BORATE DEPOSITS IN THE KRAMER DISTRICT, KERN COUNTY, CALIFORNIA

By L. F. Noble

INTRODUCTION

The Kramer borate deposits lie in the southeastern part of Kern County, Calif., not far from the boundary of San Bernardino County. They are about 7 miles northwest of Kramer, 4 miles north of Rich, and 13 miles northeast of Muroc, small stations on the

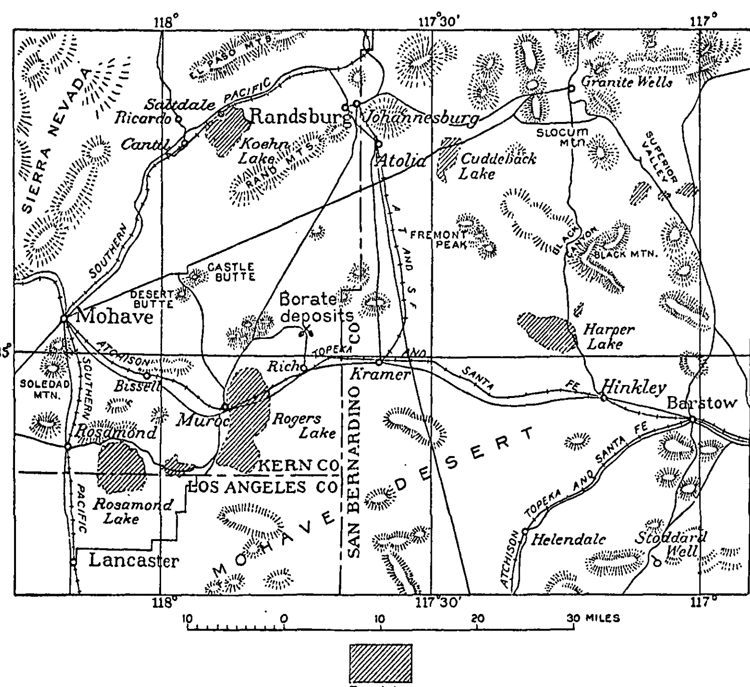

FIGURE 9.—Map showing location of borate deposits near Kramer, Kern County, Calif.

Atchison, Topeka & Santa Fe Railway between Mojave and Barstow. These stations are all connected with the deposits by roads, but Rich is at present the shipping point for the ore. The location of the deposits is shown on the accompanying index map (fig. 9), and the topography of the region is shown on the Searles Lake topographic map of the United States Geological Survey.

The discovery of the deposits was purely accidental, for they lie beneath a broad alluvial plain whose featureless surface of sand and gravel affords no clue to what is beneath. In 1913 a well was being drilled for water in this plain on the desert homestead ranch of Dr. John K. Suckow, a physician of Los Angeles. The site of the well was at least a mile from the nearest outcrop of rock. After the drill had gone through the alluvial deposits of sand and gravel that form the surface of the plain and had penetrated the bedrock beneath the alluvium it struck a hard, crystalline material which proved to

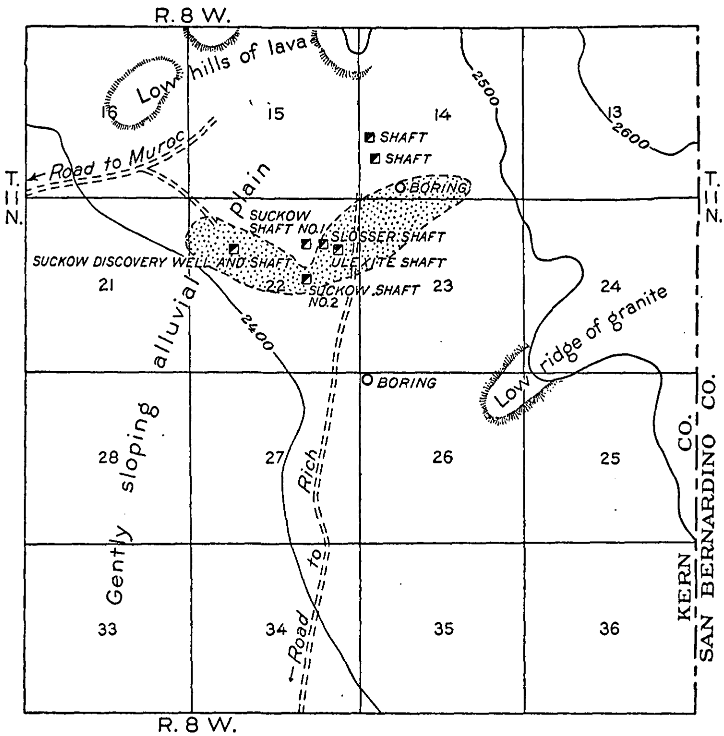

FIGURE 10.—Map of a part of T. 11 N., R. 8 W. San Bernardino meridian, Calif., showing area (stippled) beneath which borate deposits have been found by sinking shafts or by drilling

be colemanite, one of the hydrous calcium borates. The strike was reported in the newspapers, and the usual excitement followed. The Pacific Coast Borax Co., to which Doctor Suckow had sold the discovery claim, and other operators entered the field and prospected the district extensively by sinking shafts and drill holes in the alluvial plain. In so far as the results of the exploration are known, they indicate that deposits of colemanite and ulexite (a calcium-sodium borate), some of them large masses, occur here and there beneath the surface in an area nearly 2 miles long by one-fourth to one-half mile wide (see fig. 10), and that although the deposits, as is usual with borates, are extremely irregular in distribution, the district is of considerable promise. It is said that all the deposits have now passed into the control of the Pacific Coast Borax Co.

Notwithstanding the large amount of exploratory work that has been done, very little information concerning the geology of the deposits has yet been made public. Recently I had an exceptional opportunity to examine one of the deposits in company with H. S. Gale. In 1924 a shaft, known as the Suckow shaft No. 2, was being sunk by the Suckow Chemical Co. in the middle of the area in which the deposits occur. This shaft, after going through about 100 feet of alluvial material, entered the bedrock and struck colemanite. As the shaft had not yet been timbered in the bedrock, it afforded an opportunity to ascertain the character and structure of the rocks in which the borate deposits occur and to examine one of the deposits which had been freshly cut. We made two visits to the shaft, one on May 25, 1924, when the shaft was down 220 feet, and the other on December 14, 1924, when the shaft had reached a depth of about 300 feet and a tunnel had been driven westward from the bottom of the shaft.

The present report is an incomplete description of the geology of the deposits, based largely upon the evidence obtained in the Suckow shaft. In brief, this evidence shows that, like all other known colemanite deposits in California and Nevada, the Kramer deposits occur in clay shales of Tertiary age that have been tilted, faulted, and afterward deeply eroded. The borates appear to have been deposited as ulexite, which in some places has altered to colemanite. I have included in the report a brief description of other areas of Tertiary rocks in the surrounding region and have discussed the possibility of correlating the borate-bearing rocks of the Kramer district with them.

A much fuller report on the Kramer deposits is in preparation by H. S. Gale. I am indebted to him for the map (fig. 10) showing the area in which the borate deposits have been found and the location of some of the shafts and borings in this area, also for much information concerning the workings other than the Suckow shaft No. 2.

GEOLOGY OF THE DEPOSITS

The accompanying cross section (fig. 11) shows diagrammatically the essential geologic features of the district where the borate deposits occur. In the southeast corner of Kern County is a large playa, or "dry lake," known as Rogers Lake. (See fig. 9.) This clay-surfaced playa, which is the lowest part of a wide basin and the sink for the drainage of a considerable area in this portion of the Mohave Desert, is bordered by broad plains of alluvium that slope gently down to it from the surrounding hills. These alluvial plains, known also as "alluvial aprons," "alluvial fans," "alluvial cones," or "detrital slopes," are the most characteristic feature of the desert region. The alluvium of which they are built consists of rock waste—sand, gravel, clay, and boulders—washed from the hills and spread out toward the lowlands. Over vast stretches of the desert it forms a mantle that masks all details of the underlying rocks. Underneath one of these alluvial plains, north of Rogers Lake, the Kramer borate deposits lie. This plain rises gently from the edge of the lake for several miles to a group of rocky hills whose position is shown at the right of the cross section (fig. 11). These hills, composed largely of tilted beds of lava, are partly buried by the alluvium that forms the surface of the plain. Long tongues of the alluvium indent them and in places extend between and far beyond them, so that they are more or less isolated one from another. The borate deposits lie beneath the alluvial plain a mile or more southwest of the hills. Their position with reference to the features just described is shown in the

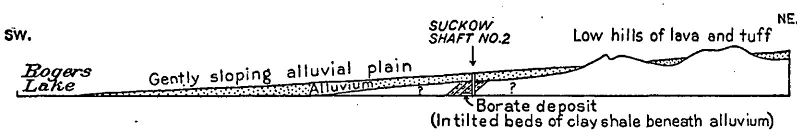

FIGURE 11.—Diagrammatic cross section showing mode of occurrence of the borate deposits of the Kramer district, Calif. Not drawn to scale

cross section (fig. 11) and on the map (fig. 10), which shows the topography of a part of the township in which they lie. The deposits occur in beds of clay shale that are buried beneath the alluvium. Associated with the shale are beds of sandstone and a bed of basaltic lava. The shale, sandstone, and lava do not lie in the position in which they were deposited but are tilted at angles of 25° to 80°, and the alluvium has been deposited across their upturned and eroded edges. Therefore, they are very much older than either the overlying alluvium or the clays that form the surface of Rogers Lake, both of which still lie in their original position and have not been consolidated into rock. The age of the alluvium and the clay of the dry lake is Quaternary; that of the shale, sandstone, and lava is Tertiary. The relations just described are shown in detail in the accompanying section through the Suckow shaft (fig. 12), and in a more general way in the diagrammatic cross section (fig. 11).

The section through the Suckow shaft shows in detail the character and succession of the rocks with which the borate deposits are associated. The borate minerals, here chiefly colemanite, occur in clay shale just above a bed of basaltic lava. The material of which this shale is composed closely resembles the clay that is being deposited upon the surface of Rogers Lake and other playas in the desert at the present time. It differs from the later clay only in that it has been consolidated into shale and has been tilted from its original horizontal position, eroded, and buried. Undoubtedly it

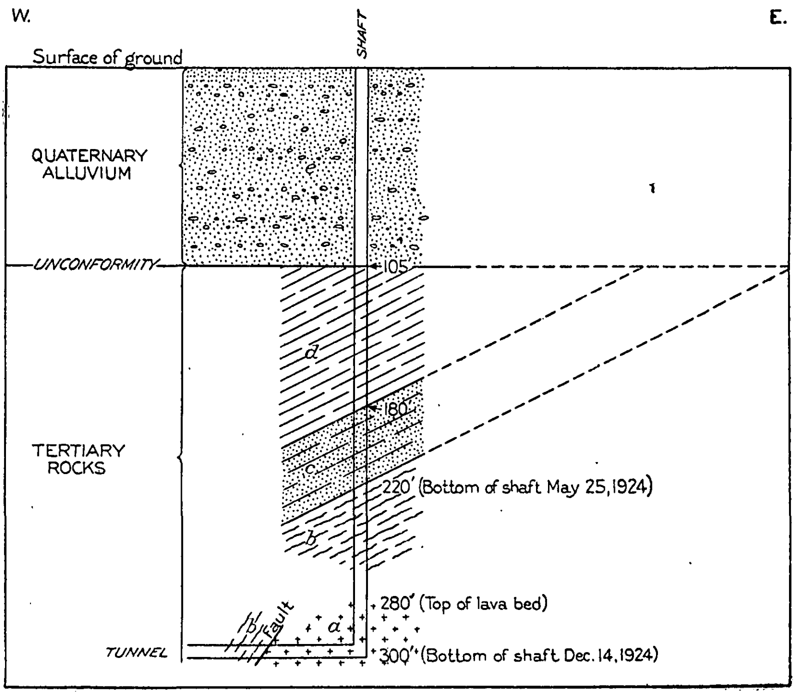

FIGURE 12.—Section through Suckow shaft No. 2, Kramer district, Calif., showing character, position, and structural relations of the rocks containing the borate deposits

(*a*) Black basaltic lava, in part vesicular and therefore probably a flow. The contact with the borate shale (*b*) where exposed in the tunnel is a fault plane dipping 50°. The nature of the contact with the borate shale in the shaft is undetermined, because this part of the shaft was timbered at the time of visit. The record of other workings in the district shows that the lava underlies the shale and that the contact is a depositional contact, the lava representing a flow upon which the shale was deposited.

(*b*) Member containing the borate deposits: Moist clay shale carrying lenses and nodules of colemanite irregularly distributed through the mass. The shale is bluish when wet but greenish when dry. It is everywhere mashed, broken, and slickensided, so that the structure is difficult to determine; much of the rock resembles fault gouge. Just under the contact with the overlying sandstone (*c*) in the shaft the dip of the shale is 25° SW., but in the tunnel leading west from the bottom of the shaft the dips are very steep—50°–80°.

(*c*) Arkose sandstone, dipping 25° SW.; upper portion rather coarse and in places conglomeratic; lower portion finer grained. The coarser beds are composed almost wholly of granite fragments and are buff; the conglomeratic phases are typical fan conglomerate. The finer beds are composed largely of volcanic ash and are greenish. The contact between the arkose sandstone (*c*) and the underlying shale (*b*) is well exposed in the shaft and is a normal depositional contact, not a fault or an unconformity; therefore no marked stratigraphic break exists between the shale (*b*) and the overlying members *c* and *d*.

(*d*) Clay shale, pale greenish, somewhat sandy; contains volcanic ash.

(*e*) Alluvium, forming surface of gently sloping plain, a typical desert waste slope and wash deposit composed of unconsolidated sand, gravel, and boulders. The alluvium rests upon a surface of erosion (unconformity), which truncates the upturned edges of the underlying beds.

was originally a dry-lake deposit. In all probability, therefore, the borate minerals, which occur as lumps and nodular masses in the shale, were originally formed in the mud of a drying lake. Probably the first borate mineral formed was ulexite or "cotton ball," and the colemanite in the deposits has been derived from it by alteration. Ulexite is of common occurrence as lumps in the mud of the present dry lakes of the desert, whereas no colemanite has ever been found in the present dry-lake deposits, and it is believed that colemanite does not form directly in this situation. Moreover, in a number of workings in the Kramer district colemanite has been found in process of alteration from ulexite. Alteration may have taken place through the agency of ground waters, perhaps while the rocks were undergoing tilting, faulting, and erosion. In some places, apparently, all the ulexite has been converted to colemanite, but in other places much or all of it is still unaltered.

The bed of basaltic lava beneath the borate-bearing shale in the Suckow shaft appears to underlie the shale throughout the district, for it is said to have been struck in all the shafts and borings that have gone through the borate-bearing shale. Undoubtedly it was poured out just before the shales were deposited, for it has been reported to be vesicular in most of the workings. The proximity of borate-bearing shales to lava is common in other borate districts, and it is believed[1] that the original source of the boron in the deposits is in the hot springs and solfataras connected with the past volcanic activity. It is probable, therefore, that the lava flow that underlies the borate-bearing shale in the Kramer district was indirectly the source of the boron.

At the time of my second visit (Dec. 14, 1924) ore was being mined in a tunnel driven westward from the bottom of the Suckow shaft No. 2 and was being shipped at the rate of 5 or 6 tons a day. This ore was colemanite taken from the shale bed B (fig. 12) just west of a point where the bed is faulted against the lava bed A. All other workings in the district were closed and boarded up.

No records of the other shafts and borings are available, except an incomplete log of the well in which the original discovery was made. The Pacific Coast Borax Co. is said to have drilled 26 holes in the district, most of them in secs. 22 and 14, and it is reported that only 8 of these failed to show some borax mineral. The water well put down by Doctor Suckow in 1913, in which the borates were first discovered, is in the NW. ¼ sec. 22. The incomplete log of the well, given to me by H. S. Gale, follows.

[1] Foshag, W. F., The origin of the colemanite deposits of California: Econ. Geology, vol. 16, p. 210, 1921.

Log of Suckow well in the NW. ¼ sec. 22, T. 11 N., R. 8 W.

	Feet
Clay, dark, putty-like	190–331
Shale, blue	331–369
Colemanite	369–410
Shale, blue	410–435
Gypsum	435–445
"Rock formation," interpreted as basaltic lava	445–450

A shaft in the NE. ¼ sec. 22, known as the Slosser shaft, after passing through the alluvium, is said to have struck borate nodules in clay shale at a depth of 110 feet and to have reached basaltic lava beneath the borate-bearing shale. According to Gale, specimens showing colemanite in process of alteration from ulexite have come from this shaft.

A shaft about 600 feet southwest of the Slosser shaft, known as the Ulexite shaft, is said to have encountered a very rich mass of compact ulexite at a depth of 110 feet and to have been sunk only 10 or 15 feet into this deposit. Many specimens of compact ulexite and a large quantity of the clay shale in which the ulexite occurs may be seen on the dump at the mouth of this shaft. I obtained a specimen from this dump which included a small spherical mass of radially disposed crystals of colemanite embedded in ulexite and evidently formed by alteration from the ulexite.

A boring 40 feet south of the Ulexite shaft is said to have encountered ulexite in quantity and to have struck basaltic lava at a depth of 190 feet. On the other hand, a shaft not 400 feet west of the Slosser shaft, known as the Suckow shaft No. 1, although it struck the basaltic lava at a depth of 180 feet, encountered no appreciable amount of overlying clay shale and no borate minerals in the shale.

A boring only 150 feet north of the Suckow shaft No. 2 struck the basaltic lava at a depth of 162 feet, although the lava lies at a depth of 280 feet in the Suckow shaft (see fig. 4), and encountered no borate minerals in the overlying shale, notwithstanding the fact that they occur in considerable quantity in the shale in the shaft.

The records just given, though incomplete, show that the borate deposits are extremely irregular in form and distribution, being present in the shale at some places and absent at others near by, and that the structure of the Tertiary rocks within which they lie is exceedingly complex. It is evident, therefore, that the occurrence of a borate deposit beneath any given spot in the alluvium that mantles the district is utterly unpredictable, and that the limits of the deposits can be determined only by underground exploration.

AGE AND CORRELATION OF THE BORATE-BEARING STRATA

No fossils have been found in the beds that contain the borate deposits in the Kramer district, and as these beds are covered with a thick mantle of alluvium they have no outcrops that can be connected with those of any other rocks in the region. Consequently no direct evidence as to the geologic age of the beds is available. The balance of probability strongly favors their Tertiary age. The fact that they have been tilted in various directions, faulted, and planed off by erosion to a surface that bevels their upturned edges and that this surface has been buried under a thick deposit of alluvium precludes their being of Quaternary age. Tilted beds of Quaternary age are not unknown in California, but none have been so profoundly disturbed as the beds of the Kramer region, nor have any been beveled by so widespread a surface of erosion and afterward buried under thick alluvial deposits. Nor can the borate-bearing beds be older than Mesozoic, for the arkose sandstone interbedded with them in the Suckow shaft contains fragments of a Mesozoic granite that crops out in many places in the surrounding region. That they are of Mesozoic age is inconceivable, for no rocks of Mesozoic age at all like them are known in this part of California. On the contrary, they resemble closely, both in general lithologic character and in degree of disturbance, beds of known Tertiary age that crop out at many places in the surrounding region.

Although undoubtedly the borate-bearing beds of the Kramer district were deposited in Tertiary time, their assignment to a definite epoch of the Tertiary is at present impossible, because of their lack of fossils and outcrops. Nevertheless, it seems worth while to summarize what is known concerning the other Tertiary deposits and to discuss the probable relation of the beds of the Kramer region to them.

The accompanying map (fig. 13) shows the distribution of the principal areas of Tertiary rocks that lie within a radius of 30 miles from the Kramer borate deposits. The areas are numbered on the map according to their distance from the Kramer area, No. 1 being the nearest, No. 2 the next, and so on; and they will be described in that order.

No. 1. The area of Tertiary rocks marked 1 on the map forms the group of low hills north and west of the borate deposits, to which reference has already been made. This area begins at a point a few miles northeast of the deposits and extends westward and northwestward about 15 miles to Desert and Castle Buttes, near the Mohave-Randsburg road. At its east end it is not more than a mile distant from the deposits at one point. The rocks of this area were first recognized as Tertiary by Hershey,[2] who mapped them as a part of the "Rosamond series." They have, however, never been described.

The rocks in the area are chiefly volcanic. In the eastern part, in the hills nearest to the borate deposits, they consist largely of black lava similar to the basaltic lava that underlies the borate-bearing shale in the Suckow shaft. A few miles farther west, where they extend along the Muroc-Randsburg road, they consist chiefly

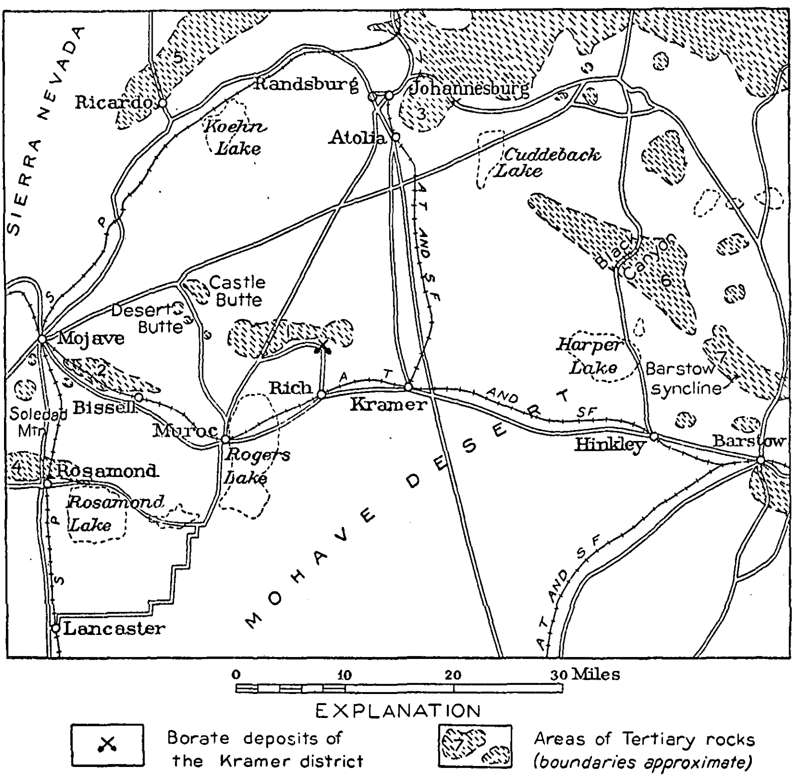

FIGURE 13.—Map showing location of principal areas of Tertiary rocks in the region about Kramer, Calif. Some smaller outcrops of Tertiary rocks that occur within the area mapped are not shown. For description of numbered outcrops see text

of rhyolitic or andesitic material—in part stratified tuff and ash, in part massive rhyolite or andesite—in which reddish and greenish colors predominate. At the west end of the area stand Desert Butte and two smaller buttes southwest of it which are masses of rhyolite remaining from the cores of eroded volcanoes. Probably these volcanoes were the source of much of the tuff and ash in the beds farther east.

[2] Hershey, O. H., The Quaternary of southern California: California Univ. Dept. Geology Bull., vol. 3, pl. 1, 1902.

Castle Butte is a pile of stratified tuff and ash cut by masses of rhyolite or andesite. In appearance and in general character these rocks in Desert and Castle Buttes and those lying along the Muroc-Randsburg road closely resemble the "Rosamond series" (see No. 4) and the rocks at the west end of the Bissell area (No. 2), described below.

Clay shale like that in which the borate deposits occur is associated with the lava and tuff at several places in the area. One outcrop of this shale which I examined lies in the SW. 1/4 sec. 3, T. 11 N., R. 9 W., about 5 miles northwest of the borate deposits, where it forms a low isolated hill capped by black lava. The shale was being mined for clay at the time of my visit.

At several places in the area the tuff and lava rest unconformably upon Mesozoic granite. Like the beds containing the borate deposits, they dip in various directions and are cut by faults. In general they appear to have suffered about as much disturbance as the borate-bearing beds.

The outcrops of Tertiary rocks in the area just described are not connected with those of any other Tertiary rocks in the region, being bordered on all sides by worn-down ridges of granite and sloping plains of alluvium. Nevertheless, the area contains rocks that closely resemble those in which the borate deposits occur, although it includes other rocks that are not represented in the sections revealed by underground exploration of the borate deposits. Moreover, the borate-bearing strata are so close to this area of Tertiary rocks that they are practically a part of it; they must have been deposited in the same Tertiary basin and under similar conditions. In all probability, therefore, they are correlatives of a part of the rocks in the area. These facts suggest that borate deposits may exist in the area, in the clay shale associated with the lava and tuff. As yet, however, none have been found.

No. 2. The area of Tertiary rocks next nearest to the borate deposits I have designated the Bissell area. This area, marked 2 on the map, begins at a point 17 miles west of the borate deposits and extends westward along the line of the Santa Fe Railway to Soledad Mountain, near Mohave. At its east end it consists of beds of limestone, chert, and greenish clay shale, which in general dip steeply southward but locally are greatly contorted. Farther west it consists of lava, chiefly rhyolite, and of tuffs of different colors. These volcanic rocks form a group of hills most of which are isolated one from another. Some of the hills are made up of massive rhyolite, like Desert Butte; others of mixtures of rhyolite and tuff, like Castle Butte. Soledad Mountain, the highest of the hills, is a conspicuous landmark in the region. The relation of the sedimentary rocks at the east end of the area to these volcanic rocks at the west end is unknown.

The Bissell area is separated from area No. 1, which lies northeast and east of it, by a continuous exposure of granite at least 5 miles wide, which forms a worn-down ridge, and from the Rosamond area (No. 4), which lies south of it, by a similar granite ridge. Southwest of Soledad Mountain, however, its outcrops are practically continuous with those of the Rosamond area.

The western part of the Bissell area, like the western part of area No. 1 around Desert and Castle Buttes, is essentially an area of rhyolite. Similar masses of rhyolite occur in the Rosamond area, and there can be little doubt that these rhyolite masses are genetically related and are of approximately the same age.

In the eastern part of the Bissell area, just north of Bissell station, the clay shale interstratified with the limestone and chert contains deposits of magnesite, which have been described by Gale.[3] The magnesite occurs in beds interstratified with the shale. Correlation of these beds at Bissell with the borate-bearing beds of Kramer, if possible, would be interesting, for it would supply an example of the occurrence of magnesite and borates in the same formation similar to that in the Muddy Mountain district in Nevada, where a huge deposit of magnesite is interbedded with a series of strata that in another part of the district contain borate deposits.[4] Sections at both places show great thicknesses of limestone that is not of marine origin and similar beds of chert and of clay shale.

The shale that contains the magnesite deposits is greenish clay shale and does not differ in any important respect from the shale that contains the Kramer borates. Like the borate shale, it is a playa or "dry-lake" deposit. On the dump of one of the shafts in sec. 14 in the Kramer district (see fig. 10) have been found fragments of a Tertiary limestone not unlike that which occurs in the Bissell section. As a rule the Tertiary beds in the desert region of California vary greatly in character within short distances, both vertically and horizontally, hence similarity of lithologic features can not safely be used to correlate them. Nevertheless, as the distance between the two areas is not great, the similarity of the beds is suggestive, and it does not seem at all improbable that the strata at the east end of the Bissell area and those of the Kramer district are roughly equivalent in age.

No. 3. About 21 miles north of the Kramer area lies an area of Tertiary rocks that extends from the Randsburg district far eastward to and beyond Pilot Knob. This area is marked 3 on the

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

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

map. The rocks in the western part of it have been described by Hulin,[5] according to whom they include a series of arkosic sandstone, conglomerate, and clay of upper Miocene age, which are intruded by rhyolite, andesite, and diabase and are overlain by flows of andesite. This area is separated from the Kramer area (No. 1) by a wide stretch of country, consisting of granite ridges partly or almost wholly buried by alluvium, and the relation of the rocks in it to those exposed in the Kramer area is unknown.

No. 4. At 25 miles southwest of the Kramer area lies an area of Tertiary rocks marked 4 on the map and designated the Rosamond area. This area begins at a point just north of Rosamond Lake and extends westward about 12 miles. The rocks in this area were first described by Hershey,[6] who applied to them the name "Rosamond series," and were examined later by Baker.[7]

The rocks in the Rosamond area are chiefly rhyolite and rhyolitic tuff of different colors, although some of them are sandstone and conglomerate. In general, they resemble the rocks in the western part of the Bissell area and those in the western part of area No. 1. No diagnostic fossils have been found in them, and their relations to other Tertiary formations in the region are unknown, yet for many years the name "Rosamond series" has been applied indiscriminately to all similar Tertiary rocks in the Mohave Desert on the assumption that they represent one period of deposition. The Tertiary beds at Ricardo, for example, and those in the Barstow syncline were referred to the "Rosamond series" by Hershey and Baker in the reports cited. Later work by Baker and by Merriam demonstrated that the beds in these two localities, at least, represent different stages in the Tertiary, and the term "Rosamond series," as applied to them, was discarded. The term is, however, still loosely applied by some geologists to many Tertiary formations in the desert whose stage in the Tertiary has not been determined and whose correlation with the rocks of the type locality has not been proved. Properly the term Rosamond if used at all should be restricted to the sedimentary rocks of the type locality—namely, the Rosamond area north and northwest of Rosamond Lake, where the rocks were first so named by Hershey.

This "Rosamond series" is probably to be correlated with the rocks in the western part of the Bissell area and with the rocks in the vicinity of Desert and Castle Buttes, in area No. 1. Its relation to the sediments of the Bissell area that contain the magnesite is

[5] Hulin, C. D., Mineralization at Randsburg, Calif.: Eng. and Min. Jour. Press, vol. 119, pp. 407–411, 1925.

[6] Hershey, O. H., Some Tertiary formations of southern California: Am. Geologist, vol. 29, pp. 365 et seq., 1902.

[7] Baker, C. L., Notes on the later Cenozoic history of the Mohave Desert region, in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 353–354, 1911.

unknown, and so is its relation to the beds of the Kramer district, from which it is separated by a stretch of country 25 miles wide in which only granite and alluvium are exposed.

No. 5. In the El Paso Mountains, 27 miles northwest of the Kramer area, lies the Ricardo area of Tertiary beds, marked 5 on the map. The beds in this area are particularly well exposed in Redrock Canyon, near Ricardo post office. They have been described by Baker[8] and by Buwalda.[9] Baker obtained vertebrate remains in many of the beds and these fossils were studied by Merriam, who states that they represent a stage younger than the upper Miocene fauna of the beds in the Barstow syncline and that they are probably of lower Pliocene age. Merriam has applied the name Ricardo formation to the Tertiary beds of the Ricardo area in which the fossils were found. He says:[10]

> While the name Rosamond may be used tentatively for the middle and late Tertiary sediments of the Mohave area, it has not been demonstrated that the several formations represented are as closely related in their depositional history as they appeared in the first investigations. It seems necessary to discuss the beds in the Barstow syncline and those at Ricardo as distinct divisions, since the evidence of the faunas indicates that the deposits were laid down in rather widely separated epochs. The known fauna of the Barstow syncline occurs near the top of the section, and it is very doubtful whether beds containing a fauna like that of the much more advanced stage of Ricardo is present in the Barstow section. The fauna at Ricardo occurs through the greater part of the Redrock Canyon section. Though it is possible that the lower Ricardo beds contain a faunal assemblage similar to that of the Barstow region, evidence indicating the presence of a typical Barstow fauna has not been obtained. The Rosamond series of Hershey may include beds containing the older fauna of Barstow, but it is doubtful whether it comprises sediments of the stage represented at Ricardo.

The Ricardo formation is largely tuffaceous but includes much arkosic sandstone and some clayey material. A few thin flows of basalt are interbedded with it. Like all other Tertiary sediments in the region these beds are essentially waste slope and playa deposits. They dip northward at an average angle of 15°, and their upturned edges have been planed by erosion to an even surface, which is covered by a mantle of Quaternary alluvium. In general, however, they have suffered far less disturbance than the beds of the Kramer and other areas described in this report, and they do not resemble the beds of the Kramer area in lithology nearly so much as the beds in some of the other areas. Therefore, it is highly improbable that they are to be correlated with the sediments of the Kramer district.

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[8] Baker, C. L., op. cit., pp. 354–357; Physiography and structure of the western El Paso Range and the southern Sierra Nevada: Idem, vol. 7, pp. 117–1421, 1912.

[9] Merriam, J. C., Tertiary mammalian faunas of the Mohave Desert: California Univ. Dept. Geology Bull., vol. 11, p. 448, 1919.

[10] Idem, pp. 440–441.

Nos. 6 and 7. About 28 miles northeast of the Kramer area lies an area of Tertiary beds, marked 6 on the map, and designated the Black Canyon area. The beds in this area have been studied and described by Baker[11] and by Pack,[12] who consider them equivalent to a part of those exposed in an adjoining Tertiary area, the Barstow syncline, marked 7 on the map. Therefore these two areas, which are practically continuous, are described together in the present report.

The beds exposed in the Barstow syncline, which lies 38 miles due east of the Kramer area, have attracted more attention from geologists than those in any other Tertiary area shown on the map. They have aroused interest for several reasons—because they contain vertebrate remains; because they have been prospected for oil; because they contain deposits of strontianite; and because they closely resemble and are in part equivalent to beds in the adjacent Calico district that contain borate deposits.

The beds are mentioned briefly by Hershey,[13] who mapped them as a part of the "Rosamond series."[14] Later they were studied by Baker,[15] who grouped them into five members and described them in considerable detail. Baker's subdivisions, beginning at the base of the series, are (1) basal breccia, (2) tuff-breccia, (3) fine ashy and shaly tuff, (4) resistant breccia, and (5) fossiliferous tuff. From the uppermost member, the fossiliferous tuff, Baker obtained an abundant vertebrate fauna, which Merriam[16] has studied and assigned to the upper Miocene epoch of the Tertiary. Merriam has applied the name Barstow formation to the beds containing this fauna. Fossils were found also in the underlying member, the resistant breccia, but none below the resistant breccia. Hershey and Baker had previously referred the beds in the Barstow syncline to the "Rosamond series," but this correlation, like their reference of the Ricardo formation to the "Rosamond," was made before the Ricardo and Barstow faunas had been studied by Merriam and found to be sharply distinct, and it has been discarded by Merriam, who states:[17]

The Barstow formation will be recognized as a division of the Rosamond series if the Barstow syncline corresponds to the type section of the Rosamond at Rosamond station, as has been assumed by Hershey and Baker. As yet it

[11] Baker, C. L., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 347–349, 1911.

[12] Pack, R. W., Reconnaissance of the Barstow-Kramer region, Calif.: U. S. Geol. Survey Bull. 541, pp. 10–11, 1913.

[13] Hershey, O. H., Some Tertiary formations of southern California: Am. Geologist, vol. 29, pp. 367, 368, 1902.

[14] Hershey, O. H., The Quaternary of southern California: California Univ. Dept. Geology Bull., vol. 3, pl. 1, 1902.

[15] Baker, C. L., op. cit., pp. 342–346.

[16] Merriam, J. C., op. cit.

[17] Merriam, J. C., idem, p. 442.

seems difficult to make certain of correlation between the Barstow syncline and the type Rosamond section, as paleontologic evidence is lacking at Rosamond. If the Barstow formation is considered as a member of the Rosamond, it is presumably a late member of the series.

In 1912 Pack[18] made a study of the Tertiary rocks in the region around Barstow to determine whether they offered any promise of oil. This study included the Black Canyon, the Barstow syncline, Calico, and a number of smaller Tertiary areas. Pack found that, although the five members into which Baker divided the Tertiary rock series could be recognized in the central part of the Barstow syncline, they could not be followed consistently, because the beds vary greatly in character both vertically and along the strike. He found, however, that for the area as a whole the series could be divided roughly into three parts, which he named the lower, middle, and upper divisions, and he has employed this threefold grouping in his report in preference to the more minute fivefold grouping of Baker. Pack's lower division corresponds roughly to Nos. 1 and 2 of Baker; his middle division to Nos. 3 and 4; and his upper division to No. 5. Pack's upper division, the fossiliferous tuff of Baker, is the upper Miocene Barstow formation of Merriam.

It is Pack's middle division that is of particular interest in the present discussion. According to Baker,[19] the beds that contain borate deposits in the Calico district not only closely resemble that part of the middle division exposed in the Barstow syncline which he has designated the "fine ashy and shaly tuff member" (No. 3) but are separated from the exposures in the Barstow syncline only by a narrow alluvium-covered basin. Undoubtedly, therefore, the borate-bearing beds of the Calico district are equivalent to a part of this middle division. The fact that the age of the strata which overlie the middle division is fixed by fossils affords the most definite evidence at present available for determining the epoch of Tertiary time in which any of the known borate deposits of California and Nevada were formed. It is true that no vertebrate fossils have been found in the fine ashy and shaly tuff member, which forms the lower part of the middle division, and that those found in the upper part of the middle division, though similar to those of upper Miocene age that occur in the overlying upper division, or Barstow formation, are too fragmentary to afford a satisfactory determination, yet the absence of any marked stratigraphic break within or between the two divisions indicates that the beds as a whole represent a continuously deposited series and therefore belong to the same epoch

[18] Pack, R. W., Reconnaissance of the Barstow-Kramer region, Calif.: U. S. Geol. Survey Bull. 541, pp. 141–154, 1913.
[19] Baker, C. L., op. cit., pp. 351, 352.

of Tertiary time. It is therefore certain that the middle division is not younger than upper Miocene and not older than lower Miocene. Probably it is upper Miocene. Therefore the Calico borate deposits are probably of upper Miocene age.

In the Barstow syncline this middle division is composed of greenish, more or less gypsiferous playa clay shale, thin beds of brownish arkose sandstone, many layers of limestone and white calcareous shale, beds of white ash, and toward the base conglomerate or fan conglomerate made up of coarse granitic fragments. It contains also deposits of strontium minerals—strontianite and celestite, which have been described by Knopf.[20] The structure of the beds in the Barstow syncline is complex; they are tilted at irregular angles and are cut by innumerable faults.

The Black Canyon area, which is 10 miles nearer the Kramer area than the Barstow syncline, contains representatives of the middle and upper divisions of the Barstow syncline. The beds that correspond to the middle division crop out in and west of Black Canyon. Here as in the Barstow syncline they consist chiefly of greenish clay shale, limestone, and sandy and ashy beds, but they also contain a few thin layers of black basaltic lava. I visited Black Canyon in November, 1924, in order to compare the beds with those exposed in the Suckow shaft in the Kramer district. The greenish shale and the ashy and shaly beds in the Black Canyon section are very similar to those in the Suckow shaft. Limestone, as already stated, occurs in one of the shafts in the Kramer district, and the presence of basaltic lava is another feature common to the two districts. Like the beds of the Kramer area, the beds of the Black Canyon section are profoundly disturbed; they dip at various angles and are cut by faults. The Black Canyon area is separated from the Kramer area by the same sort of granite country that separates the Kramer from other Tertiary areas and these areas one from another—alluvial slopes and worn-down granite ridges. It is therefore impossible to determine the relation of the beds of the Kramer area to those at Black Canyon. Nevertheless, the similarity of the rocks and their like degree of disturbance suggest, in the absence of evidence to the contrary, that the beds of the two areas are roughly equivalent in age.

CONCLUSIONS

From the foregoing discussion it is evident that although the borate-bearing beds of the Kramer area are certainly Tertiary their correlation with any of the other Tertiary rocks in the region and the determination of the epoch of the Tertiary to which they belong is

[20] Knopf, Adolph, Strontianite deposits near Barstow, Calif.: U. S. Geol. Survey Bull. 660, pp. 257–270, 1918.

at present a matter of speculation, because (1) the age of the beds in only two areas—the Ricardo and the Barstow—is fixed by fossils; (2) the areas are all isolated one from another by the surrounding granite and alluvium; and (3) similarity of lithology in Tertiary beds in this region is not proof of equivalence in age, similar conditions of deposition having been repeated many times and in many basins.

The rocks which the beds of the Kramer area resemble most both in lithology and in degree of disturbance and to which it appears most likely that they are equivalent are those in the east part of area No. 1, those that contain the magnesite deposits in the east part of the Bissell area, and those of the upper Miocene (?) middle division of the Barstow syncline exposed in that syncline and at Black Canyon. It is practically certain that the beds of the Kramer area are not equivalent to the lower Pliocene Ricardo formation and that they are older. Their relation to the volcanic rocks of the Rosamond area, to the similar volcanic rocks in the western part of the Bissell area and in the western part of area No. 1, and to the rocks of the Randsburg area is unknown.

In brief, it is probable that the Kramer borate deposits are of upper Miocene age. It is highly improbable that they are younger or older than Miocene.