BULLETIN 51

Geology of the Questa Molybdenum (Moly) Mine Area, Taos County, New Mexico

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Local structure and stratigraphy, and detailed description of mineral deposits as related to regional geology, with guides to ore exploration in the surrounding area

1956

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY
CAMPUS STATION SOCORRO, NEW MEXICO

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FRONTISPIECE

View of Sulphur Gulch showing W level dump (lower left), landslide covering portals of Glory Hole workings (center), and the altered area — hydrothermal pipe — at the head of Sulphur Gulch (treeless area, upper right).

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Abstract

The Questa molybdenum mine (known locally as the Moly mine), 6 miles east of Questa, in the Taos Range of the Sangre de Cristo Mountains, Taos County, New Mexico, is unique in containing high-grade molybdenite ore in fissure veins, whereas in most other mines production is from low-grade, disseminated deposits. The true nature of the veins first was recognized in 1916. In 1920 the Molybdenum Corporation of America acquired the property, and the mine has been in almost continuous production since then. Total production to Jan. 1, 1956, was 18,095,000 pounds of molybdenite. Mining is by overhand, horizontal slicing in stull-supported stopes; concentration is by flotation.

The Taos Range is made up chiefly of Precambrian metamorphic rocks overlain by Tertiary volcanic rocks. In the vicinity of the mine, Precambrian amphibolites and quartz-biotite schist of the amphibolite complex are overlain by Cabresto metaquartzite, and all these units are intruded by Precambrian granite. Late Paleozoic and Mesozoic sediments crop out along the eastern edge of the range and in small scattered areas elsewhere in the range. At the mine, conglomerates, arkosic graywackes, siltstones, and limestones overlie the Precambrian and are correlated tentatively with the Pennsylvanian-Permian Sangre de Cristo formation. A thick sequence of Miocene (?) volcanics (the volcanic complex) overlies the older rocks. The lower series of this complex includes andesite and quartz latite flows, breccias, and tuffs (the andesitic series); these in turn are overlain by an upper series of rhyolite flows, breccias, and tuffs (the rhyolite series). Numerous dikes, sills, and small plugs of rhyolite and andesite may be the intrusive equivalents of this volcanic complex. Late Tertiary soda granite stocks and dikes intrude the older rocks. Quaternary alluvial gravels cover the valley bottoms and terraces, and mud-flows form fans in Red River Canyon at the mouths of some of the side gulches.

Folding is not an important structural feature of the Taos Range. Faults are common, the majority being divisible into three systems: (1) north trending thrust faults along the east edge of the range, active during late Cretaceous and early Tertiary time, with thrusting toward the east; (2) north to northwest trending high-angle frontal faults along the west edge of the range and associated parallel faults throughout the range, active during late Tertiary and early Quaternary time; and (3) east to northeast trending high-angle faults throughout the range, active during the Precambrian or Paleozoic, with later Tertiary and Quaternary movement along some faults. Fractures parallel the east to northeast trending fault system. The Precambrian rocks show foliation, which most commonly strikes N. 50° E. to N. 70° E. and dips vertically.

Important local structures are superimposed on the regional structures of the Taos Range, forming the structural pattern in which the ore deposits occur. The mine is located in a downfaulted zone several

miles wide, trending east, and extending across the range. In this zone, the Miocene (?) volcanics and older rocks have been downfaulted in an irregular pattern. This downfaulting occurred during and shortly following the extrusion of the volcanics. Some areas within the down-faulted zone were brecciated intensely during the faulting.

The soda granite stocks are localized along the downfaulted zone. The intrusion of the granite fractured and pushed aside the intruded rocks. The stocks themselves are fractured in an irregular pattern. Brecciation is common at the contact between the granite and the intruded rocks, but fracturing parallel to the contact occurs locally. This fracturing parallel to the granite contact is called sheeting throughout this report. The sheeting is well defined in the Questa molybdenum mine, forming the fissures in which most of the veins occur. The following theory is suggested to explain this sheeting and brecciation. After the outer shell of the granite stock solidified, the continued upward movement of the still-fluid core resulted in a stress couple between the resisting solidified shell and the plastic core. This stress resulted in fracturing and shearing of the solidified shell. Where weak volcanic rocks or favorably oriented regional structures existed in the country rock, and could relieve much of the stress, sheeting developed; where more resistant rocks were intruded, the solidified shell of granite was subjected to a larger fraction of the total stress and brecciation occurred.

Two types of Tertiary alteration have affected large areas. Hydrothermal solutions following the passageways provided by the more intensely brecciated areas in the downfaulted zone along Red River have altered the brecciated rocks, forming the "hydrothermal pipes" of this report. Weathering has formed striking bare yellow areas where these pipes crop out.

A halo of rock surrounding the soda granite stocks is propylitized. Precambrian schist, Pennsylvanian-Permian (?) sediments, and the Tertiary andesitic series are altered; other rock types are not affected appreciably. Feldspars are altered to epidote; the ferromagnesian minerals alter to chlorite and magnetite. Carbonates are present as cavity fillings, and pyrite is disseminated through the propylitized area.

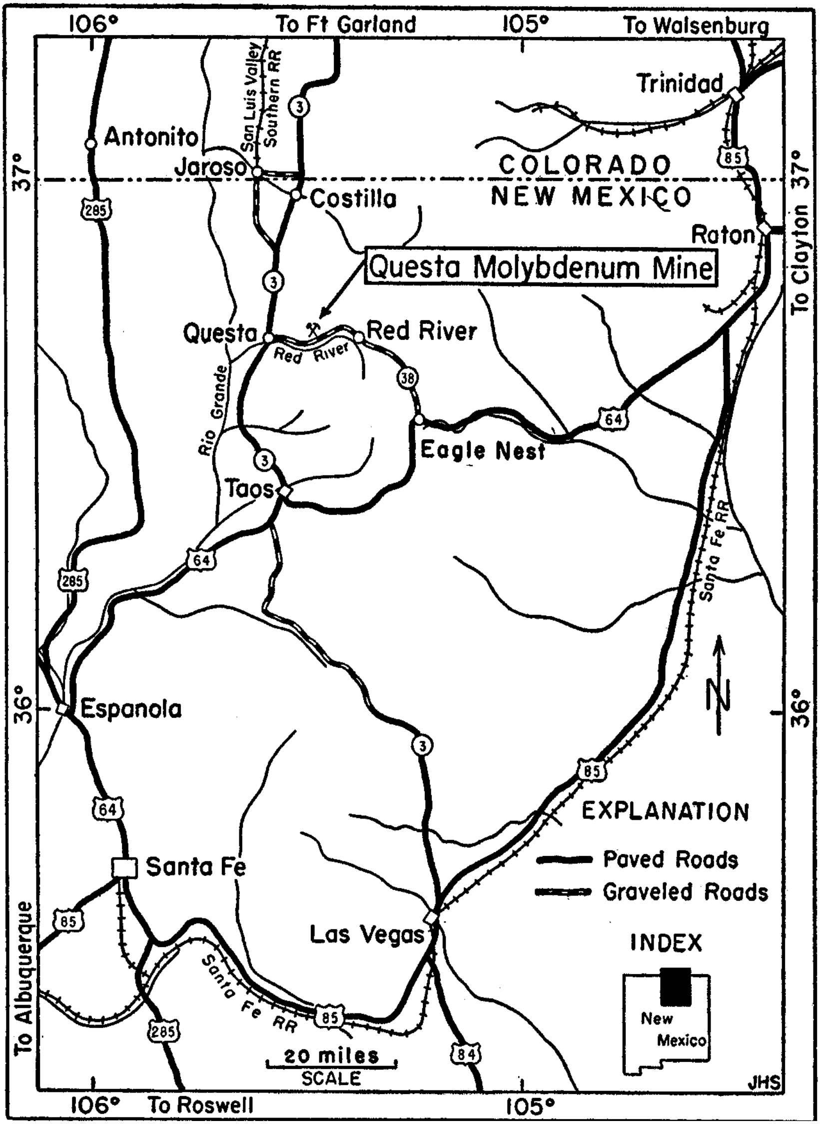
The Questa molybdenum mine is the only mine in the area. The ore occurs in the Sulphur Gulch soda granite stock along a locally east-ward striking, southward dipping contact with propylitized rocks. Most veins roughly parallel the contact, ranging in thickness from less than 1 inch to over 7 feet. In detail, the veins are complex. Commonly they pinch and split; at places they cross the granite contact and pass into the propylitized rock, where they die out. Individual veins are not continuous downdip or laterally, but their general position along the granite contact is taken by other veins. Steeply dipping veins are commonly thicker than the gently dipping ones, and therefore contain most of the ore shoots.

The veins are largely quartz and molybdenite, with locally abundant biotite, fluorite, pyrite, chalcopyrite, calcite, and rhodochrosite. The apparent order of deposition was: (1) quartz; (2) quartz, molybdenite, and biotite; (3) pyrite and chalcopyrite (some quartz and molybdenite); (4) fluorite; and (5) calcite and rhodochrosite. At any place along a vein, this sequence of mineralization may be repeated completely or in part. On the basis of its mineralogy, this deposit is classified as a hydrothermal deposit of mesothermal intensity. Wall-rock alteration is not intense; usually it extends only a few inches from the veins. Silicification is common, feldspar is locally altered to montmorillonite and sericite, and disseminated pyrite is scattered through the rock.

The veins were deposited as cavity fillings during late Tertiary time, soon after the intrusion of the soda granite, when hydrothermal solutions from the granite entered the sheeted zone. Where the sheeting dips steeply, the fractures were opened the widest, forming the space in which the ore shoots most commonly are found.

Many small mineral deposits have been prospected unsuccessfully for molybdenum, gold, silver, copper, lead, and zinc. Nearly all these deposits apparently are late Tertiary and were formed by hydrothermal solutions emanating from the soda granite intrusives. All the minerals present in the small deposits are present in the Questa molybdenum deposit, but in varying proportions. There is a rough zonal arrangement of the minerals outward from the stocks; the higher temperature minerals are most abundant near the centers.

Future possibilities for mineral production in the area are poor when considered in terms of present economic conditions. The hydrothermal pipes should be studied in more detail for possible low-grade, disseminated copper deposits. Large low-grade, disseminated molybdenite deposits of minable size may occur around the margins of the Tertiary granite stocks; known deposits are too small to be mined profitably. Although the possibility of finding other important ore de-posits is remote, large tonnages of molybdenite-bearing rock occur in small scattered areas and could be mined at high cost if a critical need should arise. Most mineral deposits in this area are concentrated in or near the tops of Tertiary granite stocks and, to a lesser degree, smaller intrusives. Such areas, especially if they show open continuous fracturing, are the most favorable for exploration.



INDEX MAP SHOWING THE LOCATION OF THE QUESTA MOLYBDENUM MINE.

Figure 1

Introduction

PURPOSE AND SCOPE

The Questa molybdenum mine, known locally as the Moly mine, is unique in containing high-grade molybdenite ore in large veins, whereas nearly all other production is from low-grade, disseminated deposits. This report describes the geology of the Questa molybdenum mine and the other nearby prospects in detail, relates this detailed picture to the regional geology, and discusses the possibilities of future mineral production in the surrounding area, offering practical guides thereto. It is hoped that the ideas presented here will be useful also in locating and evaluating other mineral deposits with similar features.

METHODS OF INVESTIGATION

The writer first became interested in the mine during the summer of 1950 while serving as an assistant to Philip McKinlay, of the New Mexico Bureau of Mines and Mineral Resources, who was mapping the Taos Range of the Sangre de Cristo Mountains.

A total of 14 months was spent during the years 1951-55 examining the mine and surrounding area. Accessible workings were mapped on a scale of 1 inch to 20 feet; the surface over the mine (area of pl 2) was mapped on a scale of 1 inch to 500 feet. Maps of Molybdenum Corporation of America were used as bases.

For the detailed surface mapping, a dividing line between outcrop and cover was set up arbitrarily. The following rules were made and followed as closely as possible during mapping. All outcrops over 50 by 50 feet in size were delineated. All dikes over 1 foot wide also were mapped. Smaller isolated outcrops that could not be shown on the map were included with the cover. Locally small, isolated outcrops surrounded by a large area of cover (soil, talus, etc.) or other rock types, but important to the overall geologic picture, are shown on the map and are exaggerated slightly in size. A number of smaller outcrops spread over an area larger than 50 by 50 feet, but not more than 20 feet apart or covering less than 25 percent of the area, were mapped as one outcrop.

An area of approximately 20 square miles in the vicinity of the mine (area of fig 26) was mapped on a scale of 1 inch to 1 mile by a series of reconnaissance traverses designed to outline the important geologic features. Most of the prospects in the area were mapped by Brunton compass and tape.

A large number of specimens of the different rock types and vein materials were collected, from which over 150 thinsections and 7 polished sections were made and examined. The laboratory work, drafting, and writing were done in Socorro, with the aid of the facilities of the New Mexico Bureau of Mines and Mineral Resources.

PREVIOUS WORK

The deposit was described initially in a brief paper by Larsen and Ross (1920). A more detailed study was made by Vanderwilt (1938), who spent 4 months at the mine, mostly in underground studies. McKinlay (1956) mapped the geology of the Taos Range, in which the mine is located. Vanderwilt's paper and McKinlay's work were the foundation for the more detailed investigation made for this report.

ACKNOWLEDGMENTS

The writer is indebted to members of the Questa molybdenum mine staff who helped in so many ways to make this report possible, including Mr. J. B. Carman, former general manager; Mr. A. L. Greslin, general manager; Mr. E. William O'Toole, mine clerk; Mr. Francis C. Rowe, mining engineer; Mr. Ben Horner, former mine foreman; and Mr. Jose Varela, mine foreman.

Sincere appreciation is due Dr. Eugene Callaghan, director of the New Mexico Bureau of Mines and Mineral Resources, for his guidance and support, to Dr. Edmund H. Kase, Jr., Dr. Robert H. Weber, and Mr. Max E. Willard for critically reading the manuscript and making many helpful suggestions, and to Dr. Brewster Baldwin for critically checking and making suggestions for Plate 2. Other members of the Bureau staff have checked various parts of the report and helped in many other ways.

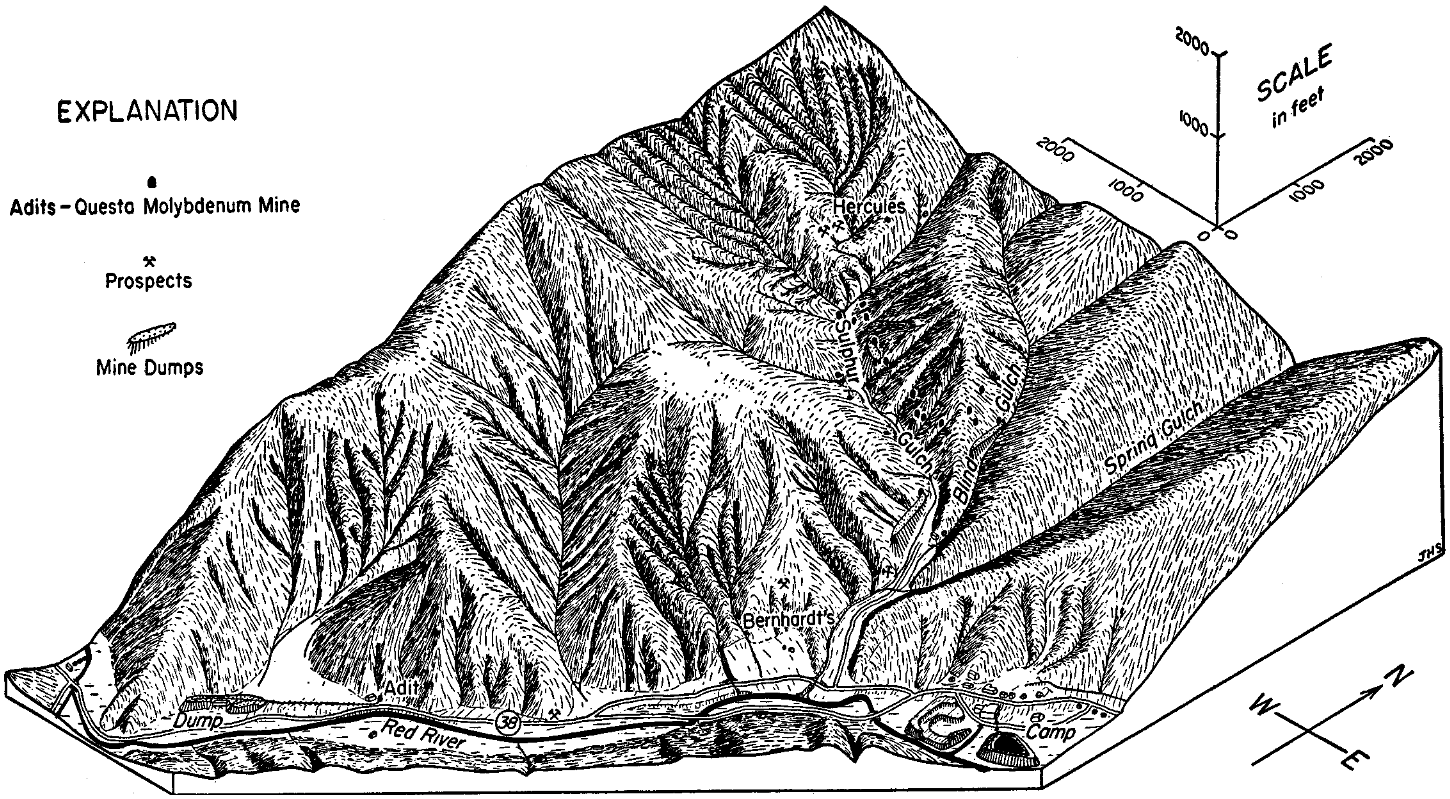
Mr. Charles Treseder did all the photography necessary in preparing the figures and plates.

Field expenses for two summers were paid by the Field Assistance Fellowship Fund of the New Mexico Bureau of Mines and Mineral Resources. A grant from the Isadore Aaron Ettlinger Memorial Fund of Harvard University provided miscellaneous expenses for one summer.

A special word of acknowledgment is due my wife Constance. She was my field assistant, did all the necessary secretarial work, and has helped in so many other ways to make the completion of this study easier and more enjoyable.

Space will not permit the mention by name of the many other individuals who helped make this report possible. Their help is gratefully acknowledged.

Figure 2



ISOMETRIC DIAGRAM OF THE QUESTA MOLYBDENUM MINE AREA.
The main haulage adit (Moly tunnel) is labeled "adit."

GEOGRAPHIC FEATURES

LOCATION AND ACCESSIBILITY

The Questa molybdenum mine is located on the western slope of the Taos Range of the Sangre de Cristo Mountains, Taos County, New Mexico (see fig 1). The various mine portals range in altitude from 8,000 to 9,000 feet. The mill, camp, haulage adit, and dump are distributed along Red River Canyon, 5-6 miles east of Questa. The adits to the older workings are along Sulphur Gulch, an intermittent tributary of the Red River (see fig 2).

State Highway 38, a graded gravel road, passes the mine and camp. It follows Red River Canyon and connects the mine with Questa, 6 miles to the west, and with the town of Red River, 6 miles to the east (see fig 1). Paved highways lead from Questa to Taos, New Mexico (to the south), and Fort Garland, Colorado (to the north). East of Red River, State Highway 38 crosses Red River Pass and continues to Eagle Nest, a distance of 19 miles. From Eagle Nest, paved highways lead to Taos and Raton, New Mexico (see fig 1). All other roads are primitive and in many places ungraded and badly washed.

The nearest railroad is at Jarosa, Colorado, 25 miles north of Questa. Jarosa is the southern terminal of the San Luis Valley Southern Rail-way, which connects with the Denver and Rio Grande Western Railroad at Blanca, Colorado (see fig 1). Only freight service is available.

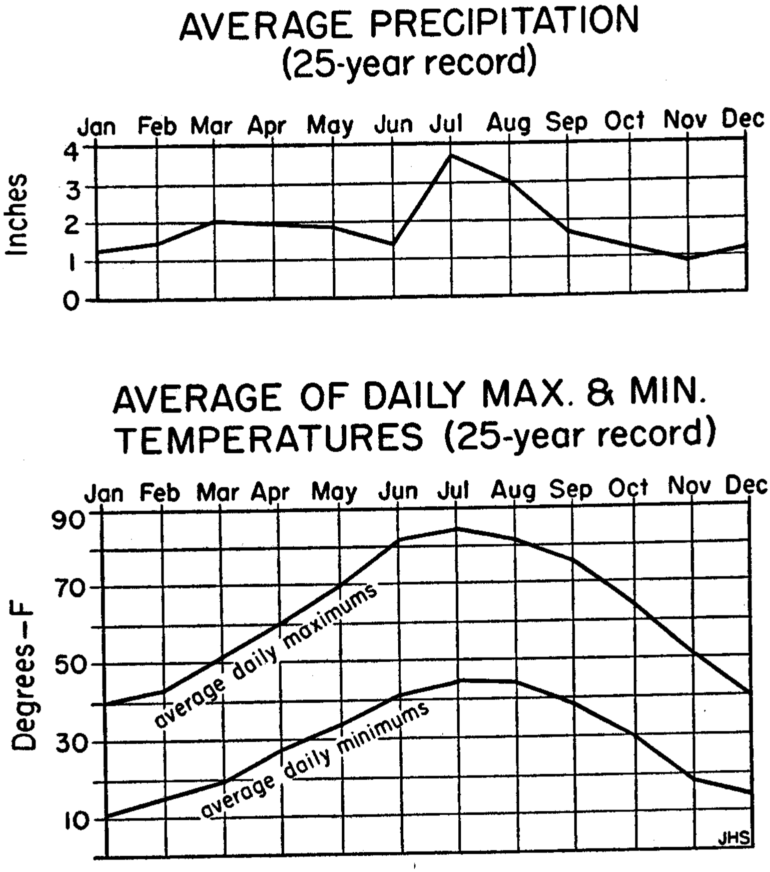
PHYSICAL FEATURES

The Sangre de Cristo Mountains, in which the mine is located, are part of the Southern Rocky Mountains physiographic province. The maximum relief in the Taos Range of these mountains is over 6,000 feet; local relief at the mine is over 3,500 feet. Wheeler Peak (elevation 13,155 ft), which lies 10 miles southeast of the mine, is the highest point in New Mexico.

The surface over the mine is drained by intermittent tributaries of the Red River (see fig 2); the largest of these is Sulphur Gulch. The Red River (called the Rio Colorado or Colorado Creek in old reports) flows westward into the Rio Grande, 4 miles west of Questa. Where the Red River passes the mine, it has an average gradient of 2.0 percent. In comparison, the lower mile of Sulphur Gulch has an average gradient of 11 percent.

CLIMATE

The climate at the mine is similar to that of the Rocky Mountains of Colorado, but is modified by the semiarid plateau to the west (see fig 3). Summer is characterized by hot days and cool nights. The rainy season is during July and August, some rain occurring also in May and June. Heavy, but localized, rains during July and August cause flash



CLIMATIC DATA FOR THE QUESTA MOLYBDENUM MINE AREA.

(Rainfall from *Climate and Man,* 1941 Yearbook of Agriculture, U. S. Dept. of Agriculture; temperatures from Molybdenum Corporation of America records.)

Figure 3

floods and mud-flows which often block the highway and occasionally damage the mine plant.

Fall is a period of warm days and cold nights. The first killing frost usually is in mid-September, and occasional snows can be expected.

Winters are mild, and the roads seldom are blocked by snow. The heaviest snowfall is limited to the higher parts of the mountains. Although the winters are long, protracted periods of freezing weather are limited to December through February. There are many sunny days, and the ground is often bare in areas exposed to the sun.

Spring arrives in late May with warmer, windy weather. Dust storms are common. The last killing frost is in mid-June. The aspen, willow, and cottonwood trees leaf out in late May or early June.

HISTORY AND PRODUCTION

Prior to 1916 the bright-yellow molybdic gossan at the outcrops of the veins was thought to be sulfur, giving the name Sulphur Gulch to the valley in which the outcrops occur. The black molybdenite was mistaken for graphite, and the mineral was mixed with grease and used locally to lubricate wagon wheels. It also served as a shiny shoe polish, which unfortunately rubbed off on everything.

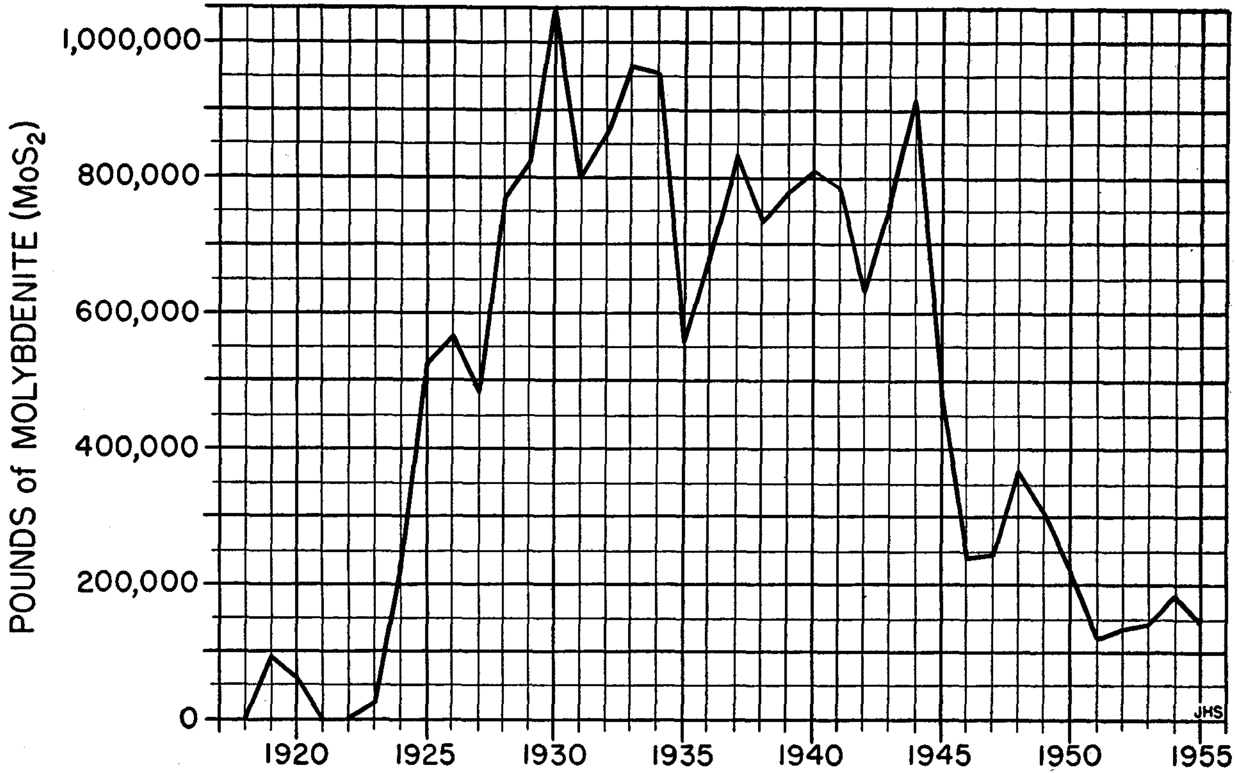
In 1916 or 1917 Jimmy Fay, a prospector having claims along Sulphur Gulch, sent a specimen of ore containing molybdenite to San Francisco to be assayed for gold and silver. The beginning of World War I had greatly increased the demand for molybdenum, and assayers were becoming aware of the value of the mineral molybdenite. When the assayer returned his report, he mentioned the presence of molybdenite and its value.

Some claims were located during the war. The Western Molybdenum Company, of La Jara, Colorado, was organized but did little to develop the claims. In November 1918, the R and S (Rapp and Savery) Molybdenum Company, of Denver, was formed and took over seven claims of the Western Molybdenum Company, filing additional claims. Development work was done throughout the winter of 1918-1919; production began in the spring. The ore was treated at a converted gold mill on the Red River, about 4 miles above the mine.

The Molybdenum Corporation of America was incorporated in 1920, in the same year acquiring the property of the R and S Molybdenum Company. Mining was discontinued during the depression of 1921; however, development work was continued. Operations were on a small scale until 1923, when a mill was built on the present mill site. In 1929, this mill was rebuilt. Because of the inaccessible location of the workings, burros were used to haul the ore from the portals to the bottom of Sulphur Gulch.

By 1941 mining and exploratory work had extended to such distances below and to the west of the lowest adit, Z tunnel level, that the present haulage adit (Moly tunnel) was driven to facilitate transporta-

Figure 4



MOLYBDENITE CONCENTRATES PRODUCED FROM THE QUESTA MOLYBDENUM MINE. (Data from Vanderwilt, 1938; Annual Reports of the State Inspector of Mines; and Mineral Yearbooks of the U. S. Bureau of Mines.)

tion, ventilation, and drainage. This adit was driven north from the Red River for 1 mile, where it joined the lowest level in the mine (8,000 ft elevation). The mill was rebuilt again at about the same time. By 1955 the workings had reached a point 240 feet below the haulage adit.

Total production to January 1, 1956, was 18,095,000 pounds of molybdenite (MoS_2). See Figure 4 for production by years.

Other companies have attempted to mine molybdenite in the surrounding area, but with little success. In 1924, the Hercules Molybdenum Corporation built a camp at the head of Sulphur Gulch. Some development work was done, but apparently little ore was found; the company abandoned the camp the following year.

More recently several adits, the BJB prospects, were driven by Bill Wilde along Goat Hill Gulch, 3 miles west of the mine. Some ore was mined, but the prospects no longer are being worked.

Dan Cisneros and Juan Aragon, of Questa, worked a group of claims, known as the Horseshoe or Bear Creek claims, for many years. These claims are located along the south side of Red River Canyon where it meets Bear Canyon, 4 miles west of the Questa molybdenum mine. No ore has been milled, although a few tons have been stockpiled.

The late Leroy Bernhardt had a group of claims along the lower part of Sulphur Gulch. A good vein of silver ore was found, but proved to be limited in extent. Only traces of molybdenite were present.

SURFACE PLANT AND MINE

The present camp consists of an office building, which also contains the warehouse and commissary, a mill, assay laboratory, cookhouse, bunkhouse, school, and houses for employees (see fig 2).

At the haulage-adit portal, 1 mile west of the camp, there is a building containing a lamp room, change room, blacksmith shop, and the compressor and generating equipment. Another small building is used for cutting mine timber. Surface track from the adit continues a quarter of a mile down the canyon to the mine ore bins and dump (see fig 2).

The mine has over 35 miles of workings, with a vertical extent of 1,200 feet. The mine is divided into three parts: (1) the Sulphur Gulch north workings, located north of Sulphur Gulch; (2) the Sulphur Gulch south workings, which include all workings south of Sulphur Gulch mined through adits on the gulch; and (3) the Tunnel shaft workings, which include all workings mined through the Tunnel shaft (a vertical winze) and the Moly tunnel. The relationship of the levels to each other and to the geology is shown by Plate 1 (in pocket).

MINING METHODS

PROSPECTING AND EXPLORATION

The veins do not form bold outcrops but are easily located by the bright canary-yellow color of the ferrimolybdite in the gossan. Underground exploration is carried on by drifting or raising along veins that have known ore shoots or appear favorable, and by crosscutting and raising to intersect known veins or explore new areas. Diamond drilling is not used.

These factors are used as guides: (1) Most of the ore shoots are near or on the contact of the granite with the altered rocks. (2) Ore-grade mineralization is usually weak in the "tight" altered rocks and strong in the more "open" granite near the contact. (3) Veins are usually thicker where the contact dips steeply. (4) Most of the ore is found where the contact has an east-west trend and a south dip. (5) Dikes of granite near the main granite mass often have good ore shoots.

Electrical prospecting (Sunberg and Nordstrom) was tried in 1917. Good ore was found in several places indicated by the survey, but many of the indications turned out to be gouge zones containing water.

DEVELOPMENT

The mine is developed by adits, drifts, crosscuts, raises, and winzes at intervals of 15-100 feet vertically. There is no standard pattern because of the irregular vein systems. Exploration openings are used wherever possible.

Drifters are used to drill a 15-hole, bottom V-cut round; this is loaded with a total of 45 sticks of 40-percent gelatin dynamite, and normally breaks 4½ feet. Stopers are used to drill center V-cuts when raising; there is no standard drilling pattern for a round. Machine mucking is used in all easily accessible drifts; hand mucking is employed in drifts on intermediate levels inaccessible to mucking machines. The rock, when granite, is moderately hard and usually stands well without timbering; the altered volcanics are usually soft and broken and require considerable timber.

STOPING

Stoping methods are adapted to local conditions. Most of the ore shoots are mined by overhand methods in open, stull-supported stopes. Where the hanging wall is weak, back filling or pillars are used for support. Much of the stoping is done by hand drilling, which is possible because of the soft vein material. This permits highly selective mining. The ore occurs so irregularly in the veins that stoping practices often must be changed every round. In narrow veins, the foot wall is broken away from the ore, and the ore shot down separately. In wide veins, no breaking of the wall rock is needed, and light shooting or picking is used. If the vein splits, the waste in between often is removed first. There are numerous other variations. Where the veins are more regular, machine drilling is used.

Reserves cannot be estimated, since mining closely follows exploration and development. Only the Tunnel shaft workings are being mined actively.

TRANSPORTATION

The ore and waste are hand-trammed to the Tunnel shaft in 1-ton end-dump cars, hoisted, and dumped into 3-ton rocker-dump cars. A storage-battery engine pulls these larger cars out the mile-long haulage adit and over the surface track to the dump and ore bins.

DRAINAGE AND VENTILATION

Water from the levels above the haulage adit drains by gravity out the various adits. Water from the workings below the haulage adit drains into a sump at the bottom of the Tunnel shaft; then it is pumped up the shaft and flows out the adit. Ventilation is natural.

MILLING METHODS

The present mill has a capacity of 50 tons of ore per day. Two types of material are milled: (1) ore from the mine, and (2) tailings from the older of two tailing ponds. Ore is trucked to the mill and stored in bins which feed through a crusher into a ball mill. The tailings are loaded into trucks by a shovel, and then hauled a short distance to bins which feed directly into the ball mill. The ball mill is run in a closed circuit with a classifier; the overflow goes to the rougher flotation cells, which remove most of the waste as tailings. The concentrates from the roughers go to the regrind mill, which is in a closed circuit with a classifier; the overflow goes to the cleaner flotation cells, which remove most of the remaining waste. The concentrates, averaging 85 percent MoS_2, are dewatered by a thickener tank, filter, and dryer, and then sacked and shipped to the company plant at Washington, Pennsylvania, where they are made into ferromolybdenum or calcium molybdate for use in alloys.

Geologic Setting

DESCRIPTIVE GEOLOGY

INTRODUCTION

The Taos Range of the Sangre de Cristo Mountains is made up chiefly of Precambrian metamorphic (amphibolites, schists, and quartzites) and intrusive (granite) igneous rocks overlain by late Tertiary volcanic rocks (andesite, quartz latite, and rhyolite flows, breccias, and tuffs) and interbedded sediments. Permian and Pennsylvanian sediments (arkosic sandstone and conglomerate, shale, and limestone) occur along the eastern edge of the range; also, a few poorly exposed outcrops of sedimentary rocks in other areas probably are late Paleozoic in age. Tertiary granitic rocks intrude the older rocks (see figs 5 and 6).

All the rock types, except the sediments, are well represented in the vicinity of the Questa molybdenum mine (see fig 5). Sediments, probably of late Paleozoic age, are present, although evidence for their correlation and dating is poor. None of the other rock units could be dated accurately because of the lack of fossil or other direct evidence of their age.

PRECAMBRIAN

Because of the poor exposures and complex relationships of the Precambrian rocks, only the granite and quartzite were mapped as separate units; the other Precambrian rocks are predominantly amphibolites, and were mapped as a single unit, the amphibolite complex. The metamorphic rocks are assigned tentatively to the Precambrian, but only because of their position below late Paleozoic (?) rocks, their metamorphic character, and their similarity to more accurately dated Precambrian rocks elsewhere in the Rocky Mountains. It must be emphasized that metamorphism alone is not a good criterion for Precambrian age.

Amphibolite Complex

The amphibolite complex covers large areas along the south side of Red River Canyon, both east and west of the mine camp (see pl 2). North of the Red River, these rocks are more limited in extent. One area of outcrop, approximately 100 feet above the canyon floor, extends west from the mouth of Sulphur Gulch to the main haulage adit (Moly tunnel). In the mine, quartz-biotite schist of the amphibolite complex is exposed in the main haulage adit (Moly tunnel). Rocks of this complex are found also in the long crosscuts extending south from the main drift of Z tunnel level, although here alteration by the Tertiary soda granite makes identification difficult (see pl 1). Vanderwilt (1938, p 610) reports that these rocks are exposed also above Z tunnel level in the east ends of No. 3 and W levels, where the workings are now caved.

The base of the complex is not exposed. The total exposed thickness in the vicinity of the mine is probably several thousand feet, although no accurate measurements could be made.

The amphibolite complex includes many varieties of amphibolite and interlayered quartz-biotite schists. The complex is not resistant to weathering, and areas underlain by these rocks usually are covered with rocky soil or talus. At a distance, the few outcrops appear darker gray than any of the other rock types, except some of the andesitic volcanics. Outcrops commonly are stained brown. A few outcrops contain alternating layers of quartz-biotite schist and amphibolite; these layers may represent bedding. No other primary structures were noted.

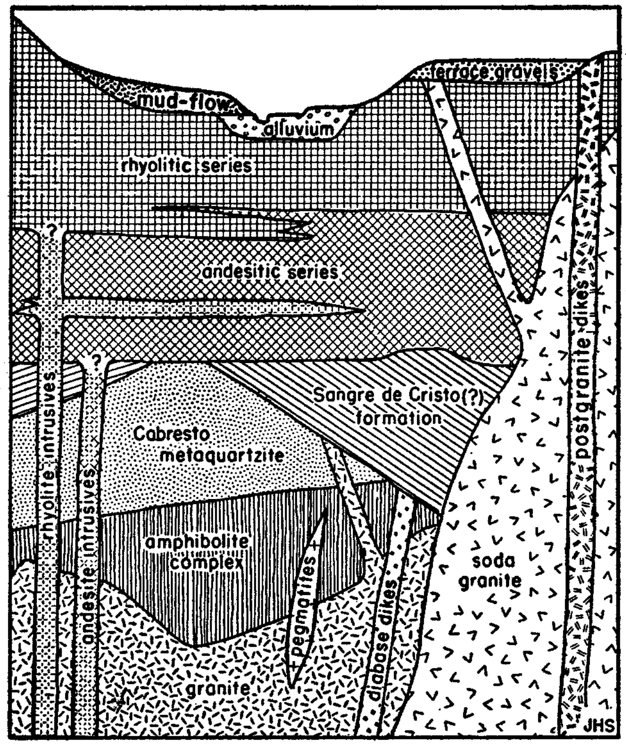
In hand specimen the rocks which have been grouped together in the amphibolite complex are massive to foliated, range from black to dark green, usually with specks or bands of white, and can be separated roughly into four varieties: (1) massive, coarse-grained; (2) massive, medium-grained; (3) gneiss; and (4) coarse-grained schist.

The massive, coarse-grained amphibolites contain large, black hornblende crystals up to 3 cm across in a fine-grained phaneritic ground-mass of hornblende and andesine (?). In thinsection large, green, subhedral crystals of hornblende, with no preferred orientation, are set in a groundmass of smaller hornblende crystals, cloudy andesine (?), and minor quartz. Epidote, in clumps of small anhedral grains, replaces the hornblende; many of the larger hornblende crystals are poikiloblastic, with inclusions of epidote and magnetite. The andesine (?) is highly altered to clay and sericite. A typical thinsection contains 70 percent hornblende, 15 percent andesine (?), 10 percent epidote, 3 percent quartz, and 2 percent magnetite, by volume.

The massive, medium-grained amphibolites are equigranular aggregates (average grain size: 3 mm) of black hornblende and white plagioclase, closely resembling a diorite in appearance. In thinsection (see fig 7) large, ragged, unoriented, green hornblende in groups or individual crystals is set in a groundmass of cloudy, lathlike to irregular aggregates of twinned andesine and small, irregular quartz grains. Magnetite is scattered through the hornblende, commonly along the hornblende cleavage. In some specimens, the hornblende is altered to chlorite and is accompanied by more abundant magnetite. In some sections the hornblende is poikiloblastic, with inclusions of quartz (?) or plagioclase (?). The andesine is altered to clay and sericite. Thinsections examined contain 45-60 percent hornblende, 30-40 percent andesine, 5 percent quartz, and 5-10 percent magnetite, by volume. Epidote probably occurs in rock of this variety, but was not noted in the sections examined.

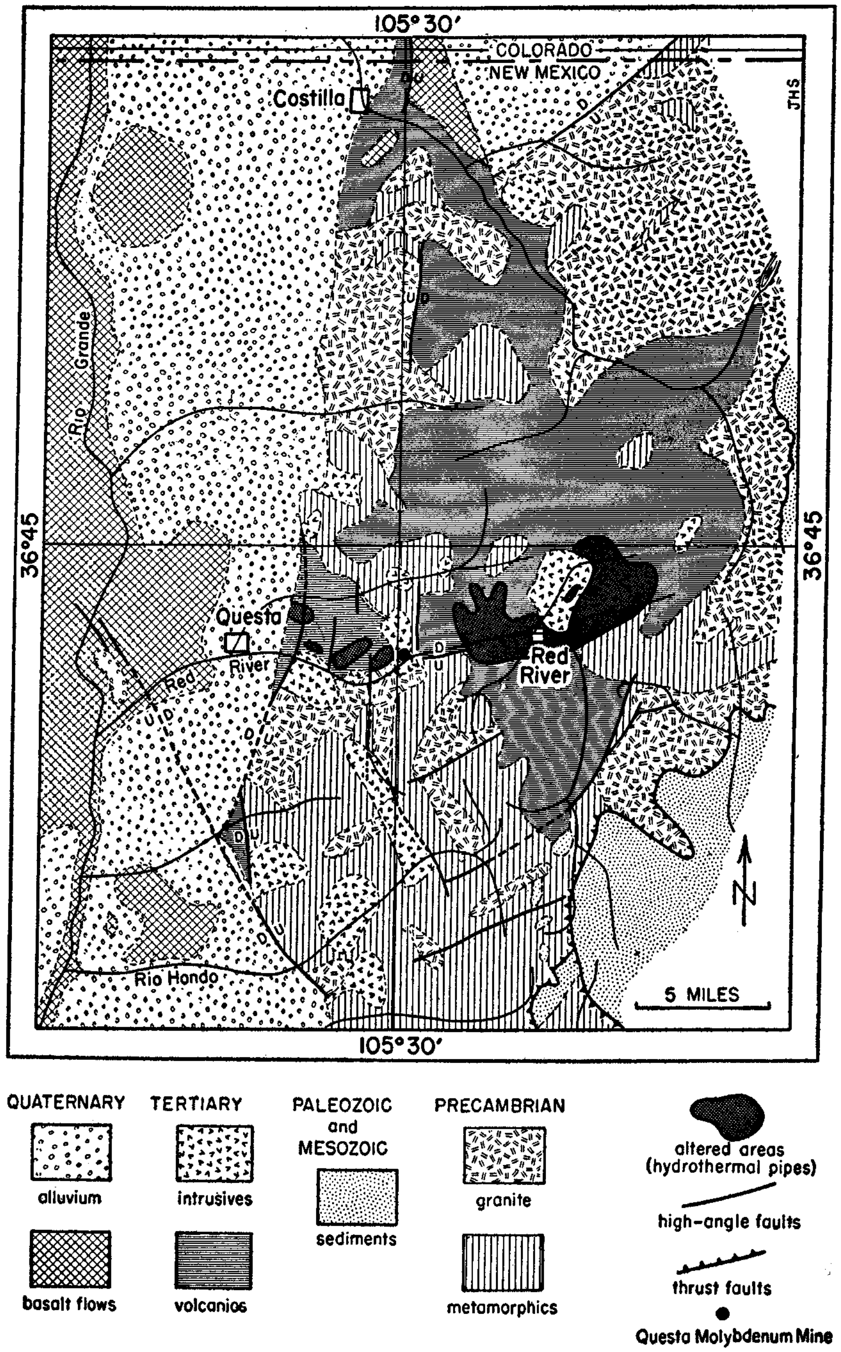
The amphibolite gneisses are coarsely foliated with oriented trains of black hornblende and white plagioclase. If the hornblende and plagioclase were not oriented, this rock type would resemble closely the massive, medium-grained amphibolite. In thinsection, small to medium-sized, green, subhedral hornblende, paralleling the plane of foliation, is set in a cloudy, granular aggregate of smaller anhedral andesine (?). Quartz grains are scattered through the andesine (?). Although the

Figure 5



AGE	UNIT		LITHOLOGY
Quaternary	alluvium		gravel, sand, silt—valley fill
	mud-flow		unsorted gravel, sand, silt
	terrace gravels		gravel
Tertiary	postgranite dikes		porphyritic quartz monzonite to monzonite
	soda granite		mostly porphyritic to inequigranular quartz-orthoclase-albite-biotite granite, some aplitic and pegmatitic granite
	andesite and rhyolite intrusives		andesite and rhyolite of varying composition and texture
	volcanic complex	rhyolitic series	light-colored rhyolite flows, breccias, and tuffs
		andesitic series	dark-colored andesite flows, breccias, and tuffs
Pennsylvanian–Permian(?)	Sangre de Cristo(?) formation		massive, gray to grayish-red conglomerate, sandstone (arkosic graywacke), and siltstone usually gradational with one another; thin limestone lenses
Precambrian	diabase dikes		black with aphanitic walls and phaneritic centers of plagioclase and augite having an ophitic texture
	pegmatite dikes		coarse quartz, albite, and muscovite
	granite		gneiss, gneissic, or massive medium-grained quartz-microcline-plagioclase-biotite granite
	Cabresto metaquartzite		massive coarsely crystalline glassy to milky quartz
	amphibolite complex		amphibolite gneiss and schist of hornblende, andesine, quartz, and epidote; and quartz-biotite schist

GENERALIZED ROCK SECTION OF THE QUESTA MOLYBDENUM MINE AREA.



GENERALIZED GEOLOGIC MAP OF THE TAOS RANGE AND TAOS PLAIN.
The volcanics include interbedded sediments. (Modified from McKinlay, 1956, pl 1 and unpublished maps.)

Figure 6

trains of hornblende follow the foliation, the individual crystals have a more random orientation. The larger, ragged hornblende is commonly poikiloblastic, with inclusions of quartz (?), and usually is altered to chlorite and magnetite. The andesine (?) shows twinning and alteration to clay and sericite. Thinsections examined contain 35-55 percent hornblende, 40-55 percent andesine (?), 10-15 percent quartz, and 5 percent magnetite.

The amphibolite schist is a finer grained variety of the amphibolite gneiss. In thinsection, this rock closely resembles the gneiss, but is finer grained.

The quartz-biotite schists range from dense black to gray, with thin, dark layers between the thicker, lighter colored layers. The gray variety resembles amphibolite schist. In thinsection (see fig 7), granular aggregates of quartz grains and some andesine (?) contain trains and individual flakes of green or brown biotite; this biotite is oriented parallel to the planes of schistosity. Most sections contain scattered apatite; one section contains several percent of euhedral tourmaline. The biotite is altered to chlorite and magnetite. The magnetite commonly is streaked along the chlorite cleavage and altered in part to hematite. Andesine shows twinning and minor alteration to clay and sericite. Where intruded by soda granite, the biotite is altered to sericite, and blebs of pyrite are scattered through the rock. Thinsections examined contain 40-60 percent quartz, 30-40 percent biotite, 5 percent magnetite, 5 percent andesine, and 0-5 percent chlorite. One outcrop of a quite different variety of quartz-biotite schist was noted. The rock resembles the gray variety of schist, except that blebs of magnetite or ilmenite up to 10 mm in size (long dimension), with white rims up to 5 mm wide, dot the rock. The blebs and rims are commonly elongate in the plane of schistosity. In thinsection a granular aggregate of approximately equal percentages of twinned andesine and quartz contains trains and individual flakes of brown biotite, and large, ragged magnetite grains, which are often elongate in the plane of schistosity. Around the magnetite grains, an area over twice as wide as the grain contains no biotite; all other areas of the thinsection contain much biotite. Apatite is scattered throughout the section.

The amphibolite complex probably is the oldest rock unit exposed in the area. Its relation to the Cabresto metaquartzite is not clear, although in the very few outcrops where both appear the quartzite apparently overlies the amphibolite complex. The Precambrian granite intruded the amphibolite complex and was intruded by dikes of all the Tertiary igneous rocks. Where the Cabresto metaquartzite is missing, the amphibolite complex is overlain unconformably by Pennsylvanian-Permian (?) sediments, or by the late Tertiary volcanic complex.

The amphibolite complex is equivalent to part of the "undifferentiated metamorphics" of McKinlay (1956, pp 7-8); his amphibolite and hornblende schist are the amphibolites of this report, and his quartz-mica schist the equivalent of the quartz-biotite schist of this report. The schist and gneiss of Vanderwilt (1938, p 610) are the quartz-biotite schists of this report; the coarse hornblende gneiss (Vanderwilt, 1938, p 611) is the amphibolite gneiss. Montgomery (1953) describes similar Precambrian rocks in the Sangre de Cristo Mountains to the south; such Precambrian rocks are common throughout the Rocky Mountains.

The amphibolite complex may be in part metamorphosed mafic volcanics (amphibolites) and interlayed metamorphosed sediments (quartz-biotite schist). Primary textures and structures are obscured; positive evidence of the character of these rocks before metamorphism is not available.

Cabresto Metaquartzite

The Cabresto metaquartzite was named by McKinlay (1956, p 8) for exposures along Cabresto Canyon, 3 miles north of the main-haulage-adit portal.

In the vicinity of the mine, the Cabresto metaquartzite is limited to an area at the head of Blind Gulch on the divide between the Red River and Cabresto Creek drainages (see fig 26). This belt of quartzite extends north across Cabresto Canyon and includes the type locality of the Cabresto metaquartzite. No quartzite has been noted in the mine.

The thickness of the metaquartzite could not be measured in the vicinity of the mine. McKinlay (1956, p 8) reports thicknesses ranging from 200 to over 1,000 feet in the quadrangle to the north.

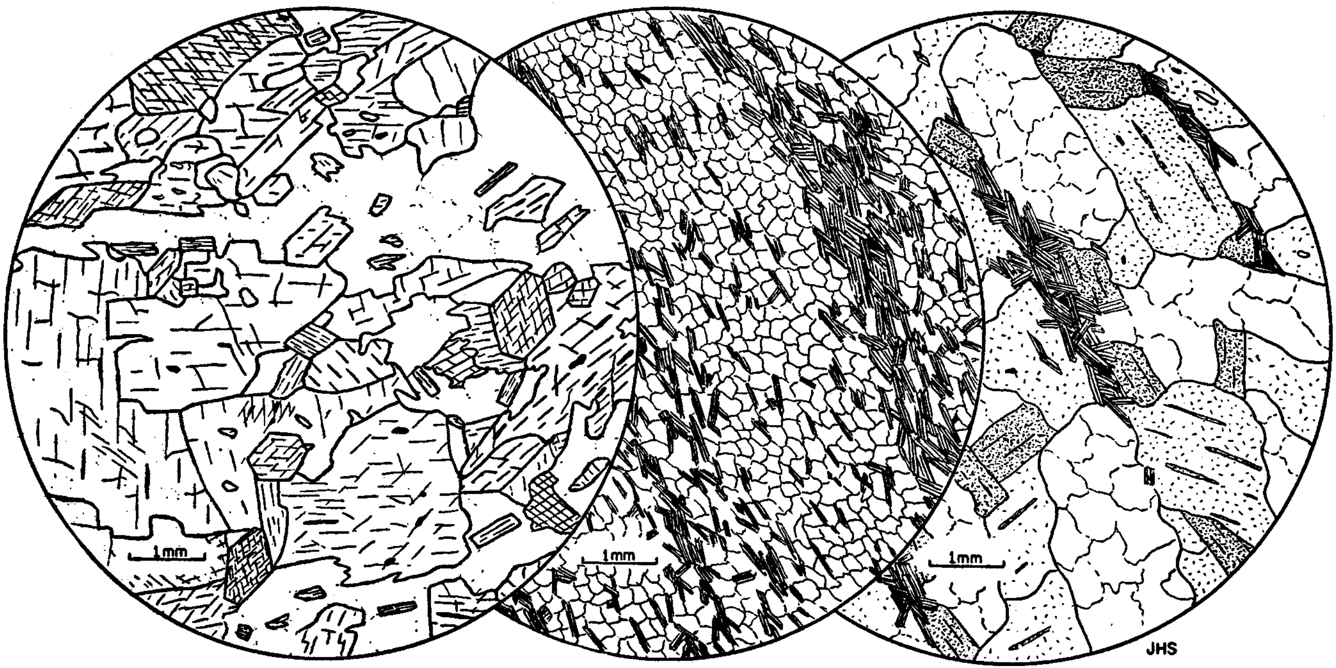
The metaquartzite commonly forms small but prominent cliffs with smooth vertical faces. At a distance the outcrops appear gray to reddish gray. On inspection the rock is seen to be made up of coarsely crystalline glassy to milky quartz containing scattered muscovite flakes, which features readily distinguish it from all other rock types in the area. Two- to 10-foot layers of massive quartzite are separated by thin bands of muscovite or biotite-magnetite-garnet. Streaks of magnetite are common in the massive quartzite and parallel to the thin bands mentioned above; they give the quartzite a faintly schistose appearance.

In thinsection the rock is a granoblastic mosaic of quartz grains, commonly with undulatory extinction, containing scattered interstitial muscovite flakes. Minor magnetite, sillimanite, tourmaline, and kyanite commonly are present. In some sections the quartz grains show a rough orientation of their long dimensions. Original quartz-grain boundaries and cement are destroyed.

The metaquartzite apparently overlies the Precambrian amphibolite complex, and is in turn overlain unconformably by the Pennsylvanian-Permian (?) sediments. It is dated tentatively as Precambrian because of its metamorphic character and similarity to other Precambrian quartzites of the Rocky Mountains.

The thick metaquartzites throughout the Taos Range of the Sangre de Cristo Mountains have been assigned tentatively to this unit by McKinlay (1956, p 8). Gruner (1920) describes these quartzites in the southern part of the Taos Range; Vanderwilt (1938, p 611) mentions

Figure 7



PRECAMBRIAN ROCKS.

MASSIVE, MEDIUM-GRAINED AMPHIBOLITE

Minerals are hornblende (with cleavage), andesine (white), quartz (white), and magnetite (black).

QUARTZ-BIOTITE

GNEISSIC GRANITE

Minerals are quartz (white), microline (lightly mottled), albite (darker mottled with cleavage), biotite, and magnetite.

their occurrence near the Questa molybdenum mine. Montgomery (1953) reports similar quartzite in the Picuris Range of the Sangre de Cristo Mountains to the south.

Granite

Precambrian granite covers two large areas in the vicinity of the mine (see p12). One of these is north of the highway, opposite the mouth of Columbine Canyon; here it forms rough, vertical cliffs over 150 feet high. The other area is exposed along Red River Canyon between the mouth of Sulphur Gulch and the main haulage adit. Here the Precambrian granite forms pinnacles, knobs, and low cliffs separated by talus slopes and soil. Precambrian granite is exposed in the mine along the first thousand feet of the main haulage adit.

In the vicinity of the mine, the granite can be divided into three varieties: (1) granite gneiss; (2) gneissic granite; and (3) massive granite. All three varieties have the appearance of a typical equigranular to inequigranular, coarse- to medium-grained granite, differing mainly in the amount of biotite and the degree to which the biotite is alined to form the foliation. The three varieties are gradational with one another. The granite gneiss has abundant biotite in elongate aggregates, which form well-defined foliation; the gneissic granite has less biotite in smaller aggregates, which form crude foliation; and the massive granite has still less biotite in irregular-shaped aggregates, which show no foliation in hand specimen. Large (up to 0.5 cm), irregular grains of glassy, fractured quartz and white to pink feldspar are set in a mosaic of smaller, stubby, white feldspar grains and biotite aggregates.

Usually these Precambrian granitic rocks are easy to distinguish from all other rock types by their granitic, plus gneissic, character, but the massive granite, having no foliation, superficially resembles the Tertiary soda granite. Underground the Precambrian granite is gray, the soda granite distinctly pink. This color difference is not so marked on the surface, but the massive Precambrian granite is nearly always coarser than the soda granite, and the biotite occurs in coarser aggregates.

In thinsection the granite (see fig 7) is made up of a mosaic of large anhedral quartz aggregates; large and small, clear, anhedral microcline grains; cloudy, stubby albite-oligoclase laths; and concentrations of biotite. The quartz commonly shows wavy extinction and fracturing. The microcline, in contrast to the plagioclase, is clear, shows polysynthetic twinning, replaces the plagioclase, and commonly contains inclusions of quartz. Many of the larger microcline anhedra have crude perthitic textures produced by small parallel streaks of plagioclase. The plagioclase in the granite ranges from albite to oligoclase, and commonly is badly altered to sericite and clay, the less altered grains showing twinning. Many subhedra of plagioclase, where they are in contact with microcline, have a fringe of untwinned plagioclase (?) around a twinned core. In the granite gneiss, biotite is abundant in trains and elongate aggregates which form the foliation. In the gneissic granite, biotite is less abundant but still forms elongate aggregates. The massive granite contains irregular biotite aggregates. The trains and elongate aggregates of biotite consist of biotite flakes which show no preferred orientation. The biotite commonly is altered to pale-green chlorite and granules of magnetite. Coarse, granular epidote and subhedral apatite are commonly associated with the biotite. Some sections contain muscovite, sphene, and zircon. Thinsections examined contain 30-40 percent quartz, 30-40 percent microcline, 10-30 percent plagioclase, 1-10 percent biotite, and 5-10 percent apatite and magnetite, by volume.

The granite intrudes the amphibolite complex and Cabresto meta-quartzite. It is overlain unconformably by Pennsylvanian-Permian (?) sediments and the late Tertiary volcanic complex, and intruded by dikes of Tertiary soda granite. Like the other Precambrian rocks, this unit is dated tentatively as Precambrian mainly on the basis of its metamorphic character.

Similar Precambrian granite (McKinlay, 1956, p 10; Gruner, 1920) crops out over much of the Taos Range of the Sangre de Cristo Mountains. Vanderwilt (1938, p 612) mentions its occurrence at the mine. Similar granite occurs throughout the Sangre de Cristo Mountains.

The Precambrian granites of the Taos Range occur as several distinctive rock types, but all seem related to a single source, as suggested by field relations, as well as by similarities in mineralogical and chemical composition. The exposures throughout the range probably represent the uppermost part of a granitic mass that underlies most of the Sangre de Cristo Mountains.

Pegmatites

Pegmatites in dikelike bodies intrude the amphibolite complex, the Cabresto metaquartzite, and less commonly the Precambrian granite.

The pegmatites are white, and range from thin stringers several inches wide to large lenses over 25 feet wide and hundreds of feet long. The common minerals are quartz, albite, and muscovite, with smaller amounts of orthoclase, magnetite, and garnet. No other minerals were noted.

Many of the larger pegmatite bodies are zoned, a core of quartz being surrounded by a zone of feldspar, muscovite, and quartz, and that in turn being surrounded by a border zone of graphic granite containing magnetite and garnet.

The pegmatites are dated as Precambrian. They cut the Precambrian amphibolite complex, Cabresto metaquartzite, and granite, but not the Pennsylvanian-Permian (?) sediments nor Tertiary volcanics. They probably represent an end phase of the Precambrian granite inasmuch as no other pre-Tertiary, granitic source-rocks are known to be present.

Diabase Dikes

Several diabase dikes crop out in the vicinity of the mine. The largest dike (see pl 2) crops out in the cliffs of Precambrian granite just north of State Highway 38, along Red River Canyon, between Sulphur Gulch and the main-haulage-adit portal (Moly tunnel). The diabase has intruded the Precambrian granite in an irregular manner, but has a general N. 60° E. trend, vertical dip, and average width of 25 feet. In the main haulage adit several small, black, aphanitic dikes cutting Precambrian granite probably are diabase.

Outcrops of diabase are marked by brownish iron oxide stains, and joints filled with brown carbonates. The rock has closely spaced, blocky jointing, and breaks down rapidly to cobble-size nodular masses. The margins of the wider dikes, as well as the entire width of thin dikes, are black and aphanitic, whereas the centers of the wider dikes are phaneritic and show the typical ophitic texture of a diabase.

In thinsection the phaneritic diabase shows an ophitic texture of crisscrossing plagioclase laths (averaging 1 mm long) and interstitial aggregates of augite (?). The plagioclase (An_{35}-An_{55}) is highly saussuritized, and the augite (?) is almost completely altered to hornblende. The hornblende usually is chloritized. Irregular masses, commonly in skeletal form, and subhedral crystals of ilmenite and magnetite are scattered through the rock. Euhedral prisms of apatite are common and widespread.

The diabase dikes intrude the Precambrian rocks, but were not observed to cut any of the younger rocks. McKinlay (1956, p 11) noted this same relationship in Costilla and Latir Peak quadrangles to the north. They are dated tentatively as Precambrian.

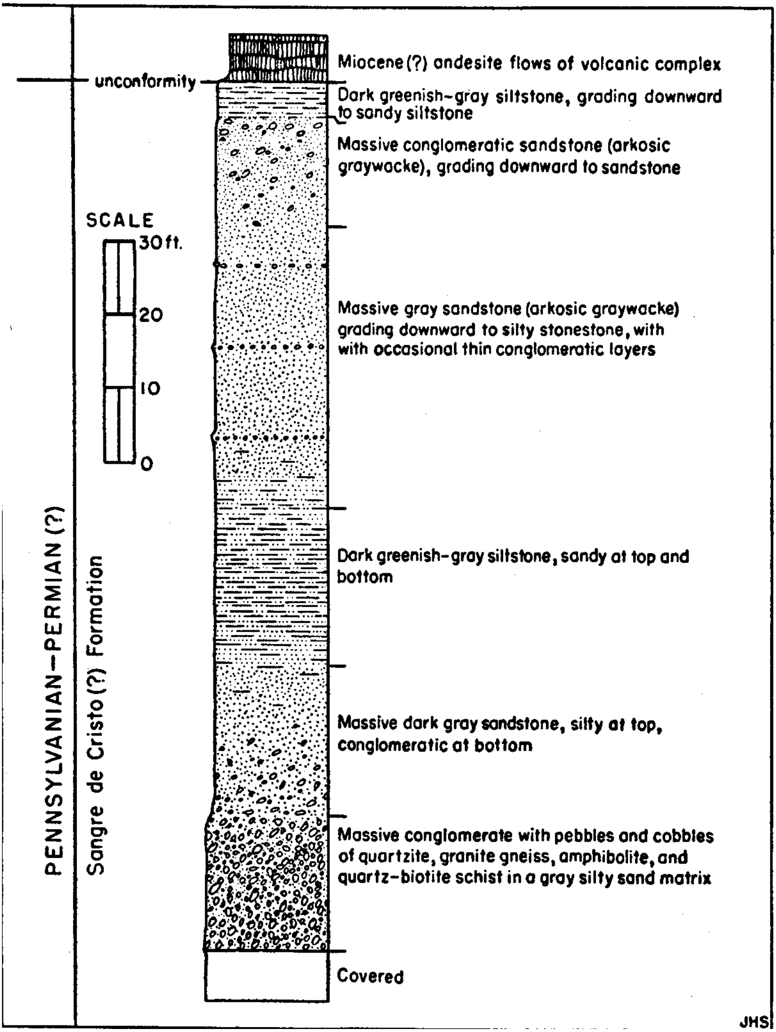
These dikes are present throughout the Precambrian rocks of the Taos Range; McKinlay (1956, p 11) called them metagabbro. Vanderwilt (1938, p 615) mentioned their presence near the mine, and Gruner (1920) noted their occurrence in the south part of the Taos Range.

PENNSYLVANIAN-PERMIAN (?) SANGRE DE CRISTO (?) FORMATION

In the vicinity of the mine, siltstone, sandstone, conglomerate, and limestone are exposed in several discontinuous belts between the Precambrian and Tertiary rocks (see fig 10 and p1 2). One belt begins just north of State Highway 38, one mile west of the main haulage adit, is next exposed north of the main-haulage-adit portal, then swings north-east, and continues to the slopes above Z tunnel dump, where it is cut off by the soda granite stock. The steeply west dipping strata of this belt are exposed also in the mine near the east ends of the No. 3, W (Vanderwilt, 1938, p 613), and Z tunnel levels, and Z winze, first level (see p1 1). North of the soda granite stock, the belt of sediments swings northwest, continuing across Cabresto Canyon and out of the area covered by this report. Another short belt starts at the mine camp and extends east one-quarter mile along the north side of the highway. Poor exposures are the rule; the rock weathers readily and usually is covered by talus from the overlying volcanic complex.

This unit is a cyclic deposit of alternating layers of massive conglomerate, sandstone, and siltstone, with occasional thin limestone lenses (see fig 8). Most layers have gradational boundaries. Bedding is poor, occasional thin layers of pebbles in the siltstone and sandstone, and the trend of the gradational bed boundaries, being the only guides to the dip and strike of the beds.

The conglomerates contain well-rounded, spherical to elongate pebbles (4-64 mm), cobbles (64-265 mm), and boulders (over 265 mm) of Precambrian granite, Cabresto metaquartzite, amphibolite, and quartz-



SECTION OF THE PENNSYLVANIAN-PERMIAN (?) SEDIMENTS NORTH OF STATE HIGHWAY 38, AT THE EAST EDGE OF THE MINE CAMP.

Figure 8

biotite schist in a groundmass of sand (2-0.062 mm) and silt (0.004-0.062 mm) corresponding in composition and texture to the sandstone and siltstone beds. The rock is so well cemented that, when broken, fractures cut through pebbles rather than around them. Occasionally the conglomerate fills channels cut in the sandstones, siltstone, or underlying Precambrian rocks. These channels contain boulders up to 5 feet across, with varying amounts of finer material. More commonly the conglomerate occurs as nonchannel deposits containing few boulders.

The sandstones are reddish-gray to gray, well-cemented, arkosic graywackes, with subangular to subrounded grains of quartz and some feldspar in a groundmass of clay, sericite, carbonaceous matter, rock fragments, and chlorite. The sandstone varies from a conglomeratic sandstone to a silty sandstone, with no one combination of grain sizes common enough to be called "average" or "normal." In thinsection subangular to subrounded quartz, microcline, and albite grains and quartzite fragments, with scattered flakes of biotite and muscovite, are set in a groundmass of clay, sericite, carbonaceous matter, iron oxides, and chlorite. Sections examined contain 45-55 percent quartz and quartzite, 5-10 percent feldspar, 1-3 percent mica, and 30-40 percent groundmass. The feldspars commonly are altered to sericite, and "ghosts" of sericite after feldspar are seen in some sections. Some sections also contain varying amounts of fine-grained epidote, usually as an alteration product of feldspar. Hornblende was not noted, although occasional masses of chlorite with magnetite may represent altered hornblende.

The siltstone is dull red to gray, and commonly contains some sand-size grains. In thinsection the rock is similar to the sandstone, differing only in the smaller size of the fragments of quartz and feldspars (mostly less than 0.1 mm).

Limestone was not noted in the area covered by the detailed mapping of this report, but is common as lenses in the belt of sediments crossing Cabresto Canyon several miles to the north. It is grayish white and very fine grained. No thinsections were examined.

The sediments have been altered where they are intruded by stocks of the soda granite. The red siltstones and the groundmass of the sandstone and conglomerate are turned dark greenish gray, up to a hundred feet out from the soda granite. Chlorite and epidote are more abundant in the altered sediments. Underground the sediments are exposed only at the edge of the soda granite stock, and it is impossible to distinguish megascopically the altered siltstone from the altered volcanics.

These sediments are dated tentatively as Pennsylvanian-Permian (?) and correlated with the Sangre de Cristo formation. The conglomerate contains pebbles of Precambrian Cabresto metaquartzite, amphibolite complex, and granite; it was deposited with the other sediments over an eroded surface on these rocks. The Tertiary volcanic complex overlies this unit, commonly with angular unconformity. Lack of metamorphism suggests that the rocks are not Precambrian. The lithology is similar to the Sangre de Cristo formation of northern New Mexico, which is the basis for correlation. No fossils were found. The possibility that this unit represents a new formation or a change in lithology of an established formation cannot be ruled out. Vanderwilt (1938, pp 612-614) mentions the presence of these sediments at the mine.

Regional studies (Read and Wood, 1947) indicate that during Pennsylvanian and Permian time the Taos Range was near the western edge of a marine basin, the Rowe-Mora geosyncline, and that a landmass, the Uncompahgre-San Luis positive area, existed to the west. The continental Sangre de Cristo formation represents a stage of offlap or marine regression.

TERTIARY

Volcanic Complex

A thick, complex sequence of volcanic rocks covers the higher slopes north of Red River Canyon (see fig 26 and pl 2). Volcanic rocks are found on all the levels in the mine, but their original character is obscured almost completely by alteration (see pl 1). The volcanics are not resistant to weathering, but only along the larger gulches has erosion been rapid enough to expose many outcrops. Most slopes are covered with talus.

The volcanics are apparently over 2,000 feet thick, although the poor exposures, plus faulting, make accurate measurements impossible.

An attempt was made to subdivide the volcanic complex during detailed mapping, but because of the poor exposures, faulting, alteration, great lateral variation of units, and large number of different rock types, it was possible to divide the volcanics into only two subdivisions: (1) a lower sequence of dark-colored volcanics, the andesitic series, and (2) an upper sequence of light-colored volcanics, the rhyolitic series. The contact between these units is gradational vertically and laterally, and each series contains units typical of the other series. To illustrate the difficulties encountered, one outcrop contained 15 distinct layers of flows, breccias, and tuffs, all less than 5 feet thick and dipping almost vertically; yet nearby outcrops contained quite different rock types, with units over 50 feet thick and a horizontal attitude! Occasionally some of the layers could be traced for some distance, but this was the exception rather than the rule. No attempt was made to study the petrography in detail.

Many units in the volcanic complex may be sills, but unless they could be identified positively as intrusives, they were mapped as part of the extrusive volcanic complex.

The dark-colored *andesitic series* consists of flows, breccias, and tuffs. Thinsections show that this series is predominantly andesite and quartz latite. Some rhyolite layers are present. A few are definitely sills and are included with the rhyolite intrusives (see p 25); others may be flows.

The andesite flows usually are purplish-gray aphanites. Some flows are porphyritic, with phenocrysts of plagioclase (usually andesine) and augite or hornblende in a glassy groundmass. Flow banding was observed, but is commonly difficult to detect. The andesite breccias contain angular fragments of the andesite flows in a purple to greenish-gray aphanitic groundmass. The andesitic tuffs are light gray to purplish gray.

The quartz latite flows usually are light-gray porphyritic rocks, with phenocrysts of plagioclase (andesine to oligoclase), quartz, biotite, and hornblende in an aphanitic to glassy groundmass. No quartz latite breccias or tuffs were noted, although such rock types probably are present.

The light-colored *rhyolitic series* contains flows, breccias, and tuffs of rhyolite, with some flows or sills (?) of more mafic rock types. The rhyolite flows are usually white to cream felsites. Many flows are porphyritic, with phenocrysts of quartz or quartz and sanidine (?); in thinsection the groundmass shows quartz, sanidine (?), and less commonly albite. Flow-banding is common. The breccias contain angular fragments of the rhyolite flows in a light-gray aphanitic groundmass. Tuffs are cream to gray; some layers are welded and contain thin, parallel bands and lenses of black glass.

The volcanics were deposited on a surface of moderate relief — flows butt against topographic highs of older rocks. The andesitic series was extruded first; then, while the last of the andesitic rocks were being deposited, the rhyolitic series was extruded and continued to be deposited after the andesitic series. That the rhyolites and mafic volcanics came from the same differentiated parent magma or came from the same vents or source is not known.

The source of the volcanics could not be established. Many rhyolite and andesite dikes and small rhyolite plugs are present (see the following section: Andesite and Rhyolite Intrusives) and probably represent feeders for some of the flows. The poor apparent stratification and the nearly vertical dip of the flow-banding in many of the outcrops have been used as evidence in support of a local source, the altered areas (hydrothermal pipes) supposedly marking the location of the vents. The writer believes that the stratification actually is good, but extremely difficult to see because of the poor outcrops and obscuring effect of hydrothermal alteration. Outcrops of unaltered volcanics commonly are stratified. The steep dip of the flow-banding is probably largely the result of movements caused by downfaulting along the Red River and by the later intrusion of the soda granite rather than the original dips. The altered areas (hydrothermal pipes) are characterized by brecciation and alteration, but apparently there was no appreciable upthrusting. Beds and flows commonly can be traced across the altered areas, and no plugs or pipelike vent fillings were observed in the altered areas, nor were blocks of older rocks thrust up into the volcanics, as would be expected if these areas represented vents. The andesitic series thickens northward until it converges with the pluglike body of quartz latite that forms Latir Peak. This feature, plus the presence of numerous and commonly large fragments of Precambrian rocks in the volcanics near Latir Peak, which are seldom found in the andesitic series near the mine, suggests that the Latir Peak plug is the source of much of the mafic volcanics. The above discussion is not intended to disprove the presence of volcanic sources in the vicinity of the mine, but to indicate the many possibilities and the need for further study.

Accurate dating of the volcanic complex could not be made directly from relations at the mine. The volcanic complex overlies the Precambrian rocks and the Pennsylvanian-Permian (?) sediments; in its entirety, except for the uppermost part of the rhyolitic series, it is intruded by the late Tertiary soda granite. The San Juan Mountains to the west are covered by a thick, widespread sequence of volcanics (Larsen and Cross, 1935). Miocene andesite, quartz latite, and rhyolite flows, breccias, and tuffs are overlain by the Pliocene to Pleistocene (?) Hinsdale volcanic series. The Hinsdale series includes the basalt flows that cap the plain west of the Taos Range. In Costilla quadrangle, north of the mine, these basalts overlie andesites, quartz latites, and rhyolites equivalent to the volcanic complex of this report (McKinlay, 1956, pp 12-15). This relationship, plus the similarity of the Miocene volcanics of the San Juan Mountains to the volcanic complex, are the reasons for tentatively dating the volcanic complex as Miocene (?). Much more information is needed before this unit can be dated with any certainty.

The Tertiary andesites, latites, and rhyolites mapped by McKinlay (1956, pp 12-15) in Costilla and Latir Peak quadrangles to the north are equivalent, at least in part, to the volcanic complex. Vanderwilt (1938, p 615) mentions the rhyolite at the mine. Park and McKinlay (1948) and Gruner (1920) mention the volcanics along the upper Red River.

Andesite and Rhyolite Intrusives

Many dikes and sills of andesite, latite (?), and rhyolite, as well as several small rhyolite plugs and a few dikes of various other rock types, are found in the vicinity of the mine (see pl 2). Dikes of rhyolite have been noted underground, but the andesite, if present, is altered and difficult to distinguish from the altered andesitic volcanic series. These intrusives are not resistant to weathering and erosion, and thus do not form prominent outcrops. Because of the variety of textures and compositions, no detailed petrographic study was made; to do so would necessitate studying thinsections from every intrusive.

Unless concordant layers of the rhyolite or andesite could be identified positively as sills, they were mapped as part of the volcanic complex. Thus units that properly could be included here have been described as part of the volcanic complex.

The dikes average less than 10 feet thick; the thickest sill was 30 feet. The rhyolite plugs are cylindrical; the largest mapped was 50 feet in diameter.

Most of the andesites and latites (?) are porphyritic, with phenocrysts of andesine (?), hornblende, augite (?), and biotite set in a gray aphanitic groundmass. Although andesine (?) phenocrysts are present in most of the andesite intrusives, the other minerals may or may not be present as phenocrysts. Where the same combination occurs in different dikes, the ratio of these minerals to one another and to the groundmass commonly is quite different. The phenocrysts of one mineral may be euhedral in one dike and anhedral in another.

The rhyolite intrusives usually have phenocrysts of quartz, quartz and orthoclase, or orthoclase set in a white to cream aphanitic ground-mass of quartz and orthoclase. The orthoclase phenocrysts are euhedral to subhedral; the quartz is anhedral. Several intrusives have no phenocrysts. One specimen had round, glassy, pink "phenocrysts" made up of a very fine-grained, granular aggregate of quartz and orthoclase.

Individual intrusives rarely exhibit relationships which establish their pre-soda-granite age; possibly some of the intrusives are post-soda-granite, although none is known to cut the soda granite. The andesites and latites (?) of this group intruded the Precambrian rocks, varying thicknesses of the andesitic series, but never the rhyolitic series. Thus the andesite and latite (?) intrusives are probably contemporaneous with the extrusive andesitic series. The rhyolites intruded the andesitic series, the Pennsylvanian-Permian (?) sediments, and the Precambrian rocks, but never cut the soda granite. Many rhyolite dikes also cut varying thicknesses of the rhyolite series, then spread out as concordant layers. Thus the rhyolite intrusives probably are contemporaneous with the rhyolitic series, although some intrusive bodies could be younger. Soda granite dikes also intrude the volcanic complex and are similar in composition and appearance to some of the rhyolite dikes, which may have resulted in misidentification. Most of the rhyolite dikes are, however, quite different from the soda granite both in composition and appearance.

The andesite, latite (?), and rhyolite intrusives may be feeders for some of their extrusive equivalents in the volcanic complex. Unfortunately, where these intrusives can be observed to spread out as concordant layers, it was not possible to identify any of the layers as flows. The similar age and mineral composition of the intrusives and similar rock types of the volcanic complex suggest a common parent magma.

Soda Granite

Three areas of soda granite (exclusive of dikes) are found along Red River Canyon near the mine (see fig 26). The Sulphur Gulch stock covers a roughly elliptical area three-quarters of a mile wide extending 1½ miles north and one-quarter mile south from the mouth of Sulphur Gulch, with the long axis trending north (see fig 10 and p1 2). It has a broad, domed top with gentle dips, and sides with steeper dips. A smaller area occurs on the north side of Red River Canyon, 2 miles west of Sulphur Gulch. A third area, the Flag Mountain stock, 4 miles west of Sulphur Gulch, has the largest outcrop area. Here the soda granite covers much of Flag Mountain on the south side of Red River Canyon, but does not extend more than a few hundred feet north of the canyon floor. Erosion has cut over 2,500 feet into the Flag Mountain stock, whereas the Sulphur Gulch stock has undergone much less erosion, and much of its domed top is preserved. Soda granite dikes are common; many have an east to northeast trend, although others are intruded in an irregular pattern.

Topographically the soda granite makes the most striking outcrops in the vicinity of the mine. Cliffs, interrupted at intervals by ledges and cut by vertical crevasses and box canyons, are common where the Sulphur Gulch and Flag Mountain stocks cross Red River, as well as along the side canyons. Areas of soda granite less commonly are covered, and outcrops are continuous, in contrast to the poor exposures of all the other rock types.

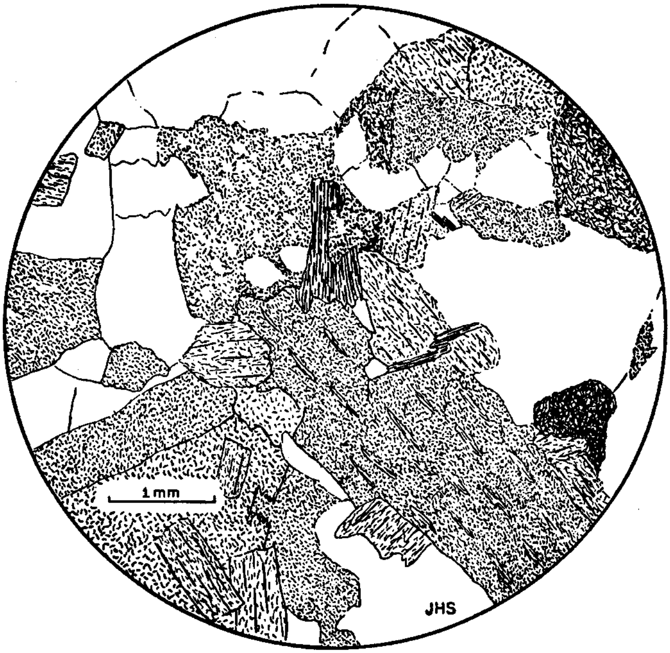
The soda granite can be subdivided into the following phases on the basis of structural, mineralogical, and textural differences: (1) "normal" or inequigranular to porphyritic; (2) pegmatitic; and (3) aplitic. The porphyritic and finer-grained inequigranular varieties of the "normal" phase usually form the margins of the stock; inasmuch as the mine workings are near the margin of the Sulphur Gulch stock, these varieties are the most common underground. Coarser inequigranular granite makes up the core of stocks. The inequigranular and porphyritic varieties of the "normal" phase are intergradational. The other phases, in contrast, show sharp contacts with each other. The pegmatitic phase intruded the "normal" phase as dikes and irregular bodies along the contact of the stock. The aplites, as small dikelets seldom more than an inch across, cut the other phases. Dikes of soda granite away from the granite stocks are all of the "normal" (inequigranular to porphyritic) phase. Aplitic and pegmatitic phases do not extend more than a few feet into the rocks surrounding the stocks.

The "normal" phase makes up over 99 percent, by volume, of the soda granite. It can be divided into two varieties on a textural basis: (1) inequigranular and (2) porphyritic. Both varieties have similar mineral compositions. They contain 30-40 percent albite (An_5-An_{15}), 25-35 percent orthoclase, 25-35 percent quartz, 0-10 percent biotite, less than 2 percent magnetite, apatite, sphene, and zircon, and varying amounts of alteration minerals.

The inequigranular variety, "normal" phase, contains pink orthoclase, white albite, and clear, glassy quartz in an inequigranular mosaic, with the larger-size grains predominating. The coarse-grained, inequigranular specimens consist of grains 4-15 mm in diameter; the finer grained specimens have grain diameters of 0.5-5 mm. In thinsection (see fig 9) this variety shows an inequigranular aggregate of anhedral quartz, subhedral twinned albite laths, subhedral to anhedral orthoclase, and books of biotite. Most of the orthoclase grains have crude perthitic textures with roughly parallel streaks of the plagioclase in the orthoclase, although the plagioclase less commonly is present as irregular blebs.

The plagioclase is mostly albite. Many orthoclase grains have irregular areas with microcline twinning. Magnetite, apatite, sphene, and zircon are present as accessory minerals. Some thinsections show little alteration of the minerals; others, widespread alteration. The feldspars are altered to sericite and clay. Biotite commonly alters to chlorite. Euhedral to anhedral pyrite grains commonly are associated with the chlorite.

The porphyritic variety of the "normal" phase of soda granite has quartz, orthoclase, and albite phenocrysts up to 10 mm across, in a pink to gray, fine-grained, phaneritic to aphanitic groundmass. Phenocrysts make up as much as 40 percent of the rock. All three minerals may be present as phenocrysts in one specimen, or quartz or orthoclase may occur alone or with albite. In thinsection anhedral quartz and subhedral to anhedral orthoclase and albite phenocrysts are set in a granular aggregate of anhedral quartz and orthoclase and subhedral albite laths. Magnetite, apatite, sphene, and zircon are present as accessory minerals. Biotite is commonly absent. Some sections contain scattered biotite flakes badly altered to chlorite. Much of the primary biotite may have



SODA GRANITE.

Minerals are orthoclase (mottled), albite (mottled with cleavage), quartz (clear), and biotite.

Figure 9

been altered completely, and specimens which now have no biotite may have contained varying amounts originally. Pyrite is scattered throughout most specimens. Perthitic textures are rare compared with the inequigranular variety. Some sections show almost complete alteration of the feldspar phenocrysts, with less alteration of the feldspar in the groundmass. Other sections show only minor alteration of the feldspars.

The pegmatitic phase is a coarse (4-40 mm), equigranular aggregate of albite and orthoclase, with or without quartz, and varying amounts of biotite. Alteration along the grain boundaries commonly makes specimens friable. The striking petrographic differences from the other phases of soda granite are the common lack of quartz and the frequently high percentages of biotite. Specimens examined contain 0-30 percent quartz, 25-55 percent orthoclase, 25-55 percent albite, 0-50 percent biotite. The one thinsection examined contains an equigranular aggregate of anhedral orthoclase and albite, and books of biotite. Nearly 50 percent of the section is biotite. This biotite shows only minor alteration to chlorite. Pyrite was not present in the section. The feldspars are altered only slightly to sericite and clay.

The aplitic phase is pink and fine-grained phaneritic to aphanitic. In thinsection the aplite shows an inequigranular aggregate of anhedral quartz and orthoclase. Coarser orthoclase commonly encloses finer grained quartz. No albite was noted. Sphene and apatite occur as accessory minerals. A few scattered chlorite flakes are present; they may represent altered biotite. The orthoclase is altered in part to sericite and clay. A typical specimen contains 40 percent quartz, 60 percent orthoclase, and small amounts of sphene, apatite, and chlorite.

It should be emphasized that the combined pegmatitic and aplitic phases make up less than 1 percent of the soda granite, by volume, the "normal" phase being over 99 percent of the volume.

The soda granite intruded the Precambrian rocks and all but the uppermost part of the Miocene (?) volcanic complex. It was intruded by later dikes, whose age cannot be determined. As has been pointed out already, the volcanic complex, hydrothermal pipes, and soda granite are related closely in time. If the Miocene (?) volcanics are correctly dated, the granite can be dated tentatively as late Tertiary. The albite granite of Vanderwilt (1938, p 617) and the alaskite porphyry of Larsen and Ross (1920) are the soda granite of this report. The miners call this unit "redrock."

The stocks and smaller bodies of soda granite probably represent the uppermost part of a larger granite body that underlies the Taos Range. The granite of McKinlay (1956, p 18) probably represents another phase of this granitic body. The soda granite and the latter granite have roughly equivalent ages (relationships are too poorly known to establish contemporaneity) and are similar mineralogically. Both contain quartz, orthoclase, albite, and biotite; the latter granite has less albite and locally contains up to 5 percent hornblende. Whether the rhyolitic volcanic series and the rhyolite intrusives represent a somewhat earlier extruded phase of the same magma is not known; the soda granite and rhyolite are related closely in time and are similar mineralogically.

Postgranite Dikes

Several dikes intruded the soda granite and cut the molybdenite veins (see pl 2). Other dikes and sills that intruded the older rocks away from the soda granite may be postgranite in age. Two large postgranite dikes were traced underground for hundreds of feet horizontally and vertically (see p1 1). Many smaller dikes also were noted underground. Four large dikes were mapped on the surface. The dikes do not weather as ridges or depressions but can be distinguished from the pink soda granite, even at a distance, by their gray color. The dikes range from 3 feet to 20 feet in thickness.

Most of these dikes are porphyritic, with pale-pink to white, 1- to 10-mm phenocrysts of feldspar and 1- to 3-mm books of biotite in a greenish-gray, fine-grained, phaneritic to aphanitic groundmass. A few phenocrysts of quartz are present in some specimens. Specimens examined contain 10-40 percent phenocrysts, the phenocrysts being 60-70 percent feldspar, 30-40 percent biotite, and 0-5 percent quartz, by volume. In thinsection euhedral to subhedral orthoclase and books of biotite are set in a fine-grained groundmass of plagioclase laths, usually with quartz and orthoclase. A few anhedral quartz phenocrysts also are present. The feldspars are altered to sericite and clay. The biotite is altered nearly completely to chlorite and magnetite. Epidote is scattered through the sections and commonly is associated with the biotite. These dikes range in composition from quartz monzonite to monzonite.

Two of the postgranite dikes are a black aphanitic rock. No thinsections of this rock type were examined.

The Tertiary monzonite porphyry dikes of McKinlay (1956, p 18) and Parks and McKinlay (1948) are similar in age and mineralogy and may be equivalent to the more common type of postgranite dikes.

QUATERNARY

Terrace Gravels

Several prominent terraces are present along Red River Canyon in the vicinity of the mine (see pl 2). The well-rounded gravels covering all these terraces or benches, which are more than 30 feet above the river, have been grouped together as terrace gravels, although they vary in age. The most prominent terrace is on the south side of, and about 60 feet above, the Red River, at the east edge of the mine camp. A second large terrace is on the south side of, and about 100 feet above, the Red River, opposite the mouth of Sulphur Gulch. A third smaller area is south of Red River Canyon, opposite the mill and 240 feet above the river.

The well-rounded terrace gravels are distinguished easily from the angular material of ordinary cover. Often the gravels contain rock types foreign to the bedrock of the bench or slopes above, making identification even more positive. The gravels are unbedded, 2-6 feet thick, and made up of well-rounded spherical to elongate boulders, cobbles, and pebbles of all the older rock types, the fragments ranging in size from one-eighth inch to 36 inches (longest dimension). Any sand or silt that was present has been removed by later erosion.

East of the mine, at the town of Red River, Parks and McKinlay (1948, p 10) report that similar gravels form the tops of many of the flat ridges, 500-1,500 feet above the canyon floor. The terrace gravels at the mine and at the town of Red River represent remnants of the flood plain and channel of the Red River during the various stages in the downcutting which formed the present canyon. There is no evidence for exact dating; some of the higher levels may be late Tertiary (Parks and McKinlay, 1948, p 10), although the lower levels at the mine probably are Pleistocene or Recent.

Cemented Gravels

Along the sides of Red River Canyon and many of the side canyons, well-cemented gravels form small ledges at levels ranging from 5 to 20 feet above the canyon bottoms (see pl 2). These "cemented gravels" are unbedded to poorly bedded, 6 inches to 15 feet thick, and made up of unsorted, angular, and, less commonly, subangular to rounded cobbles, pebbles, sand, and silt of all the older rock types. The feature which distinguishes this material from talus, mud-flows, etc., is the yellow-brown to shiny-black limonitic cement which makes up to 20 percent of the rock. Commonly up to 50 percent of the space between the rock fragments is not filled by cement, leaving a very porous rock.

Water draining the outcrops of the altered areas (hydrothermal pipes) is rich in dissolved iron salts. This iron-rich water drains through the stream gravels, mud-flows, and talus along the valley bottoms, unless rising temperatures, evaporation, or other factors cause the iron salts to precipitate, thus forming the limonitic cement. Later erosion has deepened the valley bottoms, leaving the "cemented gravels" as erosion-resistant ledges along the valley sides. This same process is taking place along Sulphur Gulch today. Because the amount of valley deepening since formation of the "cemented gravels" is small compared with the terraced gravels, this unit is dated tentatively as Recent.

Alluvium

All the material which covers the valley bottoms and has been re-worked by the streams is comprised in this unit, including channel and flood-plain gravels, as well as the low terraces (less than 5 feet above the stream) that are being formed as the streams continue downcutting.

Mud-Flows

Along the Red River, the bottoms of many of the side canyons and arroyos are filled with mud-flows which extend out into Red River Canyon as thick fans. The clearest example of a mud-flow in a valley bottom is along Sulphur Gulch, and the best example of a mud-flow fan is approximately 200 yards west of the mouth of Sulphur Gulch (see p12).

Each mud-flow is made up of unsorted angular debris ranging from large boulders to clay. It is distinguished easily from alluvium by the angular material, lack of sorting, and various surface features. Each flow can vary from several inches to many feet in thickness. The fans and valley fillings are made up of many flows, giving a bedded appearance. The greatest measurable sequence is 35 feet thick. The surface of the mud-flow sequence commonly is covered with gullies and paired parallel ridges.

A mud-flow is formed when a rainfall of cloudburst intensity is concentrated over the altered and brecciated rocks of a hydrothermally altered area (hydrothermal pipe) or, less commonly, on talus slopes. The loose material, near its angle of repose, is lubricated and begins to move to the bottom of the slopes, where it mixes with the more abundant water, forming a mud-flow having the appearance and consistency of fresh concrete. The flow moves down the valley bottom pushing debris ahead of it and picking up more material from the slopes. Flows more commonly cut gullies at first, then deposit their coarsest material along the flanks of the flow, which produces twin ridges as the swifter moving, more fluid material in the middle flows on, and finally spread out and deposit the remaining silt and clay, or discharge into the Red River. Whether a flow cuts or deposits at a given spot depends on many factors: the ratio of water to solids (the more water, the farther it will travel before depositing material), slope, size of the flow, etc. Many of the gullies on the flows are produced by the slow runoff of residual water after a mud-flow or as the result of subsequent gentle rain.

The mud-flows are of special interest because of the damage they do to roads, the mill, and the mine camp. The camp and mill are located where an unusually intense rain is necessary to start mud-flows in short gullies. Only one rain has caused much damage. Mud-flows following this 15-minute rain tore out several thousand feet of flume, buried cars, and blocked the road, spreading up to 8 feet of muddy debris. Between the mine and the town of Red River the highway crosses thick mud-flow fans. Here each main gully drains a large area of loose material, and mud-flows occur frequently during the rainy season, often blocking the highway. The flows become hard, once the water has drained out, and are difficult to remove.

Cover

The soil, talus, and other loose material that could not be mapped as an outcrop of any of the rock units already discussed are placed in this unit. Terrace gravels, alluvium, and mud-flows have been mapped as separate units, although they could have been included properly with this unit.

STRUCTURAL GEOLOGY

INTRODUCTION

The structure of the Taos Range of the Sangre de Cristo Mountains is extremely complex. The Precambrian rocks were folded and otherwise deformed, metamorphosed, intruded in a complex pattern by great masses of granite, and subjected to later stresses that tend to obliterate earlier structures. After erosion and the deposition of Carboniferous and Mesozoic sediments, the Precambrian rocks were thrust eastward over these younger rocks. Accompanied by volcanic activity, the range was later block-faulted and tilted along its present western edge.

The Questa molybdenum mine is located in an east-west down-faulted zone several miles wide, extending across the range, in which a number of structural features combine to form a structural pattern quite different from that found in the rest of the range. This zone apparently has served to localize the soda granite intrusives and the hydro-thermal pipes (altered areas); both are found almost entirely within the zone. This zone also controls the drainage pattern. Bitter Creek and the Red River form an almost straight line along the south edge of the zone, deviating from this straight line only where the resistant late Tertiary granitic stocks deflect their courses. Cabresto Creek follows the north edge of the zone. High-angle faults of the zone have downfaulted Tertiary volcanics and Pennsylvanian-Permian (?) sediments, forming a grabenlike structure of tilted blocks.

The term "breccia pipe" often has been used to describe "tubes" of brecciated rock in which the brecciated material has been thrust upward in the "tube." To avoid confusion, the term "hydrothermal pipe" is used in this report to describe a tubelike body of brecciated rock, showing only minor movement of the brecciated rock, that also has served as a passage for hydrothermal solutions. It is important to recognize the dual character of these features. They are altered areas as well as brecciated areas.

At the mine, structures related to the intrusion of the soda granite are superimposed on the regional structures and structures of the zone of downfaulting.

REGIONAL STRUCTURES

Folds

Folding is a relatively unimportant structural feature in the Taos Range. Folding in the Precambrian rocks is obscured by later deformation and metamorphism. McKinlay (1956, p 20) states that the Precambrian rocks in the northern half of the Taos Range are folded along N. 70° E. and N. 20° E. axes. Paleozoic and Mesozoic rocks are too limited in extent to show a pattern of folding. The belt of Pennsylvanian-Permian (?) rocks in the vicinity of the mine forms a faulted syncline with an east-west trending axis (passing through the Sulphur Gulch soda granite stock) and a steep plunge to the west. The Tertiary volcanic complex shows no obvious folding.

Faults

Three groups of faults are common in the Taos Range: (1) north trending thrusts; (2) north trending high-angle faults; and (3) east-northeast trending high-angle faults. Many other faults are present but were not classified.

Thrust faults are a prominent feature along the east edge of Taos Range (see fig 6). The thrusts have a general north trend, dip gently to the west, and are dated as late Cretaceous to early Tertiary (McKinlay, 1956, p 21). No thrusting was noted in the vicinity of the mine. In the Sangre de Cristo Mountains of Colorado (Goddard, 1935) thrusting occurred from late Cretaceous to early Eocene.

The Taos Range has been uplifted and tilted eastward along a fault zone paralleling the western edge of the range (see fig 6). The frontal fault which crosses the Rio Hondo southeast of the mine trends northwest. A few miles north of the Rio Hondo a north trending fault zone, which extends north into Colorado, starts along the northwest trending fault and becomes the frontal fault of the range. From here the northwest trending fault extends out into the plain. The total vertical displacement is estimated to be over 6,000 feet (McKinlay, personal communication). The Tertiary volcanics and Quaternary basalts have been displaced by movements along this fault zone, indicating Pleistocene-Recent movement. Earlier movement probably occurred. Throughout the Taos Range other high-angle faults have the same general north trend, dip-slip movement, and nearly vertical dip as the frontal fault north of the Rio Hondo. In the southwest corner of the range, where the frontal fault trends northwest, these faults locally have a northwest trend. Movement along these faults is, at least in part, contemporaneous with movement along the frontal-fault zone, and probably is the result of the same forces. Faults of this system are found in the vicinity of the mine, and several were noted underground. They cut the soda granite and older rock, and show horizontal displacements of the soda granite contact in the tens of feet. Several of the post-soda-granite dikes are intruded along the faults.

Another system of high-angle faults, having a general east to north-east trend, is found throughout the range (see fig 6). Most of these faults displace the Precambrian rocks, but none of the later rocks; a few displace the Tertiary volcanics. Displacements are small, and many parallel fractures occur along which no detectable movement took place. In this system are included many of the faults and fractures that make up the downfaulted zone along the Red River.

The most important feature in the downfaulted zone extending along the Red River is the faulting of the Miocene (?) volcanic complex and older rocks. This downfaulting occurred during and shortly following the extrusion of the volcanics, forming a grabenlike area. Although the zone trends east-northeast, no through-going faults could be traced, even if present, because of the poor exposures. However, numerous short segments were noted. These have various orientations, but the majority trend east-northeast. The result is a jumble of blocks which have been tilted and downfaulted in varying amounts. Part of this movement probably resulted from the later intrusion of the soda granite.

The Pennsylvanian-Permian (?) sediments and Tertiary volcanic complex have been downfaulted several thousand feet. In most areas north and south of the downfaulted zone the base of the volcanic complex is at elevations of over 10,000 feet; in the zone itself the base is commonly below 8,500 feet. Although the difference in elevation of the base of the volcanics could have resulted from the filling of a large valley, the displacement of the Pennsylvanian-Permian (?) sediments found below the volcanics definitely indicates faulting. Precambrian diabase dikes and Tertiary rhyolite and andesite dikes commonly trend parallel to these faults, as do the older Precambrian to Paleozoic fault systems, suggesting that the downfaulted zone was downfaulted along much older existing fractures and faults. Although the volcanic complex is downfaulted several thousand feet, the soda granite shows only minor east-west faulting and interrupts the faults along the south edge of the downfaulted zone without any evidence of displacement, suggesting that faulting took place shortly after the extrusion of the Tertiary volcanics, but before the intrusion of the soda granite. This faulting may be the result of the removal of large amounts of magma from below the area. Many areas to the north are downfaulted, probably as the result of the extrusion of the thick volcanic pile covering the area.

It is interesting to note that the downfaulted area lies along a northeast trending belt of volcanic activity. This belt extends from the Springerville, Arizona, volcanic field to the Spanish Peaks in Colorado, and includes the Mt. Taylor area, Jemez caldera, Taos Plateau volcanoes, and the volcanic rocks of the Taos Range. Possibly this belt reflects a deep-seated zone of weakness, which would also explain the unusual trend of the downfaulted zone.

Nearly vertical peripheral faults that strike perpendicular to the contact of the Sulphur Gulch stock are common; the displacement on these faults is rarely more than 10 feet. Slickensides indicate varied directions of movement; many have strike-slip orientations. Few of the peripheral faults could be traced any distance, but die out rapidly away from the soda granite contact.

Fractures

Only one fracture system seems to be common throughout the range; other systems may occur but have not been detected. This fracture system trends east to northeast and dips vertically to steeply north. The fractures roughly parallel Precambrian foliation, which is also the most common trend of the pre-soda-granite dikes, and the east-west trending, high-angle fault system.

Fracturing in the Sulphur Gulch soda granite stock and surrounding rocks was studied in detail underground and on the surface by recording the orientation and density of fracturing at numerous stations. Structures formed by post-soda-granite tectonic movements are negligible, greatly simplifying this study. The fracture data obtained were plotted in various ways and brought out the following facts. The soda granite at many places contains three sets of fractures. (A set is a group of parallel fractures.) Along the contact intense brecciation, now delineated by brown to yellow limonite staining, commonly obscures any regular pattern. Although the granite contains three sets of fractures, none of these sets is similarly oriented throughout the stock; nor is the relative orientation of the three sets of fractures to one another constant from place to place.

Fracturing in the Sulphur Gulch stock roughly parallel to the contact is especially well defined along Sulphur Gulch, where it strikes east-west. Throughout this report this fracturing is called sheeting. Although the sheeting is concentrated in the outer 50 feet of the granite and roughly parallels the limits of the stock, it does not follow all of the irregularities but commonly cuts directly across them. Where the con-tact flattens abruptly, the fractures continue at the steeper dip and die out in the granite. Sheeting fractures passing deeper into the soda granite commonly bifurcate and die out. Individual fractures converge with the contact at small angles, and some pass into the propylitized rock, where they too die out. Individual fractures are not continuous but are replaced both laterally and downdip by other fractures, commonly in an en echelon manner. Where the sheeting extends upward to levels at which the steeper dipping sides of the stock change to the gentler dips of the domed top, the sheeting continues at the steeper dip, cuts across the contact, and dies out in the softer altered rocks. Some of the sheeting fractures curve toward the contact, reversing in dip as they approach the contact. This sheeting apparently was formed by the up-ward force of intruding soda granite (see p 63).

The sheeting is not a regional feature resulting from regional forces. The fractures do not extend any distance into surrounding rocks or into the soda granite where the granite contact changes from the local east-west trend.

On the domed top of the Sulphur Gulch stock, where sheeting is absent, irregularly oriented fractures are common. Slickensides are conspicuous on these irregular fractures but have no preferred orientation.

In the mine area the other rocks have been fractured in a different manner from the soda granite. The fracturing and faulting are irregular, except for the regional east-west striking, vertically dipping fractures found throughout the Taos Range. It was impossible to separate fractures and faults caused by the granite intrusion from those caused by the forces that produced the downfaulted zone.

Brecciation

Widespread brecciation occurs in the downfaulted zone. Many of these brecciated areas served as passageways for hydrothermal solutions; these are the hydrothermal pipes.

Brecciation with little movement is the important structural feature of the hydrothermal pipes. The pipes do not show a sharp change from unbrecciated to highly brecciated rock, but have gradational boundaries. The intensity of brecciation within each pipe ranges greatly. The pattern of this brecciation is irregular, large masses of unbrecciated rock being present within the pipe. Faulting is common, but most displacements are small; the different volcanic layers can be traced across the altered-brecciated areas.

Precambrian granite and amphibolite complex, Pennsylvanian-Permian (?) sediments, and the Tertiary volcanic complex, with the associated rhyolite and andesite intrusives, are all brecciated in one or more of the hydrothermal pipes. The soda granite dikes which intrude the hydrothermal pipes are relatively unbrecciated compared to the surrounding rocks. Thus most of the brecciation occurred after the Tertiary volcanic complex was deposited, but before the intrusion of the soda granite.

The brecciation is related closely in time and space to the development of the downfaulted zone along Red River. Brecciation undoubtedly was widespread during downfaulting, and the hydrothermal pipes probably represent the most highly brecciated areas. Later intrusion of the soda granite may have caused additional brecciation but was not the main brecciating force. As has been pointed out, the soda granite dikes that cut hydrothermal pipes are relatively unbrecciated. Moreover, none of the rock types have been thrust upward within the hydro-thermal pipes, which commonly occurs where the upward intrusion of igneous rocks has formed breccia pipes.

Foliation

Foliation is well developed in the Precambrian amphibolite complex and granite. In the vicinity of the mine, it strikes N. 50° E., to N. 70° E. and dips vertically. This orientation is by far the most common throughout the range.

ALTERATION

INTRODUCTION

In the vicinity of the mine two types of Tertiary alteration have affected large areas: (1) A halo of propylitic alteration in the rocks surrounding the soda granite stocks has obscured the original character of the rocks, changing them to a greenish-gray color. (2) Hydrothermal solutions, using the brecciated areas in the downfaulted zone as passage-ways, have altered the brecciated material, and later weathering has formed the distinctive bare, yellow-stained, easily eroded areas that mark the location of the pipes. The wall-rock alteration along the veins of the ore deposits is described under Mineral Deposits, Wall-Rock Alteration (p 59).

HYDROTHERMAL PIPES

The brecciated rock of the hydrothermal pipes has been altered hydrothermally (see fig 10 and pl 2). No attempt was made to study this alteration in detail. The altered areas are conspicuous because of their yellow color, "badland" topography, and treeless outcrops. The altered material in these areas erodes rapidly, forming numerous gullies, steep slopes, and cliffs. All the pre-soda-granite rock types have been altered, the intensity of alteration usually varying directly with the intensity of brecciation. The original character of the rock is recognizable except where alteration is most intense. Large masses of unbrecciated rock within the hydrothermal pipes remain relatively unaltered. Alteration also has taken place along single isolated fractures and faults at some distance from the pipes.

The alteration minerals are pyrite, quartz, kaolinite, sericite, chalcopyrite, and carbonates. Other alteration minerals are undoubtedly present. Pyrite is the most common and widespread, occurring as grains disseminated through the rock and, less commonly, as crumbly, irregular masses that yield high gold assays. The quartz has silicified some of the rock and also occurs as spongy masses in the tuffs. Most of the feldspars in the altered rocks have been altered completely to kaolinite and sericite. It is difficult to determine whether the kaolinite was developed through hydrothermal alteration or weathering.

Later weathering, with accompanying oxidation of the disseminated pyrite and lesser chalcopyrite, has formed many secondary minerals, which are responsible for the yellow color in the outcrop of the hydrothermal pipes. Limonite, jarosite, selenite gypsum, specularite, malachite, and manganese oxides were recognized. Many other secondary minerals probably are present. This still-active process of alteration is similar to the oxidation of porphyry copper deposits (Bateman, 1951, p 226). A large part of the oxidized sulfides is dissolved in the surface and ground water and removed from the altered areas. Some of the iron salts precipitate out as FeOH to form the limonitic minerals which stain the rocks and form the cement of the "cemented gravels." Boxworks are found from which the sulfides are completely removed; commonly they contain no residual limonite. Weathering removes the oxidation products so rapidly that fresh sulfides are commonly exposed. The veins and secondary enrichment in the hydrothermal pipes are covered under Mineral Deposits (pp 72-3).

The disseminated alteration minerals occur in all the pre-soda-granite rock types. Dikes of relatively unaltered soda granite cut the disseminated alteration. The age relations and minerals suggest that the disseminated alteration was formed by low-temperature hydrothermal solutions as a late phase of the volcanic activity following the extrusion of the Tertiary volcanic complex.

It has been suggested that this alteration is the result of deuteric alteration of the volcanics, and thus would not extend to any depth (or be hydrothermal pipes). However, the altered areas show no spacial relationship to the volcanics but are spacially related to the brecciated areas in the downfaulted zone along Red River. This brecciation was formed after the extrusion of the volcanics. Precambrian and Paleozoic (?) rocks also are altered. More important, however, is the complete lack of such alteration north of the downfaulted zone, although much larger areas of the same Miocene (?) volcanic rocks are present. Evidence of this type of alteration at depth is found in the Moly tunnel, the only place where mine workings at depth are under the surface exposure of an altered area. Here disseminated pyrite occurs in Precambrian granite but is not readily recognized as the same type of alteration, because the striking yellow staining and other effects of surface weathering are missing.

PROPYLITIC ALTERATION

A halo of rock surrounding the soda granite stocks has been propylitized (see fig 10). The intensity of this propylitic alteration decreases rapidly away from the granite; the original character of the rocks, in a zone several hundred feet out from the granite contact, is almost completely masked. On the surface, outcrops are limited, but underground exposures are excellent. The miners call the propylitized rocks "greenrock."

The altered rocks are greenish-gray to greenish-black, owing to the abundant chlorite and epidote. The Precambrian quartz-biotite schist, Pennsylvanian-Permian (?) sediments, and Tertiary andesitic series are intensely altered. The Pennsylvanian-Permian (?) shales and Tertiary andesitic series lose all their original features. The pebbles, cobbles, and boulders of quartzite and granite gneiss in the Pennsylvanian-Permian (?) conglomerates remain relatively unaffected, whereas the groundmass is altered; hence these beds can be recognized easily regardless of the intensity of the alteration. The Precambrian quartz-biotite schist shows faint schistosity even where intensely altered, but underground it is difficult to distinguish from the propylitized volcanics. The Precambrian granite and amphibolite complex, and the Tertiary rhyolitic series, are only slightly altered, even when in contact with the soda granite.

In thinsection completely altered specimens of the andesitic series show 40-80 percent chlorite, 5-30 percent epidote, 0-30 percent quartz, 5-20 percent carbonate (by volume), and some sericite. Pyrite is common as scattered grains, but is not universally present. Magnetite is scattered throughout the rock. The chlorite and sericite occur in fine flakes, the quartz in anhedral grains and aggregates, the epidote in irregular fractured grains, and the carbonate as cavity fillings and veinlets. Feldspars are altered to epidote; the ferromagnesian minerals are altered to chlorite, epidote, and magnetite. Away from the granite, where the alteration is less intense, the plagioclase feldspars commonly are only partially altered to epidote; biotite and other ferromagnesian minerals, however, are completely altered to chlorite. Where these same minerals occur in the schist and sediments, they are similarly altered.

Propylitization in its broadest sense means alteration with the formation of epidote and chlorite, in most cases accompanied by quartz, carbonate, and sericite. Schwartz (1939, pp 195-197) gives a good summary of the American literature on propylitization; Coats (1940) summarizes the foreign literature. As these two papers point out, the term has been used to describe many types of alteration, which have been produced in several different ways. Although most writers have restricted the term to alteration of mafic rocks, Schwartz (1939, p 195) points out that the process is not limited to mafic rocks but may affect the ferromagnesian minerals of silicic rocks. Other writers have made various other restrictions in defining propylitization.

Callaghan and Buddington (1938, p 30) mention that such alteration may be the result of several processes: (1) automorphism, or alteration during the final stages of formation of magmatic minerals by igneous solutions originating in the same magma; (2) contact metamorphism, or alteration of intruded rocks by heat and hydrothermal solutions from an igneous body; and (3) wall-rock alteration along a vein by hypogene solutions prior to or contemporaneous with the formation of the vein. Many examples of propylitization formed by each of these processes have been described (Schwartz, 1939, pp 195-197; Coats, 1940).

As used in this report, propylitization is defined as alteration to chlorite, epidote, quartz, carbonate, and sericite, with no restriction as to the type of rock affected or the process of formation.

Because the propylitized rocks of this report form a halo around the soda granite stock with decreasing intensity of alteration outward, it is assumed that this example of propylitic alteration was formed by con-tact metamorphism; that is, by heat and hydrothermal solutions from the soda granite. Without chemical analyses no attempt can be made to determine in detail what elements were introduced or removed during alteration. Silica, sulfur, water, and carbon dioxide certainly must have been introduced, indicating that hydrothermal solutions did play a part in the alteration.

GEOLOGIC HISTORY

Little is known about the Precambrian and early Paleozoic history of the area. During the Precambrian, sediments and volcanics were intruded by granite and metamorphosed to form the amphibolite complex and Cabresto metaquartzite. During much of early Paleozoic time the Taos Range probably was part of, or near, the shallow Central Colorado Basin embayment.

In late Paleozoic time the area to the west was uplifted to form the Uncompahgre-San Luis geanticline. This positive area was eroded, and great thicknesses of clastic sediments were dumped at the edge of the deepening basin to the east, the Rowe-Mora geosyncline. These clastics include the Sangre de Cristo formation.

Little is known about events during most of the Mesozoic. In late Cretaceous and early Tertiary time eastward thrusting occurred along the east edge of the present Taos Range. At about the same time the late Paleozoic sediments were intensely folded, and were later eroded, leaving only scattered remnants. The range then was block-faulted and tilted along its present western edge, the area to the west being down-faulted. This faulting probably started in the Oligocene and has continued till the present.

During Miocene (?) to Pleistocene time volcanic activity accompanied the faulting. The volcanic complex probably was extruded during the Miocene. In the mine area the downfaulted zone was downfaulted during or shortly following the extrusion of the volcanic complex; stress during faulting brecciated some areas. These brecciated areas served as passageways for later hydrothermal solutions, which altered the brecciated rocks of the hydrothermal pipes.

Accompanying this activity, probably in Miocene or Pliocene time, soda granite was intruded to form stocks and dikes. The continued upward force of intrusion fractured the solidified outer margin of the Sulphur Gulch stock and enclosing rocks. Magmatic fluids, concentrated in the still-fluid core of the stock, escaped into these fractures and formed veins. Basalt flows covered the plain to the west during Pliocene and early Pleistocene time. The present topography is the result of Quaternary erosion.

Mineral Deposits

INTRODUCTION

The Questa molybdenum mine is the only mine in the area. Many other small deposits in the surrounding area have been prospected for molybdenum, gold, silver, copper, lead, or zinc, but always with unfavorable results. Nearly all these deposits, including that of the Questa molybdenum mine, apparently are late Tertiary in age and were formed by hydrothermal solutions emanating from the soda granite intrusives.

Oxidation and enrichment of the disseminated sulfides in the hydrothermal pipes may have formed minable copper deposits at depth, al-though the present scanty evidence is unfavorable. More detailed study is needed.

QUESTA MOLYBDENUM MINE DEPOSIT

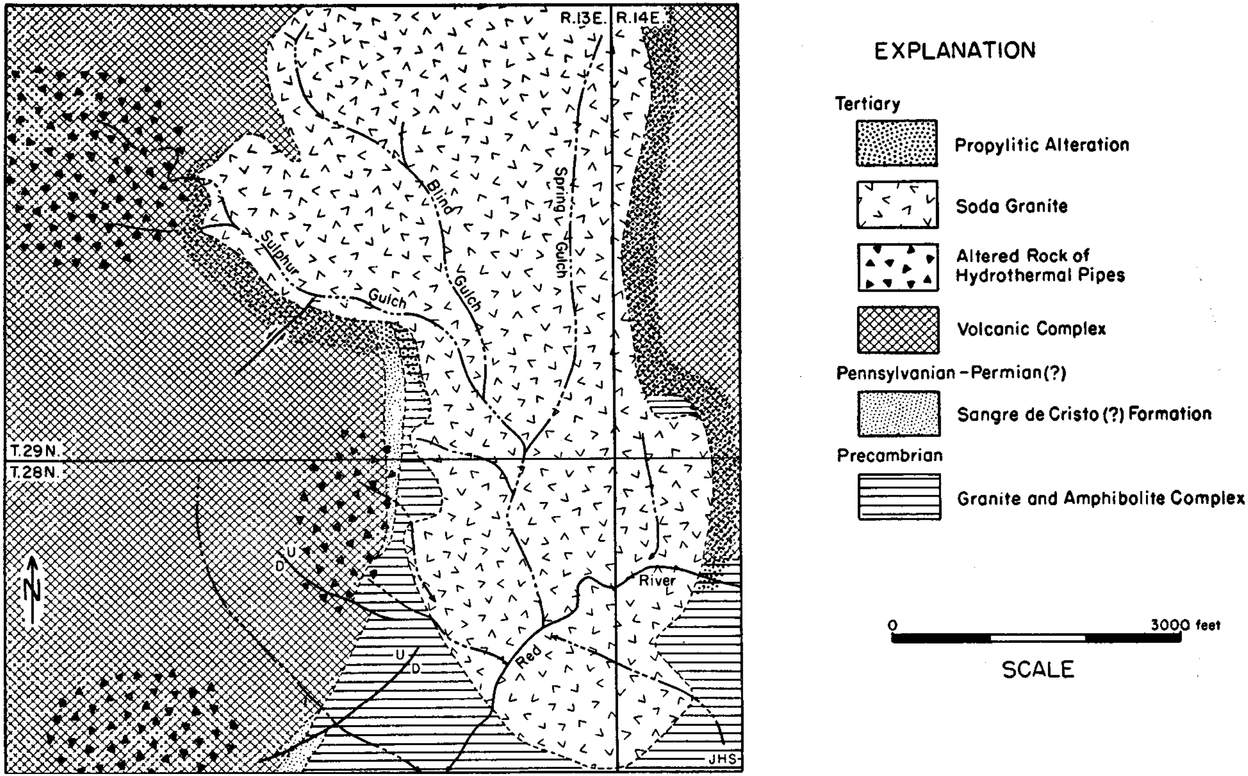
INTRODUCTION

A group of molybdenite-bearing veins form the mineral deposit in which the Questa molybdenum mine is located. This deposit is unique in containing high-grade molybdenite ore in fissure veins, whereas most other production is from low-grade disseminated deposits. The ore occurs in the Sulphur Gulch soda granite stock along a locally east striking, south dipping part of the contact with propylitized rocks. Most veins parallel the contact, range from less than 1 inch to over 7 feet in thickness, and are largely quartz and molybdenite, with locally abundant biotite, fluorite, pyrite, chalcopyrite, calcite, and rhodochrosite. The veins were deposited as cavity fillings during late Tertiary time soon after the soda granite was intruded. The upward force of intrusion apparently sheeted the granite along the contact, and hydrothermal solutions from the granite entered the sheeting to form the veins.

SPACIAL RELATION OF VEINS TO ROCK UNITS AND STRUCTURE

The veins of the ore deposit occur along the western side of the Sulphur Gulch soda granite stock where the north trending contact locally strikes east and dips to the south. To the east and west, where the contact swings north-south, very few veins are found. At the surface the east-west portion of the contact is over 1,500 feet long. The propylitized Tertiary andesitic series is in contact with the soda granite over much of the area where the veins occur. On the upper levels, at the east end of the deposit, the propylitized Pennsylvanian-Permian (?) sediments, dipping steeply to the west and striking northwest, are in contact with the soda granite. East of these sediments Precambrian quartz--biotite schist is in contact with the soda granite where the contact begins to swing south. The Sulphur Gulch soda granite stock, in which the deposit is found, is in the downfaulted zone and near several hydrothermal pipes.

Figure 10

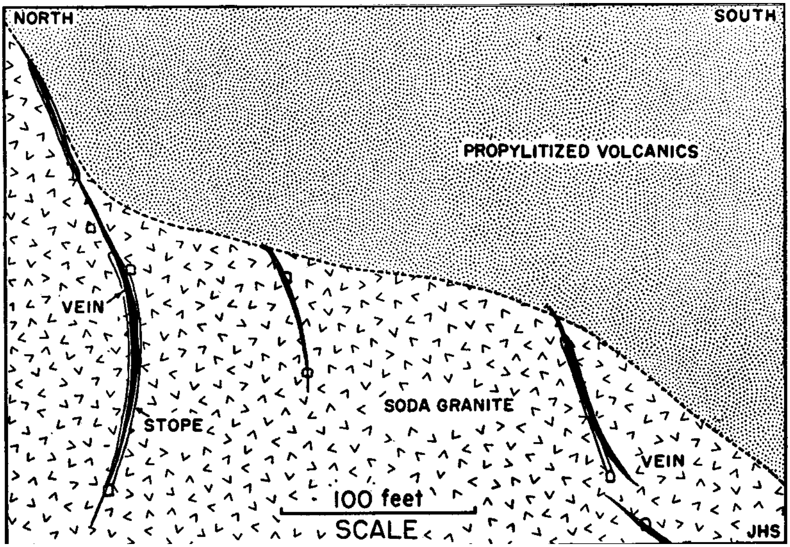


GENERALIZED GEOLOGIC MAP OF THE QUESTA MOLYBDENUM MINE AREA.

Although the contact of the Sulphur Gulch stock has a general east-west trend in the mine, locally it strikes in many other directions. These irregularities in dip and strike reflect the "bumps," depressions, noses, ridges, valleys, and terraces found on the stock (see pl 1 for examples). Although the limits of the soda granite stock are usually well defined, where the contact shows marked change in dip or strike, areas of mixed material are common. In these areas angular xenoliths are enclosed by the soda granite. Many large, isolated xenoliths are also present and usually have lenslike shapes roughly paralleling the contact. Some of these xenoliths have not broken free from the rock mass in contact with the soda granite; one end has sunk a few feet into the granite, and the other end has remained attached, leaving a wedge-shaped mass of granite between the block and the "country rock." Other xenoliths have sunk evenly into the granite (see fig 14), a tabular mass of granite separating them from the "country rock." These features make the detailed spacial relationship between the veins and the rock units more complex.

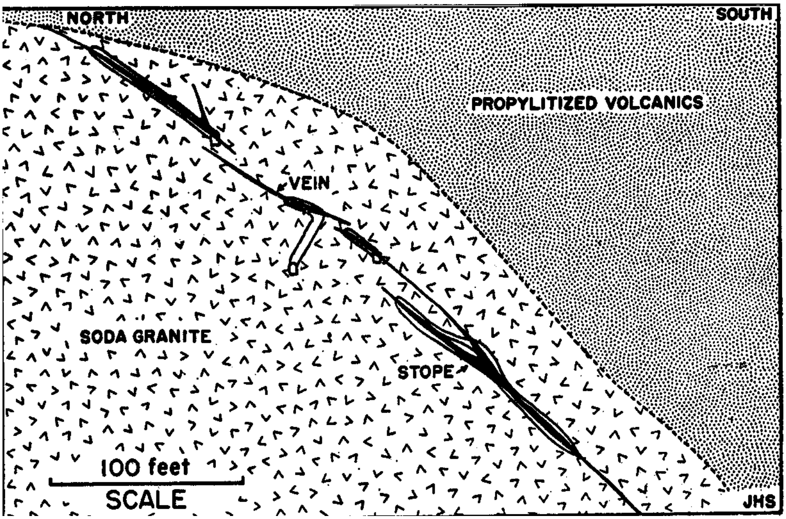
The veins of this deposit can be classified according to their geometric relation with the granite stock into the following four groups: (1) veins on the contact or in the granite parallel to the contact of the stock; (2) veins in the granite near the contact which are not parallel to the contact; (3) veins in granite dikes near the stock; and (4) irregular stockwork veins in brecciated rock along the contact, in both the granite and propylitized rock.

Most of the veins belong to the first group. They follow the contact, or are in the soda granite within 50 feet of the contact and roughly parallel to it (see p1 1). Dips range from vertical to horizontal, but average 45 degrees. In this group are included most of the veins and nearly all the ore shoots. These veins are fissure fillings along the sheeting in the soda granite, which is especially well developed along the locally east-west striking shoulder of the stock, where the veins occur. Thus the veins are present along the steep sides but are absent in the domed top of the stock. In detail, therefore, the veins show the same relations as the sheeting. The veins cut across any protruding irregularities in the soda granite stock (see fig 13), remaining parallel to the general attitude of the contact. Where the contact suddenly changes dip, the veins continue on at the same dip and pass out into the propylitized rock, where they pinch out in the softer, less brittle material, or pass into the soda granite, where they divide into numerous veinlets which rapidly die out. The same situation occurs laterally along a vein where abrupt changes in strike occur (see fig 17). Individual veins commonly converge with the contact at small angles, either updip, downdip, or laterally, and some continue out into the propylitized rock, where they pinch out. Many veins are not continuous downdip or laterally, but are replaced by other veins, usually in an en echelon manner (see figs 12 and 15). Many en echelon veins are connected by many thin veinlets. Steep veins will commonly reverse their dip when they pass into the propylitized rock or into the stock (see fig 11). As this group of veins extends upward to



CROSS-SECTION THROUGH NO. 3, W, AND GLORY HOLE LEVELS OF THE QUESTA MOLYBDENUM MINE SHOWING VEINS PINCHING OUT AS THEY EXTEND INTO THE GRANITE STOCK.

Figure 11



CROSS-SECTION THROUGH NO. 3, W, AND GLORY HOLE LEVELS OF THE QUESTA MOLYBDENUM MINE SHOWING EN ECHELON VEINS PARALLELING CONTACT.

Figure 12

where the steeper dipping sides of the stock change to the gentler dips of the domed top, they continue at the steeper dip, converging with the contact and then continuing into the propylitized rock, where they pinch out. Some of these veins curve toward the contact, becoming less steep as they approach the contact. Where large xenoliths of propylitized rock have sunk into the granite, the veins continue at their same general dip, following the shortest path, which may be the granite con-tact, the top or bottom of the xenolith, or a combination thereof (see fig 14).

The second group, those veins which are near the contact but not parallel to the contact, fill irregular fractures in the outer margin of the stock. These fractures are associated with the sheeting on the sides of the stock and are found in the domed top of the stock, where sheeting is lacking. All the veins that crop out north of Sulphur Gulch are of this type (see pl 2). This type of vein is small and discontinuous. A few ore shoots were found in the domed top of the stock; along the sides of the stock very few ore shoots are found in veins of this type. Dips are to the north, east, and west; many strike parallel to the contact, but other random orientations are common. Like the first group, these veins pinch out where they extend into the propylitized rocks or away from the con-tact into the granite.

The third group of veins fill fractures in the soda granite dikes that extend out from the stock (see fig 18). A few important ore shoots have been mined in these veins. Dips and strikes vary but commonly have the same orientation as the dikes.

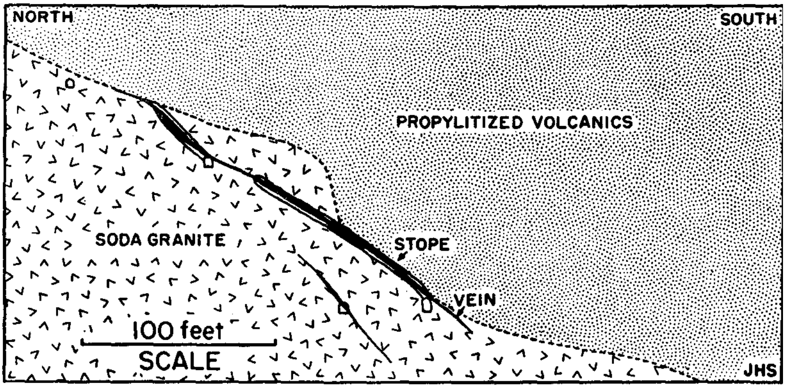
The fourth group form a stockwork of thin irregular veinlets in the brecciated areas found along the contact. These brecciated areas occur where irregularities, with sudden changes in dip and strike, are present along the contact of the stock. These low-grade, disseminated, stockwork ores contain large tonnages of mineral-bearing rock, but are too low grade to mine under present conditions.

It should be emphasized that most of the veins that crop out belong to the second group, which are rarely productive, and that the highly productive veins of the first group seldom reach the surface.

Several structural features offset or cut the veins. The regional north-south trending, high-angle faults cut and offset the veins tens of feet. Postgranite dikes commonly were intruded along these faults. Some peripheral faults (see fig 15) around the soda granite stock offset veins (usually less than 10 feet), whereas others cross veins without offsets.

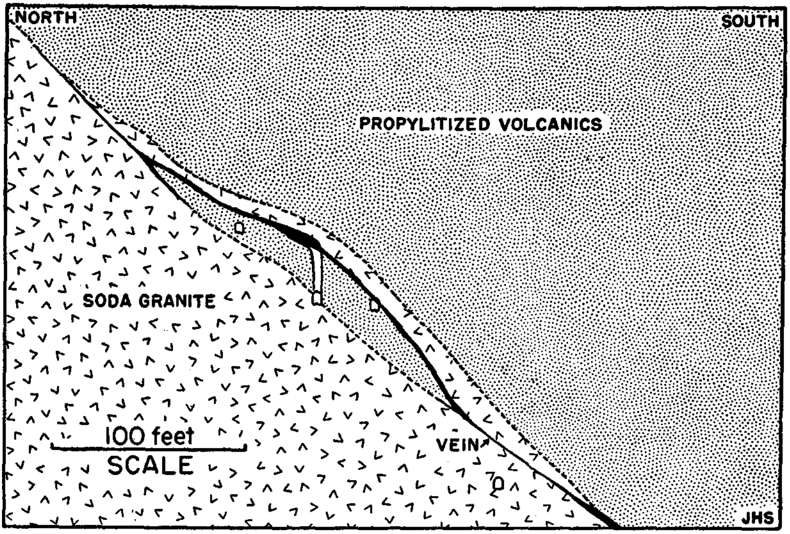
SIZE AND FORM OF VEINS

The size and form of the veins in the Questa molybdenum mine vary greatly over short distances. The veins range from film-thin layers to over 7 feet in thickness. The film-thin layers containing only molybdenite are called "paint" by the miners; thin veins are called "streaks." In general the thickest veins are found where the contact of the granite stock dips steepest. It has already been pointed out that veins on the



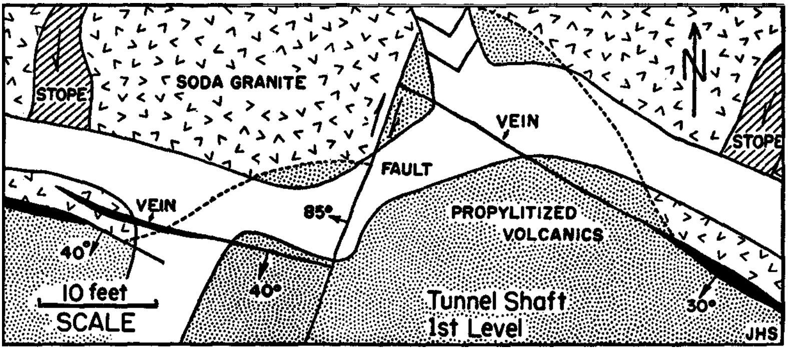
CROSS-SECTION THROUGH NO. 3, W, AND GLORY HOLE LEVELS OF THE QUESTA MOLYBDENUM MINE SHOWING VEIN CUTTING ACROSS IRREGULARITY OF THE CONTACT.

Figure 13



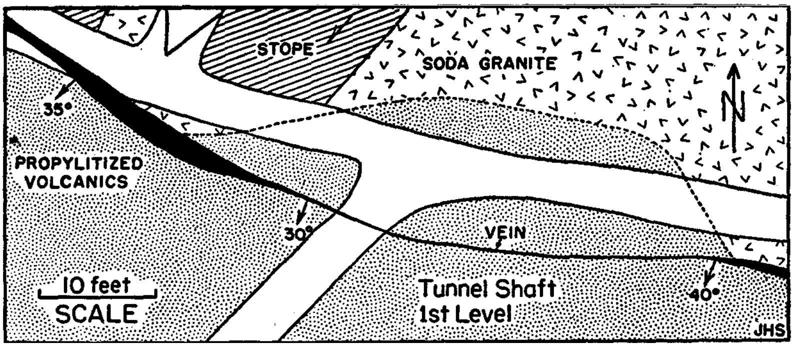
CROSS-SECTION THROUGH NO. 3, W, AND GLORY HOLE LEVELS OF THE QUESTA MOLYBDENUM MINE SHOWING A STOPE BLOCK, OR LARGE XENOLITH, AND A VEIN.

Figure 14



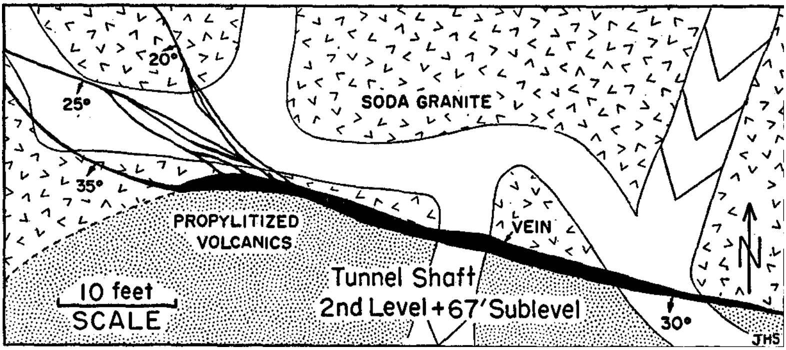
PLAN OF A LEVEL IN THE QUESTA MOLYBDENUM MINE SHOWING EN ECHELON VEINS, PINCHING OF VEINS AS THEY EXTEND INTO THE PROPYLITIZED VOLCANICS, AND A VEIN OFFSET BY FAULTING.

Figure 15



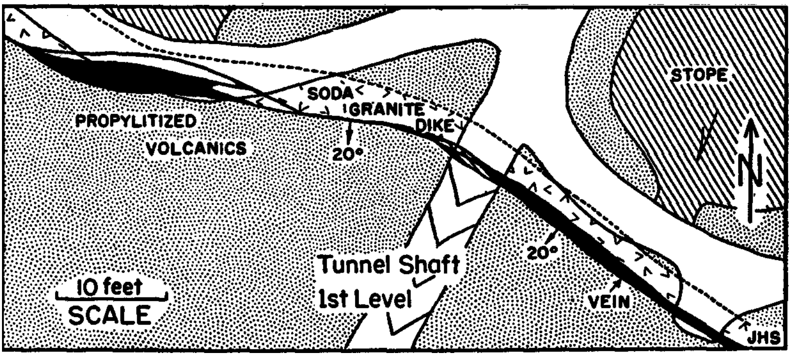
PLAN OF A LEVEL IN THE QUESTA MOLYBDENUM MINE SHOWING A VEIN PINCHING AS IT EXTENDS INTO THE PROPYLITIZED VOLCANICS.

Figure 16



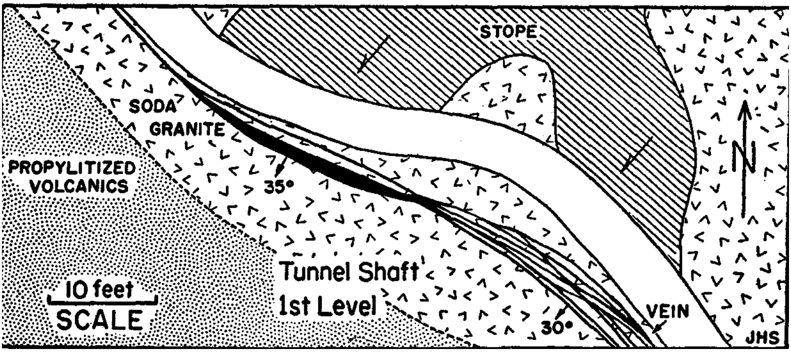
PLAN OF A LEVEL IN THE QUESTA MOLYBDENUM MINE SHOWING A VEIN THAT DIVIDES INTO MANY SMALL VEINS AS IT EXTENDS INTO THE SODA GRANITE.

Figure 17



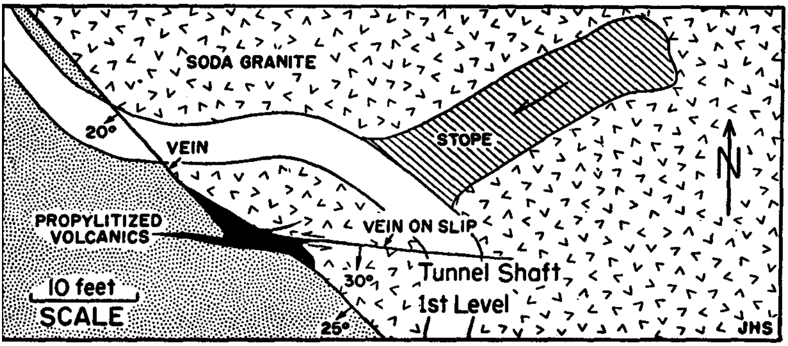
PLAN OF A LEVEL IN THE QUESTA MOLYBDENUM MINE SHOWING A VEIN ALONG A SODA GRANITE DIRE.

Figure 18



PLAN OF A LEVEL IN THE QUESTA MOLYBDENUM MINE SHOWING A VEIN IN THE SODA GRANITE PARALLELING THE CONTACT.

Figure 19



PLAN OF A LEVEL IN THE QUESTA MOLYBDENUM MINE SHOWING AN ORE SHOOT AT THE INTERSECTION OF TWO VEINS.

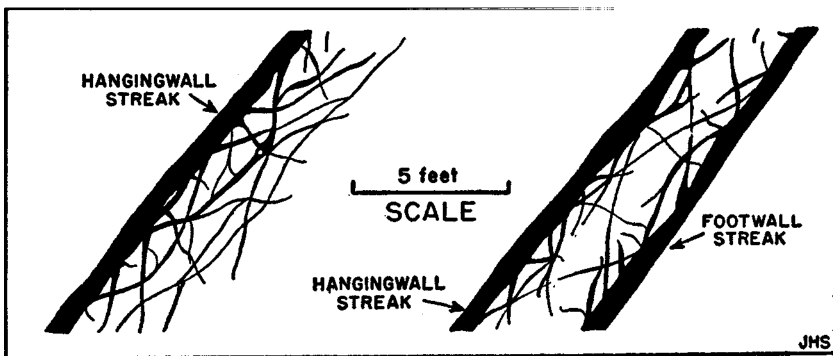
Figure 20

margin of the soda granite stock pinch out when they extend out into the surrounding propylitized rock or deeper into the granite.

Commonly a vein splits into parallel veins a few feet apart with wall rock between, and then reunites (see fig 19); these are the "splits" of the miner. Many thick veins thin rapidly, commonly to "paint," and then open again, or stop completely (see pl 4A); these are the "pinches" of the miner. Many veins have one well-defined wall; the other wall is marked by many small veinlets forming a stockwork radiating out into the wall rock (see fig 21). The well-defined wall commonly shows movement; this is a "shear" or "slip." Very commonly each of two parallel veins, only a few feet apart, has one well-defined wall, with the respective irregular walls facing each other (see fig 21). Where two such veins are close enough so that the small veinlets extending out from the irregular wall of each are interconnected, the two veins actually become one vein having two well-defined walls with brecciated wall rock full of veinlets in the center; where farther apart, such veins form a true "split." In either case, the two veins often are mined as one unit, the well-defined wall of the upper vein being called the "hanging wall streak," and that of the lower vein being called the "foot wall streak." Many other veins have two well-defined walls, with only minor wall rock as gangue; either or both walls may be "shears" or "slips." A few veins have no well-defined walls, but instead have small veinlets or stockwork extending into both the hanging and foot walls. No change in form or size of veins with depth is apparent.

ORE SHOOTS

In this report ore shoots are defined as portions of a vein or veins which are thick, rich, and extensive enough to be mined under prevail-



CROSS-SECTION OF TWO VEINS.

Black is vein minerals; white is "country rock."

Figure 21

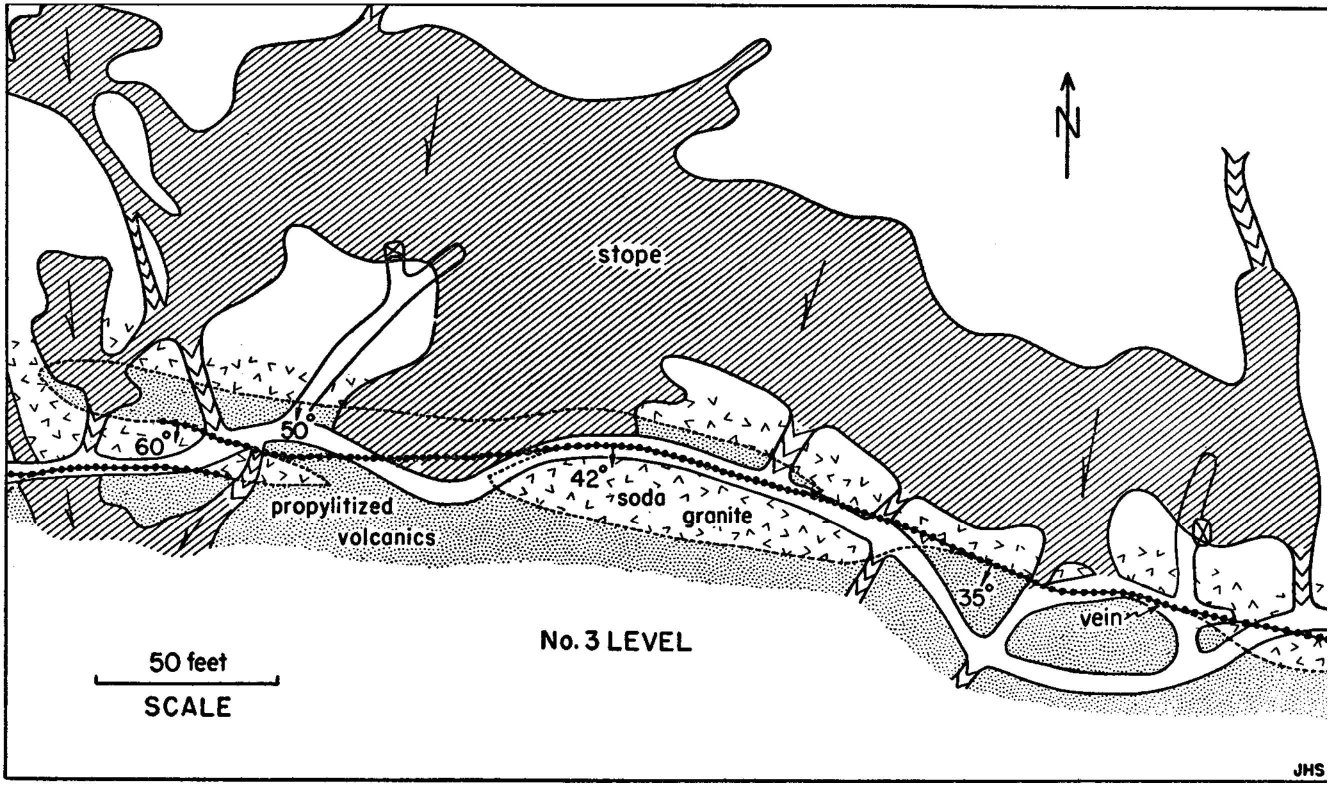
ing costs and methods. Therefore, not only can one vein have an ore shoot, but the two veins of a "split," when mined as a unit, would form an ore shoot, although if separated neither might have an ore shoot. It should be emphasized also that what might be an ore shoot at one time, may not be at another, when prevailing costs and methods are different.

Since the limits of an ore shoot are never known in the Questa molybdenum mine until the ore is removed, the ore shoots which will be described in this section are now delineated roughly by stopes. Actually the shape of an ore body is not always the same as that of the stope used to mine it; for example, thin veins often are mined by removing some of the wall rock along the vein.

Nearly all the ore shoots are lenticular, and usually are longer along the strike than downdip (see fig 22). Such ore shoots supply over 90 percent of the ore mined. They range from 600 feet to less than 10 feet along the strike, and from 300 feet to less than 10 feet downdip. Thicknesses range from 7 feet to less than 1 foot; the thinner shoots must be of high grade. Nearly all these ore shoots are found in the veins paralleling the contact, although some are found in the other types of veins. They are larger, thicker, and more common where the veins and granite contact dip steeply, and become smaller, thinner, and less frequent where the contact dips less steeply. Changes with depth are hard to determine, because not only do methods and cost of mining affect the limits of the ore shoots, but the amount of exploration and development on a given level determines how many ore shoots are exposed. From top to bottom the mine has shown a cyclic pattern of these lenticular-type ore shoots. One level will have many large ore shoots, the next lower level a few small ore shoots, the next level no ore shoots, the fourth level a few ore shoots, and the fifth level many large ore shoots; then the cycle repeats. These cyclic changes with depth are related closely to the changes in dip of the granite contact with depth. In the mine the Second winze, fifth level (elev. 8,007 ft), had many, large ore shoots; the Tunnel shaft, first level (elev. 7,906 ft), had fewer, some-what smaller shoots; and the Tunnel shaft, second level (elev. 7,814 ft), the lowest level in the mine, has still fewer and smaller shoots. If only these three lower levels were considered, it would seem that the mine were reaching the bottom of the ore deposit; when, on the other hand, the cyclic pattern is examined, it appears likely that good ore shoots may be found deeper. However, the total volume of ore produced per level has shown an overall decrease with depth; this may indicate bottoming.

A few ore shoots are cylindrical or wedge-shaped. Their long dimension commonly is downdip. They range up to 100 feet in long dimension, but seldom are more than 20 by 5 feet in cross-section. Although ore shoots of this type supply less than 10 percent of the total tonnage of ore, they usually are much richer than the lenticular ore shoots. They occur at the intersection of a vein with another vein, fracture, fault, or the granite contact (see fig 20). No correlation was found between the

Figure 22



PLAN OF A TYPICAL LARGE STOPE IN THE QUESTA MOLYBDENUM MINE.

size and location of this type of ore shoot and the dip of the contact. Nor was any change with depth noted; ore shoots of this type occur at random over the same east-west striking portion of the stock where the veins are found.

VEIN MINERALOGY

Introduction

Most veins consist largely of quartz and molybdenite, although fluorite, pyrite, chalcopyrite, biotite, calcite, and rhodochrosite are locally abundant. Many other minerals are present in smaller amounts.

TABLE 1. VEIN MINERALS OF THE QUESTA MOLYBDENUM MINE

*Apatite	$(CaCl,CaF)Ca_4(PO_4)_3$	*Hübnerite	$MnWO_4$
Biotite	$H_2K(Mg,Fe)_3Al(SiO_4)_3$	Limonite	$2Fe_2O_3 \cdot 3H_2O$
Calcite	$CaCO_3$	Malachite	$CuCO_3 \cdot Cu(OH)_2$
Chalcopyrite	$CuFeS_2$	Molybdenite	MoS_2
Chlorite		Pyrite	FeS_2
Ferrimolybdite	$Fe_2O_3 \cdot 3MoO_3 \cdot 8H_2O$	Quartz	SiO_2
Fluorite	CaF_2	Rhodochrosite	$MnCO_3$
Galena	PbS	†Rhodonite	$MnSiO_3$
Graphite	C	*Sphalerite	ZnS

* Minerals not identified during present study.
† Mineral not positively identified.

Some veins contain only one or two minerals. Most veins have local concentrations of one or more minerals, resulting in frequent changes in mineralogical composition.

Ore Minerals

Molybdenite. Molybdenite, called "moly" by the miners, is the only ore mineral. It is found widely distributed in distinct veins and disseminated through the wall rock (see pls 4, 5). Quartz, pyrite, chalcopyrite, biotite, fluorite, and rhodochrosite (in order of decreasing abundance) are common associated minerals. The molybdenite usually is found in irregular aggregates in the vein, although less commonly it forms a banded structure of alternating layers of quartz and molybdenite, the molybdenite filling fractures in the quartz (see pl 5A). Commonly it is intergrown with quartz and biotite, but not with the other sulfides. Lenticular masses of quartz in the vein usually are covered with molybdenite "paint"; when broken out as one piece, as they frequently are during mining, they appear to be pure masses of molybdenite. Such masses make more attractive specimens than pure molybdenite, because they do not crumble readily. In polished sections small but perfect crystals of molybdenite are found scattered through quartz. This molybdenite usually is fine grained, although coarse flakes are found occasion-ally. Molybdenite is also frequently found alone as thin coatings along fractures, called "paint," or as finely crystalline material, called "mud," disseminated through fault gouge, turning the gouge dark gray. Occasionally it occurs as large crystals in quartz, or with coarse orthoclase, quartz, and biotite in pegmatitic "veins" (see p1 5B). These pegmatitic "veins" are actually molybdenite-rich dikes of the pegmatitic phase of the soda granite (see p 29). Molybdenite "paint" usually cuts all other minerals. The veins are not sampled underground; therefore, the percentage of molybdenite could not be determined accurately. The ore as delivered to the mill is upgraded by hand sorting, but some dilution results from wall rock broken during blasting. These factors tend to cancel each other, so that the grade of ore milled gives a fair estimate of the percentage of molybdenite in the ore shoots. In the past, the ore at the mill contained 4-20 percent molybdenite, by weight; today the ore averages 1-4 percent.

Gangue Minerals

Apatite. Apatite was reported by Larsen and Ross (1920) but was not noted by the writer. The mine staff could remember no occurrences; hence its occurrence must have been very limited.

Biotite. Biotite is associated with quartz and molybdenite, and, though not quantitatively important, is widely distributed and locally abundant. Biotite is found in cracks in quartz, intergrown with quartz and molybdenite, or as segregations in quartz. The miners consider the presence of the "mica" to be an indicator of rich ore, because the biotite is abundant in the ore shoots but rare elsewhere in the quartz-molybdenite veins. The biotite usually occurs as coarse flakes (1-20 mm) having a bronze-brown color, compared to the shiny black biotite of the soda granite. In thinsection some of the biotite shows alteration to chlorite.

Calcite. Calcite occurs in the center of the larger quartz-molybdenite veins and as breccia fillings where these veins are crushed; it is more common in the margins of ore shoots than in the shoots themselves. Veins of brecciated fluorite also commonly contain calcite as breccia filling. In these occurrences the calcite in some instances is intergrown with rhodochrosite. More commonly it is found alone in fractures in the propylitized rocks, or as veinlets, with or without rhodochrosite, in the soda granite or propylitized rocks. Calcite, though widespread, is not quantitatively important. It is usually white and finely crystalline, although vugs with good crystals are found occasionally. Where associated with rhodochrosite, it is commonly pink. This pink variety is manganese-rich, and a complete series may exist between it and the rhodochrosite.

Chalcopyrite. Chalcopyrite occurs in the quartz-molybdenite veins associated with pyrite, or alone in irregular aggregates and bands. It also occurs with pyrite, or pyrite and quartz, in veinlets containing no other minerals. Although the chalcopyrite commonly cuts molybdenite and quartz, it also is found as masses in molybdenite and quartz. More rarely it is associated with galena and sphalerite. Although not quantitatively important, it is widespread and locally abundant. The chalcopyrite occurs as aggregates of tarnished, brass-colored, irregular grains, which commonly show many fractures in polished section. Pyrite, also, rapidly becomes tarnished, once exposed by the workings, and is difficult to distinguish from the chalcopyrite.

Chlorite. Chlorite, the most abundant alteration mineral in the propylitized rocks, is rare in the veins. In the veins it is a secondary mineral resulting from the alteration of biotite.

Ferrimolybdite. Ferrimolybdite, or molybdic ochre, is found in the outcrop of the quartz-molybdenite veins, where it forms a gossan which extends only a few feet below the surface. It also is found encrusting molybdenite exposed in the older workings. The ferrimolybdite is a secondary mineral resulting from the oxidation of molybdenite in the presence of water and the oxidation products of pyrite and chalcopyrite. In the mine openings molybdenite alters to ferrimolybdite at a much slower rate than the alteration of pyrite to limonite. It occurs as bright canary-yellow needles and fibrous aggregates.

Fluorite. Fluorite is the third most abundant mineral in the veins and is distributed widely throughout the deposit. It is found in the quartz-molybdenite veins as irregular segregations, most abundantly at the margins of ore shoots, but also to a minor extent in the ore shoots. Although associated with molybdenite and quartz, it never is intergrown with it. At places fluorite is surrounded by quartz and molybdenite, but more commonly it cuts these minerals. Veins containing mainly molybdenite and quartz change in a short distance to veins consisting mostly of fluorite. Fluorite also occurs as angular brecciated pieces in rhodochrosite-calcite veins, and alone in veins ranging up to 2 feet thick. The fluorite is purple, blue, green, and less commonly white or clear; one color may shade into another within a mass. Purple and blue fluorite is found most frequently where associated with molybdenite in the ore shoots; the green fluorite, at the margin of ore shoots or in veins containing only fluorite. No crystal faces were noted, and cleavage is not well defined, although the fluorite commonly is badly fractured in an irregular pattern.

Galena. Galena occurs only rarely. It is found in small pockets, alone or with chalcopyrite and sphalerite. Only one or two such pockets are encountered on an average mine level.

Gold. Gold is occasionally reported as "traces" in assays of ore. Its association with other minerals is not known.

Graphite. Graphite apparently is intimately mixed, at places, with molybdenite. Because of its similar appearance and properties, it is difficult to detect except by analysis.

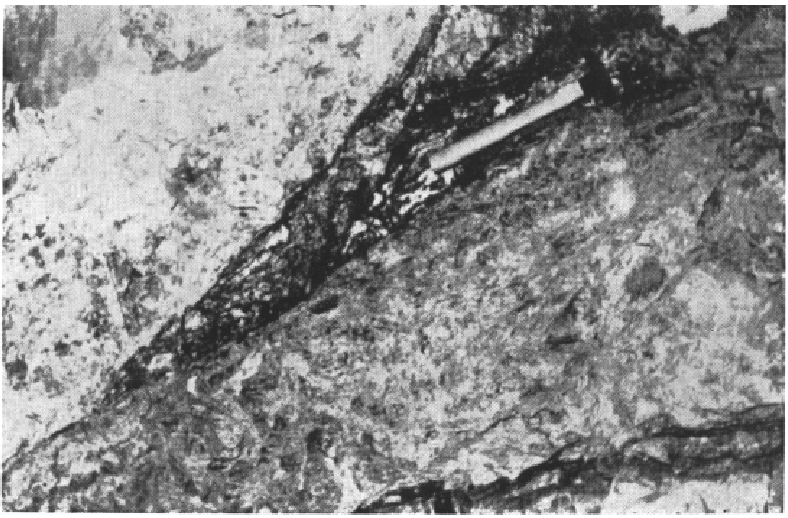
PLATE 4
TYPICAL VEINS

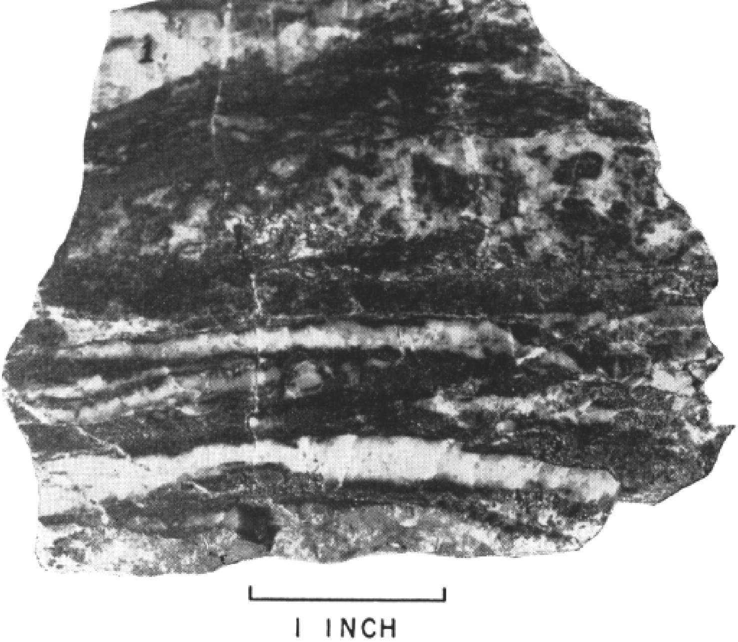
A. TYPICAL QUARTZ-MOLYBDENITE VEIN IN THE QUESTA MOLYBDENUM MINE

A small fault or "slip" forms the hanging wall. The vein is banded above and to the right of the geologist's pick.

B. PINCH IN A VEIN

The vein dips to the left and pinches downward.





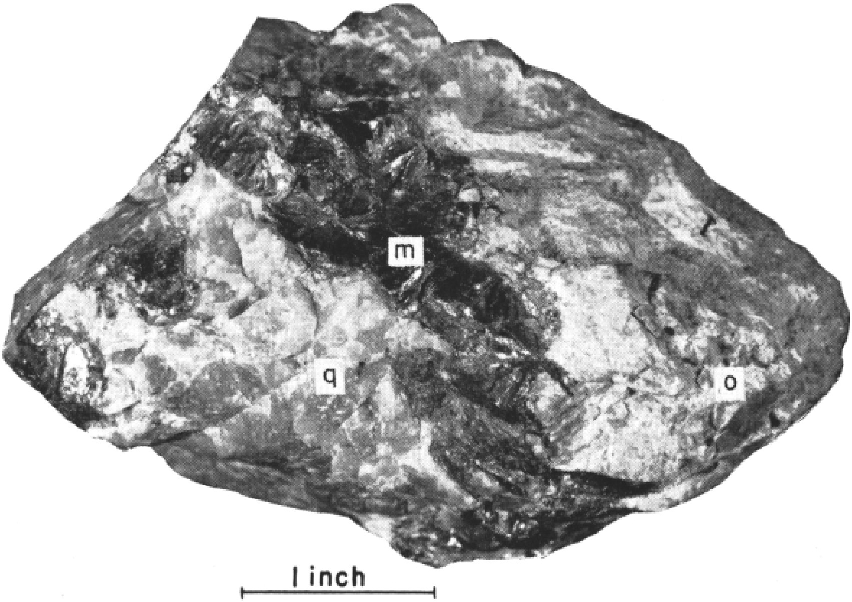


PLATE 5

SPECIMENS OFVEIN MATERIALS

A. SLICED SPECIMEN OF A BANDED QUARTZ-MOLYBDENITE VEIN.

The white mineral is quartz; the black mineral, molybdenite. (Specimen taken fromvein shown in pl 4B.)

B. SPECIMEN FROM A PEGMATITIC “VEIN.”

Molybdenite occurs as flat, tabular crystals. Symbols: m, molybdenite; o, orthoclase; q, quartz

Hübnerite. Hübnerite has been reported in the mine only once (Vanderwilt, 1938, p 267), as a few scattered crystals in the quartz of a vein. The writer found several crystals in the quartz of a molybdenite-quartz vein in the Horseshoe prospect near the mouth of Red River Canyon; the veins at this prospect are similar to those at the Questa molybdenum mine.

Limonite. Limonite is found in the outcrops of the veins, where it forms a gossan and is intimately mixed with ferrimolybdite. It also is found underground staining the walls of the workings, at places mixed with malachite or ferrimolybdite. It is a secondary mineral resulting from the oxidation of pyrite and chalcopyrite, and forms much more rapidly than ferrimolybdite. Boxwork containing residual limonite is scarce in the veins. More commonly the limonite is transported some distance before depositing as stains or botryoidal crusts, or is carried out of the mine in the water. At the portal of Z tunnel, which drains the older levels of the mine, large amounts of colloidal limonite are precipitating from the drainage water. The limonite is red, brown, and yellow, as well as combinations of these colors.

Malachite. Malachite occurs at a few places with the limonite. It produces a bluish-green stain but is quantitatively unimportant. It is an oxidation product of chalcopyrite or cupriferous pyrite (?). Most oxidized chalcopyrite in the mine shows no associated malachite stains, the copper being removed in the ground water.

Orthoclase. Coarse orthoclase occurs with quartz, biotite, and molybdenite in the pegmatite "veins" (molybdenite-rich dikes of pegmatitic soda granite). Such orthoclase is quantitatively unimportant, and the dikes are unimportant commercially, although of interest in a discussion of ore genesis.

Pyrite. Pyrite is the fourth most abundant mineral in the veins and is distributed widely throughout the ore deposit. It occurs intergrown with chalcopyrite and associated with the quartz and molybdenite as streaks or bunches in the veins, as veins without other minerals, and as streaks and masses in barren-quartz veins. It commonly cuts quartz and molybdenite, but also is found as masses in these minerals. The brass-colored pyrite usually occurs as aggregates of irregular grains showing much fracturing in polished section; less commonly, as cubes up to 10 mm square.

Quartz. Quartz is the most abundant gangue mineral. It occurs with the other vein minerals, commonly as lenticular masses, although locally it is absent. Intergrowths with molybdenite and biotite are common. Vein quartz, with stringers of molybdenite filling parallel fractures in the quartz, forms a banded structure (see pl 5A). It also occurs in small veins without other minerals, or with pyrite and chalcopyrite. The quartz is fine grained and ranges from milky white to grayish white or pale pink; crystals occur, however, in a few vugs. Pink quartz is regarded as a favorable indication of ore by the miners; the presence of such a relation was not confirmed.

Rhodochrosite. Rhodochrosite occurs alone, with brecciated fluorite, with calcite, and in cracks in the quartz-molybdenite veins. It is intergrown commonly with calcite. Distribution is spotty, and the mineral is quantitatively unimportant. Like fluorite, it occurs more commonly along the margins of an ore shoot rather than in the ore shoot, and therefore is considered as an indicator of a lack of ore by the miners. It is always fine grained and pink until exposed to the air, when it becomes ironstained. The miners call it "candy"!

Rhodonite. A specimen of a dark-red, fine-grained mineral was found in a vein of calcite and rhodochrosite. This mineral was much harder than the carbonates and was insoluble in warm HCl. Conclusive tests were not made, but the mineral is identified tentatively as rhodonite.

Silver. Like gold, silver is reported occasionally as "traces" in assays of ore. Its association with other minerals is unknown.

Sphalerite. Sphalerite occurs only rarely, in small pockets with chalcopyrite and galena.

Wall Rock and Gouge. Angular fragments of brecciated wall rock and gouge commonly occur as gangue in the veins.

Changes with Depth

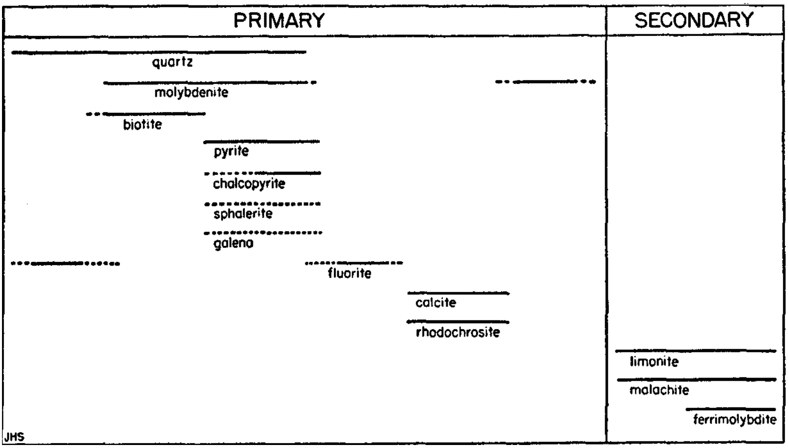
Most minerals in the veins show no apparent changes with depth in relative amounts, association, or appearance. The ratio of chalcopyrite to pyrite apparently increases slightly with depth, but the total amount of these sulfides in the veins shows no apparent change. No sphalerite has been noted on the lower three levels of the mine, suggesting a possible decrease of sphalerite with depth; however, sphalerite is so rare that such a relation cannot be proved or disproved. Vanderwilt (1938, p 630) reported that rhodochrosite was found only sparingly in the veins along the domed top of the soda granite stock and was relatively more abundant in the veins along the steep sides of the stock. Near the surface rhodochrosite may have been removed in solution by ground water.

Paragenesis

The sequence of mineralization was determined from megascopic relations; thinsection and polished-section studies were useful principally in confirming megascopic observations. As most of the vein minerals are transparent under the microscope, thinsection study proved more useful than polished-section study.

With the possible exception of a break prior to the deposition of the carbonates, the deposition of the various minerals was continuous. Quartz was the first vein mineral, followed by the main ore deposition of biotite, molybdenite, and quartz. With the continued formation of quartz and molybdenite, pyrite was deposited, accompanied by chalcopyrite, galena, and sphalerite. Fluorite apparently was deposited next, followed by the formation of the carbonates, calcite and rhodochrosite.

The secondary minerals limonite, ferrimolybdite, and malachite began to form once the veins were exposed by erosion or mining. At places, however, erosion is so rapid that molybdenite is found in the outcrops of the veins.



PARAGENESIS OF THE VEIN MINERALS OF THE QUESTA MOLYBDENUM MINE.

Figure 23

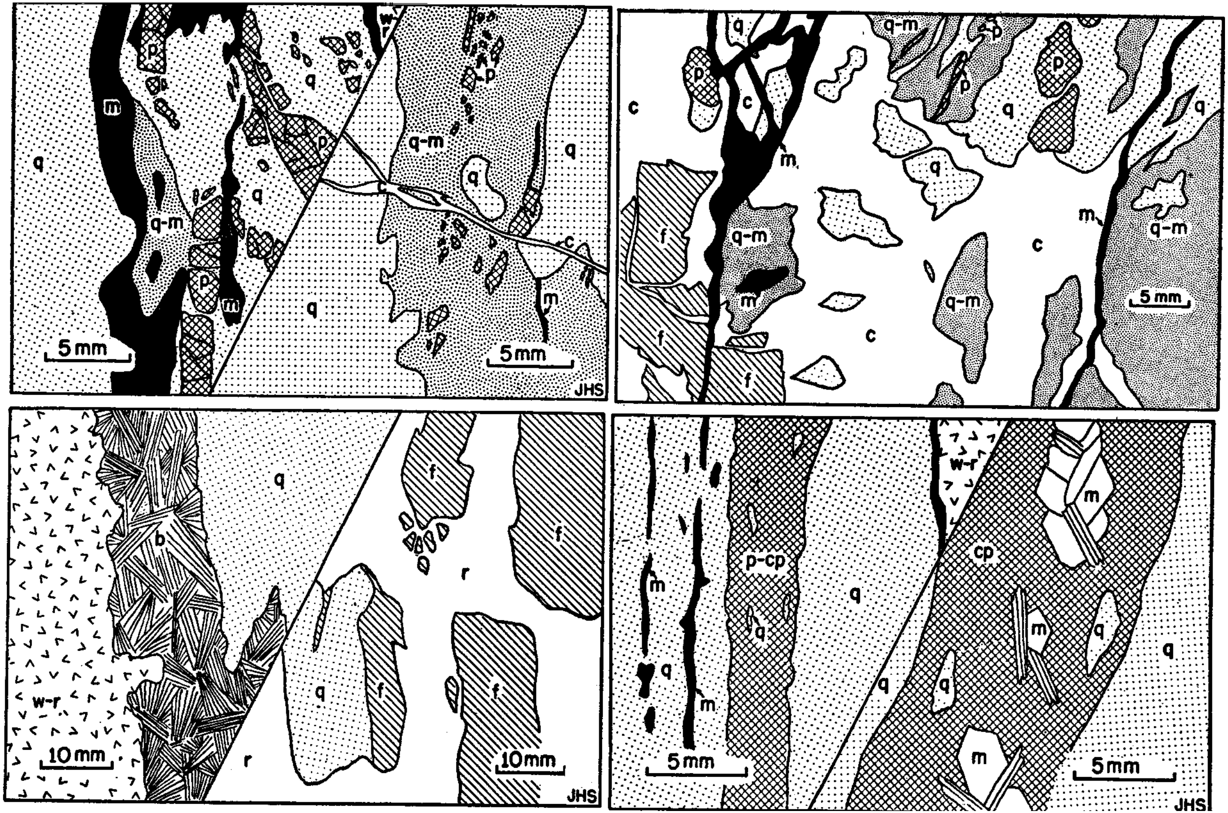
The paragenetic relationships of apatite, gold, silver, graphite, hübnerite, and chlorite could not be determined. Relations suggest that some fluorite may be the earliest mineral deposited, and that most of the fluorite is later than all the sulfides. Fluorite, where it is in contact with quartz, molybdenite, and pyrite, shows few clear-cut relations.

At any given point in the veins, one or more minerals commonly are missing, indicating that at various times during deposition the vein was not open at that spot, hydrothermal solutions containing the necessary ions were not available, or physical or chemical conditions were not right for deposition. It is also quite common for the sequence to be repeated (recurrent) in part or in full, so that the relationships are con-fused. It must be emphasized that the sequence of mineralization given in Figure 23 is a generalization for the mine as a whole, and that in detail many minor variations occur.

WALL-ROCK ALTERATION

The hydrothermal solutions which formed the veins also altered the wall rock. This alteration affects relatively small volumes of rock. Silicification occurs along the small barren-quartz veins, and less commonly

Figure 24



DRAWINGS OF POLISHED SECTIONS OF VEIN MINERALS.

Symbols: b, biotite; c, calcite; cp, chalcopyrite; f, fluorite; m, molybdenite; p, pyrite; q, quartz; q-m, fine grains of molybdenite in quartz; r, rhodochrosite; w-r, wall rock. Vein widths are long dimensions of drawings.

along the quartz-molybdenite veins, but seldom extends more than an inch or two from the veins. This alteration occurs only in the soda granite. Where most intense, all the minerals except quartz are replaced, and thinsections show a granular aggregate of quartz. At several spots in the mine large areas of soda granite have been silicified, the granite appearing gray instead of the usual pink. The silicified granite is much harder and more difficult to drill and break. In thinsection this rock shows orthoclase and albite phenocrysts in a fine-grained groundmass of granular quartz, differing from the ordinary porphyritic granite in the lack of feldspar in the groundmass.

Some of the feldspars in the soda granite are altered partly or completely to montmorillonite and sericite, giving the finer grained soda granite a white color; the porphyritic soda granite shows white phenocrysts. This alteration is confined to narrow zones (usually less than a foot) along veins and fractures.

Disseminated pyrite is scattered throughout the wall rock. In thin-section this pyrite is associated occasionally with biotite, which is partially altered to chlorite; more commonly it is found without biotite or chlorite. Disseminated pyrite is characteristic of the propylitic alteration; all or part of the pyrite in the granite may have been deposited during propylitization.

A white clayey gouge is common along shears in the soda granite and propylitized rocks. The gouge usually is confined between two smooth walls, which nearly always show slickensiding. Molybdenite "paint" or thicker veins commonly follow these slickensided walls, so that the gouge becomes the center, hanging wall, or foot wall of a vein. Slips or faults in the mine away from the veins show brecciated granite or propylitized rock, which, although unaltered to clay, still have smooth slickensided walls. At places such breccia is partially altered and gradational with the unaltered breccia and the gouge. In most cases the closer the fault breccia approaches a vein, the more intense the alteration becomes. However, the intensity of brecciation has in part controlled the degree of alteration. The gouge along faults or slips in the soda granite is composed of feldspar and quartz; clay and sericite, as alteration products of feldspar; small segregations of vein minerals; and small angular fragments of soda granite. All evidence suggests that the gouge in the soda granite was formed where fault-breccia has been hydrothermally altered by the vein-forming solutions. Gouge is much less common in the propylitized rocks and is found as two distinct types: (l) green gouge, consisting of chlorite, clay, sericite, and small fragments of propylitized rock; and (2) white gouge, similar to the gouge found in the soda granite. The green gouge probably represents the hydrothermal alteration of fault-brecciated, propylitized rocks. The origin of the white gouge is less certain. Small soda granite dikelets in the propylitized rocks commonly are badly brecciated; if altered by the hydro-thermal vein solutions, they would form a white gouge in the green propylitized rocks.

MOVEMENTS DURING VEIN FORMATION

Movements occurred in the veins at various times during their formation. It is these movements that resulted in the more clear-cut paragenetic relations. The carbonates occur in fractures and as breccia filling of the earlier minerals. Fluorite commonly is brecciated; pyrite fills cracks in the quartz and molybdenite; biotite and molybdenite fill cracks in the quartz; and molybdenite is slickensided.

Slickensided surfaces on molybdenite are quite common and striking. At first glance the slickensided molybdenite seems to indicate post-molybdenite movement; careful examination, however, often proves that the movement was premolybdenite. Molybdenite commonly is deposited along a slickensided surface; when the material is removed from one side of the resulting molybdenite veinlet during blasting, a "fossil slickenside," or cast of molybdenite, results. In a similarly deceiving fashion, molybdenite "paint" commonly covers a slickensided slip in such a thin layer that the grooves of the slickensides are preserved; the surface looks like a thick slickenside vein of pure molybdenite. Many of the slickensides do, however, represent slips which cut and displaced the molybdenite.

The slickensided slips in the vein commonly are curved, die out rapidly, seldom extend more than a foot, show various directions of movement, and do not extend into the wall rock. The slips forming the hanging wall or foot wall of the veins, in contrast, are continuous for long distances. Locally the quartz in the vein is sheeted, and molybdenite fills the fractures to form the banded vein material.

The pattern of brecciation and fracturing in the veins suggests that the shearing which opened the fractures in which the veins were deposited, continued intermittently throughout the period of vein formation. This continued shearing caused movement along the wall of the veins, as well as movement and brecciation in an irregular pattern in the veins. Masses of more shear-resistant minerals within the veins rotated and slid in the softer molybdenite, or were brecciated and fractured when the soft molybdenite was not present.

GENESIS

Manner of Emplacement

The minerals of the veins were deposited as fissure fillings by solutions which penetrated along fractures and deposited where movement had left open space in the fractures. There is little evidence of replacement.

Depositional Control

Because the veins are fissure fillings with only minor replacements, the formation of open spaces is one of the most important factors in depositional control. It was important not only that fractures were formed and opened, but that they formed a regular pattern, with large, continuous openings; brecciation or irregular fracturing results in small irregular veins. Minability depends on the thickness and continuity of the veins.

The evidence, although inconclusive, suggests the following theory for the formation of the sheeting in which most of the veins are found. As the soda granite was intruded upward, the force of intrusion formed a couple with the intruded rocks resisting the intrusion. As the outer layer of soda granite became solid, it helped the intruded rocks resist the upward movement of the still-fluid core of the stock. The stress caused by this couple was released by fracturing in the solidified granite and intruded rock. The resulting sheeting is not uniform on all sides of the stock. The reason for this is not entirely clear. Possibly, where the weak propylitized volcanics were present, or the regional east-west striking, vertically dipping fracture system was favorably oriented, much of the intrusive stress would be released by these features, and the solidified granite shell could absorb the remaining stress by fracturing in a less intense and more regular fashion. Where more resistant (competent) rocks occur, more of the stress was taken up in the granite, and brecciation occurred. In contrast to the regular pattern of the sheeting on the steep sides of the stock, the upward force of intrusion produced an irregular pattern of fracturing in the domed top.

Not only was the granite sheeted, but movement took place along the contact and fractures, helping to release continuing stress. Numerous slickensides give evidence of this movement. It is this movement which resulted in the open spaces. The fluid central part of the granite magma moved upward relative to its outer solidified crust, resulting in movement along the earlier fractures and outer contact. Thus, where the contact or fractures changed from a steep dip to a gentler dip and then to a steep dip again, movement would result in sliding along the gentler dip and parting along the steeper (see fig 25). Throughout the mine the thicker veins and ore shoots occur where the veins and contact dip steepest, supporting this theory. Although the sheeting usually shows dip-slip movements, the network of other fractures, as well as some of the sheeting fractures, released the stress by movements which show no simple pattern and caused complexities within the ore shoots.

Once fractures have formed relieving certain components of the stress, the local details of the stress pattern will be changed, and differently oriented fractures may form under continuing stress, even though the overall magnitude and direction of the forces causing the stress remain the same. Thus continuing stress accompanied by continuing fracturing will result in a complex fracture pattern which at first may seem to be the result of several periods of fracturing by quite different and unrelated forces, although all have resulted from the same force, but under changing stress conditions resulting from continuing fracturing.

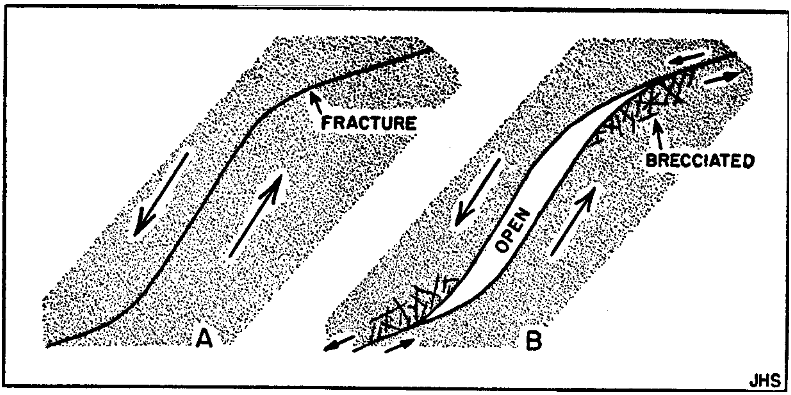
Movements continued during vein formation, with further deposition as the continuing movements opened space. Therefore, the width of a vein does not reflect necessarily the width of the open space along the premineralization fracture.

If two surfaces are held together, and one is moved in relation to the other, any irregularities on either surface will be placed under much greater stress per given area than would normally occur if no irregularities were present. This is the process which probably caused the more intense brecciation associated with contact irregularities in which the stockwork veins occur; any irregularities of the contact would have been subjected to large stresses during the continued upward movement of the center of the stock in relation to the margin.

It has been suggested that the hydrothermal solutions themselves have forced open the fractures; however, although this force may have aided the formation of open spaces, it certainly was not the dominant one; gently and steeply dipping fractures would have opened equally wide. It is doubtful that the hydrothermal solutions were under sufficient pressure to open such fractures.

Although the force of intrusion of the soda granite probably produced the fractures and openings in which most of the ore shoots in the mine are found, it is important to realize that other forces, with their resulting structures, could have produced the necessary open spaces. For example, some ore shoots are found where an opening was produced by the intersection of fractures and/or faults.

Other factors besides the presence of open spaces have controlled the formation of the veins and ore shoots. The relative importance of these factors is difficult to evaluate. The soft propylitized rocks formed a barrier to the continued upward movement of the ore solutions, allow-



FORMATION OF THE OPEN SPACE IN WHICH THE ORE SHOOTS OCCUR.
Coupled forces (long arrows) were relieved by movements (short arrows) that opened the steeper dipping parts of the fracture.

Figure 25

ing the solution to remain longer in the open fractures. Veins are lacking around most of the margins of the soda granite stock, which may reflect the absence of this effective dam, as well as the absence of proper fracturing. Changes in temperature, pressure, and chemical characteristics, as well as other factors, also controlled deposition.

It has been pointed out that as a stock cools, magmatic fluids will be concentrated in the upper part of the stock below the already solidified outer shell. The fluids will enter any existing cracks in the chilled border or surrounding rock, forming veins. This means not only that continuous, open fractures must be present, but that fractures located in or near the upper part of a stock are most favorable as loci of veins. If erosion has removed the upper part of a stock, most of the veins probably will have been removed also.

Physical Conditions

Biotite is considered to be an indicator of high-temperature deposition, galena and chalcopyrite of intermediate temperatures, and rhodochrosite of low temperatures. The relative ages of these minerals suggest that the solutions were introduced first at high temperatures and pressures, and that with time the temperature lowered and the pressure decreased. However, the evidence does not allow specific determinations of temperature-pressure relationships. Nor have minerals always proved reliable as temperature indicators. Molybdenite, for example, once considered a high-temperature mineral, now is known to deposit over a wide range of temperatures.

Source of the Ore-Forming Solutions

Most molybdenite deposits, including the Questa molybdenum mine, Climax mine, and the "porphyry coppers," are associated with Tertiary granitic (granite to quartz monzonite) intrusives, suggesting a genetic relation. Not only are the veins and soda granite stock at the mine spacially related, but they are also closely related in time. It seems probable that the ore-forming solutions and granite intrusives came from the same magma; the outer part of the granite intrusives solidified, concentrating the molybdenite-bearing solutions in the remaining magma. These solutions escaped along fractures, depositing the vein minerals, where open space was available.

Age

If the intrusion of soda granite is dated correctly as Miocene or Pliocene, the veins can be dated as late Tertiary. The veins were formed after the outer shell of the soda granite stock solidified, but while the core was still fluid.

Summary of Vein Formation

The following is a summary of the most probable sequence of events during formation of the veins. The soda granite intruded the older rocks as stocks. As the outer margins of the stocks solidified, the upward push of the still-plastic core caused fracturing in the solidified margins paralleling the contacts. In most cases irregular fracturing or brecciation occurred, leaving small, discontinuous open space or no open space. Occasionally, when conditions were right (for example, the presence of regional fractures or soft propylitized rocks to take up some of the stress), the granite fractured and opened in such a manner that many large, continuous open spaces were formed in a relatively concentrated area. Continued movement took place along these fractures, opening them widest where they had steep dips. The veins of the Questa molybdenum mine were deposited in just such a concentration of large, continuous open spaces by hydrothermal solutions from the fluid core of the soda granite stock. The softer propylitized rocks acted as a barrier to prevent continued upward movement of the solutions; this, plus resulting decreases in temperature and pressure, caused the deposition of the vein minerals.

CLASSIFICATION

On the basis of its mineralogy, the Questa molybdenum mine deposit can be classified, according to Lindgren, as hydrothermal of mesothermal intensity. Conditions during the deposition of the earlier vein minerals (biotite, quartz, molybdenite) may have approached hypothermal intensities; the youngest minerals (carbonates and fluorite) may have been deposited under epithermal conditions. Telescoping is indicated by the deposition of all these minerals at the same spots in the veins.

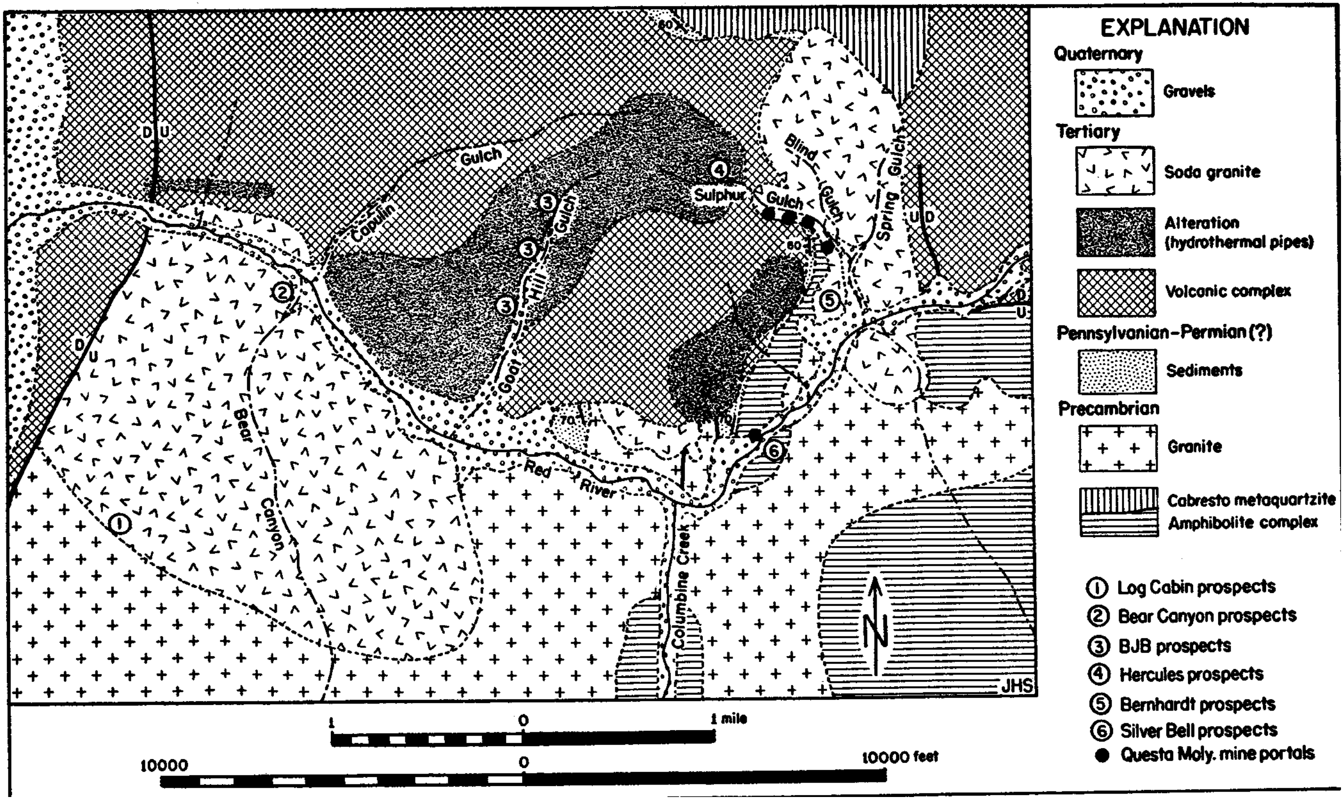
This deposit is similar in many ways to the Climax, Colorado, deposit. Both were formed by hydrothermal solutions from Tertiary granitic intrusives. Although wall-rock alteration is similar in both deposits, much larger volumes of rock have been affected at Climax. Both deposits contain important amounts of quartz, molybdenite, fluorite, pyrite, chalcopyrite, and rhodochrosite, and smaller amounts of hübnerite, galena, and sphalerite. Climax has cassiterite, monazite, and topaz, which are not known at Questa. Questa has abundant biotite; Climax has none. The most striking difference is the size and form of the veins. Questa has large, continuous veins; Climax is a stockwork of very thin veins and disseminated molybdenite.

Nearly all other molybdenite production comes from the porphyry copper deposits. The porphyry copper and other molybdenite-bearing deposits are markedly different from the Questa deposit, although many similarities exist.

OTHER MINERAL DEPOSITS

Although the Questa molybdenum mine is the only deposit in the area which has been mined on any considerable scale, many other deposits have been prospected. The most interesting of these are described below in some detail.

Figure 26



GEOLOGY OF THE AREA COVERED BY RECONNAISSANCE MAPPING.

The locations of the various prospects and Questa molybdenum mine are shown.

BEAR CANYON (HORSESHOE) PROSPECTS

The Bear Canyon (Horseshoe) prospects are located along the south side of Red River Canyon, at its junction with Bear Canyon, 5 miles west of the mill (see fig 26). A portal on the Red River is the entrance to the only extensive workings (see fig 27); several small prospect holes are found in the walls of Bear Canyon. Juan Aragon and Dan Cisneros, of Questa, worked these prospects for many years, this property now containing the largest footage of workings of any prospect in the area covered by this report. No ore has been milled, although a few tons have been stockpiled.

The veins encountered in the workings and on the surface cut the Flag Mountain soda granite stock. The contact of the stock is over 800 feet to the north of the nearest exposed vein, and the granite is fractured much less than at the Questa molybdenum deposit. Along this contact the soda granite is in contact with the Tertiary volcanic complex, but outcrops show little mineralization or favorable fracturing. The veins follow slips and fractures in the granite, most commonly striking east-west, with steep dips to the north and south; others show random orientation. No brecciation accompanied by stockwork veinlets of molybdenite has been encountered.

The veins range from "paint" to 3 feet thick; there is no relation between the angle of dip and the thickness of the vein. "Splits" and "pinches" are common, as in the Questa molybdenum mine. Very few pockets of ore were found; none can be called ore shoots under the definition used in this report (see p 51). Pockets usually are found at the intersection of a vein with another vein, fracture, or fault.

The veins consist largely of quartz, with some molybdenite, pyrite, chalcopyrite, and minor biotite and fluorite. Hübnerite occurs rarely as small masses in quartz. Mineral associations and textures, paragenesis, and wall-rock alteration are similar to the Questa molybdenum deposit.

Although this deposit in most respects is similar geologically to the Questa molybdenum deposit, there are important differences. The veins thus far explored are not near the soda granite contact; fractures and veins are less common, tighter, and form no definite pattern.

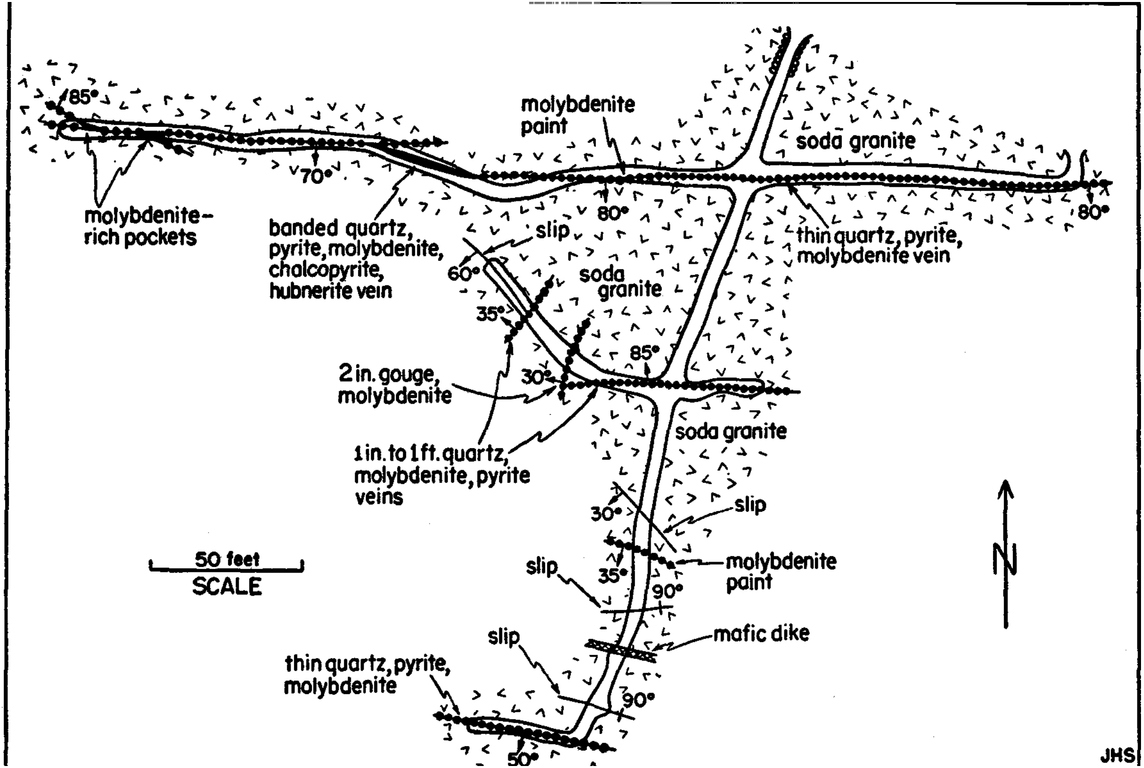
LOG CABIN CANYON PROSPECTS (STEVE'S PROSPECT ?)

Several old prospects along Log Cabin Canyon, on the west side of Flag Mountain, expose molybdenite-quartz-pyrite veins similar to those at the Bear Canyon prospects (see fig 26). These veins are in the Flag Mountain soda granite stock. In the 1930's the Molybdenum Corporation of America drove an adit to the southeast along the canyon, intersecting several of these veins, but no ore shoots were encountered.

BERNHARDT PROSPECTS

Leroy Bernhardt had a group of claims along the west side of Sulphur

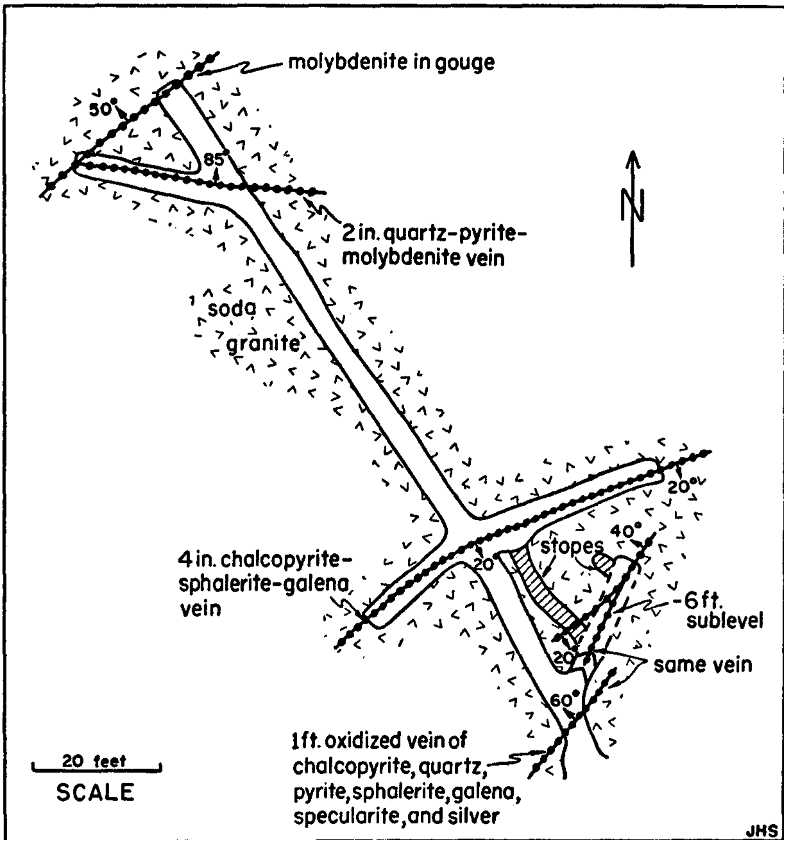
Figure 27



GEOLOGY OF THE BEAR CANYON (HORSESHOE) PROSPECT.

Gulch, between Spring Gulch and Red River (see fig 26 and pl 2). A number of prospect pits and several adits are scattered over these claims; all are in the Sulphur Gulch soda granite stock. No ore was mined.

The southern adit cuts several veins (see fig 28). An oxidized vein exposed at the surface contained specularite, quartz, pyrite, chalcopyrite, sphalerite, and galena, striking N. 45° E. and dipping 40°-60° NW; it assayed 50 ounces of silver per ton. This vein was about a foot wide at the surface, but as it was explored downward, it pinched out less than 6 feet below the surface. During this downward exploration another similar vein, striking N. 60° W. and dipping 20° S., was encountered. It was less than 6 inches thick and extended down till it intersected the first vein. This second vein contained chalcopyrite, with only small amounts of sphalerite and galena and low silver assays.



GEOLOGY OF THE SOUTHERN BERNHARDT PROSPECT.

Figure 28

Similar discontinuous veins, differing mainly in the percentages of the various minerals, are found in a number of prospects along the south side of Red River Canyon, from Columbine Canyon to Sulphur Gulch. The adit was extended northwest 120 feet, but cut no additional chalcopyrite-sphalerite-galena veins. Several thin veins containing molybdenite, quartz, pyrite, and chalcopyrite were exposed, but no ore pockets were found. The granite in the adit is not highly fractured; its contact is over 200 feet to the east.

The northern adit was driven approximately 100 feet into the west side of Sulphur Gulch along a mineralized shear zone which extends over l,000 feet to the east, trending N. 80° E. and dipping vertically. The soda granite has been badly brecciated and altered along this shear zone. The alteration is similar to that found along the veins in the Questa molybdenum mine; small quartz veins are accompanied by silicification of the soda granite, pyrite is disseminated through the rock, and feldspar phenocrysts are altered to clay. Molybdenite "paint" coats many of the fractures. The mineralized shear zone extends east in the soda granite, crossing about 100 feet north of the junction of Sulphur and Spring Gulches. Several caved adits and prospect holes have explored the shear zone; nothing is known of their history. Pyrite and chalcopyrite grains are scattered through the rock; partial oxidation has occurred, and limonite, malachite, and azurite stains are common. Small masses of purple fluorite and quartz veinlets also are common.

HORNER PROSPECTS

At the head of Blind Gulch (see pl 2), three adits are driven in the soda granite of the Sulphur Gulch stock. The one adit which is not caved extends N. 65° E. for 85 feet along a shear zone having a N. 65° E. trend and 85-degree dip to the southwest. Mineralization is very weak. Pyrite, chalcopyrite, quartz, limonite, and malachite are found in small amounts as veinlets and disseminations in the crushed rock of the shear zone. No molybdenite was noted.

HERCULES PROSPECTS

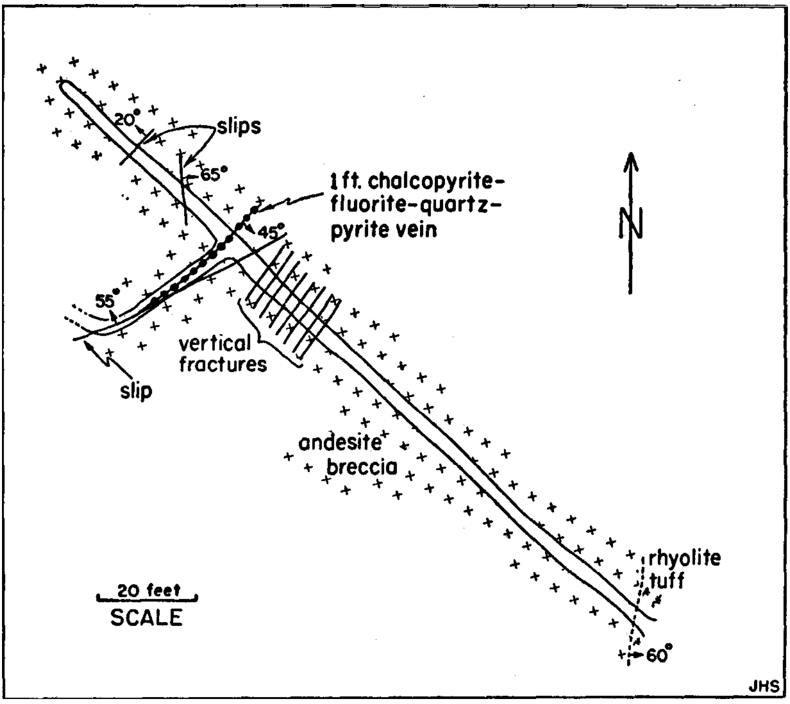
In 1924 the Hercules Molybdenum Corporation did some exploration work at the head of Sulphur Gulch, northwest of the Questa molybdenum mine deposit (see fig 26 and pl 2). Several adits were driven along mineralized shear zones in a hydrothermal pipe of altered Tertiary volcanic-complex rocks. No ore shoots were found. The adits are caved, but the surrounding surface shows small fluorite-pyrite-chalcopyrite veins, quartz veins accompanied by silicification, and some molybdenite "paint" along fractures. The shears trend east-west.

BJB PROSPECTS

Three adits are located along Goat Hill Gulch in the volcanic complex and a less intensely brecciated part of a hydrothermal pipe (see fig 26). These prospects, known as the BJB prospects, were last worked by Bill Wilde.

The northernmost adit is known as the Hawk tunnel (see fig 29). The portal is in rhyolite tuff, whereas the rest of the adit is in andesite breccia. The wall rock is not brecciated, being a resistant mass in a hydrothermal pipe. An irregular vein of chalcopyrite, pyrite, quartz, and green fluorite, trending N. 45° E. and dipping 45° SE., was exposed. The chalcopyrite occurs in massive chunks rather than in aggregates of fine grains, which is more commonly the case in the altered areas. The hill in which the vein occurs is stained red, whereas the surrounding outcrops show the more typical yellows of the hydrothermal pipes. There is no record of production.

A short distance up the gulch a crumbly mass of pyrite over 4 feet square is found in the side of the gulch. Mr. J. B. Carman (personal communication) reported that assays of this material showed scattered gold values of a few hundredths of an ounce, with one sample of 0.17-ounce Au. This is an isolated mass, and no additional pyrite masses could be found.



GEOLOGY OF THE HAWK TUNNEL, NORTHERNMOST BJB PROSPECT.

Figure 29

The middle adit is now badly caved. It extends north for about 400 feet. The adit is in fine-grained rhyolite and andesite. Secondary gypsum fills many open fractures. Small, irregular pyrite-chalcopyrite-fluorite veins are common, and a drift (250 feet from the portal) was driven west along one of these. Molybdenite does not occur with the other minerals, but is common as "paint." A short side drift about 150 feet from the portal extends 20 feet to the west along a slip striking N. 80° W. and dipping 75° S. "Mud" (gouge impregnated with molybdenite) and pyrite occur along this slip, and small masses of molybdenite are found in adjacent fractures. A few small masses of galena were found on the dump.

The southernmost adit extends N. 45° W. for 475 feet in alternating porphyritic and fine-grained andesite. A few irregular pyrite-chalcopyrite-fluorite veins are present, and molybdenite paint is found on the dump. Along this adit, a winze, now filled, hit a small pocket of molybdenite.

OTHER PROSPECTS IN HYDROTHERMAL PIPES

Many prospects, including the Hercules and BJB prospects described above, explore veins in hydrothermal pipes. These irregular veins cut the large masses of unbrecciated rock commonly found in the hydrothermal pipes, but pinch out where they continue into the surrounding, softer, intensely-brecciated parts of the pipes. The veins contain pyrite, chalcopyrite, quartz, fluorite, molybdenite, and less commonly galena and sphalerite.

These veins probably were formed by the same hydrothermal solutions as the Questa molybdenum mine veins. No minerals are present in these veins which are not found in the veins of the mine; they are all of similar age and have the same mineral relations.

SILVER BELL PROSPECT

Several prospects are located along the south side of Red River Can-yon, between Sulphur Gulch and Columbine Canyon (see fig 26). The best known is the Silver Bell prospect, opposite the Moly tunnel portal. These prospects are in the Precambrian granite and amphibolite complex, and expose small, irregular veins of quartz, pyrite, chalcopyrite, sphalerite, galena, specularite, and silver. The veins are similar to the silver-rich vein in the southernmost Bernhardt adit, except that sphalerite and galena make up a larger percentage of the vein minerals. Less commonly the veins have only fine-grained galena filling brecciated quartz. Similar veins are found in the Hornet prospect, along Cabresto Canyon, 2 miles north of the Sulphur Gulch stock.

SUMMARY AND CONCLUSIONS

The veins of the various deposits, including the Questa molybdenum mine, have many similarities. No minerals were noted in the deposits which do not occur in the Questa molybdenum mine, and the textures and paragenetic relations are similar. The minerals occur in varying proportions in the different deposits, but this can be explained by varying conditions, lack of open space when conditions were right for the deposition of a given mineral, varying distance from the source of the hydrothermal solutions, etc. Wall-rock alteration is mineralogically quite similar in the deposits, although more intense in the Questa molybdenum mine.

Although the evidence is not conclusive, a common source, the soda granite intrusives, is suggested for the deposits. Not only does the similar vein mineralogy and wall-rock alteration support this view, but there is a rough zonal arrangement of minerals outward from the soda granite stocks. The later, lower temperature minerals of the Questa deposit are found in larger percentages farther from the soda granite stocks (farther from the supposed source). Possibly, after depositing the higher temperature minerals (biotite, etc.) closer to the source, the solutions de-posited the lower temperature minerals at the lower temperatures and pressures existing away from the stock. Near the stock, where the higher temperature minerals were deposited, decreasing temperature and pressure with time allowed telescoping, with deposition of the lower temperature minerals at the same spot. No rhodochrosite has been found in the outer zone, where it should be expected to occur. Possibly the fractures were filled completely with earlier minerals, leaving no room for its deposition. If present, rhodochrosite would be stained and difficult to recognize, and near the surface would have been removed in solution by ground water; manganese stains are common. Until more conclusive evidence is found, the possibility remains that some of the deposits may not be related genetically to the Questa deposit and soda granite.

The size and location of the veins in the prospects depend on the degree of fracturing. This varies with rock type and intensity of the fracture-producing stress. The soda granite most commonly shows proper optimum fracturing and contains most of the larger veins. The hydrothermal pipes are intensely brecciated, and the veins are small and discontinuous. At the other extreme, the Precambrian rocks contain only a few relatively tight fractures and small, short veins. Under stress the "hard" rocks would develop continuous fractures along which solutions could travel and deposit, whereas the softer rocks would yield without forming fractures through which solutions could pass.

SECONDARY ENRICHMENT IN HYDROTHERMAL PIPES

Disseminated pyrite and lesser chalcopyrite are widespread in the hydrothermal pipes, suggesting the possibility of secondary-enrichment copper deposits at depth. The sulfides have been oxidized at the surface and carried away in solution, leaving boxworks with little or no residual limonite.

How much secondary enrichment has taken place is not known. Unfortunately, no estimate of the copper content of the disseminated sulfides could be made in the time available. Chalcopyrite is present, and the pyrite may be copper-bearing. Malachite staining is not common, nor is it indicative of the amount of copper present. The removal of much of the altered rock by erosion before oxidation of the sulfides, as well as the removal of much of the oxidized material dissolved in surface water, has carried away some of the copper which normally would have been carried downward by the ground water to form an enriched zone. Whether these processes have been active on their present scale since the deposition of the disseminated sulfides is not known. The yellow color of the altered areas is not considered a favorable sign of copper mineralization. Posnjak and Tunell (1928) state that yellow gossans are indicative of moderate to high percentages of sulfides, with a high proportion of pyrite to copper-bearing sulfides. There are exceptions, however, to this rule.

Although the meager evidence suggests the absence of economically important enriched zones, it should be emphasized that more detailed and exhaustive work is necessary before the presence of low-grade copper deposits in the hydrothermal pipes can be discounted completely. For this reason, the hydrothermal pipes definitely deserve more detailed study.

"Hydrothermal pipes" occur at Copper Creek, Arizona (Kuhn, 1941). Here the pipes are brecciated areas at the intersection of fracture zones. Molybdenite occurred in these pipes in minable amounts.

FUTURE POSSIBILITIES AND GUIDES

This section discusses favorable locations and guides to ore for the area covered by reconnaissance mapping (see fig 26). This information can be applied also to the entire Taos Range. Two points should be emphasized: (l) A careful study of this report, together with additional study of the area, including field work and physical testing, should be made before money is spent on development or mining. (2) Economic considerations are not covered in any detail, although some economic factors are mentioned.

HIGH-GRADE MOLYBDENITE DEPOSITS

Questa Molybdenum Mine

By far the best possibility for new high-grade ore shoots is the down-ward extension of the ore body along the local east-west trending con-tact of the soda granite stock. The veins on the lowest levels in the mine contain fewer ore shoots with increasing depth. This has been considered as evidence of bottoming. However, this pattern of fewer ore shoots with increasing depth has occurred over vertical ranges of several hundred feet at several higher levels in the mine (see p 52), only to have the pattern reverse as lower levels were developed (so that more ore shoots were found with increasing depth). Thus the decreasing ore on the lowest level does not necessarily indicate bottoming. Whether ore shoots below the present lowest level could be mined profitably depends, of course, on economic conditions.

The following guides have proved useful in the past, and would hold true for downward extension of the veins:

1. Nearly all the veins occur along the locally east-west trending contact of the Sulphur Gulch soda granite stock; where the contact swings north or south few veins are found.
2. The ore shoots are usually on the soda granite contact or in the soda granite within 50 feet of the contact; veins in the propylitized rocks are tight, with few ore shoots.
3. Most ore shoots are found where the veins and contact dip steeply; gentle dips usually are associated with thinner veins.
4. Ore shoots are found also at the intersection of a vein with another vein, fault, or fracture.

Because the veins commonly change dip and strike rapidly, projection from level to level results, at the best, in only a rough estimate of their position.

Other Areas

The most favorable areas to explore for new high-grade molybdenite deposits are in the surrounding rocks or margins of the tops of the Tertiary granitic stocks (including the soda granite), where open, continuous fracturing provides space in which ore shoots can occur (tight or irregular fractures and brecciation being unfavorable), and a capping of relatively impervious rock prevents the rapid loss and nondeposition of the hydrothermal solutions. It should be remembered that if erosion has removed the upper several thousand feet of a stock's outer shell, most of the veins probably have been removed.

On this basis the Flag Mountain stock is a favorable area. The north side of the stock shows no open, continuous fracturing or mineralization, and erosion has removed at least the top 2,500 feet (vertically) of this margin of the stock and any veins which might have been present. The south side of the stock is not eroded below its domed top, and the steeper sides of the stock may be sheeted and have ore shoots. Although this is a favorable area, its inaccessible location, plus the uncertain possibilities, would make exploration very expensive and risky. Veins follow fractures in the center of the stock, but are tight, the few ore shoots being too widely separated to produce minable ore.

Although the north side of the Sulphur Gulch stock has not shown any promising signs at the surface, erosion has not removed the domed top; like the south side of the Flag Mountain stock, the steeper sides of the stock may contain ore shoots. Here, also, exploration would be expensive and risky because of the inaccessible location.

The remaining areas covered by the reconnaissance map are unfavorable. Locally fracturing may be open and continuous enough to have small ore shoots; the possibility, however, of large shoots is poor, unless some new structural control is found.

When comparing the possibilities of other areas with the geology at the Questa deposit, it is unsafe to conclude that since good ore was found below poor surface showings at the mine, the same situation can be expected elsewhere. Actually most of the veins which crop out at the Questa deposit are not the same veins or type of veins which contain the ore shoots (see pp 44, 46).

In summary, under present economic conditions this area is unfavorable for the profitable discovery and working of new high-grade molybdenite deposits. The two most favorable areas would require a large amount of expensive exploration and development, with no certainty of discovering minable ore bodies. It should be emphasized that, at present, high-grade molybdenite producers have difficulty competing with low-grade mines except under especially favorable conditions. In case of a critical need for molybdenite, large amounts could be produced at high cost from the numerous small pockets in the Flag Mountain and Sulphur Gulch soda granite stocks.

LOW-GRADE MOLYBDENITE

Large tonnages of low-grade molybdenite ore occur in brecciated rocks of the area, but a detailed study of grade and tonnage will be necessary to establish their economic value. Such deposits occur in or near the granite stocks, where brecciation is intense and widespread. Large volumes of brecciated rock containing stockwork ores are found in the mine along the soda granite contact where the contact shows sudden changes in strike or dip (see p 46). All such areas so far opened in the mine have been too small or of too low grade to be commercial. Similar areas probably occur on the margins of the Flag Mountain stock. The hydrothermal pipes commonly show molybdenite as small pockets and "paint" along fractures, but never in large enough percentages to be mined except as a byproduct.

In summary, large tonnages of low-grade molybdenite ore occur, but known deposits are not large enough to be mined by block caving or open pit methods, which would be necessary for profitable operation. If large enough bodies are found, they probably will be along the contacts of the soda granite stocks or in the hydrothermal pipes. The small, known deposits of this type, like the high-grade molybdenite deposits, could produce large amounts at high cost if a critical need arose.

LOW-GRADE COPPER

The hydrothermal pipes may contain low-grade, disseminated cop-per deposits (see p 75). Pyrite and lesser chalcopyrite are found as disseminated grains and in veins throughout the areas of alteration. At the surface pyrite is present in much larger amounts than chalcopyrite, but no estimate of the percentage of copper present can be made without a more detailed study. At present the pyrite-bearing rock is being eroded so rapidly that oxidation does not decompose much of the pyrite and chalcopyrite; where oxidation does take place, most of the decomposition products are carried out of the area by surface drainage. Thus, a zone of secondary enrichment may be lacking or thin. However, more detailed study, followed by physical testing, will, be necessary to evaluate the possibilities properly. Molybdenite occurs as "paint" along fractures, and assays of the pyrite often show gold values; thus, molybdenite and gold may be present in sufficient amounts to be economically important as byproducts.

OTHER TYPES

Fluorite, sphalerite, galena, hübnerite, gold, silver, and rhodochrosite occur in many scattered deposits, but it is doubtful that an important minable deposit of any of these minerals will be found. However, small rich pockets may be found which can be mined profitably on a small scale.

SUMMARY AND CONCLUSIONS

The area covered is unfavorable for the discovery of new minable de-posits of any kind under present economic conditions. However, several possibilities exist which are worthy of more detailed study. The hydrothermal pipes should be studied in detail for possible low-grade copper deposits. Further, the margins of the Tertiary granite stocks should be explored for large, low-grade molybdenite deposits, although known deposits are small. In this regard the low-grade stockwork ores in the Questa molybdenum mine warrant special attention; future exploration in the mine should be done with this in mind. The possibility of finding other important ore deposits is remote, although large tonnages of molybdenite occur in scattered pockets, which could be mined at high cost if a critical need should arise.

The following two guides, which have proved useful in the area covered by this section of the report, should prove useful in exploration throughout the Taos Range:

1. Mineral deposits are concentrated in or near the tops of the Tertiary granitic stocks and (to a lesser degree) smaller intrusive bodies. Most of the veins associated with deeply eroded stocks have been removed by erosion.
2. Most mineral deposits in the area were deposited as fissure fillings. Open, continuous fracturing is a favorable sign for high-grade deposits, large areas of brecciated rock being favorable for low-grade deposits.

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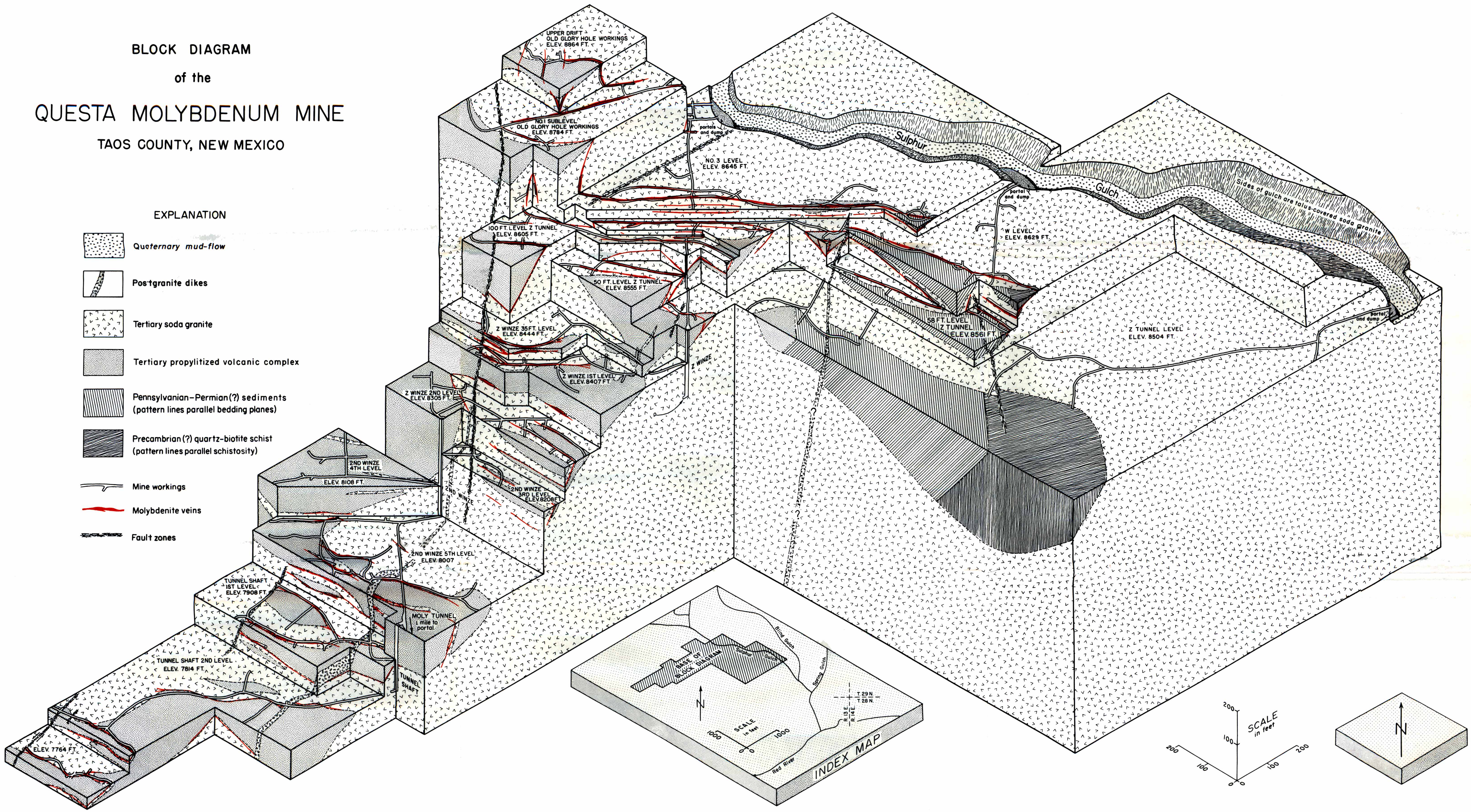
BLOCK DIAGRAM of the QUESTA MOLYBDENUM MINE

TAOS COUNTY, NEW MEXICO

EXPLANATION

- *Quaternary mud-flow*
- Postgranite dikes
- Tertiary soda granite
- Tertiary propylitized volcanic complex
- Pennsylvanian–Permian(?) sediments (pattern lines parallel bedding planes)
- Precambrian(?) quartz-biotite schist (pattern lines parallel schistosity)
- Mine workings
- Molybdenite veins
- Fault zones



GEOLOGY AND DRAFTING BY JOHN H. SCHILLING, 1952–1955
WORKINGS FROM MOLYBDENUM CORPORATION OF AMERICA MAPS

GEOLOGIC MAP AND SECTIONS

QUESTA MOLYBDENUM MINE AREA

TAOS COUNTY, NEW MEXICO