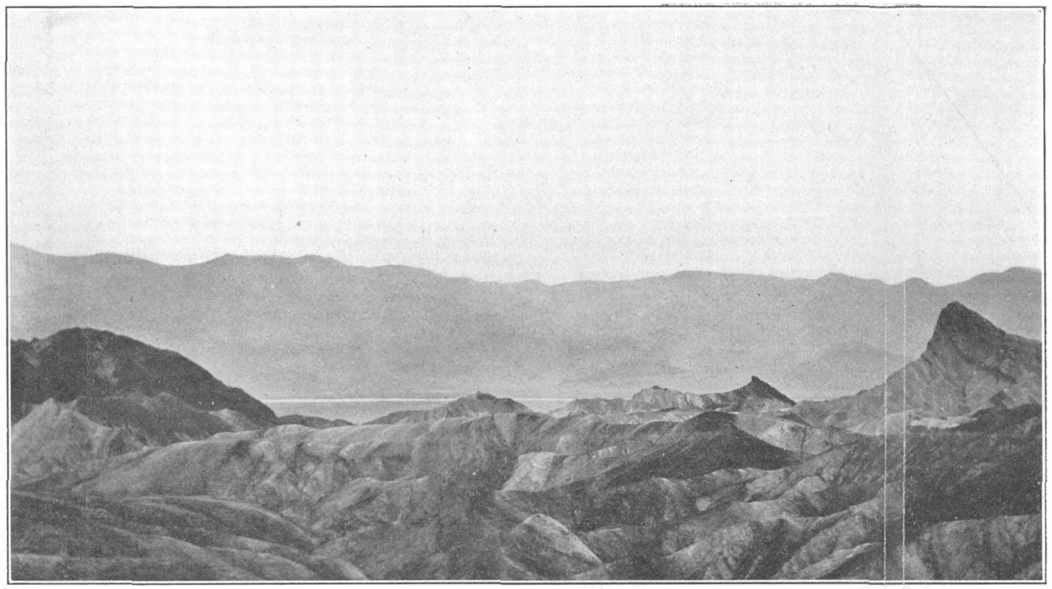
	A-44	S-16	T-12(214)	Z-3
$NaNO_3$	2.59	2.17	6.25	[a]1.12
NaCl	24.42	15.82	5.70	3.56
Na_2CO_3	.27	.07	.05	2.10
Na_2SO_4	12.08	5.34		
Undetermined	.99	.22	1.68	1.39
Total	40.35	23.62	13.68	8.17

[a] Nitrate content of this sample erroneously tabulated as 0.12 per cent in Bulletin 724, instead of 1.12 per cent.

These analyses show that sodium chloride is prevailingly the most abundant soluble salt in the caliche and therefore the salt that may be said to characterize it. In all but one sample, that from the Upper Canyon field, the sodium chloride greatly exceeds any other salt; and even in the Upper Canyon sample it is nearly as abundant as sodium nitrate, the most abundant salt.

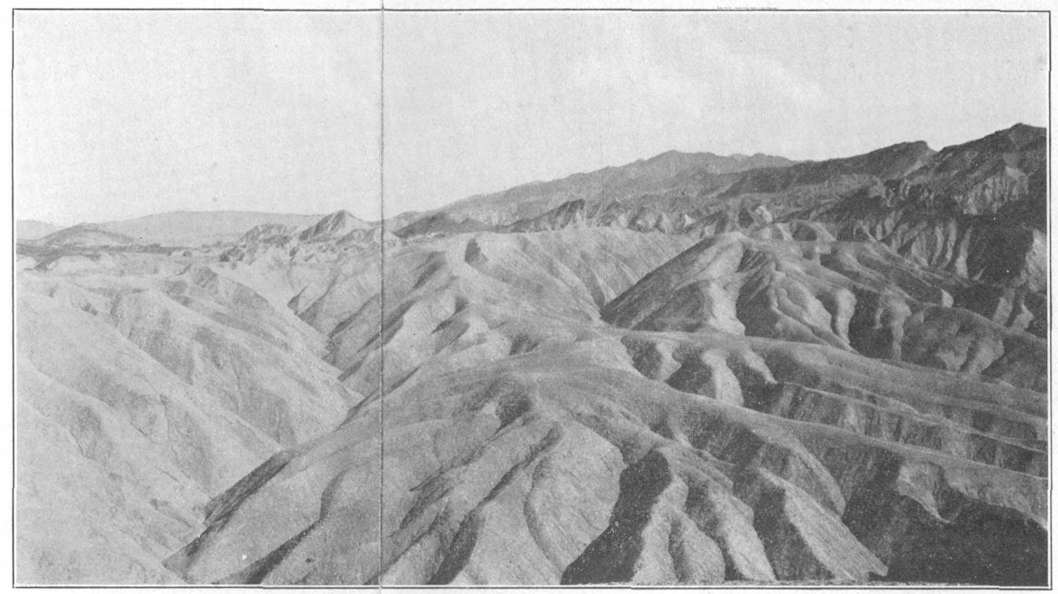
The principal other soluble salts present in the caliche are sodium nitrate, sodium sulphate, and sodium carbonate, but the amounts of these salts fluctuate widely, so that the composition of the caliche differs considerably in the different samples. For example, sodium nitrate is the most abundant salt in the Upper Canyon sample but is only third in abundance in the other three. Sodium sulphate is second in abundance in two samples but is absent in the other two. Sodium carbonate is second in abundance in one sample but is present only in insignificant amounts in the other three.

The results of these analyses, considered in connection with numerous qualitative tests of the caliche and overlying soil made during the several nitrate investigations here mentioned, lead to the following generalization concerning the soluble salts present in the caliche as contrasted with the soluble salts present in the overlying "efflorescent" layer of loose soil. The soluble salts in the soil are chiefly sulphates with a subordinate but fluctuating amount of



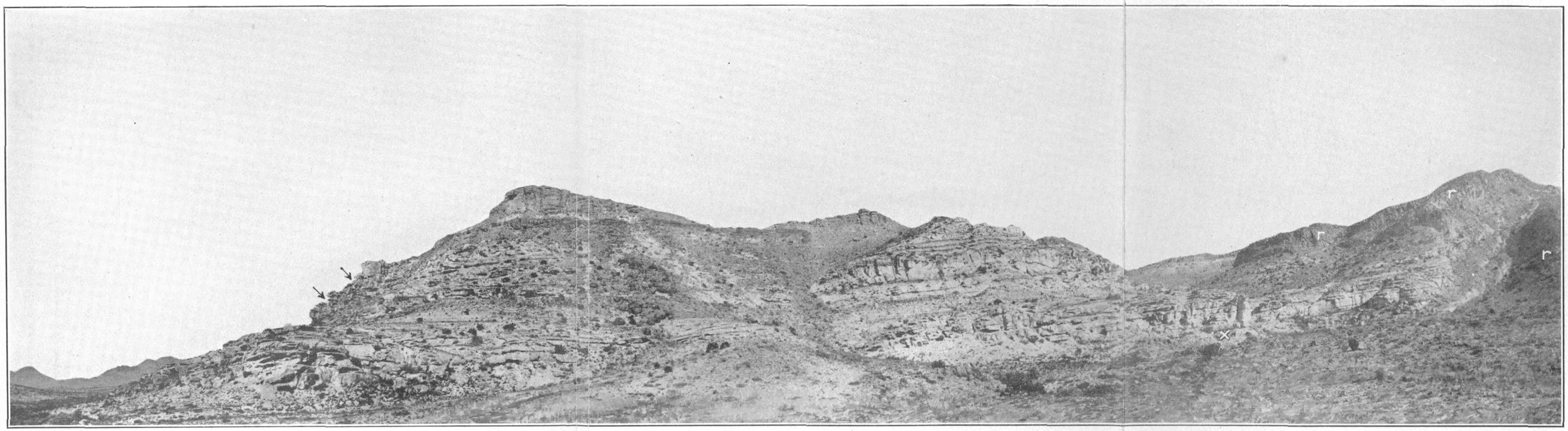
A. TERTIARY STRATA SOUTH OF FURNACE CREEK

View southeast. Typical clay hill. Ground shows absence of vegetation.



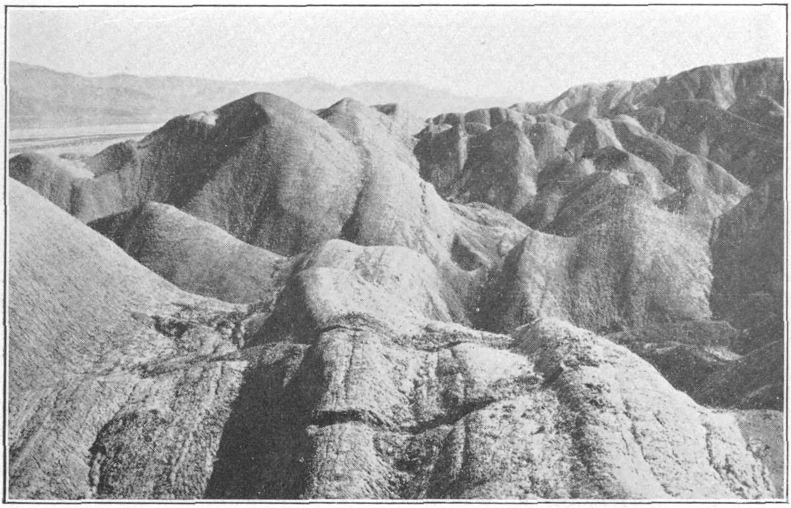
B. TERTIARY STRATA SOUTH OF FURNACE CREEK

View west. Death Valley and Panamint Range in background.



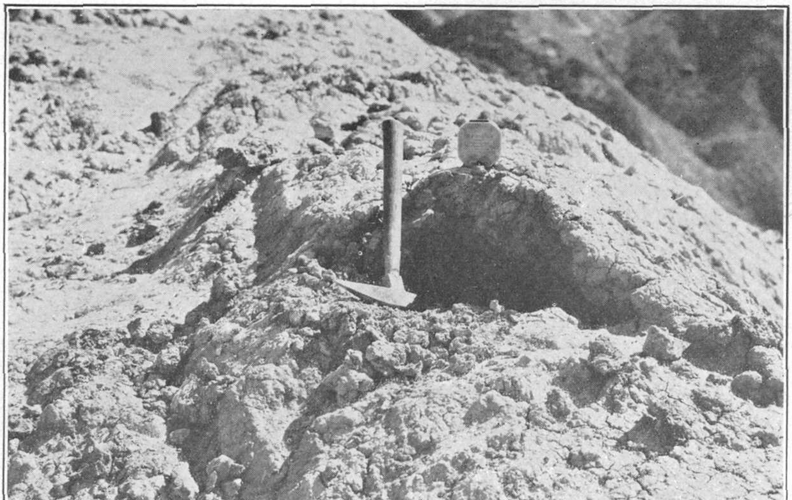
C. PANORAMA OF AREA COVERED BY EBERENZ-BEACH NITRATE CLAIMS

View from west to east. Arrows show locality of samples 2–4 ×, Tunnel and samples 1, 5, and 6; r, rhyolite.



A. BLISTER CALICHE ON GREEN SHALE, CONFIDENCE FIELD

Pits mark width of outcrop of green shale.

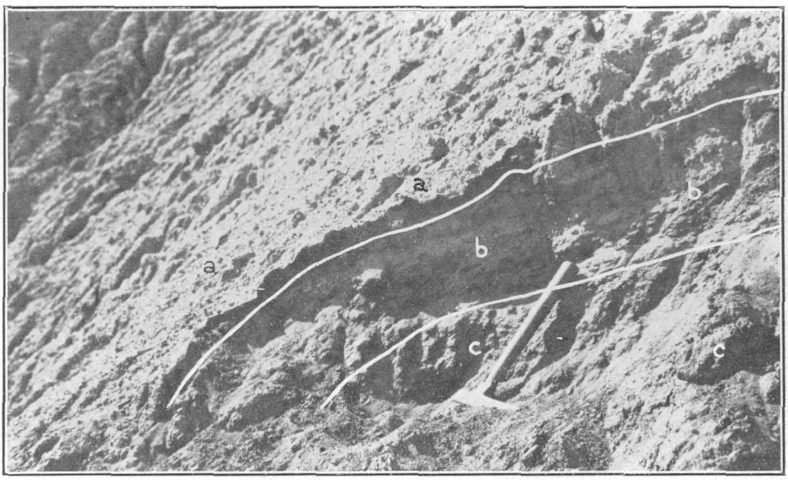


B. NEAR VIEW OF BEDS SHOWN IN *A*

Caliche blister. Hammer head marks characteristic cavity; compass rests on arch of blister.

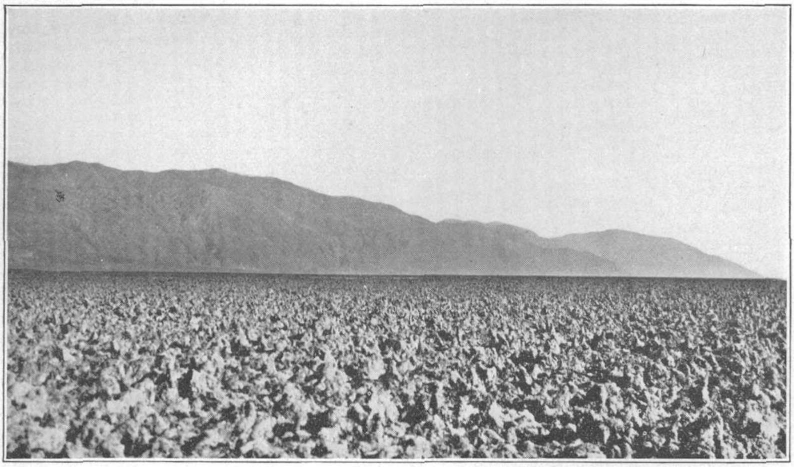
A. NITRATE GROUND IN AMPHITHEATER CANYON, SARATOGA FIELD

×, Locality where samples were taken for nitrification tests 3, 4, and 5.



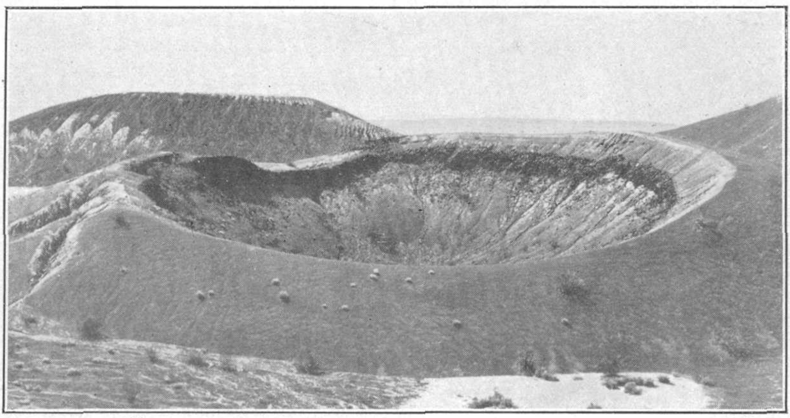
B. EXCAVATION AT LOCALITY SHOWN IN *A*

a, Surface clay (sample 3); b, efflorescent layer (sample 4); c, caliche (sample 5).

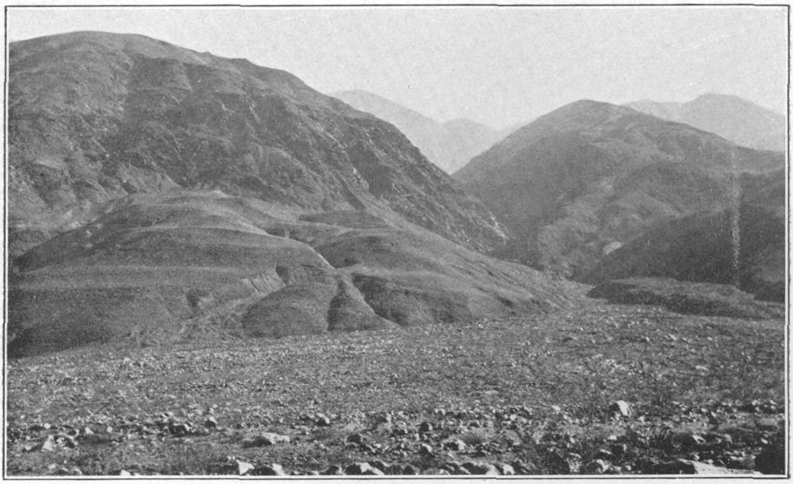


A. SALT DEPOSIT ON FLOOR OF DEATH VALLEY

Note the rough surface

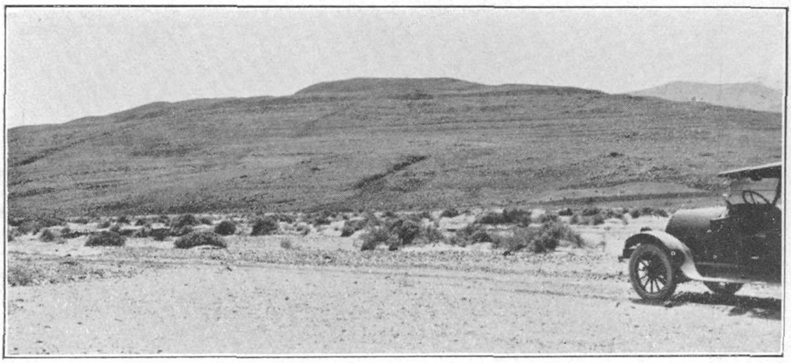


B. RECENT CINDER CONE IN NORTH DEATH VALLEY NEAR MOUTH OF UBEHEBE WASH



A. STRAND LINES, PANAMINT VALLEY

East side, 4 miles north of Goler Canyon.



B. STRAND LINES, SOUTH END OF DEATH VALLEY

Cut in basalt hill 2 miles northwest of Ashford Mill.

chlorides and an insignificant amount of nitrates; whereas the soluble salts in the caliche are chiefly chlorides with subordinate but widely fluctuating amounts of nitrates and sulphates. As contrasted with the soil and caliche layers, the bedrock strata beneath these layers contain a far smaller proportion of soluble saline material. At the few places where chemical tests have been made the most abundant soluble salt in the bedrock appears to be sodium chloride. Nitrate is present at many places but is insignificant in amount, and whether it is present at depths below 10 or 12 feet, the greatest depth reached in any of the excavations, is not known. The caliche and overlying layers, however, constitute a blanket that conforms generally with the surface of the ground without regard to the attitude of the bedrock strata, but certain types of rock—clay beds, for example—appear to be more favorable for the accumulation of caliche than others. At Bully Hill, in the Upper Canyon field, the richest of the larger nitrate-caliche areas, some 1,200 feet of inclined strata were exposed in prospecting operations without disclosing any bed that contained more than a trace of nitrate. There is therefore little reason to suppose that beds rich in nitrate occur at depth in any of the fields investigated. Insoluble sulphates, chiefly gypsum, are present nearly everywhere in the bedrock strata of the clay-hill areas and at most places are abundant also in the soil and caliche. The rude zonal arrangement of the salts just described—soluble sulphates characterizing the loose soil layer and soluble chlorides and nitrate characterizing the caliche layer—appears to be the rule in all the clay-hill nitrate deposits.

COMPLETE ANALYSES OF BLISTER CALICHE FROM THE CONFIDENCE NITRATE FIELD

One of the essential steps in a systematic study of the origin of the clay-hill nitrate deposits is the making of numerous complete analyses of the different types of caliche and the bedrock beneath the caliche. Although this study was beyond the scope of the present investigation it seemed worth while for record to have one complete analysis of caliche made. For this analysis the blister caliche of the Confidence nitrate field was selected. (See pls. 1 and 16.) That caliche was chosen because it is the richest in nitrate of all found during the Geological Survey's investigation. The blister caliche is confined sharply to the outcrop of a bed of green shale at this locality but the bedrock below shows no more enrichment here than elsewhere. (See pl. 16, *A*.) A 48-pound sample of blister caliche taken during the exploration of the Confidence field yielded 15.63 per cent of sodium nitrate, and two hand-sorted samples contained 22.18 and 22.21 per cent. The Confidence field was revisited in 1921 and another sample of the caliche was taken near the locality where the first rich samples had been obtained.[68] The later sample represented about 25 pounds of the caliche gathered at random over an area of about 200 square feet. with no attempt to sort the material. It was pounded up on canvas, averaged down to about half a pound, and analyzed in the chemical laboratory of the Geological Survey by R. K. Bailey, with the following result:

Chemical composition of blister caliche from Confidence nitrate field, California

Total soluble salts	43.12
Insoluble matter	49.59
H_2O	7.29
	100.00
Composition of salts (as per cent of total soluble salts):	
Cl	35.34
SO_4	6.08
NO_3	23.19
B_2O_3	.65
ClO_3	Trace.
I	None.
IO_3	None.
Ca	.70
Mg	.23
K	.51
Na	33.30
NH_4	None.
	100.00

The analysis just given is similar to some analyses of Chilean caliche,[69] although the blister caliche contains less nitrate than most of the Chilean material. Like the Chilean caliche, the blister caliche consists chiefly of sodium chloride and sodium nitrate, with subordinate sulphates and chlorides of calcium, potassium, and magnesium, and contains a small amount of borate and a trace of chlorate. Indeed, it appears to differ from the Chilean caliche essentially only in containing no iodine. However, the composition of the caliche in the clay-hill deposits, like that of the caliche in Chile, is known to be exceedingly variable; and one complete analysis of one type of clay-hill

[68] Noble, L. F., and others, op. cit., pp. 19, 57.

[69] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 256, 1924.

caliche is certainly insufficient to afford a fair standard of comparison. It is possible that other analyses of the clay-hill caliche at some other locality may reveal the presence of iodine. Iodine has been reported to the Geological Survey in a deposit of sodium nitrate, apparently of the clay-hill type, said to lie about 5 miles south of Rawhide, Nev., and to be adjacent to a deposit of epsomite, but this deposit has not been examined by the Geological Survey.

Perhaps the most interesting feature shown by the analysis just given is the presence of borate in the caliche, for it suggests that the association of borates with nitrates in the clay-hill caliche may be more common than has been supposed. The caliche was tested for borate in the field in only one other clay-hill area, the Owl Spring nitrate field, but an unmistakable reaction for boron was obtained. (See p. 24.) The borate in the caliche there is probably derived from borate in the bedrock strata, because some of those strata gave a reaction for boron. Undoubtedly the caliche at places in the Furnace Creek district (pp. 86–88), where the underlying strata contain deposits of colemanite and ulexite, would be found to contain borates.

NITRIFICATION TESTS IN CLAY-HILL AREAS AND IN LEACH LAKE

Another essential step in a study of the origin of the clay-hill nitrate deposits is to determine whether fixation of nitrogen from air in soil through the agency of bacteria is taking place in the vicinity of the deposits, and, if so, to what extent. With this possibility in mind the writer collected, in October, 1918, eight samples of different layers of ground in the nitrate deposits to be tested for activity in nitrification. The samples were collected in sterilized bottles, sealed immediately, and sent to Washington, where they were turned over to the Bureau of Plant Industry for testing. They represent material from the Saratoga, Confidence, and Zabriskie nitrate fields and from Leach Lake. Of these samples five represent soil, one caliche, one soil and caliche taken together, and one loose material lying in a cavity in caliche. Of the soil samples one (No. 3 in the table) represents surface soil—the typical compact surface clay layer of the nitrate fields; three (Nos. 2, 4, and 8) represent loose saline clay soil at depths ranging from 2 to 17 inches beneath the surface—the typical "efflorescent" or "sulphate" layer overlying the caliche; and one (No. 1) represents saline clay 10 to 12 inches below the surface of the playa, or "dry lake." A description of the samples is given in the following table:

Samples tested for nitrification

No.	Locality	Material	Depth (inches)	Remarks
1	Leach Lake near middle of lake. (See pp. 13-16 and pl. 3, *C*.)	Clay beneath surface of dry lake. Moist, because wet by a rain a few weeks before sample was taken.	10-12	Chemical analysis of a duplicate sample showed a nitrate content of 0.29 per cent (calculated as $NaNO_3$) and a trace of soluble K.
2	Saratoga nitrate field, 5 feet east of 187-foot mark near south end of trench No. 3 in hill No. 3. (See pl. 17, *A*; also Bull. 724, pp. 43, 44, 45, pl. 11.)	Loose powdery clay soil containing efflorescent salts, chiefly Na_2SO_4 and NaCl.	3- 9	At the surface is the characteristic compact layer of sterile clay, 3 inches thick. Beneath it is the usual "efflorescent" or "sulphate" layer of loose powdery clay mixed with soluble salts, 6 inches thick. At most places this layer gives "negative" to "weak" reactions for nitrate. The sample represents this layer. Beneath it is salty caliche of the compact Saratoga type, overlying greenish sandy clay of Tertiary age dipping steeply. Chemical analysis of a sample of the caliche representing a strip 17 feet long showed 3.06 per cent of sodium nitrate (see Bull. 724, pp. 19, 44, sample S-68), and analysis of a hand-sorted sample of the same caliche showed 11.10 per cent of sodium nitrate. All material at this locality dry.
3	Saratoga nitrate field, 5 feet west of spur cut No. 2 in Amphitheater Canyon. (See pl. 17; also Bull. 724, p. 47.)	Surface soil, compact sandy clay exhibiting usual cauliflower-like surface and supporting no vegetation (*a*, pl. 17, *B*).	0- 2	Sample taken from the typical clay layer that forms the surface in the clay-hill nitrate areas, here 2 inches thick. At most places this surface clay gives no reaction for nitrate, but at some places it gives a "weak" reaction. All material at this locality dry.
4	do	Loose powdery sandy clay soil containing efflorescent salts, chiefly Na_2SO_4 and NaCl (*b*, pl. 17, *B*).	2- 8	At most places this layer gives "negative" to "weak" reactions for nitrate.
5	do	Caliche (*c*, pl. 17, *B*)	8-16	Chemical analysis of a duplicate sample showed 7.06 per cent of $NaNO_3$. Beneath the caliche lie steeply dipping beds of gray arkosic sandstone of Tertiary age.
6	Confidence nitrate field. (See pl. 16; also Bull. 724, p. 57 (G, H), pl. 12.)	Blister caliche and clay soil overlying it.	0- 8	The blister caliche is 6 inches thick and is overlain by 2 inches of compact sterile clay soil. The sample represents a vertical column of caliche and soil taken together. Beneath the caliche are tilted beds of greenish clay of Tertiary age apparently consisting largely of fine volcanic ash. The blister caliche is the richest in nitrate of all discovered by the Geological Survey. (See p. 91.) All material at this locality dry.
7	do	Loose powdery clay mixed with much saline material.	12-16	The material represented by this sample lies on the floor of a cavity inside one of the caliche blisters. (See pl. 16, *B*). This material gives a very strong field reaction for nitrate. It grades downward into steeply dipping beds of clay that underlie the caliche and contain very little nitrate.
8	Zabriskie nitrate field, near 10-foot trench at locality X_1. (See p. 69, fig. 4, and pl. 12, *A*.)	Loose granular flaky clay soil. Moist, because wet by a rain a few weeks before sample was taken.	12-17	The soil grades down into a horizontal bed of loosely consolidated sandy clay of Quaternary age, which probably contains volcanic ash. No caliche layer is present. Chemical analysis of a duplicate sample showed 0.32 per cent of $NaNO_3$ and a trace of soluble K. (See pp. 69-70.)

The following report was submitted by the Bureau of Plant Industry:

The eight soil samples collected from the California nitrate districts by Mr. L. F. Noble * * * were tested for nitrification by adding a small measured quantity of soil to 50 cubic centimeters of nutrient solution containing ammonium sulphate. The solutions were incubated at 28° C. for two weeks. The nitrate nitrogen in the solutions was determined after the residue of ammonia from the ammonium sulphate had been boiled off. The results from the duplicate determinations were as follows:

No. of sample	Locality	Nitrate found in solution
1	Leach Lake	0.0
2	Saratoga nitrate field	.0
3	do	.4
4	do	.0
5	do	.2
6	Confidence nitrate field	.1
7	do	.0
8	Zabriskie nitrate field	.0

Sample No. 3, the sample from the Saratoga nitrate field, appears to be the only sample where nitrification was appreciable. Samples 5 and 6, although showing some nitrification, are in my opinion within the limits of experimental error. Even sample 3 is not showing rapid nitrification. It is fair to state therefore, that all of the samples submitted are relatively much less active than the usual samples of surface soil.

From this letter it appears that the one sample which represents soil at the surface is the only sample that shows appreciable nitrification. Accordingly the results of the tests establish a strong presumption that nitrification is relatively much less active in the soils of the clay-hill areas of this desert region than it is in the soils of moister regions. They also suggest that the nitrification takes place chiefly in the surface layer of the soil rather than in the underlying "efflorescent" layer or in the caliche, but the nitrate thus formed could accumulate in the caliche layer.

More samples should be collected and tested, however, before these results are regarded as conclusive. The samples above described were all collected at the end of a long hot desert summer, a season in which the maximum day temperatures usually reach and often exceed 115° and in which all moisture is drawn from the soil. Perhaps nitrification in the soil is more active during the cooler and relatively moister winter. Conceivably, therefore, other samples taken in the spring would show more active nitrification.

ORIGIN OF CLAY-HILL NITRATE DEPOSITS

The clay-hill caliche deposits of southeastern California are not commercially valuable, and the quantity of nitrate in them is insignificant in comparison with that in the vast deposits of Chile. Nevertheless these deposits comprise some tracts of caliche hundreds of acres in extent that contain small amounts of nitrate, besides other tracts a few acres in extent that contain between 3 and 4 per cent and still smaller patches that contain much more than 4 per cent. Samples of caliche that contain between 10 and 15 per cent have been analyzed. These facts are interesting to the student of saline deposits, for in California, as in Chile, no satisfactory explanation of the origin of the nitrate has yet been found. Inasmuch as the nitrate in the Californian deposits may be similar in origin to that in the Chilean deposits, the problem of its origin is of more than local scientific interest. It may perhaps be solved by careful observation in the field in connection with chemical and bacteriologic investigation, but as the purpose of the Geological Survey's work during the World War was to find, in the shortest time consistent with systematic effort, whether workable deposits of nitrate exist in the region, it was neither possible nor advisable to devote time to this scientific research. The explorations brought out many facts concerning the occurrence of the nitrate, however, and afforded opportunity to make some tests of the numerous hypotheses hitherto advanced to account for the origin of the nitrate. These observations may be useful as evidence in a further study of the problem. Accordingly it seems worth while to discuss these hypotheses briefly, giving the tests recognized as applicable to the hypotheses, the evidence available, and the conclusions that seem warranted. Doubtless this analysis of the problem will be unsatisfactory to the reader, because no definite conclusion is yet possible. Probably the hypotheses enumerated cover most of the possibilities. Therefore, the correct explanation may lie in one of them or in a combination of one or more. The evidence, however, is insufficient, hence it is not at present possible wholly to dismiss from consideration even those that are seemingly improbable, except No. 1 and perhaps No. 13. The object in presenting the following analysis is to clarify the problem and to indicate the lines along which further investigation may profitably proceed.

ANALYSIS OF THE PROBLEM

HYPOTHESES

1. MARINE WATERS

Tests applicable.—Observation; evidence of presence of marine waters in region in Tertiary or Quaternary time.

Evidence available.—No Tertiary or Quaternary strata of marine origin nor any other evidence of the presence of marine waters in Tertiary or Quaternary time has been found in the desert region of southeastern California east of the Salton Sink and the extreme western border of the Mohave Desert. The strata that underlie the caliche areas are terrestrial deposits laid down in lakes or on the slopes bordering lakes.

Conclusions.—This source may be dismissed from consideration both as a recent and as an ancient source.

2. SALINE RESIDUES OF EVAPORATED LAKES

Tests applicable.—Test saline deposits of present dry lakes for nitrate. Test beds of rock salt in Tertiary or Quaternary strata for nitrate, because these salt beds represent evaporated brines of ancient lakes.

Evidence available.—According to Gale,[70] nitrate is not known to be present in the salt body of Searles Lake notwithstanding an early report concerning its presence there. Tests in the salt body and brine of Danby Lake yielded no reaction for nitrate. (See pp. 59–61.) The deposit of rock salt on the floor of Death Valley covers an area of many square miles in the lowest part of the valley. Most of the surface of the salt is very rough. (See pl. 18, *A*.) A well drilled 1,100 feet below the surface of the salt went through alternating layers of salt and clay to the greatest depth reached and did not penetrate bedrock. Numerous tests of the surface salt have been made but have failed to reveal a trace of nitrate. The clay surfaces of some less saline playas contain nitrate, as shown by tests at Leach Lake. (See p. 15.)

Every bed of rock salt in Tertiary or Quaternary strata tested was found to be barren of nitrate. (See pp. 59–62, 86.)

No deposit of clay-hill caliche can conceivably have been formed directly by the evaporation of standing water, because the caliche is a blanket deposit conforming to the slopes of the hills upon which it lies. (See fig. 1.)

Conclusions.—Apparently deposits from strong brines like the deposits at Searles and Danby Lakes are a highly improbable source, but less saline playa clays may be a possible source, as shown by the presence of nitrate in the clay surface of Leach Lake, because the strata underlying the clay-hill areas contain many beds which represent ancient playa clays. The caliche itself is nowhere the saline residue of an evaporated lake or the deposit of a playa.

3. GUANO IN CAVES, CREVICES, ETC.

Tests applicable.—Observation.

Evidence available.—A few small accumulations of guano were noted in caverns in the Zabriskie area (see pp. 70–71), but none were noted in or near other clay-hill areas. Inasmuch as the caliche is a blanket deposit covering hills and hollows alike it is not conceivable that any considerable amount of nitrate from guano deposits

[70] Gale, H. S., op. cit., p. 297.

in cavities could be washed into the soil and caliche from neighboring areas, even if the neighboring areas contain guano deposits, because many caliche-covered hills project high above the drainage channels that lead through them.

Conclusions.—Highly improbable as a present surface source, because seemingly inadequate and because none of the larger or richer clay-hill caliche areas are near such deposits. Seemingly improbable as an ancient or buried source because the strata underlying the clay-hill caliche areas are not known to contain phosphate, a constituent of guano.

4. ACTION OF NITRIFYING BACTERIA ON ORGANIC MATTER IN SOIL

Tests applicable.—Chemical determination of organic matter in soil samples. (Some of this organic matter may have been derived from underlying strata (see No. 9) and become part of the soil through general erosion.) Collection of soil samples in sterilized bottles for bacterial examination. These two determinations have not been made.

Evidence available.—Almost total absence of vegetation is one of the most striking features of clay-hill caliche areas (see for example, pls. 4 (*B*, *C*), 5 (*A*, *B*), 6, 9, 11, 12, 15 (*A*, *B*), 16, and 17), and so is entire absence of visible organic matter in soil.

Conclusions.—Possible, although seemingly improbable because of absence of visible organic matter in soil.

5. FIXATION OF NITROGEN FROM THE AIR IN SOIL AND ON SURFACE OF ROCKS THROUGH AGENCY OF BACTERIA

Tests applicable.—Collection of samples in sterilized bottles and testing for activity in nitrification. A few such samples have been collected and tested (see p. 94) but not enough to yield conclusive evidence.

Evidence available.—The few samples collected and tested proved to be relatively much less active in nitrification than the usual samples of surface soil in less arid regions. (See p. 95.) This, however, was to be expected, because of hostile climatic conditions. Headden[71] has shown that nitrification takes place not only in the soils of arid regions but upon the surfaces of all kinds of rocks as well.

Conclusions.—Possible, because nitrification was proved in one of the few samples collected and tested. Headden's results, moreover, make this possible source worthy of careful consideration. This hypothesis is attractive because it could be applied to other types of nitrate deposit than the clay-hill type, as, for example, the nitrate in Leach Lake, the Vivet Eye deposit, and the deposits on volcanic rocks at West Well and at San Simon, above described.

[71] Headden, W. P., The fixation of nitrogen in Colorado soils: Colorado Agr. Coll. Agr. Exper. Sta. Bull. 178, June, 1911; Occurrence of nitrates on rocks: Bull. 277, May, 1922.

6. FIXATION OF NITROGEN ON LEGUMINOUS PLANTS

Tests applicable.—Observation.

Evidence available.—Practically no vegetation of any kind grows upon the clay-hill caliche areas. (See No. 4.)

Conclusions.—Possible but seemingly wholly inadequate.

7. NITRATE PARTICLES IN AIR BY OXIDATION OF AMMONIA OR BY MECHANICAL ACTION OF THE WIND

Tests applicable.—Collect and test dust samples after quiet and windy periods. Test samples of rain water. These tests have not been made.

Evidence available.—High winds and dust storms common in the region.

Conclusions.—Possible, but no conclusive evidence available.

8. NITRIC ACID IN RAINFALL FROM ELECTRICAL DISCHARGES DURING THUNDERSTORMS

Tests applicable.—Collect samples of rain water during thunderstorms and test.

Evidence available.—Although the annual rainfall of the region averages probably less than 3 inches, the most violent and heavy rains are summer thunderstorms.

Conclusions.—Possible, but no conclusive evidence available.

9. ORGANIC MATTER ENTOMBED IN STRATA AT TIME OF DEPOSITION

Tests applicable.—Chemical determination of organic matter in samples of underlying strata selected as in test 14. This has not been done. Samples should be sealed to prevent access of air and surface bacteria.

Evidence available.—Practically no traces of visible organic matter or fossils found in strata. Exceptionally some marly beds contain masses of what appear to be silicified plant stems, but these beds are very rare. Algal limestones occur in some but not all clay-hill areas.

Conclusions.—This source possible but seemingly improbable because of extreme scarcity of fossils. However, it is conceivable that organisms that would have left no vestiges may have been entombed in the strata.

10. NITROGEN GASES EXPELLED DURING VOLCANIC ERUPTIONS AND CARRIED INTO SOIL AND ROCKS BY RAINS RESULTING FROM CONDENSATION OF ERUPTED WATER VAPORS

Tests applicable.—Observation; proximity of clay-hill caliche deposits to areas of volcanic activity would be suggestive. Associated substances of possible volcanic origin such as boron and chlorine might be expected in the caliche. Hypothesis could be tested negatively as follows: Near Paria, in southern Utah, are extensive outcrops of the Chinle formation which are covered with a clay soil and ground similar in appearance to that in typical clay-hill nitrate areas. The locality is many miles from the nearest evidence of volcanic activity, so that the Tertiary or Quaternary volcanic factor is definitely excluded there. If this ground upon examination should prove to contain clay-hill nitrate caliche the volcanic hypothesis could not be invoked to explain the origin of the nitrate. This test has not been made.

Evidence available.—Tertiary or early Quaternary volcanic rocks lie near most if not all clay-hill caliche areas examined. The strata underlying most clay-hill caliche areas contain more or less volcanic ash—evidence that intense volcanic activity prevailed in the region while the strata were being deposited. Chlorides are abundant, and some caliche contains boron. Borates occur in underlying clays at places.

Conclusions.—Possible and entitled to careful consideration as a Tertiary and early Quaternary source of nitrate, because nearness of caliche deposits to areas of Tertiary and early Quaternary volcanic activity and association with strata containing explosive volcanic material may be significant. Seemingly very unlikely as a late Quaternary source, because the caliche is a product of later Quaternary time and there is no evidence of widespread volcanic activity in the region in the late Quaternary. It is true that recent cones exist in Owens Valley, at Lavic and Amboy, in the Mohave Desert, and at the mouth of Ubehebe Wash, in North Death Valley. The cone figured in Plate 18, *B*, is the smallest of a group of five craters, one of which is 780 feet deep. It is probably very recent, because only two small gullies have been cut in the loose and easily eroded ash that forms the sides of the cone. The other craters are older, but all are late Quaternary. Ash erupted from the craters covers the ground for about a mile in every direction.

None of the late Quaternary volcanoes are near caliche areas, and the volcanic activity that they represent is utterly insignificant in comparison with that which prevailed in the Tertiary period.

11. NITROGEN GASES IN IGNEOUS ROCKS

Tests applicable.—Collect and test for gas content samples of igneous rocks near caliche areas or associated with the strata underlying caliche areas. These tests have not been made. Boron-bearing minerals in adjacent areas or in the strata themselves might be an indicator—for example, datolite, tourmaline, colemanite, ulexite.

Evidence available.—Strata underlying nitrate-bearing caliche near Furnace Creek contain deposits of colemanite and ulexite.

(See p. 87.) Strata underlying caliche in the Owl Spring field contain borate. (See p. 24.) Some caliche in the Owl Spring field reacts for borate. Blister caliche in the Confidence field contains borate. (See pp. 92–93.)

Conclusions.—Possible, although very little evidence is available. Occurrence of borates in underlying strata and in general region may be significant.

12. NITROGEN IN SPRING WATERS

Tests applicable.—Collect and test spring waters for ammonium chloride, boron, etc. This has not been done.

Evidence available.—A number of hot springs rise in Amargosa Valley, and the waters of these springs are probably of deep-seated origin, but the springs appear to have no significant relation to the caliche of the clay-hill areas in the valley. Hot springs also rise in the Furnace Creek region. Elsewhere springs rise in or near some caliche areas, but at no place do they appear to have any significant relation to the caliche.

Conclusions.—No conclusion possible, because no evidence concerning composition of spring waters is available. Might be an indirect source of nitrate in underground waters beneath the caliche areas, but in no direct sense can the clay-hill caliche deposits be considered spring deposits, because the caliche is a blanket deposit conforming to the topographic surface upon which it lies. (See fig. 1.)

13. NITRATE CONCENTRATED IN BEDS OR VEINS IN STRATA UNDERLYING THE CLAY-HILL AREAS

Tests applicable.—Observation of exposed cross sections of the strata and in excavations dug in the strata.

Evidence available.—Beds or veins of sodium chloride, gypsum, celestite, colemanite, and ulexite observed in strata, but no concentrations of nitrate.

Conclusions.—This source highly improbable, because after prolonged and careful search in excavations dug in the strata and in exposed cross sections no beds or veins of nitrate were found. At some places (see pp. 23, 86) the sodium chloride in the caliche is obviously derived from beds of sodium chloride in the underlying strata.

14. NITRATE DISSEMINATED IN STRATA UNDERLYING THE CLAY-HILL AREAS

Tests applicable.—Obtain samples of underlying strata from deeper sources than any of the excavations dug in the Geological Survey investigations, so as to avoid influence of surface waters in cracks, etc., and determine soluble salts. Present analyses are inconclusive, because material was not so selected.

Evidence available.—Sodium chloride and gypsum were found to be widely disseminated in underlying strata, particularly in clay beds. Nitrate was found to be present in the strata as far down as the Geological Survey's excavations reached, but the amounts diminish very rapidly with depth. For example, in the deepest excavation,[72] 3.50 per cent was found in the caliche 1 foot below the surface of the ground, 0.11 per cent in the underlying strata at a depth of 4 feet, and less than 0.05 per cent, or traces, at a depth of 8 feet.

Conclusions.—This source of nitrate is possible, but the evidence available is inconclusive. In all probability the chlorides, sulphates, and borates associated with nitrate in the caliche are derived from chlorides, sulphates, and borates in the underlying strata, and it is this relation that suggests that the associated nitrate may be similarly derived. There would be little reason to doubt that nitrate disseminated in the strata is a proximate source of the nitrate in the caliche if sampling at depths removed from surface influences should reveal the presence of small amounts of nitrate in the strata.

ACCUMULATION OF CALICHE

FIRST HYPOTHESIS

Statement.—Upward movement of soluble salts by ground water and subsurface moisture through capillary action.

Tests applicable.—Procure if possible samples of ground water and test for soluble salts. Obtain samples of underlying strata from deeper sources than any of the excavations thus far made or studied so as to avoid surface influences, and test for moisture and soluble salts—practically the same test as No. 14. Relative proportions of soluble salts in strata should agree fairly well with relative proportions of same salts in caliche. Moisture samples should be sealed and tested as promptly as possible. These tests have not been made.

Evidence available.—Water table in most clay-hill caliche areas is apparently many feet below surface at present time. But strand lines across alluvial fans at levels over 600 feet above the present surface of Searles Lake and more obscure (and probably older) strand lines in Panamint and Death Valleys indicate that there have been one or more periods of moister climate in the region in late Quaternary time. During such periods the water table must have stood much higher than it does now. Some of the shore lines in Panamint and Death Valleys are shown in Plate 19, *A* and *B*. Those illustrated in Death Valley are cut in basalt at the north end of the Confidence niter hills at a point 2 miles northwest of Ashford

[72] Noble, L. F., and others, op. cit., p. 42, pl. 8.

Mill. A similar set of strand lines is cut in dissected alluvial-fan deposits in an embayment at Mormon Point, a few miles north of the locality illustrated. Those illustrated in Panamint Valley are also cut in old dissected alluvial-fan deposits.

Regarding subsurface moisture (as distinguished from ground water) in the underlying strata: All sandy beds and many clay beds in the clay-hill areas appear very dry, but many beds of saline clay and all beds of rock salt are visibly moist, even in areas where no rain has fallen for a year or more.

Conclusions.—Although conclusive evidence from tests is not available, this is certainly a possible process by which the salts associated with nitrate in the caliche are brought into the surface zone, but whether nitrate is one of the salts thus brought up is not yet definitely known.

Climate is probably important; in moister periods the ground water may have been the dominant factor, leaching the salts out of the rocks; in more arid periods, as at present, the subsurface moisture is the dominant factor, bringing the salts to the surface zone and depositing them there through evaporation.

SECOND HYPOTHESIS

Statement.—Downward movement from soil and surface sources. If both this process and the preceding process are involved, this process would tend to mask the first.

Tests applicable.—Observation. Follow several nitrate-bearing cracks downward, making tests at several levels in each to determine variation in nitrate content. These tests have not been made.

Evidence available.—Nitrates and chlorides observed in cracks below caliche extend downward a foot or more into bedrock. Samples in excavations show rapid decrease downward in total nitrate content. Karst topography [73] (sink-hole drainage) in all the more saline clay-hill areas is striking evidence of downward movement of surface waters. Probably this topography was produced largely during the last moister period, because the heaviest rains to-day do not moisten the ground deeper than the caliche zone.

Conclusions.—This process is certainly possible under favorable conditions. Climatic factor is probably important; in moister periods salts would tend to be removed through sink-hole drainage; in drier periods rains would penetrate only as far as caliche zone (as they do to-day) and leave soluble salts there upon evaporation; the salts deposited in this situation would be protected from being dissolved or washed away in surface water by the peculiarly im-

[73] Noble, L. F., and others, op. cit., pp. 69, 70, pl. 29, *A*.

pervious character assumed by the compact clay layer of the top soil when it becomes wet. (See p. 21.)

THIRD HYPOTHESIS

Statement.—Enrichment by general erosion.

Tests applicable.—Observation. (1) Soluble salts should leach out of top soil and accumulate below surface. (2) Saline material should show rough zonal arrangement as effect of relative solubility of salts. (3) Texture of underlying strata should affect localization of deposits: (*a*) Sand and gravel should favor deep penetration of solutions and dissemination of salts rather than enrichment, but deposits might be localized at clay layers if they were near enough to surface; (*b*) clay, being impervious, should prevent deep penetration and favor localization of deposit at top of bedrock.

Evidence available.—(1) The clay-hill caliche is an accumulation of soluble salts below the surface soil at the contact zone between soil and bedrock.

(2) Compact clay layer of top soil at surface contains little soluble material; underlying efflorescent layer, more; caliche, most. (See pp. 2, 42, also fig. 1 and pl. 9, *C*.) Saline material in these layers shows rough zonal arrangement in order of relative solubility—sulphates chiefly in efflorescent layer; chlorides and nitrates chiefly in underlying caliche. The conformity of zoned salts to topography is striking in most of the clay-hill areas and indicates close relationship between arrangement of deposits and processes of general erosion.

(3) (*a*) In general, sandstone areas are notably barren of caliche. The chief exception is the Amphitheater Canyon caliche (see pl. 17, *A*, *B*), overlying sandstone in the Saratoga field,[74] but even here thin partings of clay occur in the sandstone, and the sandstone itself contains clay. (*b*) Practically all caliche deposits overlie clay strata. All are localized at top of bedrock.

The reasons for certain sharp variations in nitrate content of caliche[75] which coincide with variations in the character of the underlying strata (for example, sharp localization of rich blister caliche in Confidence field on green clay (see pl. 16, *A*), and certain variations on other kinds of strata in the Saratoga field) have not been studied enough to be understood, but it is possible that rock texture is the determining factor.

Conclusions.—This appears to be the dominant process involved.

CONCLUSIONS REGARDING ORIGIN

There are many possible primary sources of the nitrate and many possible combinations. Which source or combination of sources is the true one is not known, because sufficient evidence is not yet available.

---

[74] Noble, L. F., and others, op. cit., p. 38. [75] Idem, pp. 19, 20.

Three processes are probably involved in the accumulation of the caliche. Enrichment by general erosion (third hypothesis) is probably the dominant process, subject to at least two controls—the quantity of saline material available and favorable climatic conditions.

Two factors must obviously enter into every hypothesis concerning the source of the nitrate and into every explanation of the mode of accumulation of the caliche. They are arid climate and time.

DEPOSITS OF OTHER MINERALS IN TERTIARY CLAYS

The widely distributed and very similar sets of Tertiary beds in the desert region, with whose outcrops most of the clay-hill nitrate deposits are associated, are apparently more worth prospecting for other nonmetalliferous materials than for nitrate. At one place or another workable deposits representing a variety of useful commodities have been found in them. An incomplete list includes volcanic ash, bentonite, different kinds of useful clay, colemanite and other boron minerals, strontium minerals (strontianite and celestite), rock salt, gypsum, and magnesite.

The deposits of bentonite at Shoshone and Ash Meadows, in the Amargosa region, are in Quaternary beds forming a part of the Zabriskie nitrate field, but bentonite has been found also in Tertiary beds in the Upper Canyon nitrate field.

A deposit of kernite, commercially known as rasorite ($Na_2O.2B_2O_3.4H_2O$), recently discovered by the Pacific Coast Borax Co. near Kramer, Calif., occurs in some of these Tertiary beds. (See pl. 1.) This deposit is probably the richest borate deposit known.

A deposit of epsomite, or "epsom salt" ($MgSO_4.7H_2O$), near Wingate Pass is associated with Tertiary beds similar in character and origin to those in the borate and nitrate districts. (See pl. 1.) A monorail tramway over 30 miles long has been built to the deposit from a point near Searles Lake, on the Trona Railroad. Whether the epsomite occurs as a blanket or surface deposit corresponding either to the efflorescent soil layer or to the caliche layer of the clay-hill nitrate deposits, or as a bed or beds in the Tertiary strata, is not known. The ground on the outcrops of the Tertiary strata in this area is exactly like that in the typical clay-hill nitrate tracts and if tested would probably reveal the presence of niter-bearing caliche.

FINAL COMMENT

Notwithstanding the adverse conclusions regarding the commercial possibilities of all the nitrate deposits so far examined in the desert region the writer does not wish to be understood as discouraging further prospecting for nitrate there. It is conceivable that somewhere in the region deposits of caliche richer than those examined may exist. Moreover, nitrate may occur in some form not now known, for the recent discovery of the rich deposit of kernite, a boron mineral whose very existence in mineralogy was unknown before the discovery, shows that the desert rocks still contain unknown possibilities. He wishes to point out emphatically, however, that in view of the failure of the actual results of the Geological Survey's investigation even remotely to fulfill the expectations that might reasonably be based on the many glowing reports concerning the known deposits, no one should undertake commercial development of any of the deposits without a full understanding of the complex chemical problems involved, the superficial character of the deposits, and the highly speculative nature of the financial risk that it would be necessary to incur.

Nor does the writer wish to discourage deep drilling in the strata underlying the clay-hill nitrate deposits, provided the enterprise is undertaken primarily for scientific purposes and with a full realization of its extremely speculative character as regards the finding of commercially workable beds or concentrations of nitrate in the strata, for the results might throw considerable light upon the problem of the origin of the nitrate. It is not yet known whether small amounts of nitrate are contained in the strata at depth, although the results of the Geological Survey's investigation are practically conclusive that such strata contain no commercially workable beds or concentrations of nitrate. The writer suggests that persons who may have occasion in the future to drill deep holes in the strata underlying the clay-hill areas in search of water or mineral deposits other than nitrate preserve carefully the cores taken out and test them for nitrate. A record thus obtained in connection with exploration for other mineral deposits would afford a cheap and feasible means of testing the strata for nitrate and of obtaining information that might be of considerable scientific interest in the study of the origin of the clay-hill nitrate.

INDEX

O