Gypsiferous Deposits on Sheep Mountain Alaska

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GYPSIFEROUS DEPOSITS ON SHEEP MOUNTAIN, ALASKA

By Richard A. Eckhart

ABSTRACT

Gypsum-bearing rocks crop out in Gypsum and Yellow Jacket Gulches, on Sheep Mountain, which is about 90 miles northeast of Anchorage, Alaska. The gypsiferous rock occurs in deposits of irregular shape in the greenstone. Both the gypsiferous rock and the greenstone are hydrothermal alteration products of the volcanic rocks of Jurassic age which comprise the bulk of the mountain. Near-surface samples of the gypsiferous rock contained an average of 25 to 30 percent gypsum; some contained as much as 50 percent. Quartz, alunite, clay, sericite, and pyrite are contaminating constituents of the ore. Six of the largest and most accessible of the gypsum deposits were mapped and calculations show that three of the deposits contain an aggregate of approximately 311,000 short tons of indicated gypsiferous rock and four of the deposits contain 348,000 short tons of inferred gypsiferous rock.

INTRODUCTION

Gypsiferous deposits occur on the south side of Sheep Mountain (see fig. 12), 112 miles northeast of Anchorage via the Glenn Highway. Sheep Mountain is a high east-trending ridge, approximately 10 miles long and 3 miles wide. It is bordered on the west by Caribou Creek and on the east by Tahneta Pass. To the north it is separated from the Talkeetna Mountains by the valley of Caribou and Squaw Creeks and from the Chugach Mountains, to the south, by the valley of the Matanuska River.

Two creeks, Gypsum and Yellow Jacket, have incised V-shaped gulches 1,500 to 2,000 feet deep in the area of the gypsiferous deposits. The sides of the gulches are steep—30° to 45°. Outcrops within the area examined are plentiful although talus is common and locally very thick. Where resistant rocks are exposed, sides of the gulches steepen to form cliffs and many areas of outcrop are not accessible. Routes of access over the area are largely confined to talus slopes, areas of soft gypsiferous rock, and the bottoms of ravines.

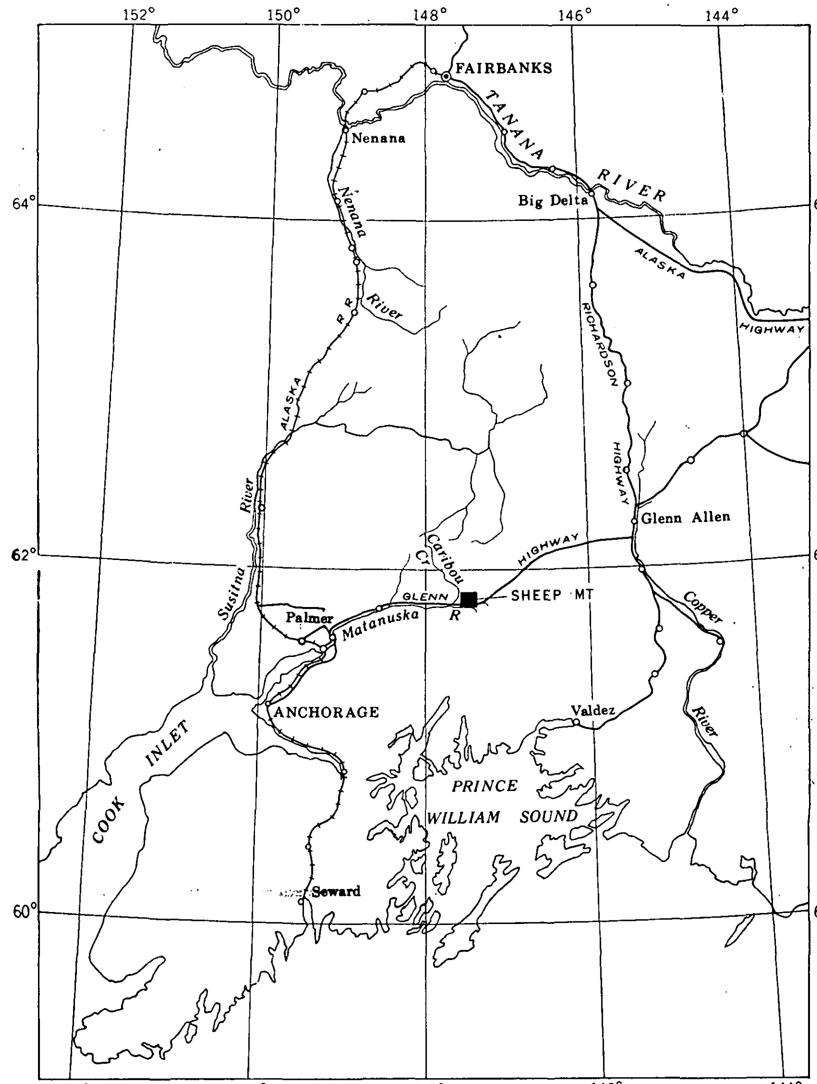

FIGURE 12.—Index map of south central Alaska showing location of Sheep Mountain.

Claims were located by George H. Fennimore in 1946. Fourteen claims are at present (1949) held by the Alaska Gypsum Queen Corp. (Mrs. George H. Fennimore, President, George H. Fennimore, and Leland Johnson, all of Anchorage, and Robert Clem of Palmer). The claims are leased to the Anchorage Gypsum Products Co. (Don Goodman, Edwin Johanson, and George Fennimore).

Improvements include two dirt roads from the Glenn Highway to the mouths of Gypsum and Yellow Jacket Gulches and a road to a proposed mill site at the base of the mountain. A small (homemade) calcining plant and two log cabins are located on the alluvial fan between the highway and the mountain. In 1947, 50 tons of calcined material were produced from the gypsiferous deposit at the mouth of Gypsum Gulch. In 1948, 50 tons of clay from a clay deposit at the mouth of Yellow Jacket Gulch were used by a brick plant in Anchorage in the manufacture of fire brick. Five tons of the clay were used in Palmer as boiler lining.

In 1947, G. M. Flint, Jr., of the U. S. Geological Survey, made the preliminary examination of the gypsiferous deposits. In 1948 the U. S. Bureau of Mines collected samples of gypsiferous rock and performed metallurgical tests on them in its Salt Lake City Laboratory.

During part of the summer of 1949, an area about 1½ square miles was examined for gypsiferous deposits. Geologic features were plotted on a special topographic map prepared by the Topographic Division of the U. S. Geological Survey; scale 1:12,120 and contour interval 100 feet (see pl. 4). Detailed geologic and topographic maps, scale 1:1,200 and contour interval 20 feet, were complied to include the six most promising areas of gypsiferous rock (see pl. 5). Control for the detailed maps was established by plane table and alidade traverse from Coast and Geodetic control points along the Glenn Highway. Details were mapped by tape and compass. The detailed maps were made by R. A. Eckhart and G. Fennimore (field assistant) and checked in the field by G. O. Gates. The 1:12,120 scale map of the area was compiled by Gates and Eckhart.

GEOLOGY

Sheep Mountain is made up of a thick section of layered volcanic rocks of Jurassic age. Within most of the area mapped these rocks have been intruded by many mafic dikes. The volcanic rocks have undergone alteration to the extent that they are now greenstone. Locally the greenstone has been altered to irregular masses of gypsiferous rock and quartz-sericite rock. Along part of the south base of the mountain faulting has placed the sandstone and shale of the Matanuska formation of Upper Cretaceous age in juxtaposition with the volcanic rocks. The only younger rocks comprise patches of Pleistocene(?) conglomerate that once partly filled the gulches of Gypsum and Yellow Jacket Creeks and the alluvial fans built by these creeks.

TALKEETNA FORMATION

The volcanic rocks comprising Sheep Mountain consist largely of interbedded tuffs, lavas, and volcanic breccias. Paige and Knopf[1]

[1] Paige, Sidney, and Knopf, Adolph, 1907, Geologic reconnaissance in the Matanuska and Talkeetna Basins: U. S. Geol. Survey Bull. 327, pp. 16–17.

included these rocks in the Talkeetna formation of Jurassic age. This formation has a wide distribution in and adjacent to the upper Matanuska Valley. During the early reconnaisance in 1906, a quartz diorite boss was mapped as being present in the area in which the gypsiferous deposits occur. This "quartz diorite mass" was not recognized anywhere within the area covered by the present investigation.

Where mapped the tuffs and breccias are light gray, gray, or greenish gray. They are well-bedded; beds of tuff range from several inches to more than 20 feet thick and beds of breccia are as much as 20–40 feet thick.

The tuffs are well-consolidated, compact, and in part, if not wholly, water-laid. They consist of rock and mineral fragments embedded in an aphanitic matrix. The rock fragments are mainly andesite and diabase. The most common mineral constituents are quartz, plagioclase feldspar (ranging in composition from andesine to labradorite), chlorite and serpentine minerals. The latter two minerals have replaced almost all the original ferromagnesian minerals and the aphanitic matrix. Some of the feldspar has been altered to an aggregate of albite, clinozoisite, and prehnite. Thin seams of calcite, local secondary quartz, and disseminated pyrite are not uncommon in these rocks.

A few thin beds of black carbonaceous shale and tuffaceous sandstone are locally intercalated with beds of tuff. A *Unio* from the shale was examined by Dr. Teng-Chien Yen. He reports that it is very similar to an undescribed species from the Morrison formation of northern Montana and is much more likely to be of Jurassic than of Cretaceous age.

Layers of breccia within the area are less abundant than layers of tuff and consist of angular fragments of porphyritic basalt and andesite in a fine-grained groundmass that is largely chloritic. The fragments vary from several inches to more than a foot in diameter.

The lava flows, which constitute the upper part of the layered volcanic rocks in the mapped area, consist of at least several hundred feet of fresh, greenish-gray to black basalts and andesites. Most of these flows are aphanitic, few are porphyritic, and some are amygdaloidal. Most of the phenocrysts are labradorite and the amygdules consist of zeolites, calcite, and quartz.

The presence of secondary minerals such as chlorite, clinozoisite, epidote, prehnite, and various serpentine minerals, indicates that the tuffs and breccias have undergone slight metamorphism and might be called greenstones. However in this report the term "greenstone" is restricted to phases of the volcanic rocks that, in the vicinity of the gypsiferous deposits, have been more intensely altered to rocks very rich in chlorite and epidote.

ZONE OF ALTERATION

The zone in which the volcanic rocks have been altered to greenstone, quartz-sericite rock, and gypsiferous rock lies within the drainage area of Gypsum and Yellow Jacket Creeks. It extends northward from the reverse fault near the south base of the mountain and crosses the crest of the mountain near the headwaters of the creeks. As seen from the air it is present on part of the north slope of the mountain. The brown, yellow, white, and red colors of the rocks and talus within the zone stand in striking contrast to the neutral hues of the tuffs, breccias, and flows.

GREENSTONE

Greenstone comprises most of the rock in the zone of alteration. It is a light to dark greenish-gray, fine-grained rock which locally shows relict textures of the parent volcanic rocks. In many places alteration has so obscured original textures that it is difficult or impossible to determine with certainty the nature of the original rock.

Propylitization was the principal process by which the greenstone was formed. Microscopic examination of several thin-sections of greenstone reveals that epidote, clinozoisite, prehnite, and a carbonate mineral have formed at the expense of original plagioclase feldspar. Chlorite, with minor fine-grained secondary quartz, commonly comprises a large part of the fine-grained matrix in which are embedded fragments of the minerals produced by propylitization and, locally, original labradorite which is badly altered and fractured. Pyroxene crystals have been largely altered to chlorite and rarely to epidote. Small cubes of pyrite are locally disseminated throughout the rock. Commonly the matrix between mineral grains and composite fragments is a finely crystalloblastic, semi-opaque mass composed essentially of epidote, leucoxene, some iron oxide, and probably some fine quartz and/or feldspar. Where developed, sphene is commonly in the form of semi-opaque clusters which are coated by leucoxene. Several specimens illustrate partial to complete replacements of olivine phenocrysts by serpentine minerals. The field and petrographic evidence strongly suggests that these rocks were originally flows of olivine basalt.

Numerous small pods and stringers of gypsum intricately cut much of the greenstone and, locally, calcite and quartz stringers are present. Many of the stringers follow joints and shears which, along with a great amount of slickensiding and fracturing, are prominent features of the greenstone. Weathered surfaces of the rock are stained with light- to dark-brown limonite.

DIKES

A large number of mafic dikes cut the greenstone. Most of the dikes were observed along Yellow Jacket and Gypsum Creeks. The full extent of the dikes was rarely traced, but it is believed that many of them are continuous across the divide that separates the two creeks. Several dikes cross the gypsiferous deposits (see fig. 13) while others, in part, border the deposits.

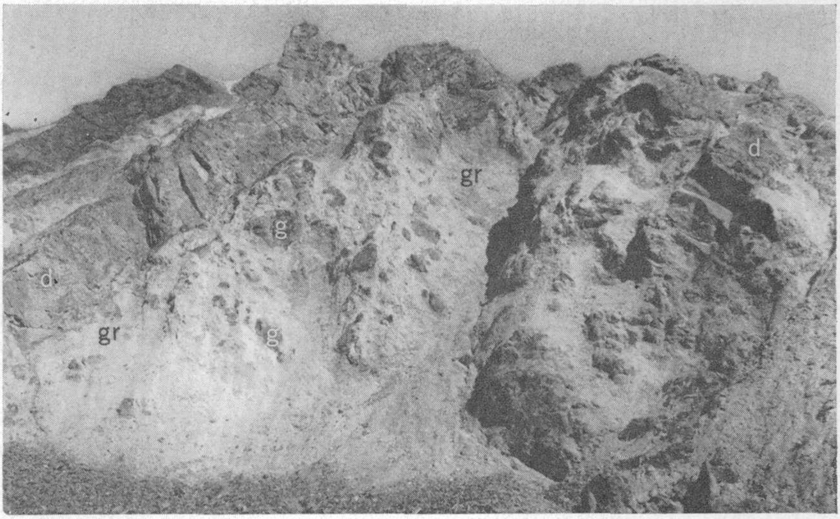

FIGURE 13.—Dikes (d), gypsiferous rock (gr), and greenstone (g) in Gypsum Gulch.

The dikes trend northeast and dip 30° to 65° N. A few dikes dip to the south. Most of the dikes in Gypsum and Yellow Jacket Gulches are less than 30 feet thick, but they vary from several feet to more than 160 feet in thickness. Locally they are so closely spaced that they form dike swarms as much as 300 feet wide.

Most of the dikes are greenish-gray to black and of basaltic composition. They are generally porphyritic with phenocrysts of labradorite and, in lesser amounts, pyroxene and olivine set in a fine-grained groundmass. Most of the phenocrysts are fairly fresh but badly fractured. Locally, some of the labradorite is altered to clinozoisite and an unidentified carbonate mineral. Pyroxene and olivine phenocrysts are commonly replaced by chlorite and serpentine respectively. Where fresh the fine-grained groundmass generally comprises small crystals of labradorite interstitial pyroxene, and accessory minerals that include magnetite, pyrite, apatite, and sphene. In altered specimens the groundmass is largely chloritic with a minor amount of epidote. Locally the dikes contain abundant secondary quartz.

QUARTZ-SERICITE ROCK

A quartz-sericite rock is one of the alteration products of the volcanic rocks. It is intimately mixed with gypsum in the gypsiferous deposits. In places the volcanic rocks are altered mainly to quartz-sericite rock to form irregular bodies ranging in diameter from a few feet to several hundred feet. One of the largest of these bodies forms a narrow ridge jutting out beneath Deposit 2 on the east side of Yellow Jacket Gulch. This is shown in plate 5.

The quartz-sericite rock is white to light gray, fine-grained, and platy. Much of it shows relict porphyritic, clastic, or trachytic textures. Its mineralogy is variable, but quartz and sericite are its most common and abundant constituents. With the possible exception of some of the quartz, none of the original constituents of the volcanic rocks remain. The groundmass has been silicified and the original feldspars have been altered to sericite and rarely to gypsum and clinozoisite. The small amounts of mafic minerals present in the original rock have been replaced by a colorless chlorite and epidote. Hematite, alunite, and a clay mineral comprise a small percentage of the rock. The presence of varying amounts of gypsum and other soft minerals gives the rock a hardness ranging from 4 to 6 or more. Outcrops of the rock exhibit a poorly developed platy structure which is also shown, though more poorly developed, in some outcrops of weathered greenstone.

Locally, small cubes of pyrite are disseminated in the quartz-sericite rock. In some outcrops surfaces of the rock are pitted. The pits are cube-shaped and apparently were formed by the leaching of pyrite.

The similarity of textures and platy structure of the quartz-sericite rock to that of the greenstone indicates that the quartz-sericite rock is also the result of the alteration of the tuffs, breccias, and flows.

GYPSIFEROUS ROCK

Gypsiferous rock comprises the bulk of the areas mapped as ore deposits and it also occurs as smaller, scattered masses in the greenstone. The composition of the rock is variable. Quartz and gypsum are its most abundant mineral constituents and clay minerals of the kaolin group and alunite are usually present. Locally, limonite and an unidentified yellow-green coating stain the rock. Platy structure is evident in some outcrops of the gypsiferous rock.

At the surface the gypsiferous rock is porous and fragmental or granular. Beneath the surface it is more compact. The rock consists largely of two intimately mixed components, white fine-grained gypsum and, for lack of a better term, altered rock. The gypsum occurs as blebs and irregular stringers cutting and cementing together fragments of altered rock. The gypsum is soft, massive, and usually contains fine-grained admixed quartz and larger siliceous fragments. Good cross-fiber vein structure is rare. Alunite and cubes of pyrite, as much as one-eighth inch in diameter, are occasionally present.

For descriptive purposes the altered rock component may be divided into a light-gray or tan variety and a dark-gray variety. These colors combined with the white (rarely pink) gypsum and brown and yellow-green stains give the ore a mottled appearance.

The light-gray or tan altered rock is similar in appearance to the quartz-sericite rock, but is usually softer and different in mineralogy. This variety of the altered rock is largely mixtures of fine-grained quartz and gypsum. Alunite and a clay mineral are commonly present. Antigorite and/or chrysotile comprise a large part of the matrix of some specimens. Sericite rarely is present as an alteration product of feldspars. In one specimen, talc appears to have replaced orthorhombic pyroxene crystals. In some of the light-gray or tan variety of altered rock, either pyrite is present as disseminated cubes or its former presence is indicated by cube-shaped pits. The hardness of this variety ranges from 3 to 6 or more depending on the relative amounts of quartz and soft minerals present. Usually it is less than 5 in hardness.

The light-gray or tan altered rock is commonly aphanitic but some of it exhibits relict porphyritic textures in which the original feldspar phenocrysts have been replaced by gypsum. Small irregular masses of gypsum in some of the light-gray or tan altered rock suggest a relict clastic texture and may indicate replacement of tuff.

The dark-gray portion consists almost entirely of quartz and is hard. Most of it is aphanitic but relict porphyritic textures are seen in some of it. Rarely, alunite is present. It may form a considerable part of the rock, however. One sample contained as much as 35 percent alunite.

The exact effect of ground water on the ore has not been ascertained. Locally, the ore at the surface appears to have been enriched with gypsum; in other places leaching appears to have taken place. Gypsum and Yellow Jacket Creeks are highly charged with mineral matter. Table 1 summarizes water analyses of these creeks by R. T. Kiser of the U. S. Geological Survey.

CLAY

Clay, also a product of alteration of the volcanic rocks, is mixed in variable amounts with the gypsiferous rock and the quartz-sericite rock in most of the deposits. It is white to yellow, sticky, plastic, and is commonly veined by stringers of white, fine-grained gypsum. A deposit at the mouth of the gulch of Yellow Jacket Creek consists in part and perhaps largely of clay.

TABLE 1.—*Water analyses, in parts per million, of Gypsum and Yellow Jacket Creeks*

	Gypsum Creek	Yellow Jacket Creek
Silica (SiO_2)	73	78
Iron (Fe)	.54	3.7
ppt[1] Fe	----------	54
Calcium (Ca)	378	372
Magnesium (Mg)	268	253
Sulfate (SO_4)	2,820	2,860
Chloride (CL)	5.5	3.0
Specific conductance (K x 10^6 at 25 C.)	3,410	3,810
pH	3.5	2.8

[1] Ppt—parts per ton.

NOTE.—In addition to the constituents reported there appears to be a considerable amount of aluminum in both creeks. No determinations were made for sodium or potassium.

MATANUSKA FORMATION

The Matanuska formation of Late Cretaceous age is exposed along part of the south base of Sheep Mountain. In the area mapped this formation consists of sandstone and shale and has been faulted down against the volcanic rocks on the north.

The sandstone is greenish-gray, fine-grained, and well-bedded. Individual layers are several inches to a few feet in thickness. They contain numerous *Inoceramus* which R. W. Imlay, U. S. Geological Survey, has determined as probably of early Late Cretaceous age.

Black shale is exposed in a very small area just north of the proposed mill site at the base of the mountain. It is massive and overlies the sandstone.

CONGLOMERATE

Erosional remants of a reddish-brown conglomerate of Pleistocene(?) age are present in the lower parts of Gypsum and Yellow Jacket Gulches. The conglomerate is composed largely of subangular greenstone and some gypsiferous rock fragments ranging from less than an inch to a foot or more in diameter; 3 to 4 inches is about average. It is coarser in its lower portion, and near its top several layers of fine-grained, red sandstone are present. For the most part the conglomerate is horizontally bedded, but beds dipping 25° to 40° S. are also present.

The conglomerate is believed to have been deposited when Gypsum and Yellow Jacket Creeks were dammed by a glacier in the Matanuska Valley. The dipping beds apparently represent deltaic deposition. The sediments were later cemented with gypsum and iron oxide that were carried in solution by the creeks.

STRUCTURE

In general, the volcanic rocks comprising Sheep Mountain strike a few degrees east or west of north and have a fairly uniform dip of about 30° to 50° to the east. Layering is obscure and attitudes are difficult to determine within the area of greenstone. There is some evidence, however, of local reversal of dip west of Gypsum Creek with the result that this creek follows approximately the crest of an anticline.

The large reverse fault (see pl. 4) crosses the entire area mapped. It trends approximately parallel to the front of the mountain and dips steeply northward. The southern side is downthrown. Comparison of the sequences of rocks north and south of the fault suggests a minimum vertical displacement of about 1,500 feet.

The fault is best exposed on the east side of Yellow Jacket Gulch. There it strikes N. 60° E. and dips 72° N., forming a steep scarp as much as 100 feet high. (See figs. 16 and 17.) Near the fault the volcanic rocks on the downthrown side are overturned to the north. Greenstone, containing the gypsiferous deposits, comprises the upthrown side. A band of white clay, several feet wide, borders this side of the fault.

South of this fault a normal fault has downthrown the sandstone and shale of the Matanuska formation against the volcanic rocks to the north.

Locally, the greenstone is broken by shear zones as much as 4 feet wide. These shear zones trend northeast more or less parallel with the dikes. Generally, along the shears gypsiferous and limonitic alteration has taken place.

GYPSIFEROUS DEPOSITS

DESCRIPTION OF DEPOSITS

What are believed to be the largest and most promising deposits of gypsiferous rock are the six mapped in detail. Their locations are shown in plate 4.

The deposits are closely associated with dikes and although their shapes are irregular, at least to some degree, shape is controlled by the attitude of the dikes and the enclosing greenstone. Masses of quartz-sericite rock and greenstone, ranging from less than a foot to tens of feet in size, are found within the deposits. Their presence is unpredictable. These masses are intricately cut by stringers and small pods of gypsum. Pyrite is abundant in many of the greenstone masses. The change from greenstone to relatively high-grade gypsiferous rock may be abrupt and take place within a few inches. A narrow limonitic zone usually separates the greenstone and the gypsiferous rock. The change from greenstone to gypsiferous rock may also be gradational through a zone of quartz-sericite rock.

Much of the gypsiferous rock of the deposits lies beneath talus ranging from several feet to more than 10 feet in thickness. Where the talus is several feet thick it consists largely of small angular greenstone fragments in its upper part and layers of varicolored clay and gypsiferous rock fragments, that are often banded in texture and color, in its lower part. The lack of greenstone fragments in the lower part suggests the layers formed by fragmentation of underlying gypsiferous rock and movement downslope. Thin, narrow-spaced stone stripes are not uncommon on the surface of the talus.

Permafrost was reached 7½ feet vertically below ground surface in the face of the open-cut on Deposit 2 and 6½ feet vertically below ground surface in the face of the open-cut on the east slope of Deposit 1.

DEPOSIT 1

This deposit is on the crest of the ridge between Gypsum and Yellow Jacket Creeks, largely between elevations 4,400 and 4,600 feet. The deposit is completely enclosed by greenstone.

The northwestern part of the deposit was mapped as gypsiferous rock containing small greenstone masses. These masses are estimated to comprise 50 to 60 percent of this area and 10 percent of the remainder of the deposit. Figure 14 shows typical greenstone pods in the northern part of the deposit.

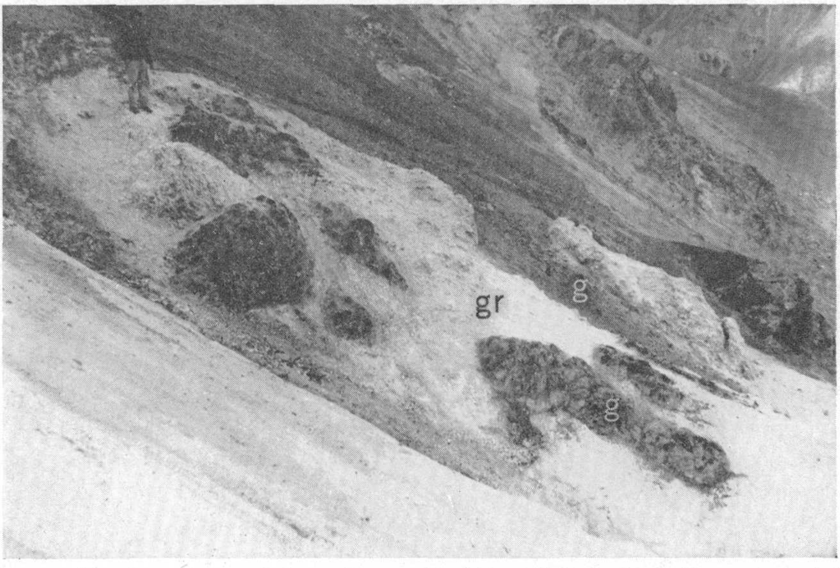

FIGURE 14.—Greenstone pods in northern part of Deposit 1; (gr) gypsiferous rock, (g) greenstone.

An irregular mass of quartz-sericite rock, about 100 feet long and 35 feet wide, lies between the gypsiferous rock and the surrounding greenstone at the south side of the deposit.

One of the dikes cutting the enclosing greenstone was traceable into and through most of the deposit. The dike also cuts several greenstone pods within the deposit. It is badly weathered and limonite-stained at the surface. The contact between it and the gypsiferous rock is very sharp. Figure 15 shows the relationships of the dike.

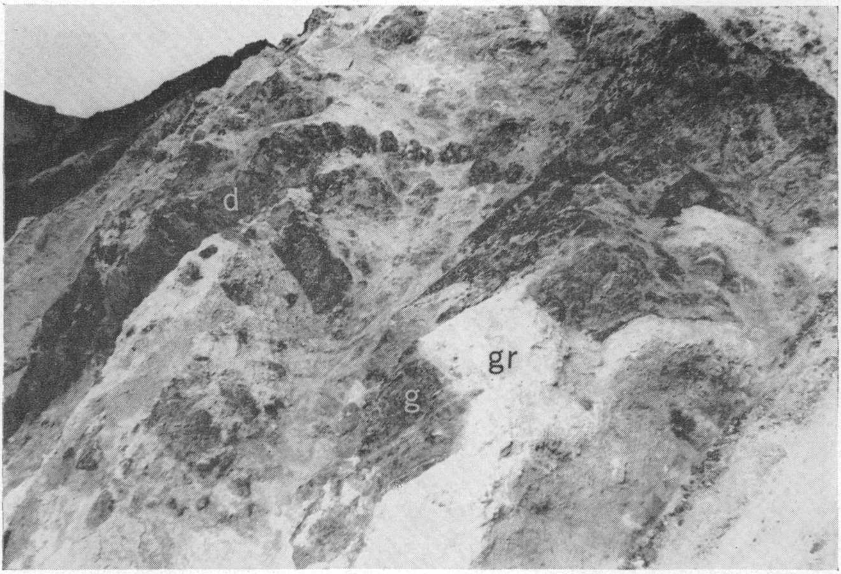

FIGURE 15.—Dike cutting gypsiferous rock and pods of greenstone in Deposit 1; (d) dike, (g) greenstone, and (gr) gypsiferous rock.

The contact between the ore and the greenstone at the north end of the deposit is concealed by thick talus. It is possible that the deposit extends some distance northward under this cover. However, a short distance north of the mapped contact greenstone is known to underlie the talus.

DEPOSIT 2

Deposits 2, 3, 4, and 5 (pl. 5 and fig. 16) comprise a discontinuous zone of ore roughly 2,400 feet long and 700 feet wide on the east side of Yellow Jacket Gulch.

Deposit 2 is near the northwest end of this zone. It crosses a spur between elevations of about 4,500 feet and 4,640 feet. In outcrop it is about 300 feet long and from 100 to 200 feet wide. Parts of the deposit are covered with talus and soil creep as much as 8 feet thick. The nature of the bedrock and the positions of contacts were determined by digging pits.

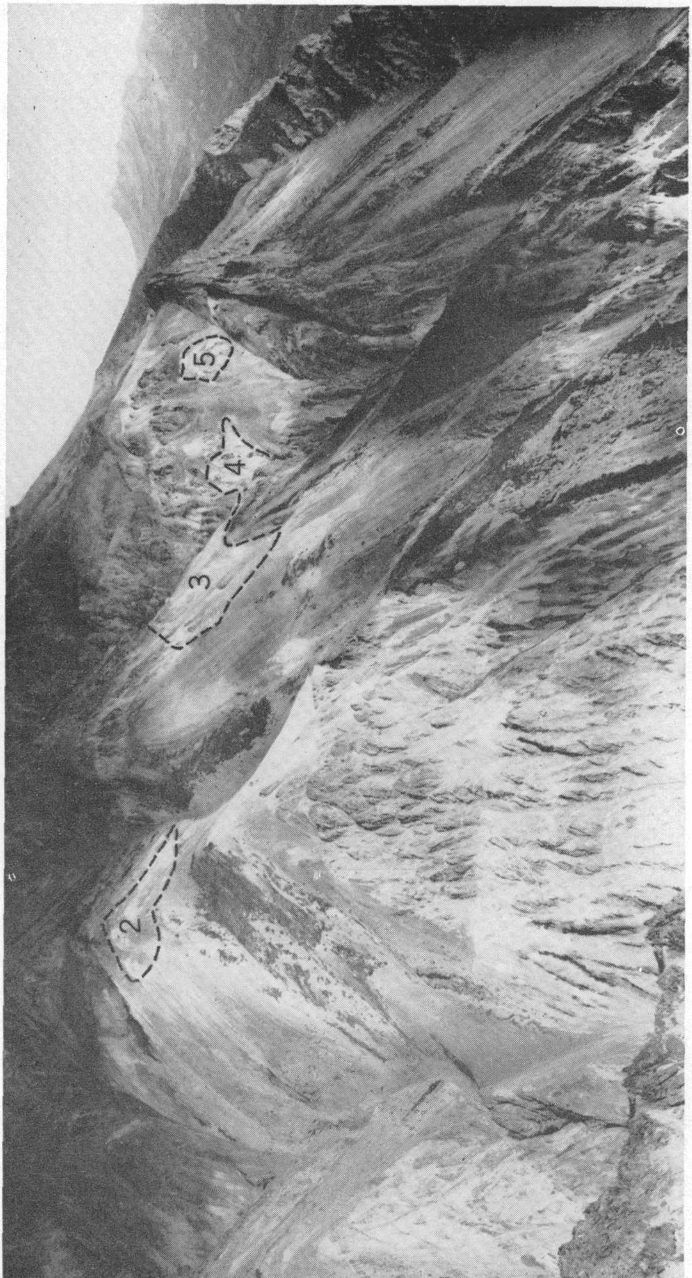

FIGURE 16.—Location of Deposits 2, 3 (in part), 4, and 5 on east side of Yellow Jacket Gulch.

At the east side and at the west side of Deposit 2 the gypsiferous rock grades into quartz-sericite rock which contains some gypsum. The relation between the traces of the contacts between the gypsiferous rock and the quartz-sericite rock and the attitude of layered volcanic rocks a few hundred feet north, suggests that quartz-sericite rock in part forms the bottom and the roof of Deposit 2. A basalt dike which dips to the north forms the southeastern boundary. The deposit is bounded on the north and south by greenstone.

Deposit 2 appears to contain the least number of pods and blocks of greenstone. A body of porphyritic basalt 50 feet long and 20 feet wide is exposed near the center of the deposit. The basalt shows little evidence of alteration although it is veined by several stringers of gypsum. Its contact with gypsiferous rock is sharp and marked by a thin band of clay and gypsum.

DEPOSIT 3

Deposit 3 is southeast of Deposit 2; the two deposits are separated by a large area of thick talus. Apparently, the geology beneath the talus is similar to that on either side of it.

In calculating tonnage, the deposit was divided into four parts—*a*, *b*, *c*, and *d*. These are shown in plate 5. All four parts are covered with talus, part *a* being separated from the remainder of the deposit by a fairly large area of thick talus. The talus over the remainder of the deposit averages about 3 feet in thickness and the underlying geology was mapped by trenching. However, it should be pointed out that due to this talus, parts of the deposit could not be mapped as accurately as Deposits 1 and 2.

Greenstone masses within the deposit consist largely of altered tuffs. Clay and quartz-sericite rock are major constituents of the deposit. Between parts *b* and *c* the quartz-sericite rock is so abundant that the area was mapped as a mixture of quartz-sericite rock and gypsiferous rock.

To the south the deposit is limited by greenstone that is believed to be an altered tuff and partly breccia. To the north a layered sequence of tuffs strikes into the deposit. Quartz-sericite rock is abundant at the contact and a few stringers of gypsum extend a short distance into the layered sequence. There apears to be a rough transition from the gypsiferous rock through a narrow zone of quartz-sericite rock to the well-bedded, slightly altered tuffs. The transition takes place within tens of feet. Several small shears occur in the tuffs near the deposit but none show mineralization.

DEPOSIT 4

Deposit 4 is southeast of Deposit 3, across a gulch incised by a tributary of Yellow Jacket Creek. Figure 17 affords a close-up view of

FIGURE 17.—Deposits 4 and 5. The white areas within the deposits are gypsiferous rock; (g) greenstone pod in Deposit 4.

this deposit. The face of Deposit 4 is barren of talus and is very steep with slopes exceeding 40°. A large part of the deposit is not readily accessible on foot. Greenstone pods comprise at least 10 percent of the deposit and quartz-sericite rock is locally very abundant.

DEPOSIT 5

Deposit 5 is at the southeast end of the discontinuous zone of gypsiferous rock on the east side of Yellow Jacket Gulch. About one hundred feet south of Deposit 5 this zone is terminated by the reverse fault previously described.

The east and west sides of the deposit are covered by thin talus. Its north and south sides are bordered by greenstone. The greenstone to the north consists of a fine-grained, pyritic, altered tuff.

For purposes of description, the deposit is divided into an upper and lower part. The lower part contains numerous pods of greenstone and quartz-sericite rock. The upper part of the deposit is covered with a thin talus and the underlying gypsiferous rock is different from that observed elsewhere. It appears to contain considerable clay and small amounts of quartz and alunite, but the dark-gray siliceous fragments in the gypsiferous rock of the other deposits is absent.

DEPOSIT 6

Deposit 6 is the smallest deposit mapped in detail but it is the most accessible of the six deposits. The deposit forms an approximate 45° slope on the east side of the mouth of Gypsum Gulch. The bed of Gypsum Creek forms the western boundary of the deposit. The north and south sides of the deposit are bounded by greenstone and its eastern exposure is limited by thick talus composed largely of greenstone fragments.

For the calculation of tonnage, the deposit was assumed to extend horizontally into the side of the gulch.

ORIGIN

Relict textures and structures in the greenstone demonstrate that it was formed by local alteration of the volcanic rocks of the Talkeetna formation. In some places the alteration continued beyond the stage of greenstone to form deposits of gypsiferous rock and deposits of quartz-sericite rock. This is shown by the following:

1. Deposits of gypsiferous rock and deposits of quartz-sericite rock are restricted to the zone of greenstone.
2. Relict textures and structures in the gypsiferous rock and quartz-sericite rock can be traced into greenstone.
3. All gradations are present between greenstone, which is cut by short, scattered irregular veinlets of gypsum, and gypsi-

ferous rock and quartz-sericite rock which contain residual pods of greenstone.

The alteration of the volcanic rocks to greenstone, gypsiferous rock, and quartz-sericite rock probably was accomplished by hydrothermal solutions.

Dikes are largely restricted to the zone of greenstone. There is no evidence that they are younger than the gypsiferous rock and the presence of secondary quartz in many of the dikes suggests they are older.

The intrusion of the dikes and the hydrothermal activity probably are related to a single phase of igneous intrusion.

GRADE

A total of 60 gypsiferous rock samples were collected from Deposits 1 through 5. They include continuous chip samples, spaced chip samples (at approximately 1-foot spacings), samples from pits and trenches dug through talus, and grab samples from outcrops. The locations of pits, trenches, and lines of samples on outcrops are shown in plate 5. Two grab samples were taken from the ore pile at the calcining plant. All this material was mined from Deposit 6.

Pits through talus covering the deposits ranged from 1 foot to 8½ feet in depth and averaged about 3 feet. Samples were usually taken from the bottoms of the pits. Most of the chip samples were taken from trenches 3 inches to 1 foot deep.

Five samples were analyzed in laboratories of the U. S. Geological Survey by W. J. Blake, Jr., and Leonard Shapiro. The determinations were made according to testing methods described in A. S. T. M. Designation C 26–33, A. S. T. M. Standards, Part 2, 1933, modified to take into account the possible presence of alunite and pyrite. Table 2 gives the results of these analyses.

Through the courtesy of the Department of Mineral Sciences of Stanford University in making available their laboratory and equipment, a simple acid soluble test was made by the author to determine the approximate amount of gypsum in 56 of the ore samples, excluding the samples shown in table 2. Table 3 summarizes the results of this test.

The acid soluble test is based on the relative solubilities of alunite and gypsum in dilute hydrochloric acid. The following procedure was used. The sample was ground to minus 100-mesh, quartered and weighed. The weighed portion was added to hydrochloric acid of 0.5 normality using the ratio of 30 milliliters of acid per gram of ore. The mixture was then heated for half an hour, decanted, fresh acid of the same normality added, and heated again for half an hour.

TABLE 2.—*Detailed analyses of samples of gypsiferous rock*

	Sample No.				
	D1-10	D2-14	D2-17	D2-19A	D2-19E
SiO_2 plus insol	55.64	44.70	70.24	62.50	63.75
Fe_2O_3 (Total)	1.48	1.35	1.69	2.65	1.47
Al_2O_3 (Total	14.27	9.31	15.59	14.24	12.29
TiO_2 (Total)	.53	.53	.53	.60	.60
CaO (Total)	9.90	17.54	8.46	7.42	10.65
MgO (Total)	.09	.11	.04	1.57	.09
SO_3 (Acid sol.)	14.14	25.43	11.45	11.13	15.67
SO_3 (Acid insol.)	11.08	0	.37	9.19	.60
K_2O [1]	.80	.04	.08	1.10	.04
Na_2O [1]	1.48	.14	.30	1.20	.10
CO_2	Trace	Trace	Trace	.10	.11
Loss on Ign	21.09	13.98	10.00	18.82	11.45
H_2O (220° C.)	5.91	10.94	5.21	4.42	6.92
Gypsum (calc. from sol. SO_3)	30.41	54.70	24.63	23.94	33.71
Alunite (calc. from insol. SO_3)	28.71	0	.96	23.81	1.55
K alunite (calc. from K_2O)	7.02	0	.70	9.65	.35
Na alunite (Total alunite-K alunite)	21.69	0	.26	14.16	1.20

[1] Alkalies with flame photometer by S. M. Berthold.

D1-10. Continuous chip sample from face of upper 6 feet of Pit 56, Deposit 1.
D2-14. Continuous chip sample along Trench 6, Deposit 2. Trench 6 was about 4 inches deep.
D2-17. From Pit 23, 18 inches deep, Deposit 2.
D2-19A. Continuous chip sample of the bottom 1 foot of the face of Pit 27, Deposit 2. Pit 27 was 8½ feet deep.
D2-19E. Continuous chip sample 1 foot long near top of face of Pit 27.

TABLE 3.—*Approximate analyses of samples of gypsiferous rock*

Sample no.[1]	Percent gypsum	T-trench, P-pit [2]	Depth of trench or pit (feet)	Length of sample trench (feet)	Remarks
Deposit 1					
D1-1	31	P54	3.5		
D1-3	17	P55	2.5		
D1-4	36	T7	.33	42	Spaced chip samples. D1-5.
D1-5	36	T7	.33	45	Up slope from D1-4.
D1-6	37	T8	.33	28	Spaced chip sample.
D1-8	34	P56	7		Open-cut-top of permafrost 6½ feet vertically below ground surface.
D1-11	40	P57	5		Continuous chip sample along face of pit.
D1-12	38	P58	.5		
D1-14	32	P59	7		
D1-15	40	P59	7		Continuous chip sample of middle 4.5 feet of face of pit.
Deposit 2					
D2—1	39	P1	7		Talus 6 feet thick.
D2—2	26	T3	.5 to 1	3.5	Continuous chip samples taken consecutively up slope. Above D2-2, 7 feet of trench was not sampled.
D2—3	25	T3	.5 to 1	9	
D2—4	31	T3	.5 to 1	16.7	
D2—5	34	T3	.5 to 1	22	
D2—6	33	T4	.33 to .5	30.5	Continuous chip samples taken consecutively up slope.
D2—7	32	T4	.5	15.5	
D2—8	19	P6	4		
D2—9	28	P7	3.5		
D2—10	25	T5	.5 to .75	22	Continuous chip samples taken consecutively up slope.
D2—11	29	T5	.5	24	
D2—12	51	T5	.5	19	
D2—13	32	T6	.33	14	
D2—15	32	P9	5		
D2—18	11	P26	5		
D2—19B	61	P27	8.5		Continuous chip samples up face of pit. Permafrost in bottom of pit.
D2—19C	30	P27	8.5		
D2—19D	31	P27	8.5		
D2—19F	32	P27	8.5		

TABLE 3.—*Approximate analyses of samples of gypsiferous rock*—Continued

Sample no.[1]	Percent gypsum	T-trench, P-pit [2]	Depth of trench or pit (feet)	Length of sample trench (feet)	Remarks
Deposit 3					
D3-1	37	P28	2.5		
D3-2	37	P28	2.5		Continuous chip sample up face of pit.
D3-3	26	P29	1		
D3-4	34				Grab sample from outcrop 15 feet east of P29.
D3-6	27	P32	7		
D3-7	27	P33	7.5		
D3-8	3	P35	3		
D3-10	28	P44	2.5		
D3-11	18	P47	3		
D3-12	46	P48	2		
D3-13	23				Grab sample from outcrop north of P48.
D3-14	27				Grab sample from small outcrop in part *d* of the deposit.
D3-15	12				Grab sample from outcrop south of part *d*.
D3-17	23				Grab sample from outcrop south of part *d*.
D3-18	25				Grab sample from outcrop in part *c*—south of P48.
D3-19	19	P49	2.5		
Deposit 4					
D4-1	23	T9	1	25	Continuous chip samples taken consecutively up slope.
D4-2	17	T9	1	15	
D4-3	29	T9	1	15	
D4-4	19	T9	1	20	
Deposit 5					
D5-1	30	T10	.33	15	Continuous chip sample.
D5-2	29	T11	.33 to .5	12	Continuous chip sample.
D5-3	30	T12	.33 to .5	18	Continuous chip sample.
D5-4	33	P51	4		
D5-5	22	P50	3		
D5-6	28	P52	3.5		
Deposit 6					
D6-1	26				Composite grab sample from ore pile at kiln.

[1] Location in plate 5.
[2] Unless otherwise noted, pit sample was taken from bottom of pit.

Care was taken not to boil the mixture during heating. After the second heating the mixture was filtered and the insoluble residue dried in an oven at a temperature of 100° to 120° C. The difference between the weight of the sample and the weight of the residue was taken to equal approximately the weight of the gypsum present in the sample.

Microscopic examinations of the residue of each sample tested usually failed to indicate the presence of gypsum. Rarely, one or two small grains of gypsum were identified under the microscope.

Mr. Leonard Shapiro also analyzed for gypsum the samples in table 2 using the acid soluble test. Table 4 compares his results with the results obtained by using modified A. S. T. M. methods (table 2).

The quartz-sericite rock intimately associated with the gypsiferous rock, and the quartz, alunite, and alteration minerals present in the

TABLE 4.—*Comparison of gypsum content in samples of gypsiferous rock, by detailed and approximate analyses*

Sample No.	Percent gypsum	
	Acid soluble test	Modified A. S. T. M. methods
D1–10	30. 2	30. 41
D2–14	54. 6	54. 7
D2–17	26. 4	24. 63
D2–19A	23. 7	23. 94
D2–19E	33. 1	33. 71

gypsiferous rock are contaminating constituents of the ore. In the 60 ore samples collected from Deposits 1 through 5, estimates of the percent of alunite were made by inspection of immersion mounts of the ore. Nineteen of the samples contained alunite in amounts ranging from an estimated 2 to 65 percent. Seven of these 19 samples were estimated to contain 20 percent alunite or more. Residues of the acid soluble test on samples in which no alunite was identified in immersion mounts of the ore, commonly, but not always, contained a little alunite when examined under the microscope.

As seen in the material of the ore pile at the kiln, the gypsiferous rock of Deposit 6 contains abundant disseminated small grains of pyrite. Very little pyrite was seen in the gypsiferous rock of Deposits 1, 2, 3, 4, and 5. Some of the fragments of quartz-sericite rock in the ore, however, are marked by small cube-shaped pits. These pits probably formed by the leaching of pyrite. Heavy mineral separations of samples D1–10, D2–14, D2–17, D2–19A, and D2–19E were examined by Theodore Woodward, U. S. Geological Survey, and the samples were found to contain only negligble amounts of pyrite and traces of magnetite.

In a sample analyzed by the Bureau of Mines, according to a letter to G. D. Jermain from S. R. Zimmerlay dated April 19, 1949, the gypsum is all minus 100-mesh in size and is mostly minus 200-mesh. The alunite is minus 65-mesh and the other constituents of the sample range in size from 20 to minus 200-mesh. To liberate these minerals from one another requires grinding the ore at least to minus 100-mesh. This reduces the soft alunite to a dust. Therefore, a good separation of the gypsum and alunite by low-cost methods, such as dry attrition grinding and air classification, is difficult. The finely crystalline nature of the gypsum prohibits concentration at coarse sizes and the lack of significant specific gravity differences among the minerals makes gravity methods impractical. Other methods, even if applicable, are probably too costly. Chemical analysis of the sample mentioned above is given in table 5.

TABLE 5.—*Assay of gypsiferous rock sample, in percent*

CaO	SO_3	Al_2O_3	SiO_2	H_2O at 250° C.	H_2O at 600° C.
10.0	24.8	14.8	29.8	5.1	[1] 10.3

[1] Includes water loss at 250° C.

By dry attrition grinding and air classification a concentrate assaying 41.9 percent gypsum and 24.8 percent alunite was made from this sample. A recovery of 52.2 percent of the gypsum and 25.9 percent of the alunite was obtained from the concentrate.

RESERVES

All calculations of reserves are based on the assumption that the specific gravity of the gypsiferous rock is 2.4, or 13 cubic feet of ore weighs one short ton. This specific gravity is slightly higher than that of gypsum (2.32), but was assumed to account at least in part for the heavier impurities in the ore, such as quartz (2.65) and alunite (2.6 to 2.8).

Deposit 1.—The northwestern part of this deposit contains 50 to 60 percent greenstone and is not included in the reserve calculations. It is estimated that the reserves calculated include as much as 10 percent greenstone, present as small masses throughout the gypsiferous rock.

Reserves were calculated by constructing five vertical sections 50 feet apart across the deposit at a bearing of N. 65° E. On each vertical section the gypsiferous rock was assumed to bottom at a line connecting the intersection of the vertical section and the lower limit of gypsiferous rock on each side of the ridge. The reserves are considered to be indicated. These indicated reserves were 206,000 tons.

Deposit 2.—Both indicated and inferred reserves were calculated for this deposit. The small masses of greenstone present in the deposit are included in the reserves.

For the indicated reserves it was assumed that the gypsiferous rock extends horizontally into the spur to straight horizontal lines connecting the points of intersection of contours with the mapped boundaries of the gypsiferous rock. For calculating reserves, the deposit is divided into horizontal blocks. The top and bottom of each block is determined by a horizontal plane through each contour.

For calculating indicated reserves, the area of gypsiferous rock used extended into the spur and to the horizontal line connecting the points of intersection of each contour with the mapped boundaries of the gypsiferous rock. In calculating inferred reserves the same size area was used for each horizontal section. Indicated reserves were 92,000 tons; inferred reserves were 92,000 tons.

Deposit 3.—As previously stated, this deposit consists of four parts, *a*, *b*, *c*, and *d*. Part *d* contains abundant greenstone masses and is not included in the reserves. An area between parts *b* and *c*, mapped as a mixture of gypsiferous rock and quartz-sericite rock, is also not included in the reserves.

It is inferred that parts *a*, *b*, and *c* contain 100,000 tons of ore, much of which is quartz-sericite rock containing some gypsum. The actual reserves may be larger, as parts *a* and *b* may be continuous across the thick talus area between them.

Deposit 4.—To calculate the reserves, five vertical sections 30 feet apart, striking N. 75° E., were constructed across the deposit. This strike is approximately at right angles to the strike of well-stratified, tuffaceous beds 600 feet to the north. It was assumed that the ore body dips 30°—about the same as the tuffaceous beds. For each section it was further assumed that gypsiferous rock extends down dip one-third the length of the section.

Greenstone masses are estimated to comprise 10 percent of the deposit. These are included in the reserves which are considered to be inferred. These reserves were 73,000 tons.

Deposit 5.—Reserves for this deposit were calculated by the same method as for Deposit 4 and are based on the same assumptions. Inferred reserves were 83,000 tons.

Deposit 6.—Ten percent of this deposit is estimated to be greenstone. This is included in the reserves. The deposit is assumed to extend horizontally into the hillside.

The reserves are considered to be indicated. They were calculated by constructing four vertical sections 50 feet apart, and one vertical section 20 feet from the last of the above four sections. These cross the deposit at a bearing of N. 75° E. On each vertical section the gypsiferous rock was assumed to be bottomed by a horizontal line drawn through the intersection of the vertical section with the lowest exposed limit of ore and by the intersection of this line and a perpendicular dropped from the intersection of the vertical section and the highest limit of ore. Indicated reserves were 12,800 tons.

TABLE 6.—*Summary of reserves*

Deposit No.	Indicated (tons)	Inferred (tons)
1	206, 000	
2	92, 000	92, 000
3		100, 000
4		73, 000
5		83, 000
6	12, 800	
Total	310, 800	348, 000

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