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Molybdenum Resources of New Mexico

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Abstract

Molybdenum minerals are widely distributed in New Mexico; seventy-four occurrences have been reported. Molybdenite [MoS_2] is the most common molybdenum mineral, as it is throughout the world; wulfenite [$PbMoO_4$], jordisite [amorphous MoS_2], ferrimolybdite [$Fe_2 (Mo0_4)_3.8H_20$], ilsemannite [$Mo_3O_8 \bullet nH_2O$], powellite [Ca(Mo,W)04], and molybdian scheelite [$Ca(W,Mo)0_4$] also are found in the state.

There are seven types of molybdenum deposits in New Mexico (the number of occurrences of each type is given in brackets):

1. molybdenite in pegmatite dikes [4]
2. molybdenite with or without other sulfide minerals in quartz veins [30]
3. molybdenite as disseminated grains and in quartz-stockwork veinlets in porphyry-copper deposits [6]
4. molybdenite as disseminated grains and in quartz-stockwork veinlets in cooper-poor porphyry-molybdenum deposits [1]
5. powellite, molybdenite, and/or molybdian scheelite in contact-tungsten deposits [13]
6. wulfenite in oxidized lead bodies [17]
7. jordisite in bedded uranium deposits [3 districts].

Ferrimolybdite is present in many of the occurrences as an oxidation product of molybdenite; ilsemannite is found in the uranium deposits as an oxidation product of jordisite. Deposits of types 1 through 5 in nearly all instances are closely associated with granitic (granite to quartz diorite) intrusive rocks. Nearly all the molybdenum deposits elsewhere in the world are of these same seven types and, for the world as a whole, occur in roughly similar proportions. The ore subtype that is not found in New Mexico but is important elsewhere is the tin-and/or tungsten-bearing quartz veins common in Asia.

Although production was small, New Mexico was one of the major sources of molybdenum during the early part of this century when wulfenite was mined from the Stevenson—Bennett mine, Dona Ana County, and the Palomas Gap and Hillsboro mining districts, Sierra County. The largest, and presently the only, molybdenum producer in New Mexico is the Santa Rita porphyry-copper mine, Grant County, from which more than 32 million pounds of molybdenite have been recovered as a by-product of copper mining. The second largest producer was the Questa molybdenum mine, Taos County, which yielded more than 20 million pounds of molybdenite from quartz veins. Although the high-grade veins have been mined out, a large low-grade porphyry-molybdenum deposit associated with the veins is now being readied for large-scale mining.

Because of its versatility and abundance, the demand for molybdenum will continue to increase rapidly. New Mexico will remain an important producer. The Santa Rita and Questa deposits both have large reserves, and the possibility of finding other minable molybdenum deposits in the state is good. The uranium deposits of the Grants area are another potentially important source of the metal.

Introduction

This report briefly describes each occurrence of molybdenum minerals in New Mexico; compares these occurrences to one another and to other deposits of the world; describes their geographic distribution and relation to other geologic features; and gives guides for exploration. It also provides background information on the history, uses, mining, concentration, processing, marketing, present production and consumption, future outlook, and resources of molybdenum in the state and world.

This bulletin brings together the extensive, scattered data on molybdenum in New Mexico. Much previously unpublished information is included that would not be readily available otherwise. It is intended to be a summary, and no attempt was made to include all the detailed data.

It is hoped that the information herein will provide a foundation for more detailed studies that will lead to the discovery of minable molybdenum deposits, as well as deposits of associated mineral commodities. I will appreciate receiving information about other molybdenum occurrences in New Mexico, as well as additional data or corrections for the occurrences described.

METHODS OF INVESTIGATION

As a result of the writer's interest in the geology of molybdenum, a number of New Mexico molybdenum deposits were examined by him from 1950 through 1960. Data from this source, as well as published data and unpublished information from a variety of sources, were summarized for each occurrence. Individual punch cards were then prepared, making it possible readily to compare the occurrences to each other and to other geologic features in a variety of ways. Punch cards previously made for most of the major, and many of the minor, molybdenum deposits throughout the world were compared to those of New Mexico deposits.

PREVIOUS WORK

Numerous publications mention molybdenum occurrences in New Mexico or describe the geologic setting in which they occur. These are listed under *References*. Many contain more detailed information than is given in this report. The reader also is referred to the general references, Anderson (1957), Dane and Bachman (1957, 1958, 1961, and 1962), Burks and Schilling (1955), and Schilling and Schilling (1956, 1961).

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Economics

HISTORY

The word *molybdenum* is derived from the Greek word *molybdaina,* meaning *leadlike.* This term and the later modifications such as *molybdena, molybditis, molybdos* were applied to all soft, leadlike materials, including the minerals now known as galena, graphite, stibnite, and molybdenite. Still later, the word *molybdaena* was used to mean only graphite and molybdenite.

In 1778, Karl Scheele, the Swedish chemist for whom scheelite was named, identified molybdenite as a distinct mineral (Scheele, 1778). Four years later, in 1782, J. J. Hjelm isolated the metal itself. The Knaben mine in southern Norway probably produced small amounts of molybdenite as early as the late eighteenth or early nineteenth century. Molybdenum was then being used in certain chemicals and dyes.

In 1894, Schneider and Company of France used molybdenum as an alloy in making steel armor plate. The first commercial use of molybdenum as an alloy was in 1898, when the Sanderson Steel Company of the United States began producing self-hardening molybdenum tool steel. Although this use stimulated considerable interest, the erratic performance of the early molybdenum tool steel due to improper heat treating discouraged further development of molybdenum in the United States as an alloying element.

Molybdenum production remained small and sporadic until World War I (fig. 1). Molybdenite was mined in the Knaben area of Norway and from several areas in Australia. Wulfenite was produced in Arizona and New Mexico. In 1913, the Kvina mine in Norway began using a flotation method to recover molybdenite, making it possible to exploit lower grade and more complex ores.

At the start of World War I, total world production of molybdenum amounted to 200,000 pounds a year. During the war, increasing demand for the new alloying metal led to extensive exploration, reopening of old mines, and opening of new ones. The Climax mine in Colorado, the Questa molybdenum mine in New Mexico, and the Moss mine in Canada were brought into production. By 1918, world production of molybdenum had risen to nearly 2 million pounds.

Large stockpiles and decreasing demand caused a collapse of the market for molybdenum at the end of World War I. Nearly all the mines had closed by 1921. Research efforts to develop peacetime uses for molybdenum were greatly expanded, particularly by Climax. The auto industries began to use increasing amounts of molybdenum steels, and the Questa and Climax molybdenum mines were reopened in 1923 and 1925, respectively. These two mines dominated world production.

Except for a slump after World War II, world production of molyb-

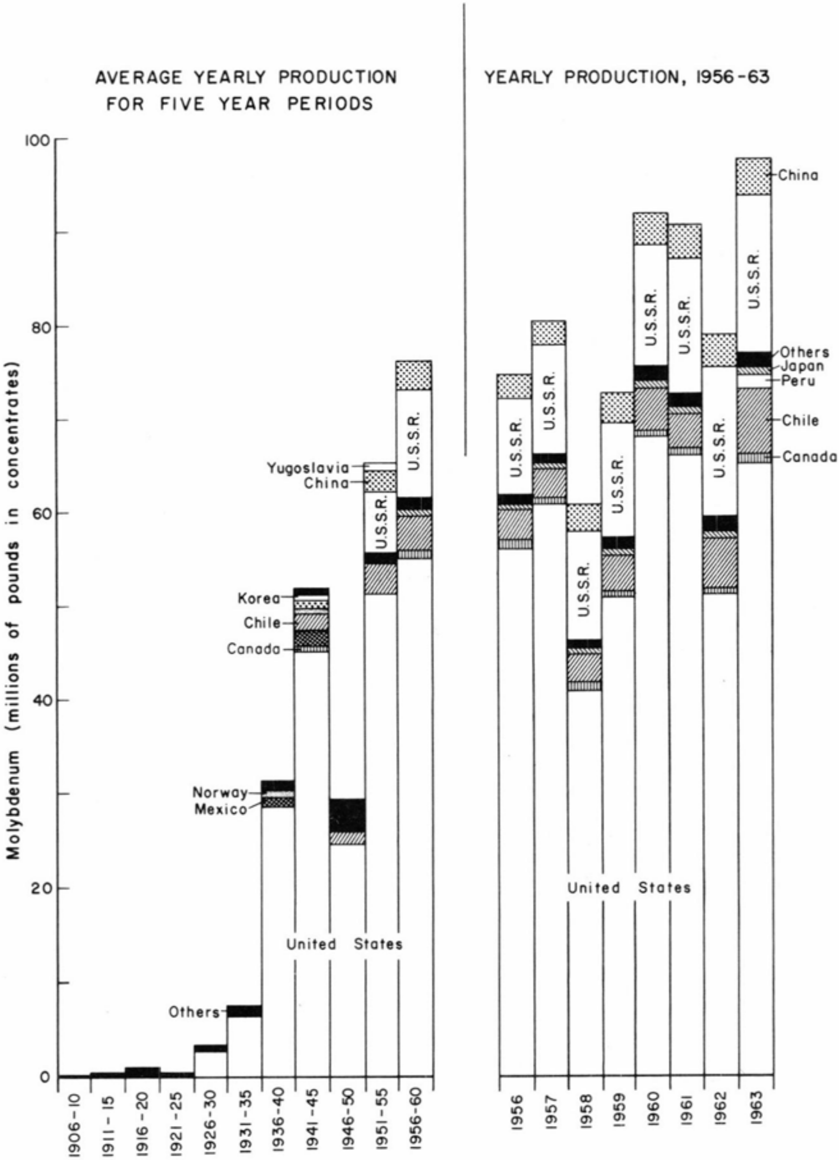

Figure 1
World production of molybdenum by countries (Russian and Chinese production estimated)

denum has continued to increase rapidly (fig. 1). In 1933, the first by-product recovery of molybdenum from copper ores began at Cananea, Mexico. In 1936, molybdenum by-product recovery was started at the Bingham Canyon mine, Utah. The following year, by-product recovery of molybdenum began at the Santa Rita copper mine in New Mexico. Many other porphyry-copper mines now produce by-product molybdenite. In 1939, recovery of molybdenum as a coproduct of tungsten mining began at the Pine Creek mine in California.

Although molybdenum is still used mainly as an alloy of steel and iron, its use as a metal, in chemicals, and as a lubricant is expanding rapidly. By 1963, world production had increased to almost 100 million pounds annually.

PROPERTIES AND USES

Molybdenum is a silvery gray metal having a higher melting point (2622° C) than all the elements except carbon, rhenium, tungsten, and tantalum. It is somewhat softer than steel. Chemically, it has valences of 2, 3, 4, 5, and 6 in stable compounds. Molybdenum does not occur free in nature. It has good thermal conductivity (about half that of copper), a high modulus of elasticity, and one of the lowest coefficients of expansion of all the pure metals (Northcott, 1956).

Molybdenum is one of the most versatile alloying elements and is extensively used in iron and steel production to increase hardness, strength, and corrosion resistance, particularly at elevated temperatures. It is a strong carbide-forming element, and much of its alloying effect is imparted through the formation of carbides. More than 90 per cent of the molybdenum consumed in recent years has been used in alloys (Schneider, 1963, p. 67-70; McInnis, 1957, p. 53-60).

Molybdenum metal has a small (5 per cent) but rapidly increasing use in the electronic, missile, and nuclear energy industries. Its use has been restricted by high production and fabrication costs, and the difficulty of preventing excessive oxidation, particularly at high temperatures. In the electronic industries, molybdenum metal is used in electronic tube supports, cathodes, glass-metal joints, and ceramic-metal seals, in electrical contacts, and in thermocouples, where a high melting point, strength at high temperatures, low vapor pressure, low electronic emissivity, or low thermal expansion is needed. The metal has found wide use in nozzles, leading edges of control surfaces, re-entry cones, heat-radiation shields, pumps, and other missile parts that are exposed to high temperatures. Molybdenum has been fabricated into heat exchangers, piping, and structural parts for nuclear reactors because of the metal's ability to absorb thermal-neutron radiation and to withstand high temperatures (Schneider, p. 74-79; McInnis, p. 51-52).

Molybdenum compounds are used as a lubricant (molybdenum disulfide), as an orange pigment (lead molybdate-chromate), in fertilizers (sodium molybdate or molybdic oxide), as chemical reagents, and as catalysts by the petroleum industry (Schneider, p. 80-84; McInnis, p. 61-63).

MINING

The methods used to mine molybdenum ore depend largely on the type of deposit. Nearly all the molybdenum presently being produced comes from low-grade, disseminated deposits of the porphyry type. These deposits are universally mined by high-volume, mass-mining methods—by open-pitting if the amount of barren overburden is not too great or by block-caving underground. The Santa Rita mine is a benched open pit with truck-skip haulage.

More selective, smaller scale methods are used in exploiting the vein and oxidized lead-zinc deposits. Cut-and-fill stoping was used at Questa, New Mexico (Carman, 1931).

CONCENTRATION

In nearly all instances, the crude ore must be concentrated before it can be sold or turned into useful products. The method of beneficiation depends largely on which molybdenum minerals and, to a lesser extent, other ore minerals and gangue are present.

Molybdenite. Molybdenite is universally upgraded by flotation (McInnis, p. 26-36). When the molybdenite is a by-product of copper mining, a molybdenum-copper flotation concentrate commonly is first produced and the molybdenite then separated from the copper by selective flotation (Hernlund, 1961). At the Big Pine mine in California, much of the molybdenum is recovered by flotation; however, some molybdenum (mostly as molybdian scheelite and powellite) is present in the scheelite (tungsten) concentrate and is recovered by digesting the concentrate in an alkaline solution and precipitating the molybdenum as a sulfide. At a few mines, by-products are being produced from molybdenite ore. At the Climax mine, Colorado, pyrite, tungsten (huebnerite), and tin (cassiterite) are recovered from the tails by gravity separation with Humphrey spirals; at the La Come mine, Canada, bismuth is recovered from molybdenite flotation concentrates by acid leaching.

Wulfenite. No wulfenite presently is being produced. When wulfenite ores were being mined, they were beneficiated by gravity or flotation methods.

Oxides. Molybdenum has never been recovered from secondary minerals; however, plans are under way to do so at the Climax mine, Colorado. In the pilot plant, flotation tailings from which the molybdenum has been removed are treated to solubilize the molybdenum-bearing minerals, ferrimolybdite, goethite, and jarosite. Activated charcoal pellets are then added to absorb the molybdenum. The molybdenum is stripped from the charcoal with ammonia, and the solution evaporated to crystallize ammonium molybdate. The ammonium molybdate is then roasted to produce molybdic oxide (*Mining World,* 1963, v. 25, n. 7, p. 44).

PROCESSING AND MARKETING

The plants that convert the raw materials to useful products almost always receive the molybdenum as molybdenite concentrates from mills at the mines. The concentrates contain 50 to 95 per cent molybdenite, but 90 per cent is considered a standard grade for price quotations. The concentrates must contain more than 80 per cent molybdenite and less than 1.0 per cent copper, less than 0.3 per cent lead, and less than 0.2 per cent combined phosphorus, tin, and arsenic to be acceptable to most buyers. The present (January, 1965) price for concentrates containing 90 per cent molybdenite is $1.55 a pound of contained molybdenum plus the cost of the container (fig. 2).

Virtually all the molybdenite (MoS_2) concentrates are roasted to molybdic oxide (MoO_3), which in turn is the starting material in producing most other molybdenum products. Technical grade (roasted concentrate) molybdic oxide in bags presently (January, 1965) sells for $1.74 a pound of contained molybdenum.

For use in alloys, the molybdic oxide is made into briquettes or converted to ferromolybdenum, calcium molybdate, or molybdenum silicide. The molybdic oxide is reduced to molybdenum metal powder ($3.55 a pound), which is used to fabricate metal parts, or increasingly is reduced to metal, which is cast directly into parts. The oxide also is converted into sodium and ammonium molybdate. Schneider (p. 57-66) describes the conversion methods used in American plants.

PRESENT PRODUCTION AND CONSUMPTION

The United States consumes 50 per cent of the molybdenum used in the world; European countries, the U.S.S.R., and Japan consume much of the rest. By 1963, world production of molybdenum had risen to almost 100 million pounds. The United States produces 70 per cent of this total, other Free World nations 10 per cent, and the Communist bloc 20 per cent (fig. 1).

The Climax mine in Colorado presently supplies 50 per cent of the world's and 75 per cent of the United States' production. Much of the remaining world output is recovered as a by-product from porphyry-copper mines in the United States (Arizona, Utah, New Mexico, and Nevada), the U.S.S.R., Chile, Peru, and Canada. Significant amounts of molybdenum also are recovered as a coproduct from tungsten mines in California and the U.S.S.R. and from vein deposits in Canada, Japan, and Norway.

New Mexico presently ranks fifth among the states (after Colorado, Utah, Arizona, and California) in molybdenum production, but it supplies only some 0.3 per cent of the world output. All the state's current production is from the Santa Rita mine, Grant County, making it one of the major molybdenum (and copper) mines of the world.

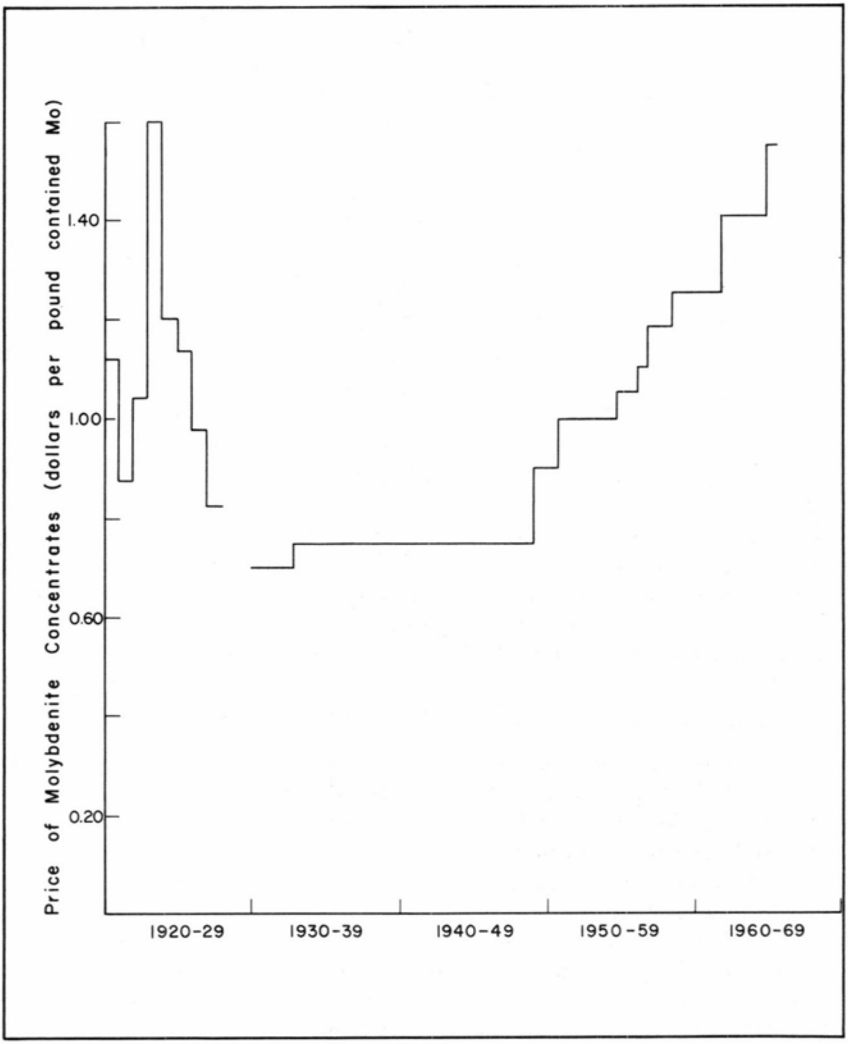

Figure 2

PRICE OF MOLYBDENITE CONCENTRATES (1920-1927 PRICES SHOWN ARE AVERAGES OF WIDELY VARYING PRICES)

FUTURE OUTLOOK AND RESOURCES

Because of its versatility and abundance, there is no doubt that the demand for molybdenum will continue to increase rapidly. United States' needs will continue to rise, but consumption in Europe, the U.S.S.R., and Japan will increase at a proportionately bigger rate. The metal's consumption in alloy steels will remain its major use because of a marked increase in demand for these steels, particularly abroad. Other uses of molybdenum are expected to consume increasing, and proportionately greater, amounts of the metal. The producers, especially American Metal Climax, can be expected to stimulate demand by continued aggressive research.

The United States for some time will remain the largest producer and supplier in the world. The Communist bloc, especially Russia, is rapidly expanding exploration and development efforts and, within the next decade, could rival the United States as a source. Chile, Canada, and Peru will have increasing production and continue to be important suppliers. A number of other nations that presently are not mining molybdenum can be expected to become significant, and in some instances important, producers.

The Climax mine will continue to dominate world production and reserves, but to a decreasing extent. Plans are presently under way to greatly expand output; proved reserves are conservatively estimated at 455 million tons of ore containing more than 2 billion pounds of molybdenum (1962 Annual Report, American Metal Climax, Inc.). Other porphyry-molybdenum deposits being explored or readied for production have substantial reserves and will be major producers; these include the Questa porphyry deposit, New Mexico, the Urad mine, Colorado, and the Hall property, Nevada.

By-product recovery of molybdenum from porphyry-copper ores will continue to increase and remain the second most important source of the metal. A number of mines (including Bingham Canyon, Utah) are increasing ore production; others (including Santa Rita, New Mexico) are improving recovery; some mines (including Bethlehem, British Columbia; Mission, Arizona; and Toquepala, Peru) have added molybdenum recovery units; and a number of other deposits (including Ithaca Peak, Arizona) are being readied for production. Reserves of molybdenum in this type of deposit are huge.

Coproduct and by-product recovery of molybdenum from tungsten ore will probably remain a relatively small but significant source of the metal. An important part of future Russian production probably will be from this type of deposit. Large amounts of molybdenum could be recovered as a by-product from many of the tungsten deposits of the western United States; the possibility of exploiting these potentially important reserves has not been given the attention it deserves.

Veins and oxidized lead-zinc deposits are not expected to be important future sources of molybdenum.

An intensive worldwide search is under way for new porphyry-copper and porphyry-molybdenum deposits. The Russians also are actively exploring and developing molybdenum-bearing tungsten deposits, but this type of occurrence is being neglected in other countries. Mass-mining plus recovery of molybdenum (as molybdenite, powellite, and molybdian scheelite), copper, and other by-products could lead to the profitable mining of tungsten-contact deposits in the western United States as well as elsewhere in the world.

Other ways will be found to increase molybdenum output. There are many potential sources of molybdenum, including bedded uranium deposits and molybdenum-bearing shales. Secondary molybdenum minerals, which currently are being wasted, will increasingly be recovered. And improved flotation methods and new techniques such as leaching will be used to recover molybdenum now lost during beneficiation.

New Mexico will remain an important producer. The new Questa open-pit mine, Taos County, tentatively is scheduled to begin production late in 1965 at an initial rate of 10 million pounds of molybdenum a year (1963 Annual Report, Molybdenum Corporation of America). If this objective is met, New Mexico will supply more than 10 per cent of the world output of molybdenum and by itself will be a bigger producer than any nation in the world except the United States and the U.S.S.R. The Santa Rita and Questa mines both have large reserves. The possibility of finding other minable molybdenum deposits in the state is good. The state's output could also be increased substantially if some way were found to recover the molybdenum associated with the uranium deposits of the Grants area.

Geology of Molybdenum

MINERALOGY

MOLYBDENUM MINERALS (TABLE 1)

Molybdenite (MoS_2). Molybdenite is the most common molybdenum mineral and presently is the only important source of the metal. Forty-seven of the seventy-four molybdenum occurrences in New Mexico contain molybdenite. It closely resembles graphite in color (lead-gray), softness, and flaky structure. It occurs widely throughout the world, the western United States, and New Mexico, usually as soft, lead-gray tabular hexagonal plates and flakes. Molybdenite is a primary mineral; it is found as an accessory mineral in granitic rocks, in pegmatites and aplites, in quartz veins, in porphyry-copper deposits, in quartz stockworks and disseminations containing no copper, in contact-metasomatic tungsten deposits, and in lead-zinc replacement bodies.

Wulfenite ($PbMoO_4$). Wulfenite is the second most abundant molybdenum mineral. Before World War I, wulfenite was the most important source of molybdenum, but presently little wulfenite is being mined. The mineral is common in the southwestern United States and elsewhere in the world, but it is less widespread than molybdenite. Seventeen of the seventy-four molybdenum occurrences in New Mexico contain wulfenite. It usually occurs as orange or yellow tabular crystals in the oxidized parts of lead-zinc replacement bodies in limestone.

Powellite ($Ca(Mo,W)0_4$). Powellite, although rare, is a more common molybdenum mineral than is generally supposed. It has never been economically important as a source of molybdenum. Powellite nearly always is impure with up to 10 per cent tungsten. It usually occurs as powdery white replacements of molybdenite in tungsten-contact deposits and probably also is present as a primary mineral in some of these same deposits. Powellite fluoresces golden yellow; this is the most widely used method of identification. Unfortunately, molybdian scheelite also fluoresces yellow. As a result, in many instances, powellite has come to mean any mineral in the powellite-scheelite series that fluoresces yellow. Known occurrences of powellite are rare in New Mexico and uncommon elsewhere, probably at least in part because of its inconspicuous appearance which leads to its being easily overlooked. Powellite has been reported from five localities in New Mexico.

Ferrimolybdite ($Fe_2(Mo0_4)_3.8H_20$). Ferrimolybdite is common in molybdenite-bearing deposits. It has been only a minor source of molybdenum. Ferrimolybdite generally is impure and mixed or associated with limonite. It is an oxidation product of molybdenite and usually occurs as fine, sulfur-yellow needles or earthy aggregates at or within a few feet of the molybdenite from which it was derived. It is the "limo-

TABLE 1. CHEMICAL AND PHYSICAL PROPERTIES OF MOLYBDENUM MINERALS

Name	Composition	% Mo	Usual color	Luster	Hardness (Moh's scale)	Specific gravity	Streak	Crystal system
molybdenite	MoS_2	60	lead-gray	metallic	1	4.7	blue-gray (on paper) greenish (on porcelain)	hexagonal
wulfenite	$PbMoO_4$	26	orange, yellow, gray-white, red, green	resinous to adamantine	3	6.7	white	tetragonal
powellite	$Ca\ (Mo,W)O_4$	39-48	gray, white, pale yellow, pale brown	pearly to earthy	4	4.2-4.5	white	tetragonal
ferrimolybdite	$Fe_2\ (MoO_4)_3 \cdot 8H_2O$	40	canary yellow	silky, earthy	1½	3.0-4.5	pale yellow	orthorhombic
ilsemannite	$Mo_3O_8 \cdot nH_2O$	—	blue-black	earthy	—	—	—	—
jordisite	MoS_2	60	gray-black	earthy	—	—	—	amorphous
chillagite	$3PbWO_4 \cdot PbMoO_4$	12	yellow	vitreous to adamantine	3½	7.5	—	tetragonal
koechlinite	$(BiO)_2(MoO_4)$	15	greenish yellow	—	—	—	pale greenish yellow	orthorhombic
lindgrenite	$Cu_3(MoO_4)_2(OH)_2$	36	yellowish green	—	4½	4.3	—	monoclinic
umohoite	$UO_2 \cdot MoO_4 \cdot 2H_2O$	22	black	vitreous	2	4.5	black	—

nite" of the molybdenum minerals and frequently is mistaken for limonite or jarosite. Although ferrimolybdite has been noted at only four localities in New Mexico, it undoubtedly is present in many of the other occurrences containing molybdenite.

Ilsemannite ($Mo_30_2.nH_20$). Ilsemannite, a dark blue double oxide of molybdenum, is rare and has never been utilized as an ore of molybdenum. Its composition is uncertain and what has been called ilsemannite may actually be several distinct minerals. Most mineralogists have applied the term *ilsemannite* to any molybdenum compound or mixture that is water-soluble and blue in solution. It reportedly is formed by the oxidation of molybdenite, jordisite, or wulfenite. Because it is highly soluble in water, it generally is found only in arid regions. Ilsemannite is fairly common in the uranium deposits of the Colorado Plateau (Rankama and Sahama, 1949). In New Mexico, ilsemannite is relatively abundant in the drier parts of the Grants uranium belt deposits, but it has not been reported from any deposit in the state that contains molybdenite or wulfenite.

Jordisite (MoS_2). Jordisite, a powdery black amorphous form of molybdenum sulfide, is a rare mineral, but it is more abundant than was realized until recently. It has never been utilized as an ore of molybdenum. Jordisite is common in the uranium deposits of the Grants uranium belt; it has not been reported elsewhere in New Mexico.

Other molybdenum minerals. There are a number of molybdenum minerals which are rare and have not been utilized as molybdenum ore. None is known to occur in New Mexico. These rare minerals-include chillagite [$3PbW0_4.PbMo0_4$], koechlinite [$Bi0_2 \cdot Mo0_4$], lindgrenite [$Cu_3(Mo0_4)_2(OH)_2$], umohoite [$UO_2 \cdot Mo0_4.2H_20$], belonesite [magnesium molybdate], pateraite [cobalt molybdate], eosite [lead molybdate-vanadate], and achrematite [lead chloride-arsenate-vanadate].

Molybdian minerals. Other minerals contain significant amounts of molybdenum. Scheelite commonly contains up to several per cent molybdenum in place of part of the tungsten, and a complete series may exist between scheelite (more tungsten than molybdenum) and powellite (more molybdenum than tungsten). The percentage of molybdenum in scheelite can be readily determined by the color it fluoresces; scheelite containing no molybdenum fluoresces blue-white, with the color changing to pale yellow as the molybdenum content increases (Greenwood, 1943). Although molybdian scheelite has not been utilized except on a small scale as an ore of molybdenum, it is a potentially important source of the metal. Yellow-fluorescing scheelite has been reported from ten of the twenty-five scheelite localities in New Mexico.

The limonite and jarosite in deposits containing molybdenum usually contain appreciable amounts of the metal. Although molybdenum has not been produced from this source, plans are under way at the Climax mine, Colorado, to recover molybdenum from these minerals.

RHENIUM IN MOLYBDENITE

There are no rhenium minerals, and although trace amounts of this rare metal are found in many minerals, it is particularly abundant in molybdenite, which contains up to 0.4 per cent. Essentially, all the rhenium now being produced is recovered from flue gas and dust resulting from the roasting of molybdenite concentrates from porphyry-copper deposits. Only a few hundred pounds of rhenium are consumed annually in the United States, but it is estimated that some 15 tons of the metal could be recovered from molybdenite concentrates presently being produced in this country.

The rhenium in molybdenite is of interest not only as the sole important source of the metal but also because the amount of rhenium in molybdenite from different types of deposits varies systematically. Molybdenites from porphyry-copper deposits are rhenium-rich; those from tungsten-contact (skarn) deposits are rhenium-poor; those from porphyry-molybdenum deposits and copper-barren quartz veins contain intermediate amounts of rhenium.

This systematic variation was first reported by Zhirov and Ivanova (1959) (fig. 3) and has since been confirmed by others. Unfortunately, extreme discrepancies exist among rhenium analyses made in different laboratories. However, analyses from a number of laboratories show internal consistencies, although the results obviously can not all be absolute; that is, they do not give the true rhenium content. There is a great need for the development of a simple and cheap, yet accurate, analytical method for determining rhenium. In the meantime, it would be helpful to have one laboratory run rhenium analyses on several molybdenite samples from as many important occurrences throughout the world as possible.

Rhenium has been extracted by the Kennecott Copper Corporation from molybdenite concentrates produced at its porphyry-copper open-pit mines in the western United States, including Santa Rita, New Mexico. Molybdenite from the Santa Rita porphyry-copper mine reportedly contains 0.1 per cent rhenium; in contrast, molybdenite from the copper-barren quartz veins of the Questa molybdenum mine contains 0.03 per cent rhenium.* The rhenium content of molybdenite from other New Mexico deposits is not known.

* Determinations by Hiskey and Meloche (1940) give the rhenium content of molybdenite from Santa Rita as 0.00175 per cent (one sample) and from Questa molybdenum as 0.00088 per cent (average of five samples). Their analyses from other deposits also are systematically lower than those of most workers.

TYPES OF DEPOSITS

There are numerous ways in which molybdenum deposits can be classified—by mineralogy, associated metals, wall rock, size, shape,

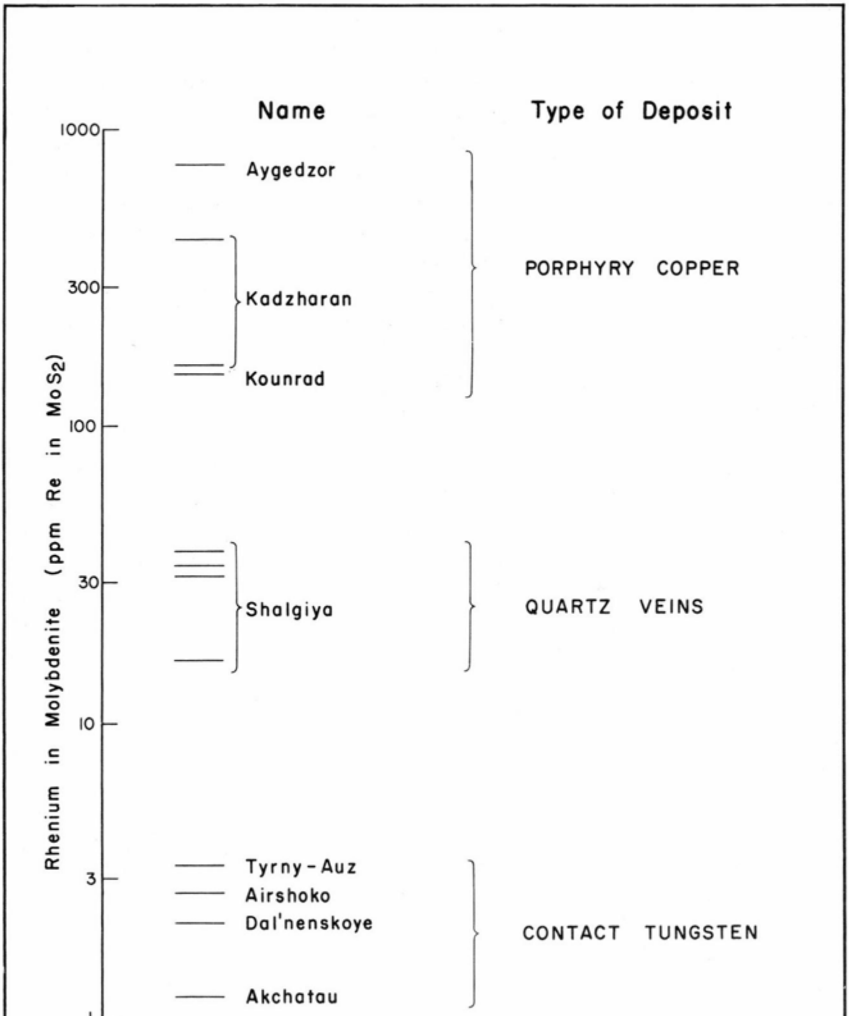

Figure 3

RHENIUM CONTENT OF MOLYBDENITE FROM DIFFERENT TYPES OF RUSSIAN DEPOSITS (MODIFIED FROM ZHIROV AND IVANOVA, 1959) grade, minability. The following grouping takes into account all these factors, providing categories that are both economically and geologically significant.

PORPHYRY-COPPER DEPOSITS

The most important source of molybdenum is the porphyry-copper deposits of the United States, Chile, the U.S.S.R., Peru, and Canada. These deposits presently supply more than half the total world output as a by-product of copper mining. The Bingham Canyon (Utah) mine, the largest copper mine in the world, has produced 8 million tons of copper and half a billion pounds of molybdenite (Cook, 1961). Other porphyry-copper mines that have produced molybdenum are the Bethlehem mine, British Columbia, Canada; the Bagdad, Esperanza, Miami, Morenci, San Manuel, and Silver Bell mines, Arizona; Ely (Ruth), Nevada; Cananea, Mexico; Toquepala, Peru; Braden, Chuquicamata, El Salvador, and Portrerillos, Chile; and the Agarak, Kodzharan, and Kounrad mines, the U.S.S.R. These mines use mass-mining methods, open-pitting or block-caving.

The Santa Rita mine, Grant County, which is the only active mine of this type in New Mexico, has produced 2.3 million tons of copper and 32 million pounds of molybdenite. The Cerrillos deposit, Santa Fe County; the Rialto deposit, Lincoln County; the Tyrone deposit, Grant County; the Copper Flat deposit in the Hillsboro district, Sierra County; and the deposit at Bent in the Tularosa district, Otero County, are other occurrences of this type (pl. 1). All except the Cerrillos deposit are in the southern part of the state.

In these deposits, chalcopyrite and other primary copper minerals, pyrite, and, in most instances, molybdenite occur as disseminated grains and in stockworks of crisscrossing quartz veinlets usually in hydro-thermally altered, acid-to-intermediate intrusive bodies and the intruded country rock. The deposits are structurally rather than stratigraphically controlled, the degree of fracturing being the important factor. Oxidation generally has taken place at the surface, and much of the copper has migrated to a zone of enrichment, while the molybdenum usually has remained in place after being converted to an oxide. The deposits presently being exploited contain from 0.5 to 2.0 per cent copper and 0.1 to less than 0.01 per cent molybdenum. (*See* Parsons, 1933 and 1957, and Jerome, 1963, for more detailed discussions of porphyry-copper deposits).

PORPHYRY-MOLYBDENUM DEPOSITS

The porphyry-molybdenum deposits differ from the porphyry-copper deposits principally in containing little or no copper and from the quartz veins in consisting of stockworks and disseminations rather than distinct, throughgoing veins. One mine of this type, the Climax in Colorado, has produced more than a billion pounds of molybdenite, more than half the total world output of molybdenum (Wallace et al., 1960). The Climax mine, which is the largest underground mine in the United States with a daily production of 40,000 tons of ore, presently exploits ore containing 0.4 per cent molybdenite. No other porphyry-molybdenum deposits are presently being mined in this country, although production is expected to begin soon at Urad, Colorado, and Questa, New Mexico. The Questa porphryry deposit is the only known porphyry-molybdenum deposit in New Mexico.

QUARTZ VEINS

Molybdenite commonly occurs in distinct, throughgoing quartz veins with or without other sulfide minerals. Pyrite and chalcopyrite usually are associated with the molybdenite, and many veins also contain fluorite, galena, and/or sphalerite. In Asia, tungsten (scheelite and wolframite), tin (cassiterite), and molybdenite occur together in quartz veins; this association is rare elsewhere in the world. In many instances, acid-to-intermediate intrusive bodies are associated with the molybdenite-bearing quartz veins. The veins show no preference as to type of wall rock but are controlled by the availability of open space. The wall rock next to many of the veins is hydrothermally altered.

The largest mine of this type, the Questa molybdenum mine, Taos County, New Mexico, produced more than 20 million pounds of molybdenite from quartz veins that contained 1 to more than 20 per cent MoS_2 but no other values. Although many other mines throughout the world have produced molybdenite from quartz veins, this type of deposit is not a major source of molybdenum. Selective underground methods are used to mine these deposits.

Some thirty of the seventy-four molybdenum occurrences in New Mexico are of this type; they are not concentrated in one area but are scattered throughout the same region in which the other types of molybdenum occurrences are found (pl. 1). In addition to the major production at the Questa molybdenum mine, small amounts of molybdenite have been recovered from quartz veins at the Romero and possibly from the Azure—Rising Sun mines, San Miguel County.

Most of the molybdenite-bearing quartz veins in New Mexico are Tertiary in age; however, those in the Petaca mining district, Rio Arriba County; in the Santa Fe district, Santa Fe County; in the Las Vegas Range, San Miguel County; and possibly some in the Big Burro Mountains, Grant County, are Precambrian in age.

CONTACT-TUNGSTEN DEPOSITS

Molybdenite and powellite commonly occur in tungsten (scheelite)-bearing contact-metasomatic deposits (tactites or skarns) developed in lime-rich rocks adjacent to granitic intrusive bodies. And the scheelite in some of these deposits contains up to several per cent molybdenum in place of part of the tungsten. The molybdenite generally is disseminated through the skarn as scattered flakes or in quartz veinlets. Although the deposition of the scheelite and skarn is mainly stratigraphically controlled, the deposition of the molybdenite is structurally controlled by fractures and faults and is superimposed on the tungsten mineralization and skarn. Pyrite and chalcopyrite generally are associated with the molybdenite.

In most instances, the molybdenum minerals are present in such small amounts that they can be recovered only as by-products. The Pine Creek mine, California (Bateman, 1956), Tyrny-Auz mine, the U.S.S.R., and Azeguar deposits, Algeria, are the only important producers of this type. Both selective and mass-mining methods have been used to exploit these deposits.

There are relatively few occurrences of this type in New Mexico, thirteen of the seventy-four. Molybdenum-bearing tungsten-contact deposits are not concentrated in one area but are scattered over the same region in which the other molybdenum deposits occur (pl. 1). Two of the deposits contain molybdenite, powellite, and molybdian scheelite; two contain molybdenite and powellite; one contains only powellite; and eight contain only molybdian scheelite. None has produced molybdenum.

OXIDIZED LEAD-ZINC DEPOSITS

Wulfenite is present in the oxidized parts of some lead-zinc veins and replacement bodies. These deposits usually are in limestones and are stratigraphically controlled and structurally localized. Before World War I, this was the most important source of molybdenum, but at present, little or no molybdenum is recovered from this type of deposit. Production of wulfenite from any mine has been relatively small; the Mammoth mine, Arizona, which has been by far the largest of this type, has produced less than a million pounds of molybdenum (Peterson, 1938). These deposits generally have been mined by selective underground methods.

The ores of these deposits are complex. Pyrite, chalcopyrite, barite, and vanadium minerals are present in many of the deposits. Sulfide (primary), carbonate (secondary), oxide (secondary), and mixed ores of lead, zinc, copper, gold, and silver have been mined together or in various combinations. Usually, the wulfenite has been recovered as a by-product or coproduct.

The wulfenite ($PbMoO_4$) is believed to have formed either (1) by the interaction of oxidized lead (galena) deposits and molybdenum-bearing thermal waters that derived the molybdenum from wall rocks or hydrothermal sources or (2) by the interaction of the oxidation products of galena with those of molybdenite or molybdenum-bearing minerals. The first theory was proposed because of the apparent rarity of molybdenite and other molybdenum-bearing minerals in deposits containing wulfenite. However, molybdenite is present in many more lead-zinc deposits than was once realized. Its absence in other deposits probably is due to the completeness with which molybdenite, like sphalerite, is destroyed by oxidation processes. Many lead-zinc deposits in which wulfenite is found either are entirely in or have not been explored below the zone of oxidation, and they contain no sphalerite or molybdenite, though some of the galena remains unoxidized. At three out of the seventeen wulfenite occurrences in New Mexico, molybdenite is known to occur in the unoxidized parts of the same deposit; in four of the remaining occurrences, sphalerite is absent but secondary zinc minerals are present. Work by Newhouse (1934) and Claussen (1934) has shown that pyrite, sphalerite, and galena from lead-zinc deposits commonly contain molybdenum (and vanadium), providing another potential source. It therefore seems likely that wulfenite (and its companion, vanadinite) is formed entirely by the oxidation of the lead-zinc deposit in which it occurs.

Seventeen of the seventy-four molybdenum occurrences in New Mexico are of the oxidized lead-zinc type. Small amounts of wulfenite have been produced from the Stevenson—Bennett mine, Dona Ana County, and the Hillsboro and Palomas Gap districts in Sierra County. The deposits containing wulfenite are concentrated in the southwestern part of the state (pl. 1).

PEGMATITES AND APLITES

Molybdenite is present in some aplite dikes and pegmatite bodies as disseminated flakes and pods. Some have been mined on a small scale, but this type of deposit has never been a major source of molybdenum. Many aplites, pegmatites, and quartz veins are in or near large granitic bodies and apparently are end-stage differentiates from the bodies. The pegmatites and aplites usually are genetically related to the quartz veins and in some cases can be seen to grade laterally into the veins.

Molybdenite occurs in Precambrian pegmatites in Rio Arriba, San Miguel, and Santa Fe counties, north-central New Mexico. These pegmatites grade into molybdenite-bearing quartz veins, and on Plate 1, they have been grouped with the quartz veins. Parts of the Tertiary quartz veins at the Questa molybdenum mine, Taos County, are pegmatitic and composed of coarse quartz, orthoclase, biotite, and molybdenite.

BEDDED URANIUM DEPOSITS

Jordisite and ilsemannite occur in many of the uranium deposits of the Colorado Plateau. Both minerals are widespread and relatively abundant in many of the deposits of the Grants uranium belt (Society of Economic Geologists, 1963).

This type differs markedly from the other types of molybdenum deposits that have been described. The other types of deposits are closely related to one another, belong to overlapping categories that are intergradational, and are simply variations of one class of deposit. They differ from the uranium deposits in being associated spatially and genetically with acid-to-intermediate intrusives; in containing molybdenite rather than jordisite; in containing significant amounts of copper, lead, zinc, and tungsten but no uranium; and in being veins and irregular bodies rather than bedded deposits. The origin of these uranium deposits remains uncertain.

Although molybdenum has not been recovered from bedded uranium deposits, the deposits of the Grants uranium belt are a potentially important source.

GEOGRAPHIC DISTRIBUTION

The known molybdenum occurrences in New Mexico are not distributed randomly but are concentrated in belts and clusters (fig. 7).

NEW MEXICO MINERAL BELT

A large part of the molybdenum occurrences in the state, as well as the Tertiary acid-to-intermediate intrusives and associated hydrothermal ore deposits, is along a north-northeast-trending zone, the New Mexico mineral belt. High-angle faults and Precambrian foliation having this same trend are common locally within the belt. A study (Burnham, 1959) of the sulfophile trace elements in sphalerite and chalcopyrite from the southwestern United States reveals that the belt is a zone of high trace-element content.

From north to south, the belt passes through the Questa mine, Cerrillos district, Ortiz district, San Pedro mine, Tijeras district, Magdalena district, Iron Mountain district, Hermosa district, Fierro iron deposits, Santa Rita mine, Bayard area, Tyrone deposit, Lordsburg district, and Peloncillo district, as well as a number of lesser districts. In terms of dollar value, considerably more than three quarters of all the metal (excluding uranium), and virtually all the molybdenum, produced in New Mexico have come from this zone.

The mineral belt cuts diagonally across the generally north-trending mountain ranges of the state, occupies "basin-and-range," "plateau," and "rocky mountain" type of environments, and seems to be independent of the present mountain structures. It may follow an ancient zone of weakness, as does the parallel Colorado (Front Range) mineral belt to the north (Tweto and Sims, 1963). During Laramide—Tertiary orogenies, magma invaded this zone of weakness, forming the definitive features of the belt, igneous bodies and associated ore deposits. Fault movements accompanied and followed intrusion of the magma.

TEXAS LINEAMENT

A number of molybdenum occurrences, other ore deposits, and acidto-intermediate intrusives in New Mexico are concentrated along the Texas lineament, a broad belt of structures, related intrusives, and ore deposits that extends (Mayo, 1958) west-northwest from trans-Pecos, Texas, through southern New Mexico and Arizona, to the Transverse Ranges of southern California. High-angle faults and aligned or elongate intrusions form individual strands within the belt. It also cuts diagonally across the generally north-trending mountain ranges and postore alluviated basins. Like the New Mexico mineral belt, it may be an ancient zone of weakness.

From east to west in New Mexico, the lineament passes through the Orogrande district, Lake Valley district, Cooks Peak district, Santa Rita mine, Tyrone deposit, Telegraph district, and a number of lesser districts; the Tres Hermanas, Vittorio, Hachita, Lordsburg, and San Simon districts are along strands to the south.

CAPITAN CLUSTER

Several molybdenum occurrences and a number of Tertiary intrusives and associated ore deposits are clustered around Capitan in Lincoln County. The Nogal, White Oaks, Jicarilla, Gallinas Mountains, Hansonburg, and Salinas Peak districts are in the cluster. Why this cluster is where it is, is not clear. There are no obvious structural controls. Mayo mentions a "vague" northeast-trending lineament extending from Bisbee, Arizona, through Santa Rita to the northern end of the Tularosa Basin (and the northwestern edge of the cluster). And intrusive bodies, molybdenum occurrences, and other ore deposits are vaguely aligned along a narrow trend extending northeast from the Hachita district, through the Cooks Peak, Macho, Lake Valley, and

Palomas Gap districts, then through the Salinas Peak, Hansonburg, and Gallinas Mountains districts which form the northwestern limits of the Capitan cluster. Whether these trends are major zones of weakness or in any way control the location of the cluster is not clear.

GRANTS URANIUM BELT

All the molybdenum occurrences of the bedded uranium type are in the Grants uranium belt which extends northwest along the south edge of the San Juan Basin. It differs markedly from the New Mexico mineral belt and the Texas lineament in containing uranium-molybdenum deposits, no other types of molybdenum occurrences or other ore deposits, and no granitic intrusives. However, although other metal deposits are absent, the Grants belt has produced more than 90 per cent of the uranium mined in the state. All the uranium deposits in which molybdenum is known to occur lie within the Grants belt.

The uranium deposits, some jointing, and the general strike of the Mesozoic rocks are the only aligned features. Faults having the same trend as the belt are exceedingly rare. The belt is relatively short, and there is little or no evidence of possible extensions to the northwest or southeast. The lack of aligned structural features suggests that the belt is not along a zone of weakness. However, the Zuni Mountains a few miles to the south of the belt are bound by northwest-trending faults and are along a lineament (Mayo) extending from Utah to southeastern New Mexico.

New Mexico Molybdenum Occurrences

The molybdenum deposits and mineral localities in New Mexico, grouped geographically, are described in this section in varying detail. The coverage is not exhaustive but summarizes our present knowledge of each occurrence. Plate 1 shows the location of the various occurrences.

PETACA MINING DISTRICT, RIO ARRIBA COUNTY

Numerous pegmatite bodies and quartz veins occur in the Petaca district. Although molybdenum minerals are not present in most of these, molybdenite does occur sparsely in a few of the bodies and veins. The pegmatites are Precambrian in age. Structural relationships and similarities in the sequence of deformation and late-stage mineralization strongly suggest that the veins are contemporaneous with and/or slightly younger than nearby pegmatites, and that the veins represent an end stage of the formation of the pegmatites. Some veins grade into pegmatite bodies. The three molybdenum occurrences in the district are all in T. 27 N., R. 8 E.

KIAWA MOUNTAIN

Small amounts of molybdenite are disseminated as flakes in quartz veins (Jahns, 1946, p. 265) at several places on the northeast slopes of Kiawa Mountain (probably in sec. 3, T. 27 N., R. 8 E.). Several small pits have been dug into the deposits, but there has been no production.

RUSSIAN RANCH

Small amounts of molybdenite occur as disseminated flakes and streaks with hematite in quartz veins and thin quartz-rich pegmatites (Jahns, 1946, p. 128, 260) along both sides of an old wagon road that extends south and south-southeast along a prominent ridge 0.3 of a mile east of the Russian Ranch in SE1/4 sec. 26, T. 27 N., R. 8 E. Several small pits expose the occurrences; there has been no production.

POSO SPRING

Small hexagonal flakes of molybdenite are associated with pyrite and other sulfides in an albite-rich pegmatite (Just, 1937, p. 69; Jahns, 1946, p. 260) about 0.2 of a mile south of Poso Spring at the bottom of La Jarita Canyon in NEJANDA sec. 27, T. 27 N., R. 8 E. There has been no development or production.

OTHER OCCURRENCES, RIO ARRIBA COUNTY

NEAR EL RITO

Wulfenite(?) was reported from a volcanic plug six miles south of El Rito (Northrop, 1959, p. 560).

BROMIDE MINING DISTRICT

In the Bromide mining district ten miles west-northwest of Tres Piedras, several small mines have produced some copper and gold from lenticular quartz veins and impregnations of sulfide minerals in shear zones in Precambrian amphibolite schist. Auriferous pyrite and chalcopyrite are common; galena, sphalerite, tetrahedrite, molybdenite, magnetite, and specularite are present locally. Garnet, epidote, hornblende, and tourmaline occur in the wall rock. There has been no molybdenum production (Anderson, p. 105).

RED RIVER BELT, TAOS COUNTY

A number of molybdenum deposits are concentrated in a belt of east- to northeast-trending, high-angle faults that form a prominent downfaultcd trench extending east-northeast across the Taos Range (fig. 4). The canyons of Red River and Bitter Creek form the southern limits of this zone; Cabresto Creek forms the northern boundary.

Within this downfaulted belt, Precambrian metamorphic rocks and Tertiary volcanic rocks have been irregularly faulted and brecciated. The more highly brecciated areas served as conduits for hydro-thermal solutions which altered (silicified, sericitized, argillized, and pyritized) the rocks; later weathering and erosion formed distinctive, bare, yellow-stained areas. These altered and distinctively weathered, eroded areas are restricted to the faulted zone; large areas of the same volcanic and metamorphic rocks north of the downfaulted zone are completely unaffected. Soda (albite-rich) granite stocks, rhyolite dikes and plugs, and quartz monzonite dikes were intruded along the zone during the late stages of igneous activity. These igneous rocks apparently were the source of the hydrothermal solutions that formed the altered areas and the ore deposits associated with the stocks and dikes.

The evidence strongly suggests that the extrusion of the volcanic rocks, downfaulting and brecciation, hydrothermal alteration, intrusion of the granitic rocks, and formation of the ore deposits all occurred during the same period of Miocene(?) igneous activity. All these features are concentrated within the east-west zone and are lacking or rare to the north and south. *(See* Schilling, 1960, p. 17-18, 20,

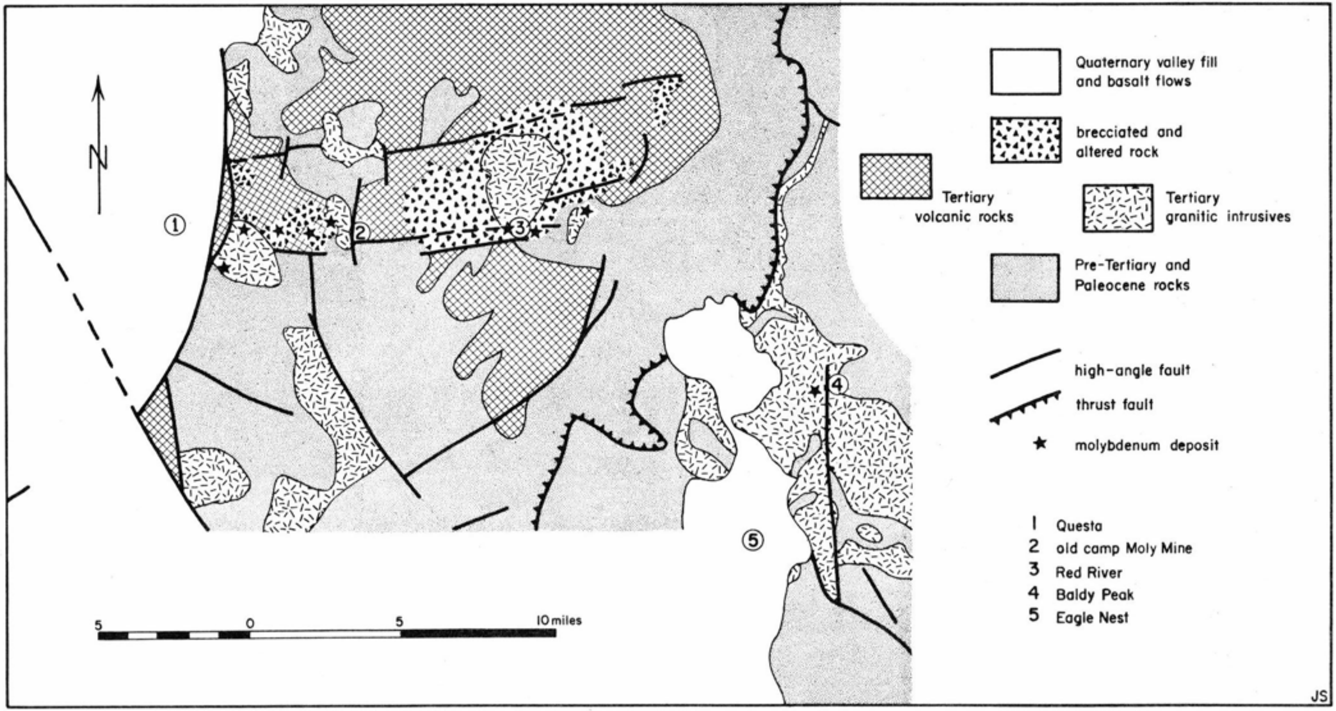

Figure 4

GENERALIZED GEOLOGIC MAP OF THE RED RIVER BELT AND ENVIRONS, TAOS AND COLFAX COUNTIES (MODIFIED FROM MC-KINLAY, 1956, 1957; SCHILLING, 1960; DANE AND BACHMAN, 1962; AND PHOTO INTERPRETATION) and Schilling, 1956, p. 23-30, 34-38, for a more detailed discussion of the features of the downfaulted zone.)

The ore deposits are fissure veins, stockworks, and disseminations in brecciated rock formed during the downfaulting and in the brecciated and sheared margins of the soda granite stocks. The wall-rock type does not appear to have had any chemical control of deposition. *(See* Schilling, 1960, p. 23-27, for a more detailed discussion of the ore deposits.) The deposits are spatially associated with the intrusives and show a zonal mineralogical pattern around the larger intrusives.

The molybdenum-bearing veins, stockworks, and disseminations are present in or near the soda granite bodies, usually within several hundred feet of the contact. Like the soda granite intrusives, the molybdenum deposits are concentrated in the east-west downfaulted and altered zone. Tertiary hornblende quartz monzonite stocks in the Taos Range north and south of the belt that were intruded earlier than the soda granite have no spatially associated molybdenum deposits.

The veins are up to seven feet thick, although thicknesses of more than a foot are uncommon. They are largely quartz, molybdenite, and pyrite, with locally abundant biotite, fluorite, chalcopyrite, calcite, and rhodochrosite; the wall rock usually is silicified, pyritized, argillized, and sericitized. The stockworks consist of molybdenite films and vein-lets containing quartz and pyrite. Disseminated molybdenite flakes generally occur with the stockworks.

Molybdenite also is widespread in the altered areas away from the soda granite intrusives. Here the molybdenite occurs almost exclusively in gray quartz veins as fine-grained flakes; the volcanic rocks contain little or no disseminated molybdenite even along molybdenum-rich veins. The andesitic rocks of the altered areas contain 3 to 10 per cent pyrite, whereas the rhyolitic rocks contain only 1 per cent. The pyrite is present in veins and as small disseminated cubes and, less commonly, octahedrons and pyritohedrons. The pyrite contains up to 36 ppm of molybdenum, as well as appreciable copper. Nearly all the copper in the altered areas is intimately associated with the pyrite. Chalcopyrite generally is rare, although locally abundant (Ratcliff, 1962).

The molybdenite occurrence at Baldy Tunnel, Colfax County, may be an eastern extension of this molybdenum-bearing belt, although it is south of the projected eastward trend of the zone.

QUESTA MOLYBDENUM MINE

The Questa (Moly, R and S) molybdenum mine has been the second largest producer of molybdenum in New Mexico, having yielded more than 20 million pounds of molybdenum sulfide (MoS_2). It is unique among the major molybdenum-producing mines of the world in having produced high-grade molybdenite ore from throughgoing fissure veins, in contrast to most of the other mines which exploit low-grade, disseminated deposits. The mine is in sec. 1, T. 28 N., R. 13 E. and sec. 36, T. 29 N., R. 13 E.; the mill, camp, and main haulage adit are along the Red River five to six miles east of Questa; the adits to the older workings are along Sulphur Gulch, which extends north from Red River between the mill and haulage adit.

History. The true nature of the veins was first recognized in 1916, when Jimmy Fay (or Fahy) had a sample assayed for copper, gold, and silver; the assayer mentioned the presence of molybdenite and its value. The Western Molybdenum Company was organized; however, little was done to develop the deposit. In 1918, the R and S (Rapp and Savery) Molybdenum Company was formed and acquired seven claims of the Western Molybdenum Company. Additional claims were located, and development work was done. Production began in the spring of 1919; the ore was treated in a converted gold mill four miles east of the mine.

In 1920, the present owners, the Molybdenum Corporation of America, acquired the property. Mining was discontinued during the depression of 1921, then was on a small scale until 1923, when a mill was built on the present site. In 1942, a haulage adit was driven north from the Red River for one mile, connecting with the lowest level in the mine and greatly improving haulage, ventilation, and drainage. By 1955, the workings had reached a point 240 feet below the adit.

In recent years, the old tailing dumps were remilled, supplementing the decreasing production of the mine. Mining ceased in 1958; however, an extensive exploration program had already been started in a search for more ore *(see* Questa Porphyry Deposit).

Mining and milling. The mine has more than 36 miles of workings, with a vertical extent of 1200 feet (for details, *see* Schilling, 1956, pls. 1 and 2). Ore shoots were located by following the veinlets encountered until they opened up; most ore shoots occurred in the granite near its contact with altered volcanic rocks. Mining was by overhand, horizontal slicing in stull-supported or open stopes; the irregularities of the ore required selective mining. The grade of the ore has varied from 1 to 40 per cent MoS_2. The flotation process was used to produce molybdenite concentrates (Carman, 1932).

Geology. Larsen and Ross (1920), Vanderwilt (1938), and Kuellmer (1961) have described the geology. A more detailed description is given by Schilling (1956), from which the following information is abstracted.

The ore occurs in the Miocene(?) Sulphur Gulch soda granite stock along a locally east-west-striking, south-dipping contact with propylitized volcanic rocks. Most of the veins are on the contact or in the granite within 50 feet of and roughly parallel to the contact. The ore zone is more than 1500 feet long at the surface but decreases in length with depth.

In detail, the veins are complex. Dips range from vertical to horizontal but average 45 degrees. Usually, they pinch and split. At places, they cross the granite contact and pass out into the softer volcanic rocks, where they die out; elsewhere, they follow granite dikes, which extend outward from the granite stock. The veins cut across any irregularities of the granite contact. Individual veins are not continuous downdip or laterally, but their general position along the contact is taken by other veins. Numerous faults offset the veins for short distances.

The veins range from thin films locally called "paint" to more than seven feet in thickness. Steeply dipping veins are commonly thicker than gently dipping ones, and therefore contain most of the ore shoots. These ore shoots are lenticular. A few cylindrical ore shoots occur at vein intersections. Numerous thin, irregular veinlets occur in brecciated areas along the contact; these zones are part of the porphyry-molybdenum deposit described below.

The veins are largely quartz and molybdenite, with locally abundant biotite, fluorite, pyrite, chalcopyrite, calcite, and rhodochrosite, and minor amounts of chlorite, galena, sphalerite, huebnerite, ferrimolybdite, limonite, and malachite. The apparent order of deposition was (1) quartz; (2) quartz molybdenite, and biotite; (3) pyrite and chalcopyrite; (4) fluorite; and (5) calcite and rhodochrosite. This sequence is often repeated completely or in part.

Wall-rock alteration is not intense, usually extending only a few inches from the veins. Silicification is widespread, feldspar is locally altered to clay and sericite, and disseminated pyrite is scattered through the wall rock.

The veins were deposited as fissure fillings, probably during late Tertiary time, and on the basis of their mineralogy are classified as mesothermal.

QUESTA PORPHYRY DEPOSIT

A large zone of the porphyry-molybdenum type of mineralization lies west and northwest of the Questa molybdenum mine workings. Within the deposit, there are two sizable bodies of much-above-average grade: (1) the Southwest Zone in N y2 sec. 2, T. 28 N., R. 13 E., west-southwest of the lower workings of the old mine, and (2) the Northeast Zone in east-central sec. 35, T. 29 N., R. 13 E., north-northwest of the lower workings of the old mine at the confluence of Sulphur and Iron gulches.

History. The possibility that the deposits of the Questa molybdenum mine extended west of their known limits had been considered for many years (J. B. Carman, personal communications). By 1954, the vein deposits were nearing exhaustion, and an exploration program was initiated by the Molybdenum Corporation of America to locate westward extensions of the known deposits *(Mining Engineering,* January 1961). Brecciated zones containing molybdenite-bearing stock-works had been exposed in the upper, northwesternmost, and lower, southwesternmost, workings, and other zones were exposed by the exploration program. Although the exposed stockworks were too small or of too low grade to be commercial, they pointed to the possibility of large, low-grade molybdenite deposits around the margins of the Tertiary granite stocks, especially in the Questa molybdenum mine area (Schilling, 1956, p. 77, 78).

From June 1957 to July 1960, exploration work was conducted with the financial assistance of the Defense Minerals Exploration Administration. A geochemical survey was made, a crosscut was extended a mile to the west from the lowest level of the old workings, some 11,000 feet of lateral drifts were driven, and about 30,000 feet of drill core were cut from the surface and underground. More than 260 million tons of ore averaging 0.25 per cent MoS_2 were found *(Mining Engineering,* January 1961).

By the end of 1961, further exploratory work had extended the boundaries of the deposit and had disclosed "two sizable areas of much-above-average grade" (1961 Annual Report, Molybdenum Corporation of America).

In 1962, it was decided to concentrate on the development of the Northeast Zone. The main access tunnel already had been extended into the area, and $633,000 were spent panel drilling, surface drilling, raising, and drifting (1962 Annual Report, Molybdenum Corporation of America).

During 1963 and the first six months of 1964, more than $4,000,000 were spent on continued development of the Northeast Zone, providing new mine services and plants and acquiring land for housing, tailing disposal, and milling. By the end of 1964, more than 28,000 feet of underground drilling, 123,000 feet of surface drilling, and 8000 feet of drifting and crosscutting had been done, and 33,000 tons of ore had been removed for sampling and bulk testing *(Metal Mining dr Processing,* December 1964).

Mining and milling. In April 1964, the Molybdenum Corporation of America announced plans to spend $18,000,000 to $20,000,000 to bring the mine into production (letter to stockholders, April 20, 1964). A mill design and construction contract was awarded to Western—Knapp Engineering Division of Arthur G. McKee and Company for a plant "capable of producing 10,000,000 pounds of molybdenum annually" and having a "capacity of about 8000 tons of ore per day." It is expected that production will begin in September 1965 and that full capacity will be reached by the end of the year.

The Northeast Zone (northeast of the southwest body, but northwest of vein deposits previously mined) will be mined initially by open-pit methods. The pit as planned will have a roughly circular shape with an average diameter of about 1600 feet and average depth of 500 feet (bottom at 8400-foot elevation). Open-pit reserves are estimated at 20,509,000 tons of ore averaging 0.297 per cent MoS_2, assuming a cutoff grade of 0.13 per cent MoS_2. Some 71,000,000 tons of waste material will be removed. Later, it is planned to mine the lower parts of the ore body, and possibly the Southwest Zone, using underground methods. About 23,000,000 tons of ore averaging 0.35 per cent MoS_2 (assuming a cutoff grade of 0.21 per cent MoS_2) have been developed for underground mining in the northeast Zone *(Metal Mining & Processing,* December 1964).

The mill will concentrate the molybdenite by conventional flotation methods; recovery is expected to be 85 to 89 per cent. The possibility of recovering additional molybdenum by leaching of tailings, waste dumps, and low-grade material is being studied (Bhappu, Reynolds, and Stahmann, 1963; Bhappu and Roman, 1964). Low-grade material will be stockpiled during open-pit mining.

Geology. The porphyry-molybdenum mineralization and the molybdenum-bearing quartz veins at Questa actually are overlapping parts of the same huge deposit. The BJB, Hercules, and Bernhardt prospects explore parts of the same deposit. The two types of occurrences are similar mineralogically but differ mainly in that the veins are in a few, wider open, more throughgoing fissures in contrast to the stockwork fissures which are relatively tight, short, and irregular, yet numerous and closely spaced. Like many of the porphyry-copper deposits, the high-grade veins were first selectively mined, and little was done to exploit the low-grade disseminated mineralization until the veins were exhausted.

The porphyry-molybdenum mineralization is along the western flank of the Miocene(?) Sulphur Gulch soda granite stock and occurs in the granite and overlying volcanic rocks which the granite intruded. Here a "buried saddle" connects the Sulphur Gulch stock with the Flag Mountain stock to the west, and the granite-volcanics contact is relatively flat. in contrast to the steeper dips where the contact is exposed at the surface and in the workings made while mining the vein deposits. The southwestern part of the deposit is covered by more than a thousand feet of barren rock, whereas the northeastern part reaches the surface. The richer sections of the deposit are in the most highly shattered rock.

Molybdenite occurs in stockworks and as disseminations in the adjacent wall rock. The molybdenite is present in the stockwork fissures in quartz veinlets with pyrite, some purple and green fluorite, and minor biotite and chalcopyrite; as thin films ("paint"); and as streaks in fault gouge ("mud"). Cubes, pyritohedrons, and irregular grains of pyrite are disseminated through the wall rock.

Faulting and fracturing during the forceful emplacement of the intrusives, and the subsequent downfaulting along the east-west belt, were superimposed on regional structures to form the structural pattern in the mine area. Zones of intensive alteration are associated with the mineralization and granitic intrusives. Silicification, pyritization, sericitization, kaolinization, and propylitization have taken place. Later weathering and oxidation have modified the alteration and mineralization.

Several secondary molybdenum-bearing minerals have been formed during oxidation (Bhappu and Roman, p. 16). Some 60 per cent of the molybdenum in the oxide minerals is contained in ferrimolybdite. The canary-yellow ferrimolybdite is locally abundant and occurs as tiny acicular crystals disseminated through the rock, as tufts and powdery coatings on molybdenite, and as late crosscutting veinlets. Much of the rest of the secondary molybdenum is in molybdenum-bearing hydrous iron oxides, with only a minor amount contained in clay as a crystalline precipitate of aluminum molybdate hydrate and as absorbed molybdenum. Partly oxidized molybdenite occurs at the surface and is increasingly common with depth. There apparently has been little vertical change in the molybdenum grade due to oxidation and leaching.

Tentatively, the following sequences of events are believed to have taken place (Schilling, 1956, 1960; Carpenter, 1960): (1) extrusion of intermediate volcanic rocks from feeder fissure dikes and central vents; (2) extrusion of most of the rhyolitic volcanic rocks; (3) emplacement of the soda granite stocks with accompanying shattering and hydrothermal alteration of the volcanic and older rocks; (4) emplacement of aplite dikelets and replacement (K-feldspathization) of the volcanic rocks and granite by aplitic fluids during late stages of emplacement and cooling of the granite stocks; (5) intrusion of rhyolite porphyry dikes and plugs, which may have been feeders for the youngest rhyolite volcanics, during the last stages of the cooling of the granite stocks; (6) sericitization and kaolinization, followed by kaolinization, succeeded by silicification, probably beginning during (3) and continuing at least through (5); (7) continuing faulting and shattering of the volcanic and intrusive rocks; (8) deposition of barren quartz veinlets containing minor pyrite and rare potash feldspar and biotite; (9) continued shattering with the deposition of quartz veinlets containing molybdenite and pyrite; (10) continued shattering and the formation of veinlets and large quartz veins containing molybdenite, pyrite, fluorite, calcite, and rhodochrosite; (11) continued shattering with the deposition of molybdenite films and minor quartz and fluorite along the fissures; and (12) continued downfaulting, forming the east-west structural trench across the Taos Range. The sequence of events described under (2) through (11) took place during a geologically short period of time and was a continuous, overlapping, locally repetitious and even regressive process that has been greatly oversimplified in this description. The granite, aplite, rhyolite porphyry, and rhyolite volcanics, as well as the hydrothermal fluids that caused the alteration and mineralization, all apparently are differentiates from the same parent magma. The soda granite bodies appear to have been localized where pretrench north-south faults cross the east-west trench, providing avenues of weakness along which the magma was intruded.

LOG CABIN CANYON (FIBBS—NOGLE, STEVE'S) PROSPECT

A long adit, several short adits, and two diamond drill holes in the bottom of Nogal Canyon (sec. 8, T. 28 N., R. 13 E.) two miles southeast of Questa transect a deposit consisting of a number of 1- to 3-inch-wide quartz-molybdenite-pyrite veins and some veins containing gouge streaked with molybdenite. The veins cut both granite and country rock along the irregular southwest contact of the Flag Mountain soda granite stock. They strike east to northeast and dip vertically. Intense brecciation and bleaching along the contact, accompanied by deposition and later oxidation of disseminated pyrite, make identification of the various rock types difficult. There has been no production (Schilling, 1960).

BEAR CANYON PROSPECT

On Red River, just west of Bear Canyon (sec. 4, T. 28 N., R. 13 E.), two connected adits with more than 750 feet of workings expose several molybdenum-bearing veins in the Bear Canyon (Horseshoe, Cisneros, Mexican, Mammoth) prospect. There has been no production, although some low-grade molybdenite ore was stockpiled on the dump. Veins consisting of quartz, with some molybdenite, pyrite, chalcopyrite, and minor biotite, fluorite, and huebnerite ranging from films to three feet in thickness, with numerous "splits" and "pinches," trend east-west and dip steeply in the late(?) Tertiary Flag Mountain soda granite stock. In contrast to the Questa molybdenum mine, the veins exposed here are not near the granite contact, and fractures and veins are less common, tighter, and form a less definite pattern (Schilling, 1960).

BJB (WILDE, GOAT HILL GULCH) PROSPECTS

Small, irregular pyrite-chalcopyrite-fluorite-molybdenite veins and molybdenite films along fractures in altered Tertiary volcanic rocks are exposed in two adits along the west side of Goat Hill (Alum) Gulch, which extends north from Red River four miles east of Questa (sec. 3(?), T. 28 N., R. 13 E.). This occurrence is above, and probably is an offshoot of, the Southwest Zone described under the Questa porphyry deposit. There has been no production. (Schilling, 1960)

HERCULES (BUENO VISTA) PROSPECT

Three short adits, now caved, north of the Questa porphyry deposit at the head of Sulphur Gulch (sec. 35, T. 29 N., R. 13 E.) expose small fluorite-pyrite-chalcopyrite-molybdenite veins, quartz-molybdenite veins, and molybdenite films along fractures and shear zones in altered and brecciated Tertiary volcanic rocks. A Tertiary soda granite dike cuts the volcanic complex. There has been no production. This occurrence probably is an offshoot of the Northeast Zone of the Questa porphyry deposit (Schilling, 1960).

BERNHARDT PROSPECTS

The Bernhardt prospects, consisting of several adits totaling more than 300 feet, are in sec. 1, T. 28 N., R. 13 E., just north of the Red River and west of Sulphur Gulch. They are bounded on the north and west by workings of the Questa molybdenum mine. There has been no production. In the main southern adit, several thin veins containing molybdenite, quartz, and pyrite are exposed; several other thin veins containing specularite, quartz, pyrite, chalcopyrite, sphalerite, and galena also are exposed. These veins are in the late(?) Tertiary Sulphur Gulch soda granite stock; the granite is not highly fractured. In the northern adit (in the west side of Sulphur Gulch several hundred feet northwest of the mouth of the gulch), molybdenite films coat fractures in a shear zone striking N. 80° E. and dipping vertically in highly altered and brecciated soda granite of the late(?) Tertiary Sulphur Gulch stock. Small quartz veins are accompanied by silicification, pyrite is disseminated through the rock, and feldspar phenocrysts are altered to clay. These occurrences are offshoots of the Questa vein deposit (Schilling, 1960).

COPPER KING MINE

The Copper King (Anaconda, Paxton) mine is in sec. 35, T. 29 N., R. 14 E., just north of the Red River opposite the mouth of Bitter Creek at the town of Red River. The mine workings consist of two connecting adits with more than 1000 feet of workings, a 50-foot shaft, a 30-foot adit, and churn drill holes made while exploring for and mining copper ore. There has been no molybdenum production.

Malachite, azurite, and some tenorite fill open spaces in several shear zones that either follow late(?) Tertiary quartz monzonite dikes in altered Tertiary volcanic rocks or cut a large body of quartz monzonite in which the silicified shear zones have prominent dikelike outcrops. Chalcopyrite and molybdenite reportedly were encountered some 600 feet below the surface in a churn drill hole (Schilling, 1960).

GRANITE (MUNDEN) PROSPECT

A 50-foot, caved adit in sec. 36, T. 29 N., R. 14 E., about half a mile east of the town of Red River and a quarter of a mile north of State Highway 38, exposes chalcopyrite and molybdenite in a prominent east-west, steeply north-dipping shear zone cutting altered, late(?) Tertiary granite (Schilling, 1960). There has been no production.

JACKS AND SIXES PROSPECT

The Jacks and Sixes prospect consists of several open cuts, a 135-foot adit, and a 190-foot adit in sec. 29, T. 29 N., R. 15 E., one and one-half miles east of Red River at a point half a mile north of Bobcat Creek, high on the west slope of a side canyon that extends north from Bobcat Canyon one and one-fourth miles northeast of the mouth of the latter. Here, quartz-molybdenite veins cut Precambrian metamorphic rocks and late(?) Tertiary granite along the northeast margin of the granite body. There has been no production. (Schilling, 1960)

COLFAX COUNTY

BALDY TUNNEL

The Baldy (Deep) tunnel (now caved) was driven east-west completely through Baldy Peak exploring for gold and copper. Baldy Peak is in the Cimarron Range five miles north-northeast of Eagle Nest. A minor footage of lateral and vertical workings follows shears and quartz veins. The tunnel penetrates Cretaceous Pierre Shale and Tertiary sediments that have been intruded by large diorite and monzonite porphyry sills. The Pierre Shale strikes N. 10° E. and dips 50°-60° NE. Near the west portal, molybdenite occurs in numerous quartz stringers (Everitt, 1953a; Pettit, 1946). There has been no molybdenum production.

GRANTS URANIUM BELT, MCKINLEY AND VALENCIA COUNTIES

The uranium deposits of the Grants uranium belt form a strip 100 miles long and 20 miles wide that extends from Gallup east-southeast-ward to Laguna (Society of Economic Geologists, 1963) (fig. 5). More

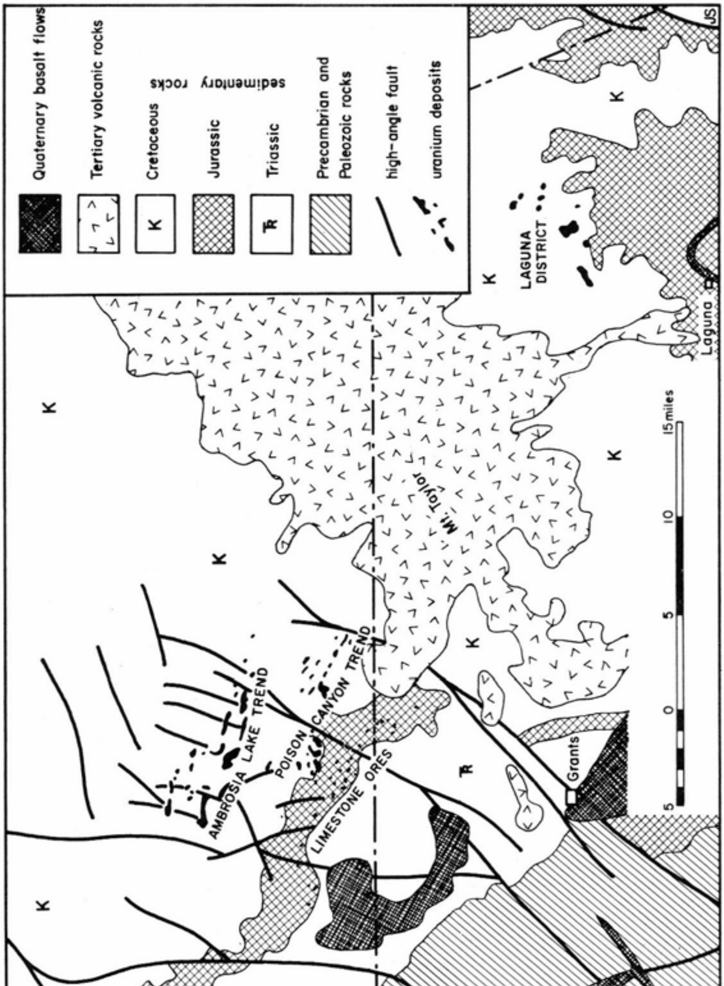

Figure 5

GENERALIZED GEOLOGIC MAP OF THE GRANTS URANIUM BELT, MCKINLEY AND VALENCIA COUNTIES than half a billion dollars worth of uranium have been produced, principally from the Grants and Laguna districts. The deposits are in a 1000- to 1500-foot-thick sequence of sedimentary rocks ranging in age from Late Jurassic to Cretaceous (Hilpert, 1963). The Late Jurassic Todilto Limestone and Morrison Formation have yielded most of the ore and contain nearly all the reserves.

Miocene to Recent volcanic rocks are present in and near the Grants belt and are considered by some to be genetically related to the uranium deposits. Except for dikes and plugs related to the volcanic rocks, intrusives are conspicuously absent. The sandstones of the Morrison Formation have been universally altered in the vicinity of the uranium deposits; the evidence suggests that the alteration may be penecontemporaneous with, and related to, uranium deposition (Austin, 1963).

SANDSTONE DEPOSITS

In Westwater Canyon Member, Morrison Formation. Most of the deposits of the Ambrosia Lake and Poison Canyon trends of the Grants district and of the Smith Lake district are in sandstones of the West-water Canyon Member of the Morrison Formation. These sandstones contain two types of unoxidized uranium deposits: (1) the primary, prefault deposits formed before the rocks were appreciably faulted or jointed and (2) the unoxidized, postfault deposits that probably resulted from the redistribution of the prefault deposits and are thus secondary (Granger et al., 1961; Granger, 1963).

The prefault deposits are west-northwest elongate, lens-shaped bodies up to 20 feet thick, several hundred feet wide, and 3000 feet long. The ore bodies apparently are not controlled by tectonic structures but are related to sedimentary structures, lithology, and textures. They contain coffinite (uranium silicate), jordisite, and pyrite in a gangue of carbonaceous matter which cements the sandstone; vanadium occurs in the carbonaceous matter and selenium is closely associated with the jordisite. The amorphous molybdenum sulfide jordisite occurs as tiny grains or sand-grain coatings on the fringes of the uranium deposits, usually in nearly carbon- and uranium-free sandstone that has been colored jet black or dark brown by the mineral (Granger). The uranium ores contain up to several hundredths of a per cent molybdenum in contrast to the jordisite-rich sandstone which contains a tenth to more than a half per cent molybdenum.

The postfault deposits are less common but more varied in shape and mineralogy. They contain coffinite, uraninite, vanadium minerals, pyrite, marcasite, barite, calcite, and the selenium mineral ferroselite; carbonaceous matter is uncommon or absent, and molybdenum minerals are extremely rare. Where faults and joints are the dominant control, the bodies are elongate parallel to the structure; where stratigraphic controls predominate, they parallel the trend of the prefault bodies.

Oxidized ores occur in the near-surface deposits. The oxidation of vanadium-poor ores has resulted in the leaching of uranium from the rock or, less commonly, in the formation of uranium silicates and phosphates; yellow uranium vanadates formed in the vanadium-rich ores. Native selenium, barite, calcite, gypsum, and manganese oxides also have been produced.

Efflorescent minerals form rapidly on the mine walls. These include uranium, vanadium, molybdenum, iron, sodium, and calcium sulfates, carbonates, and bicarbonates. Dark blue stains of the molybdenum hydroxide ilsemannite, a postmine oxidation product of jordisite, are common on mine walls and are locally disseminated through the rock. Ilsemannite is quite water-soluble and thus is found only in the drier mines.

In Jackpile Sandstone, Morrison Formation. The deposits in the Laguna district are in the Jackpile Sandstone of the Morrison Formation. Most of the deposits are tabular, elongate uraniferous-carbonaceous bodies that are similar to the deposits in the Westwater Canyon Member (Kittel, 1963; Granger). Coffinite, uraninite, pyrite, and marcasite are common; selenium, molybdenum, and vanadium minerals are present but apparently in smaller amounts than in the Westwater Canyon deposits. Most of the tabular bodies are oxidized to some extent and have mineral assemblages similar to those of near-surface Westwater Canyon deposits. Postmining minerals are rare in the open-pit mines, such as the Jackpile.

LIMESTONE DEPOSITS

Numerous, small uranium deposits occur in the Todilto Limestone, mainly along the south edge of the Grants district (McLaughlin, 1963; Granger). Production has been less than one per cent of that from the sandstone. Most known deposits have been mined out and little exploration is being done. The primary deposits are narrow, irregularly elongate bodies along the axes of minor anticlines, and contain uraninite (abundant), coffinite (relatively rare), vanadium oxides, fluorite, pyrite, hematite, marcasite, galena, and barite. Fluorite is present in only a few of the Todilto deposits and apparently is absent where coffinite or vanadium minerals are abundant. Northrop (p. 357) mentions that a "minute quantity of molybdenite" occurs in the Haystack area of the Grants district. Many of the Todilto deposits have been oxidized; uranium vanadates and silicates are common.

PIPE DEPOSITS

The uranium deposit at the Woodrow mine in the Laguna district is in a steeply dipping, 30-foot-diameter, pipelike, cryptovolcanic(?) or collapse(?) structure cutting the Morrison Formation. It differs markedly in shape and mineralogy from the sandstone deposits of the Grants belt (Wyle, 1963). There is a similar, but relatively unmineralized, pipe at the Jackpile mine (Hilpert and Moench, 1960). The Woodrow pipe contains coffinite, uraninite, pyrite, marcasite, barite, and galena and is unique among the deposits of the Grants belt in locally containing chalcopyrite, covellite, sphalerite, wurtzite, and cobaltite. The ore is partly oxidized to a depth of about 100 feet; uranium sulfates are common, but uranium vanadates are absent because of the very small amount of vanadium present.

BERNALILLO COUNTY

HELLS CANYON MINING SUBDISTRICT

Pyrite, chalcopyrite, and minute flakes of molybdenite occur in quartz stringers in shattered and silicified Precambrian schist at the Star Lode and other prospects along Hells Canyon in the northern Manzano Mountains (Statz, 1912). The prospects are small. There has been no molybdenum production.

CERRILLOS—SAN PEDRO CLUSTER, SANTA FE COUNTY

Molybdenum mineralization is associated with a cluster of Tertiary granitic intrusives in southwestern Santa Fe County. Molybdenite, wulfenite, powellite, and molybdian scheelite are present.

MINA DEL Two

The Mina del Tiro is in the NW1/4 sec. 8, T. 14 N., R. 8 E. one and three-quarters miles north of Cerrillos. The mine consists of a number of shafts and prospect pits made while mining lead-zinc ore. A vuggy quartz vein up to six feet wide contains thick streaks and disseminations of galena and sphalerite. Even though the galena and sphalerite have been only slightly affected by weathering, small, tabular, yellowish gray crystals of wulfenite are abundant on the primary minerals where cracks and vugs provide open space. The vein, which can be traced for more than 1300 feet at the surface, lies on the footwall of a shear zone striking N. 45° E. and dipping steeply northwest in Tertiary hornblende monzonite porphyry. A number of other similarly oriented shear zones with accompanying lead-zinc veins are exposed in the surrounding area (Disbrow and Stoll, 1957).

CERRILLOS PORPHYRY—COPPER DEPOSIT

A porphyry-copper deposit is exposed in north-central sec. 8, T. 14 N., R. 8 E. two miles north-northeast of Cerrillos, between the Mina del Tiro to the west and the Cash Entry mine to the northeast. The deposit was diamond-drilled while exploring for copper, but there has been no further development or production. The porphyry-copper mineralization is in monzonite porphyry and syenite (corresponding roughly to the Tertiary intrusive unit Ti_i and to a minor extent Ti_4 of Disbrow and Stoll) forming a 600-foot-wide annular ring nearly enclosing a small, circular, coarse-grained monzonite stock (Wargo, 1963). The stock itself is unmineralized except for a thin zone at its contact. This rock type apparently has not been recognized elsewhere in the Cerrillos mining district; the stock is not shown on Disbrow and Stoll's plate 1. The deposit consists of malachite and chrysocolla at the surface and disseminated grains and thin veinlets of chalcopyrite and rare bornite below the zone of oxidation. There has been no secondary enrichment; the copper grade is approximately the same in both the unoxidized and oxidized parts of the deposit but varies from 0.2 to 1.0 per cent. Molybdenite occurs as rare, thin stringers cutting the copper mineralization. Galena and sphalerite veinlets also cut the copper mineralization.

CUMMINGTON HILL

At Cummington Hill, sec. 24, T. 13 N., R. 7 E., in the Old Placers (Ortiz) mining district, yellow-fluorescing (molybdian) scheelite, pyrite, and minor chalcopyrite form irregular bodies and disseminations along steeply dipping, northeast- to east-trending faults and tension fractures in the Ortiz monzonite porphyry laccolith and adjacent silicated (garnetized) limestone and shale. The minerals also occur as tabular bodies along flat to gently dipping bedding planes in the garnetized limestone (Dale and McKinney, 1959). Powellite reportedly is associated with the scheelite in these contact deposits (Kelley, 1952). Molybdenite occurs in the district (Northrop, p. 358), probably in the same deposits.

SAN PEDRO MINE

The San Pedro mine is in the New Placers mining district, fourteen miles by road south of Madrid and one mile east-northeast of San Pedro. Extensive underground workings were made mining coppergold-silver ore; there has been no molybdenum production. Chalcopyrite associated with garnet, calcite, specularite, quartz, pyrite, and locally some scheelite occur as irregular replacement deposits in metamorphosed limestone beds and locally in interbedded shales of the Pennsylvanian Madera Formation. The sediments, which dip gently to the east, have been intruded by rhyolite porphyry sills and a syenite-monzonite laccolith and offshoot dikes and sills. Locally, the limestone and shale overlying the laccolith have been altered to garnet-rich tactite; outward or beyond the tactite, the limestone has been marmorized and the shale changed to hornfels. The ore is between the tactite and marble in a zone up to 130 feet wide and 90 feet thick that has been mined for a length of 2400 feet. East-west fractures and faults apparently localized both the mineral deposits and the tactite.

Small amounts of molybdenite are exposed in the lower workings of the mine as tiny dendritic crystals and lumps up to 2 inches across at the contact between garnet and chalcopyrite. Pyrrhotite and rare chalcopyrite are disseminated in the syenite in the Swan Tunnel level (Smith et al., 1945).

Kelley reports that powellite is associated with the scheelite in the mine.

OTHER OCCURRENCES, SANTA FE COUNTY SANTA FE MINING DISTRICT

Molybdenite reportedly occurs in the Santa Fe mining district (Northrop, p. 358) probably in Precambrian pegmatitic veins similar to those in San Miguel County to the east.

LAS VEGAS RANGE BELT, SAN MIGUEL COUNTY

Numerous pegmatite dikes and white quartz veins cut the Precambrian rocks that form the core of the arcuate, north-trending Las Vegas Range of the Sangre de Cristo Mountains. Many of these dikes and veins locally contain molybdenite and other sulfides.

The pegmatites usually are simple in composition and contain only feldspar, quartz, and muscovite. Many of the quartz veins grade into pegmatite dikes, and some contain feldspar and muscovite. No dikes or veins cut the Pennsylvanian and younger sedimentary rocks of the area, and most are spatially associated with the Precambrian granites, strongly suggesting that the pegmatites, veins, and sulfides are late-stage differentiates of the same magma as the granite intrusives.

The molybdenite-bearing pegmatites and quartz veins of the Petaca mining district are similar in age, environment, and probable genesis to those in the Las Vegas Range.

AZURE—RISING SUN MINE

The Azure—Rising Sun mine is in the Rociada mining district, four miles southwest of Rociada and some twenty miles northwest of Las Vegas. The mine was developed by 160- and 172-foot shafts with more than 600 feet of workings on two levels. Calcite, pyrite, bornite, chalcopyrite, and molybdenite occur in a group of white quartz veins, striking N. 20° W. and dipping 75° E, in Precambrian quartz-biotite schist. The veins average 5 feet in width and extend for more than 3000 feet along their strike. Epidote, garnet, amphibole, specular hematite, and tourmaline are present in the vein walls and locally in the veins themselves. Quartz veins and pegmatites containing pyrite, chalcopyrite, sphalerite, galena, and minor molybdenite cut Precambrian rocks elsewhere in the district. A small amount of molybdenite may have been produced (Harley, 1940, p. 52).

ROMERO MINE

The Romero (Santo Nino, Hoover) mine is in the Porvenir mining district, two miles north of Porvenir and fifteen miles northwest of Las Vegas, in a saddle high on the south side of Hermit Mountain (sec. 36, T. 18 N., R. 14 E.). Several hundred pounds of coarse, high-grade molybdenite ore were shipped in 1914; 25 tons of molybdenite ore reportedly were mined in 1916 but apparently not shipped. The mine consists of a 90-foot shaft and 800-foot adit (200 feet below the shaft). Molybdenite, chalcopyrite, scheelite, and bismuthinite occur together as small, scattered pockets in a white, coarse-grained pegmatitic quartz vein striking N. 60° E. The vein cuts pink, coarse-grained granite (or quartz monzonite) and contains some orthoclase, muscovite, and fluorite. Abundant brown limonite and canary-yellow ferrimolybdite and some malachite and azurite are present at the surface. Other quartz veins and pegmatites containing molybdenite and chalcopyrite occur in the surrounding area (Bush, 1915; Horton, 1916, p. 78; Harley, 1940, p. 56; Everitt, 1953b).

TECOLOTE MINING DISTRICT

Small amounts of pyrite, chalcopyrite, molybdenite, and other sulfides are present in pegmatite dikes and white quartz veins cutting Precambrian granite, gneiss, and schist in the Tecolote mining district (Harley, 1940, p. 57) which is three to fourteen miles northwest of Chapelle on the Atchison, Topeka, and Santa Fe Railway and fourteen miles southwest of Las Vegas. There has been no molybdenum production.

SOCORRO COUNTY

MAGDALENA MINING DISTRICT

The Magdalena mining district is at the north end of the Magdalena Mountains. The district has been a major producer of lead, zinc, and copper, as well as some gold and silver. Austin (1960) reports that scheelite occurs as disseminated grains in silicated limestone (skarn) and to a limited extent as scattered grains along weakly mineralized joints in the granitic intrusives. The skarn is adjacent to the granitic stocks of the district except at the Linchburg mine, where a shallowly buried stock is believed to underlie the area. The scheelite is associated with galena, sphalerite, and pyrite. The scheelite was formed early, either during or immediately following silication, and the galena and sphalerite then replaced the host rock. Most of the scheelite is molybdian and fluoresces creamy yellow; however, some grains show alternating blue and creamy yellow bands when exposed to ultraviolet radiation.

Horton (p. 77) mentions that molybdenite occurs in quartz breccia "near Magdalena."

SOCORRO PEAK MINING DISTRICT

Wulfenite(?) reportedly occurs in the lead deposits on Socorro Peak, four miles west of Socorro (Northrop, p. 56). Narrow veins containing silver halides in quartz-barite gangue cut Tertiary volcanic rocks consisting chiefly of rhyolite and trachyte flows and pyroclastics. Small amounts of galena in abundant barite gangue are disseminated along major fault zones in Pennsylvanian sediments. Faulting and fracturing is common and widespread in the district. A large mass of monzonite porphyry is exposed underground (Anderson).

HANSONBURG MINING DISTRICT

The barite-galena-fluorite deposits of the Hansonburg (Bingham) mining district are on the west face of the Oscura Mountains near their north end, twenty-eight miles east of San Antonio and four miles south-southeast of Bingham post office on U.S. Highway 380. A number of open cuts and some underground workings were made while mining barite-galena-fluorite ores. Copper ores have been mined from the Hansonburg Hills several miles to the west. Barite, fluorite, galena, and quartz fill the open-space fissures, fault breccia, and small caves along fractures and faults in Pennsylvanian Madera Limestone. The massive, noncherty limestone beds are the most favorable host rocks, as they are intensely shattered along faults, whereas the less massive beds are folded or have broken cleanly. Solutions dissolved open spaces along the joints and faults and silicified the walls. The silicification apparently sealed off the wall rock and prevented replacement of the limestone by the ore minerals which then were deposited as unusually large and perfect crystals in the open spaces. Galena and fluorite were deposited first, barite later. Microscopic blebs of chalcopyrite are enclosed in the galena. Small amounts of anglesite, cerussite, covellite, malachite, azurite, and numerous other supergene minerals including rare wulfenite (Northrop, p. 561) also are present locally. Hornblende diorite sills and dikes intrude the limestones, but not in the immediate vicinity of the deposits (Kottlowski, 1953).

NOGAL MINING DISTRICT, LINCOLN COUNTY

The Nogal mining district lies principally on the east flank of the Sierra Blanca southeast of Carrizozo. The Sierra Blanca is an igneous complex, which consists of a thick sequence of predominantly andesitic Tertiary volcanic rocks that have been intruded by small monzonite stocks and later dikes ranging from rhyolite to lamprophyre and basalt in composition.

Lead-zinc-silver-gold deposits occur as simple veins and breccia zones striking east-west or, less commonly, north-south in the volcanic rocks. Sphalerite, galena, pyrite, calcite, and/or quartz are common.

The molybdenum occurrences are in or near a monzonite stock. They contain disseminated molybdenite and pyrite but no sphalerite or galena. The Bear Creek Mining Company reportedly is exploring a molybdenum occurrence a few miles to the south in the south-central part of T. 10 S., R. 11 E.

RIALTO PROSPECT

The Rialto prospect in sec. 27, T. 9 S., R. 11 E. is developed by the 380-foot Fulmer adit, a small pit, a shallow shaft, and four diamond drill holes totaling 2319 feet. The inner 100 feet of the Fulmer adit and the drill holes contain molybdenite, chalcopyrite, and pyrite as small veinlets and disseminated grains in a sericitized and silicified Tertiary monzonite stock; the mineralized interval in the adit averages 0.18 per cent MoS_2. A small pit, some 1500 feet southeast of the Fulmer adit, exposes molybdenite, pyrite, and minor copper stain in brecciated monzonite in the hanging wall of a small fault. The dump of a shallow shaft, half a mile north of the Fulmer adit, contains a few specks of molybdenite in highly pyritic monzonite. A thick mantle of soil covers almost the entire area (Griswold and Missaghi, 1964). There has been no production.

WATER DOG PROSPECT

The Water Dog prospect in sec. 36, T. 9 S., R. 12 E. consists of an old adit and four drill holes, ranging from 50 to 150 feet deep. A minute amount of molybdenite occurs in two of the drill holes. All the drill holes are in highly altered, brecciated, and silicified Tertiary latite volcanics containing 1 to 5 per cent pyrite (Griswold, 1959).

OTHER OCCURRENCES, LINCOLN COUNTY GALLINAS

MOUNTAINS MINING DISTRICT

Anderson (p. 24) mentions that wulfenite occurs in the Gallinas Mountains mining district, which is about ten miles west of Corona at the north edge of Lincoln County.

JICARILLA MINING DISTRICT

In the Jicarilla mining district (T. 5 S., R. 12 E.), some powellite and scheelite occur in small areas of skarn in the limestones of the San Andres Formation immediately adjacent to the contact with a laccolith(?) of monzonite and monzonite porphyry (Griswold, 1959).

CATRON COUNTY

SCHWARZ CABIN

Molybdenite reportedly occurs near the old Schwarz cabin (Fayette Rice claims) on Little Dry Creek in the Mogollon Mountains, southwestern Catron County (Elliot Gillerman, written communication, 1964). Specular hematite occurs here as rosettes and hexagonal plates associated with pyrite in vesicles in andestite; probably the hematite was misidentified as molybdenite (Robert **H.** Weber, written communication, 1964).

TYRONE CLUSTER, GRANT COUNTY

Molybdenum mineralization is present at a number of places in the Big Burro Mountains near Tyrone. There are two types of occurrences: (1) molybdenite in Precambrian pegmatites and Precambrian(?) quartz veins and pods that cut Precambrian rocks and have no apparent relation to the Tertiary intrusive rocks and (2) molybdenite in the Tyrone porphyry-copper deposit which is in a Tertiary quartz monzonite stock and surrounding Precambrian granite, and in more throughgoing quartz veins that probably are offshoots of the porphyry-copper deposit.

ECCLES CANYON

Hewitt (1959, p. 75) states that "About two handfuls of molybdenite were found in the blast debris from a prospect pit [in Eccles Canyon, in the eastern part of R. 17 W. or the western part of R. 16 W., T. 19 S.] . . . . Apparently the mineral occurred in a small lens as a primary sulfide accessory to the pegmatite, or else it was related to a small quartz vein that transects the pegmatite." The Precambrian pegmatite consists of quartz, microcline, and oligoclase with minor biotite and muscovite. Scheelite occurs in quartz veins in this area; most of it is molybdian and fluoresces brilliant yellowish white; however, the scheelite in a few of the younger veins fluoresces bluish white.

Extremely rare molybdenite was also found in other pegmatite dikes near the old Bar 6 windmill on the Tyrone—Redrock road (Elliot Gillerman, personal communication, 1964), which is in the same general area.

PACEMAKER PROSPECT

The Pacemaker prospect is in the northeast corner of T. 19 S., R. 16 W., 300 feet south of State Highway 25 3.4 miles southwest of the junction with the Mangas Creek road. Shallow shafts, open cuts, and trenches were dug exploring for tungsten. Molybdenite occurs in a quartz inclusion in the Precambrian granite about 300 feet north of the main workings. In the main workings, sporadic scheelite is present in quartz pods and along shears striking N. 50° E. in the granite (Dale and McKinney).

BEAUMONT MINE

The Beaumont mine is five miles west of Tyrone in the E1/2 sec. 13, T. 19 S., R. 16 W. It is developed by workings from a 350-foot inclined shaft made while mining silver ore. Abundant molybdenite occurs in the deeper parts of the mine in a quartz vein on the hanging wall of the main vein. The main vein strikes N. 70° E., dips 60°-75° SE, and contains argentite, native silver, argentiferous galena, and pyrite (Gillerman, written communication, 1964). There has been no molybdenum production.

BOLTON & WILSON PROPERTY

Paige (1911) reports that a little molybdenite fills fractures at one point on the Bolton & Wilson property. In the same area, quartz, pyrite, chalcopyrite, chalcocite, and copper carbonates occur in ill-defined shear zones and fractures trending north to northeast. The country rock is Precambrian granite cut by quartz monzonite porphyry and a few mafic dikes. There is no reported molybdenum production.

What is now referred to as the Bolton & Wilson property consists of several shafts and pits five miles west-southwest of Tyrone on the east side of Iron Gulch in the NW1/4 sec. 24, T. 19 S., R. 16 W., one half to one mile south of the Beaumont mine. The molybdenum occurrence could not be located in the field. It is likely that the Bolton & Wilson property at one time included the Beaumont mine, and thus it is possible that Paige was referring to the Beaumont occurrence.

TYRONE PORPHYRY—COPPER DEPOSIT

The Tyrone porphyry-copper deposit includes a roughly circular area in the Big Burro Mountains, which is more than two miles in diameter, with Tyrone on the northern edge. Extensive underground workings were made while mining high-grade parts of the copper deposit; later, extensive drilling was done which outlined a large, low-grade, copper ore body. There has been no molybdenum production.

The porphyry-copper deposit is in Precambrian Burro Mountain Granite and the Tyrone quartz monzonite stock which intrudes the granite. The mineralization shows no apparent preference as to host rock. Blebs and specks of chalcopyrite and rare sphalerite and molybdenite occur in a stockwork of pyrite-quartz veinlets, with pyrite as disseminations in the wall rock adjacent to the stockwork fractures. Fluorite around the edges of the deposit was deposited later than the sulfides. Abundant sericite, quartz, and kaolinite, and smaller amounts of chlorite and epidote have been formed by hydrothermal alteration of the wall rock.

The copper minerals chrysocolla, malachite, azurite, cuprite, native copper, turquoise, and tenorite(?) have been formed in the oxidized, upper parts of the deposit. Here, chrysocolla is the most abundant copper mineral. Limonite, hematite, jarosite, manganese oxides, and chalcedony also are common in the oxidized zone. An irregular blanket of supergene chalcocite up to 500 feet thick represents an enriched zone between the oxidized and primary parts of the deposit and constitutes the bulk of the ore (Paige, 1922; Gillerman, written communication, 1964).

SANTA RITA—PIN OS ALTOS CLUSTER, GRANT COUNTY

A number of ore deposits, as well as the Late Cretaceous—Tertiary granitic bodies with which they are associated, are exposed in an east-west elongate window of pre-Tertiary rocks within a block bounded by northwest-trending, high-angle fault systems. North and south of the window, Tertiary and Quaternary volcanic rocks and alluvium cover the older rocks (fig. 6).

The rocks exposed in the window are largely Paleozoic limestones and dolomites divided into lower and upper sequences by the Devonian Percha Shale. There are no Triassic or Jurassic rocks, but Cretaceous sandstones and shales are present.

A period of intense igneous activity occurred during Late Cretaceous and Tertiary time. The most significant event was the emplacement of the large granodiorite and quartz monzonite bodies at Pinos Altos, Copper Flat, Fierro—Hanover, and Santa Rita. The intruded sediments were uplifted, steeply folded, and pushed aside by these bodies. A complex sequence of dikes, sills, laccoliths, and plugs was intruded before and after the large igneous bodies. The final phase of this igneous activity was the extrusion of the lavas and pyroclastic material that cover the areas to the north and south of the window.

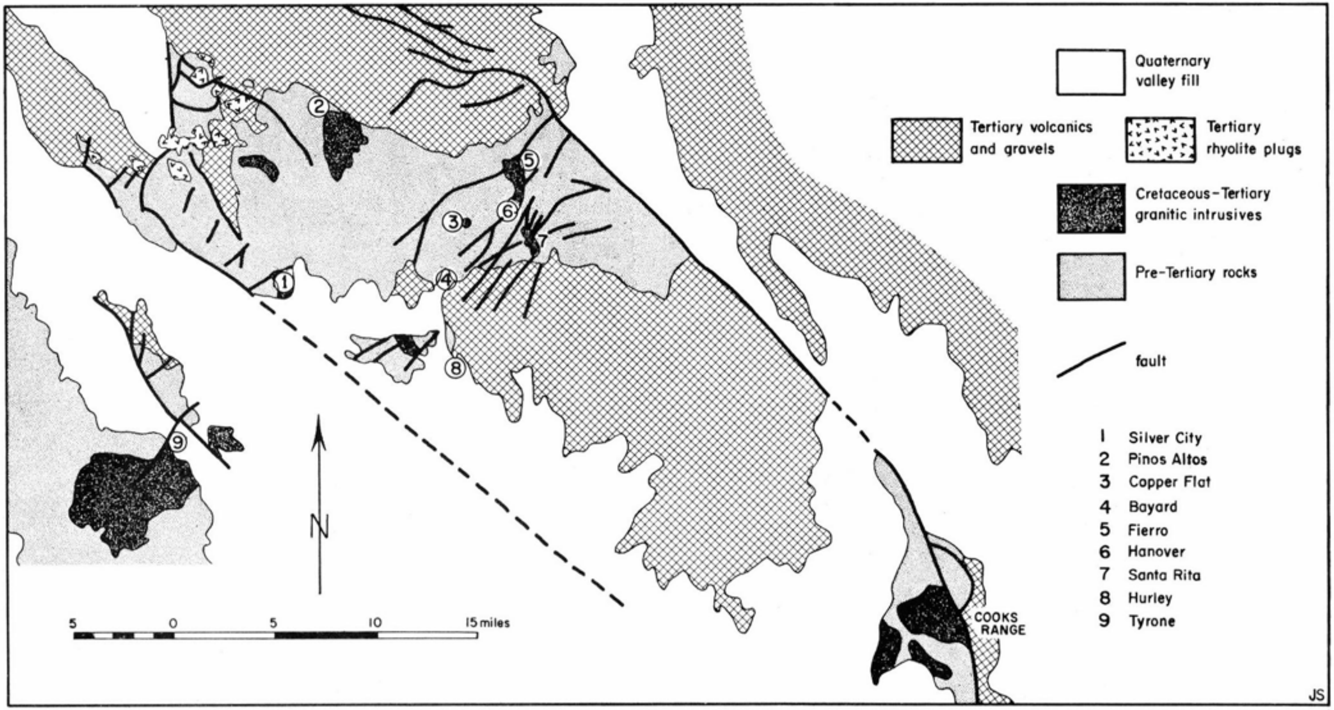

Figure 6

GENERALIZED GEOLOGIC MAP OF THE SANTA RITA—PINOS ALTOS—TYRONE REGION, GRANT COUNTY (MODIFIED AFTER ORDONEZ, BALTOSSER, AND MARTIN, 1955)

Extensive north- to northeast-trending high-angle faults were formed before the intrusion of the large igneous bodies. Recurring movement took place along many of these faults until after the final phase of igneous activity.

Important amounts of copper, zinc, lead, molybdenum, iron, manganese, gold, and silver have been produced from deposits in the window. The most important of these are the Santa Rita porphyry-copper deposit and the Fierro—Hanover iron and zinc deposits, which are in or near large granitic bodies, and the Bayard lead-zinc veins, which are in the north- to northeast-striking faults.

PORTLAND MINE

At the Portland mine, near Pinos Altos in the Pinos Altos mining district, large blades of molybdenite locally are associated with 0ˉ11-copyrite (Elliot Gillerman, written communication, 1964) in northeast-trending quartz veins in a hornblende quartz monzonite stock. The veins also contain pyrite, sphalerite, and galena. There has been no molybdenum production.

FIERRO IRON DEPOSITS

A number of open-pit and underground iron mines are located in the vicinity of Fierro in T. 17 S., R. 12 W. The Union (Republic) mine is in the NEN sec. 16, the Jim Fair mine is in the NWIA sec. 10, and the El Paso mine is in the northern part of sec. 15. These mines exploited contact metasomatic magnetite bodies that replace Ordovician El Paso Limestone, and to a limited extent other limestones, at or near the contact of the Hanover—Fierro granodiorite stock. The iron ore consists largely of magnetite and subordinate specularite; chalmersite, pyrite, chalcopyrite, sphalerite, and molybdenite are present locally, commonly in veinlets cutting massive magnetite. The ore normally contains about 0.6 per cent copper. Elsewhere around the stock, the limestones contain large replacement bodies of sphalerite and skarns of garnet, hedenbergite, epidote, zoisite, diopside, wollastonite, serpentine, and ilvaite. The sphalerite is most abundant at distances of a few hundred to a thousand feet from the stock. The skarns were formed first, the magnetite bodies next, and the sphalerite bodies last (Anderson). There has been no molybdenum production.

BAYARD AREA

The Ground Hog, Bull Frog, Lucky Bill, and other mines in the vicinity of Bayard and Vanadium in the southwestern part of the Central mining district have produced lead, zinc, copper, silver, and minor vanadium (Lasky, 1936; Lasky and Hoagland, 1948). There has been no molybdenum production. In the area, Cretaceous quartzites, sandstones, and shales were intruded by Late Cretaceous or Early Tertiary quartz diorite sills. Numerous, steeply dipping faults and granodiorite porphyry and quartz latite dikes cut the older rocks; a few of the faults offset Tertiary volcanic and sedimentary rocks that cover the older rocks. Nearly all the faults and dikes trend northeast, forming a zone several miles wide. Fissure veins occur along many of the faults. There were three periods of mineralization; each was preceded by the injection of igneous rocks followed by rock alteration that passed as a continuous process into vein formation. The sequence of events was as follows: (1) intrusion of quartz diorite sills; (2) faulting; (3) formation of quartz-pyrite veins; (4) injection of granodiorite dikes in the Bayard area and of granodiorite stocks at Santa Rita, HanoverFierro, and Copper Flat elsewhere in the Central mining district; (5) faulting; (6) formation of quartz veins containing important amounts of pyrite, chalcopyrite, sphalerite, and galena; (7) erosion, oxidation, leaching, and enrichment resulting in the formation of locally abundant chalcocite, cerussite, limonite, manganese oxides, wulfenite, endlichite, and some bornite, covellite, azurite, malachite, chrysocolla, anglesite, plumbojarosite, pyromorphite, calamine, smithsonite, willemite, and cuprodescloisite; and (8) subsequent volcanic activity, intrusion of quartz latite dikes, renewed faulting along some of the earlier breaks, minor quartz-pyrite mineralization, and erosion. Albitization, propylitization, silicification, calcitization, and sericitization preceded and accompanied vein formation.

Wulfenite was one of the last minerals formed and is common in the oxidized zone of nearly all the veins as orange to yellow tabular crystals associated with the vanadium minerals in drusy cavities and embedded in cerussite. At the Bull Frog mine, the wulfenite occurs at the surface and dies out at a depth of 10 feet; in the Ground Hog mine, wulfenite is present to depths greater than 400 feet.

SANTA RITA MINE

The Santa Rita (Chino) porphyry-copper mine is the largest producer of copper and molybdenum in New Mexico, as well as being a major world producer of both metals. More than 2.3 million tons of copper and 32,000,000 pounds of MoS_2 have been produced through 1963.

History. The Spanish began mining the deposit about 1800. At first, only native copper was mined, but later a crude smelter was built to treat the ore. The copper was shipped to Mexico for use in coinage. Underground mining continued until 1910, when open-pit operations began. The mine, mill, and smelter are operated by the Chino Mines Division of the Kennecott Copper Corporation.

Mining and milling. Some 23,000 tons of ore and 45,000 tons of waste are mined daily from the benches of a circular open pit more than a mile across and a thousand feet deep, using shovels, trucks, and skip hoisting. Until recently, train haulage was used. The mine-run ore contains 0.85 per cent copper and 0.010 to 0.016 per cent MoS_2 (Burke, 1964). The ore is shipped ten miles by rail to the mill and smelter at Hurley, where a concentrate of copper minerals and molybdenite is produced by flotation. The molybdenite is separated from the copper by further flotation. Molybdenite was not recovered prior to 1937. Formerly, only some 60 per cent of the molybdenite in the ore was being recovered; a new molybdenum recovery plant was built recently to improve production.

Geology. This porphyry-copper deposit is in a biotite granodiorite porphyry stock and to a lesser extent in the adjacent Pennsylvanian to Cretaceous limestones, shales, and sandstones. The mineralization occurs as stockwork veinlets and disseminated blebs forming an irregular body that is circular in plan and up to 600 feet thick. Prior to mining, the ore body was partly covered by an oxidized and leached capping up to 400 feet in thickness.

Magnetite was deposited first in the shattered rocks, followed by quartz, pyrite, and molybdenite. Chalcocite occurs as replacements of and coatings on the pyrite. The chalcocite may be entirely supergene or partly hypogene. Although Kerr et al. (1950) mention that chalcopyrite appears to be rare, Leroy (1954) states that it apparently is relatively common as specks in the pyrite. The molybdenite occurs as tiny, flattened grains along the edges of quartz veinlets and in the adjacent country rock.

The stock has been extensively shattered and altered. The copper mineralization is spatially associated with late argillic-hydromica alteration in which the biotite is converted to hydromica and the feldspars are argillized. Copper mineralization is absent to rare in the less altered rock and in the highly silicified and sericitized areas.

Oxidation has resulted in the formation of minor native copper, cuprite, malachite, azurite, and chrysocolla. The chalcocite may have been formed by secondary enrichment processes, possibly by the oxidation and leaching of an upper section of the deposit which was later removed by erosion, or it may have been deposited, at least in part, by late-stage hydrothermal solutions. Oxidized copper minerals have been found at a depth of twelve hundred feet; chalcocite has been noted to a depth of one thousand feet in prospect drill holes. (Ballmer, 1953; Kerr et al.; Leroy; and Ordonez, Baltosser, and Martin, 1955).

OTHER OCCURRENCES, GRANT COUNTY

GRANDVIEW MINE

The Grandview mine, in the Swartz (Carpenter) mining district, is in Grandview Canyon seven miles southwest of Kingston on the west slope of the Black Range. The mine is developed by underground workings made while mining lead-zinc ore. Quartz, pyrite, galena, sphalerite, and some chalcopyrite occur as irregular replacement bodies and stringers along a 30-foot-wide shear zone (Grandview fault) striking N. 55° E. in limestone. Smithsonite and cerussite supplant the sphalerite and galena in the oxidized zone at the surface (Anderson). Molybdenite reportedly is present in the mine, but nothing is known of the mode of its occurrence.

LAKE VALLEY—MACHO ZONE, SIERRA COUNTY

The lead-zinc deposits of the Lake Valley, Macho, and Old Hadley (Graphic) mining districts lie along a N. 35° E.-striking zone of fractures and faults. Veins of the Macho and Old Hadley districts are in these structures. The veins and the ore bodies at Lake Valley occur where cross faults cut the zone.

The source of the mineralizing solutions is not evident. The nearest exposed intrusive body is eight miles away. Early(?) Tertiary latite dikes parallel the mineralized zone on the north at the Macho district.

LAKE VALLEY MINING DISTRICT

Most of the mines of the Lake Valley mining district are in the SW1/4 sec. 21, T. 18 S., R. 7 W., half a mile north of the town of Lake Valley. The district contains extensive surface and underground workings made while mining silver and manganese ore. There has been no molybdenum production. Bedded, manganiferous silver-lead deposits replace the basal layers of the "crinoidal limestone member" and the upper layers of the "blue limestone member" of the Mississippian Lake Valley Formation. The deposits occur mainly in a drag zone along a fault striking N. 40° W. Faults with minor displacements strike N. 45° E. The primary minerals are argentiferous galena, manganiferous ankerite, chert, and some silver sulfantimonides and pyrite. Oxidation and secondary enrichment have transformed much of the primary mineralization into abundant manganese oxides, limonite, manganiferous calcite, and gypsum, some cerargyrite, cerussite, and smaller amounts of embolite, native silver, vanadinite, and wulfenite. Little zinc, copper, or gold is present (Jicha, 1954).

MACHO MINING DISTRICT

The Macho mining district is mainly in sec. 20, T. 19 S., R. 7 W., about eight miles southwest of Lake Valley. Lead-silver ores were mined underground from veins up to 2 feet wide that follow fractures and faults trending N. 30°-40° E. in Early(?) Tertiary porphyritic pyroxene andesite flows, breccias, and tuffs of the Macho Formation. Chloritization, silicification, and sericitization occur along the veins and in parallel barren fractures and faults. The veins consist chiefly of quartz, barite, and galena with considerable pyrite, calcite, manganese oxides, limonite, vanadinite, cerussite, sphalerite, anglesite, hemimorphite, and wulfenite (Jicha).

OTHER OCCURRENCES, SIERRA COUNTY IRON

MOUNTAIN MINING DISTRICT

The Iron Mountain mining district is on Iron Mountain at the north end of the Sierra Cuchillo. The surface and underground workings in the district were made exploring for tungsten and beryllium. Contact-metasomatic beryllium and tungsten deposits occur in irregular bodies of dark-colored, iron-rich silicated rock (tactite) replacing Paleozoic limestone and calcareous shale at or near contacts with mid-Tertiary(?) sills, dikes, and pluglike masses of rhyolite, granite, and aplite. The tungsten deposits are in massive-bedded tactite consisting of coarsely crystalline magnetite and andradite garnet, locally abundant scheelite, powellite, hedenbergite, specular hematite, and small amounts of fluorite, apatite, diopside, iron-rich amphibole, quartz, feldspar, spinel, idocrase, biotite, chlorite, willemite, pyrite, pyrrhotite, sphalerite, and galena. Powellite has been reported at the Scheelemite, Parker Strike, Lucky Strike, and Scheelite Gem prospects in NW1/4 sec. 2, T. 10 S., R. 8 W. (Jahns, 1944, pl. 18) and the Black Bed prospect in the SW% sec. 11. A few grains of molybdenite were noted during milling tests in a composite sample of scheelite ore from the district (Dale and McKinney, p. 65). Most of the minor constituents are distinctly younger than the magnetite and garnet. Scheelite and powellite commonly occur as disseminations or fracture fillings. The scheelite is molybdian, containing 3 to 12 per cent molybdenum and fluorescing pale golden yellow to rich creamy white. At the Scheelite Gem prospect, molybdian scheelite is accompanied near the surface by orange to canary-yellow crusts of tungstite and ferrimolybdite (Jahns, 1944).

In the Goat Hill Canyon area, NW1/4 sec. 14 (Jahns, 1944, pl. 17), several bodies in the tactite contain smithsonite, willemite, hemimorphite, wulfenite, anglesite, cerussite, and copper oxides and carbonates.

HERMOSA MINING DISTRICT

The lead-silver mines and prospects of the Hermosa (Palomas) mining district are at the south end of the Sierra Cuchillo. Argentiferous galena and bornite, chalcopyrite, pyrite, and native silver in a gangue of talcose clay form irregular pockets, lenses, and pipes along the intersections of certain fractures just below a shale bed along a flat anticline in lower Magdalena Limestone. Wulfenite is present locally in the deposits as small cubes. There has been no molybdenum production (Anderson).

HILLSBORO MINING DISTRICT

The Hillsboro mining district is near the town of Hillsboro in the NW1/4 T. 15 S. and SE1/4 T. 16 S., R. 7 W. The numerous mines and prospects were opened mainly while mining gold-silver-copper ore. Sanford and Stone (1914) report that some wulfenite was mined in the district prior to 1917; apparently molybdenum was recovered from this ore.

At Copper Flat, an inverted funnel-shaped quartz monzonite porphyry body intruded early(?) Tertiary andesite volcanic rocks; latite dikes radiate outward from the main intrusive mass. A porphyry-copper deposit occurs in a brecciated and sericitized zone in the southern part of the intrusive body and to a lesser extent in the intruded andesite volcanics. The deposit consists of disseminated grains and stringers of pyrite, chalcopyrite, chalcocite, azurite, malachite, and cuprite and of quartz stockworks locally containing abundant pyrite, chalcopyrite, and some molybdenite and bornite. Biotite and feldspar occur in the quartz at several spots (Kuellmer, 1955).

Quartz fissure veins follow shear zones in and along the latite dikes and less commonly in the volcanic rocks. Chalcopyrite, pyrite, and, more rarely, galena and sphalerite are locally abundant in these veins. Molybdenite is common in the parts of the veins nearest to the Copper Flat intrusive. Like the dikes, most of the veins trend northeast, converging toward the Copper Flat intrusive body, and are continuous over distances of up to several miles (Harley, 1934, pl. 6).

In the southernmost part of the district, small, irregular pockets of oxidized replacement ore consisting of manganese oxides, cerussite, anglesite, wulfenite, vanadinite, galena, endlichite, limonite, calcite, and quartz occur in the Fusselman Dolomite along the contact with the overlying Percha Shale. The bodies apparently do not extend far from the surface. Wulfenite is abundant, usually as yellow tabular crystals up to an inch long (Harley, 1934).

SILVER TAIL PROSPECT

The Silver Tail prospect is ten miles southwest of Hillsboro in the E1/2 sec. 21, T. 17 S., R. 8 W. in the Black Range. Silver and tungsten ores have been mined from two interconnected adits containing some 500 feet of workings. Molybdenum-bearing scheelite is present as disseminations and in thin quartz-calcite veinlets in highly altered and fractured andesite (Dale and McKinney).

PALOMAS GAP (CABALLO MOUNTAINS) MINING DISTRICT

In the vicinity of Palomas Gap in the Caballo Mountains (SWIA T. 14 S., R. 4 W.), there are a number of prospects and several small mines made exploring for or mining lead, vanadium, and fluorite. The deposits consist of galena, fluorite, barite, quartz, calcite, cerussite, anglesite, copper carbonates, and locally abundant vanadinite, wulfenite, cuprodescloizite, descloizite, and pyromorphite in fissure veins cutting Magdalena Limestone (Harley, 1934). Molybdenum was produced from a small amount of wulfenite mined from the Gladys claim in 1914 (Horton, p. 34).

SALINAS PEAK MINING DISTRICT

Northrop (p. 237, 258) mentions that molybdenite and ferrimolybdite reportedly occur at Taylor Canyon.

ORGAN CLUSTER, DONA ANA COUNTY BEAR

CANYON MINING DISTRICT

The Bear Canyon mining district is northeast of Organ in the SW1/4 sec. 28 and NW1A sec. 33, T. 20 S., R. 5 E. in the southern part of the San Andres Mountains. Small workings were made while mining lead and barite; there has been no molybdenum production. Highly irregular replacement deposits of abundant barite, some galena and fluorite, and minor quartz occur along a thrust fault, both in limestone fault breccia and in Ordovician El Paso Limestone in both plates of the fault. Although some limestone occurs in the lower plate, which is mainly Precambrian granite and schist, most of the limestone in the area is in the upper plate. Galena and fluorite occur next to the limestone walls and fragments; barite makes up the rest of the mineral assemblage. Cerussite, anglesite, vanadinite, and wulfenite are present in the oxidized parts of the deposits. Other barite-galena-fluorite replacement deposits occur in Silurian Fusselman Dolomite two and one-half miles northeast, near the crest of the San Andres Range, but contain no vanadinite or wulfenite (Dunham, 1935).

STEVENSON—BENNETT MINE

The Stevenson—Bennett mine (SE% sec. 11 and NE1/4 sec. 14, T. 22 S., R. 3 E.) in the Organ mining district consists of extensive underground workings made while mining lead-silver ores. Molybdenum was recovered from wulfenite in 1918 (McInnis, p. 47).

Tabular and irregular lead-zinc replacement deposits occur in Silurian and Ordovician dolomite associated with faults, fractures, and brecciation in the north-trending Torpedo—Bennett fault zone; the mineralization is limited on the north and south by postmineralization, east-west faults. A sheet of quartz monzonite porphyry cuts the dolomite but is offset by the faults of the zone. About 300 feet east of the fault zone, Tertiary quartz monzonite intruded the Precambrian granite that forms the east wall of the zone.

The Bennett ore body, the largest in the mine, is in a fracture zone striking north and dipping 70° W. It is tabular, has a maximum length of nearly 500 feet, is 10 to more than 20 feet wide, and has a known vertical extent greater than 600 feet. Near its top, where the fractures cut the porphyry sheet, little primary ore was deposited, and above the sheet, the ore body becomes irregular and does not extend to the surface. Laterally, the ore body passes into barren fractures in silicified dolomite. Below the zone of oxidation, the ore body consists of pyrite, galena, sphalerite, quartz, and silicified dolomite. The oxidized part of the body contains limonite, cerussite, wulfenite, and minor anglesite and smithsonite. Wulfenite, though somewhat less common than cerussite, was locally abundant and was one of the most important ore minerals (Dunham). Koning (1948) has described the wulfenite; Hess (1924, pl. 9) has a photograph of wulfenite from this deposit.

Sanford and Stone mention that molybdenite is "associated with the lead and silver ores at Organ."

TEXAS CANYON MINE

The Texas Canyon mine is in secs. 34 and 35, T. 22 S., R. 4 E. on the east flank of the Organ Mountains, seven miles southeast of Organ. The underground workings were made mining gold ore and exploring for gold-silver-copper ore; there has been no molybdenum production. A 2- to 6-foot-wide vein, striking N. 75° E. and dipping steeply north, in monzonite and quartz monzonite contains abundant quartz, considerable barite, pyrite, and chalcopyrite, and some molybdenite, tetradymite, and argentite. The oxidation zone extends only to a depth of 20 feet (Dunham).

molybdenum-bearing scheelite is present in contact-metasomatic deposits in limestone adjacent to an irregular quartz monzonite intrusive body.

HILLTOP MINE

The Hilltop (Dome, Sunrise, Granite Gap) mine is in the SWIA sec. 35, T. 25 S., R. 21 W. at Granite Gap in the Peloncillo Mountains. There are several shafts (the deepest 250 feet), pits, and trenches made exploring for tungsten and lead-copper-silver mineralization. Molybdenum-bearing scheelite occurs as disseminations in silicated (garnetized) limestone on or near the contact with a quartz monzonite stock, and at a few places in quartz veins cutting the intrusive body (Dale and McKinney).

BAKER—STANDARD PROSPECT

The Baker—Standard prospect is a mile north of Granite Gap in secs. 23, 26, and 27, T. 25 S., R. 21 W. Blue- and yellow-fluorescing (molybdian) scheelite occurs as disseminations and veinlets along a bedding-plane fault striking N. 30° W. and dipping 55° SW in silicated (garnetized and epidotized) limestone several hundred feet northeast of the quartz monzonite stock. At this point, there is no tactite in the limestone along the edge of the stock (Dale and McKinney).

SCHEELITE PROSPECT

The Scheelite prospect is in secs. 27- and 28, T. 25 S., R. 21 W. on the west slope of Cienega Peak in the Peloncillo Mountains. A 20-foot adit has been driven into one of several discontinuous pockets of massive garnet-tactite along the contact between a pendant of limestone and the quartz monzonite stock. Small crystals of molybdenum-bearing scheelite are disseminated through the tactite, and thin veinlets of scheelite cut the granite within five or six feet of the contact (Dale and McKinney).

LITTLE HATCHET MOUNTAINS, HIDALGO COUNTY

In the Sylvanite mining district, which is in the southern part of the Little Hatchet Mountains, copper-gold-silver-bearing quartz veins cut the large, irregular Sylvanite quartz monzonite porphyry stock, and tungsten-bearing contact-metasomatic bodies are present in the limestone adjoining the intrusive.

EAGLE POINT PROSPECT

The Eagle Point claims are in sec. 22, T. 29 S., R. 16 W. on the southwestern slope of the Little Hatchet Mountains. The workings consist of a 70-foot-long open cut, an inclined adit, and numerous trenches made exploring for tungsten. Molybdenum-bearing scheelite occurs as tiny veinlets and small, disseminated grains in masses of silicated (garnetized) limestone in a roof pendant(?) in the quartz monzonite intrusive body. The pendant is a limestone member of the Cretaceous Playas Peak Formation (Dale and McKinney).

CACTUS PROSPECT

At the Cactus prospect, in the NEIA sec. 10, T. 29 S., R. 16 W. on the west side of the southern spur of the Little Hatchet Mountains, shallow shafts, pits, and trenches have been made exploring for tungsten. Yellow-fluorescing molybdian scheelite and pyrite occur in a 5- to 15-foot-wide, 1500-foot-long zone of silicated (garnet-epidote-quartz) limestone striking N. 50°-75° W. and dipping steeply southwest along the edge of the quartz monzonite intrusive body (Dale and McKinney).

SANTA MARIA TUNNEL AND FARIA SHAFT

The Santa Maria tunnel and Faria shaft, also known as the Bader property and Little Hatchet mine, are in sec. 21, T. 28 S., R. 16 W., south of Livermore Spring in the Sylvanite mining district.

The Santa Maria tunnel transects badly broken ground in the footwall of a north-northeast-trending, west-dipping part of the Copper Dick fault. Contact-metamorphosed shale, limestone, and conglomerate of the Lower Cretaceous Broken Jug Formation, and intrusive monzonite of the Sylvanite stock are cut by lamprophyre dikes. A few hundred feet from the fault, a vein consisting of quartz, calcite, barite, chalcopyrite, and pyrite follows sheeting in a lamprophyre dike trending northeast; northwest-trending, offshoot faults from the Copper Dick fault offset the vein. Molybdenite is disseminated in the vein walls and forms films along joints at one place in the tunnel (Lasky, 1947, pl. 27). Powellite reportedly occurs in the tunnel (Northrop, p. 407).

In the Faria shaft, several hundred feet southeast of the Santa Maria tunnel, a one- to two-foot-wide, north-trending, steeply north-dipping vein in sediments in the bottom of the shaft consists of stringers of calcite veined and intergrown with epidote and containing threads, blebs, and disseminated grains of pyrite, pyrrhotite, and molybdenite.

One quarter of a mile east of the Santa Maria tunnel in a small prospect, molybdenite occurs in contact-metasomatized rock.

OTHER OCCURRENCES, HIDALGO COUNTY

LORDSBURG MINING DISTRICT

The Lordsburg mining district is in the vicinity of Valedon, three miles southwest of Lordsburg. There are several large base-metal mines in the district, as well as smaller mines and prospects. There has been no molybdenum production.

East- and northeast-trending, steeply dipping quartz veins occur in faults in the margins of an irregular, horseshoe-shaped body of granodiorite and in adjacent Lower Cretaceous basalt flows which the diorite intruded. The veins contain abundant chalcopyrite, some galena, sphalerite, and pyrite, and small amounts of barite, fluorite, calcite, rhodochrosite, tourmaline, and specularite. Molybdenite reportedly is present in small amounts (Northrop, p. 500). The deposits are of the copper-tourmaline type. Malachite, azurite, chrysocolla, chalcocite, covellite, cerussite, anglesite, hemimorphite, and some wulfenite and cuprodescloizite occur in the zone of oxidation and enrichment. At the Anita mine, wulfenite was found in the vein outcrop (Kelly, 1958). The order of deposition was (1) tourmaline and specularite in the veins and wall rock; (2) quartz and pyrite; (3) quartz and chalcopyrite; (4) quartz, sphalerite, galena, and barite; (5) quartz, rhodochrosite, calcite, and fluorite; and (6) the supergene minerals resulting from the oxidation, leaching, and enrichment of the primary minerals. Sericitization and silicification of the wall rock occurred during deposition of (2), (3), and (4) (Lasky, 1938).

LUNA COUNTY

IRISH ROSE MINE

The Irish Rose (Morlock, Brinkman, Kimmic) mine is in the west-central sec. 29, T. 24 S., R. 12 W. in the middle hills of the Victorio Mountains. The mine consists of a 125-foot inclined shaft with several hundred feet of workings on two levels and several pits and trenches, made while mining and exploring for tungsten. There has been no molybdenum production.

A 0.5- to 3-foot quartz vein, containing some muscovite, limonite, pyrite, wolframite, scheelite, beryl, cerussite, wulfenite, and fluorite, strikes due north and dips 50°-60° E in Ordovician El Paso Limestone. The vein is exposed for 500 feet on the surface; to the south, it terminates against a Tertiary alkalic granite porphyry dike that trends north-northwest (Griswold, 1961).

Guides for Molybdenum Exploration

The following discussion is intended to encourage prospecting for molybdenum in the state by providing guides for exploration; that is, by describing briefly the areas and environments in which minable molybdenum deposits are most likely to be found. Although the conclusions given here are applied specifically to molybdenum in New Mexico, much of what follows is applicable also to other metals and other areas. This is not the last nor the complete word; to find molybdenum mines, these general concepts and opinions must be supplemented and modified. Some basic concepts of mineral exploration, obvious to the exploration geologist, are included for the benefit of those less familiar with the nature of exploration.

GENERAL GUIDES TO ORE

STRUCTURES

Faults, fractures, and brecciation are important factors in localizing hydrothermal mineralization. Magmas follow such ruptures as avenues of least resistance; they are conduits along which hydrothermal solutions travel, and they provide open spaces in which the ore minerals can be deposited. Particularly favorable situations include zones of concentrated faulting that are persistent in extent and time; intersections including faults with faults, faults with folds, and faults with favorable host rocks; large areas of shattering or brecciation; and domes. Areas where these features are absent are relatively unfavorable.

INTRUSIVE ROCKS

The presence of Mesozoic and Tertiary acid-to-intermediate intrusive rocks is a guide to molybdenum, as well as to other metal deposits. Most molybdenum deposits of the quartz-vein, contact, and porphyry types occur in or close to intrusive bodies of granite, syenite, quartz monzonite, monzonite, granodiorite, and quartz diorite. No apparent preference is shown for rocks of a particular composition. Stringham (1958) suggests that most of the Cretaceous—Tertiary metal deposits in the western United States are closely associated with "aphanite porphyry" that (Stringham, 1960) has been intruded passively and has sharp crosscutting contacts, weak flowage and cooling features, and a uniform composition (many geologists do not agree with this theory). As a general rule, large intrusive bodies with relatively small outcrops—those that have not been eroded deeply enough to remove the ore deposits commonly concentrated in the upper margins of the body—are the most favorable (Butler, 1915).

The Late Cretaceous—Tertiary, acid-to-intermediate intrusive rocks of the state are concentrated in the New Mexico mineral belt, Texas lineament, Capitan cluster, and Santa Rita cluster (pl. 2).

ALTERATION

Argillization, sericitization, silicification, propylitization, feldspathization, and other types of hydrothermal alteration are common in many metal deposits, including those containing molybdenum, and have been widely used as guides to ore. Alteration, such as argillization and sericitization, that whitens and tends to decompose the rock is readily recognizable; however, alteration types such as silicification and feldspathization tend to "freshen" the rock and thus are more easily overlooked. The complete or near absence of alteration is an unfavorable feature.

SPECIFIC GUIDES FOR MOLYBDENUM

MOLYBDENUM OCCURRENCES

The presence of widespread molybdenum mineralization in an area makes it more likely that there also are minable molybdenum deposits. Conversely, the absence of molybdenum occurrences is unfavorable. As noted below, however, molybdenum-bearing outcrops of many deposits are comparatively inconspicuous and may have escaped recognition.

GOSSANS

In contrast to the oxidized sections of copper, zinc, and lead deposits, the gossans of most molybdenite deposits are not distinctive, and their color and appearance can not be used as a guide to ore. The most common oxidation products of molybdenite (ferrimolybdite, molybdian limonite, molybdian jarosite) can not be distinguished visually from the oxidation products of pyrite and other sulfide minerals which occur with the molybdenite. And in most instances, molybdenite box-works are not distinctive. The secondary molybdenum minerals wulfenite, powellite, and ilsemannite can be more readily recognized by their tabular crystals, yellow fluorescence, and dark blue color, respectively, but are absent or rare in most molybdenum deposits.

Although considerable copper, lead, and zinc usually are removed from ore deposits during oxidation, molybdenum, when oxidized, generally is not transported more than a few feet, and there is little leaching or enrichment. Thus, the molybdenum grade in the gossan commonly is essentially the same as that of the primary ore.

WALL ROCK

There are three characteristics of rock which determine its suitability as a host for ore: (1) the amount, spacing, and continuity of the open space formed when the rock is ruptured or shattered; (2) its permeability; that is, the amount of connected open space where the rock is unruptured; and (3) its chemical reactiveness. Molybdenum deposits occur in every conceivable type of wall rock. Porphyry-type deposits occur in acid-to-intermediate igneous bodies but commonly extend into the surrounding intruded rocks without showing a particular preference as to type. Most of the lead-zinc bodies containing wulfenite or molybdenite are in limestone. Nearly all contact-tungsten deposits are in silicated limestone or other limy rocks. The molybdenum-bearing bedded uranium deposits are in sandstone.

ALTERATION

No one variety of alteration is uniquely associated with molybdenum mineralization. There is some suggestion that silicification is more common, widespread, and intense in deposits containing abundant molybdenite, compared to similar deposits in which molybdenite is rare or absent.

Silicated limestone (tactite, skarn) is a guide to contact-tungsten deposits, many of which contain minable amounts of molybdenum, copper, and other metals.

ASSOCIATED METALS

Minable deposits of molybdenum usually contain appreciable amounts of copper, tungsten, or uranium. If minerals of these metals are present, the possibility of finding molybdenum in the same environment is increased. If the copper is in a porphyry-type deposit, the tungsten in a contact deposit, or the uranium in a bedded deposit, the possibilities are further improved.

Lead, zinc, gold, silver, and tin deposits generally contain some molybdenum but seldom in minable quantities. Iron, manganese, cobalt, nickel, platinum, beryllium, antimony, and mercury deposits rarely contain molybdenum. The presence of appreciable amounts of any of these metals in environments that are copper-, tungsten-, and uranium-poor is an unfavorable feature.

TRACE ELEMENT ANOMALIES

During the formation of a hydrothermal ore deposit, small amounts of certain metals are dispersed in the surrounding country rock; as the deposit is weathered, oxidized, and eroded, trace amounts of these same and other metals are further dispersed in surface and ground waters, soil and rocks, plants, and air. These primary and secondary halos are clues to exploration targets. (For the techniques of geochemical prospecting, *see* Hawkes and Webb, 1962.) Molybdenum is an excellent tracer element and is useful in narrowing the search for copper, tungsten, and uranium, as well as for molybdenum deposits. Conversely, primary copper, tungsten, uranium, and tin halos and secondary copper and uranium halos may be indicative of molybdenum mineralization; except in placers, tungsten and tin are too widely dispersed by secondary processes to be useful guides. Rhenium also is an indicator of molybdenum, but apparently it is present in such small amounts in most halos that more refined analytical methods must be developed before it can be a useful exploration tool.

SELECTION OF FAVORABLE REGIONS

Before a favorable district or target can be found, it is necessary to narrow the search by eliminating unfavorable areas from consideration and by delineating the possible molybdenum-bearing regions in which the search can be concentrated.

FAVORABLE REGIONS

A number of lineaments crisscross the Southwest. These structural belts consist of faults, foliation, aligned and elongate intrusive bodies, fold axes, and other features forming strands in and parallel to the trend of the lineament. Because ore deposits and other helpful guides are concentrated along some of the more clear-cut lineaments, such as the Colorado mineral belt, or at the intersection of several prominent lineaments, such belts and their intersections represent advantageous regions (fig.7).

Postore (Late Tertiary—Quaternary) cover blankets large areas within the favorable regions (pl. 2). Much of the cover is either bolson-fill clastic sediments (so-called alluvium or valley fill) of the intermontane basins or volcanic rocks of the Datil Plateau and other smaller areas. In most instances, the areas where the cover is thin have not been delineated; such delineation must be the first step in the search for minable deposits. It is obviously useless to hunt for ore deposits where they are so deeply buried that profitable mining would be impossible. Hopefully, buried deposits in areas of thin cover can be pinpointed by projecting guides and trends into the covered area and/or using appropriate geophysical and geochemical methods. Finding buried ore deposits remains difficult and expensive, and there is a great need for cheaper, more reliable, and definitive techniques. However, because most covered areas are essentially unexplored, the possible rewards also are great. The pediments (planed rock surfaces, partly or completely covered with alluvium) that flank many of the mountain ranges in New Mexico warrant special attention.

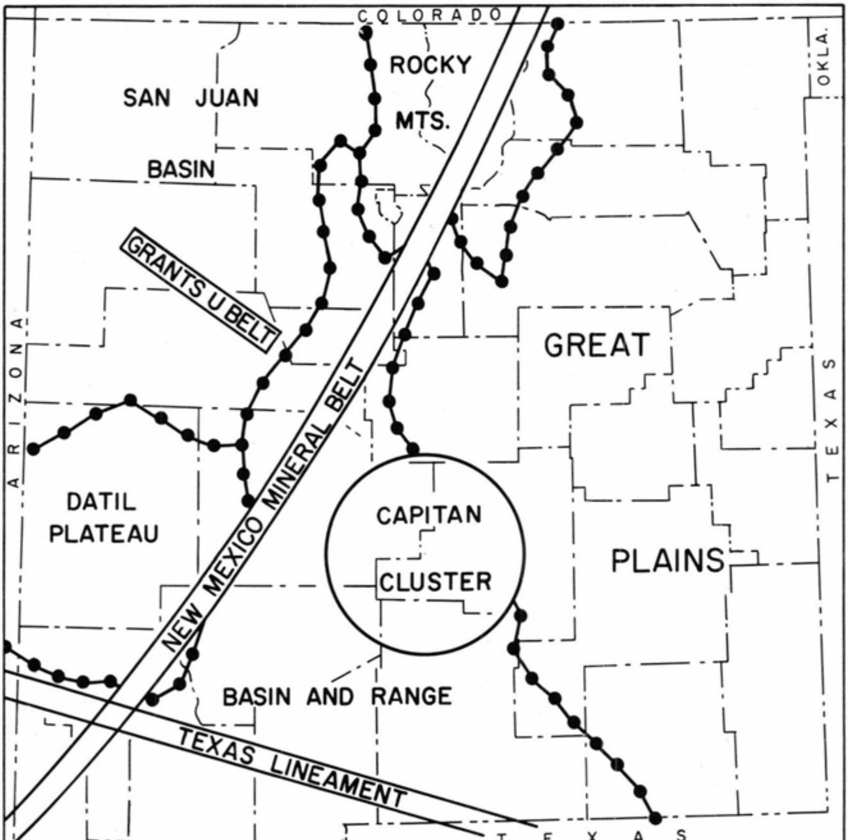

Figure 7

DIAGRAMMATIC MAP SHOWING MINERAL BELTS AND CLUSTER AND PHYSIOGRAPHIC SUBDIVISIONS OF NEW MEXICO

Once the search has been narrowed to a favorable region, the next step is to locate districts (mineralized areas), then targets (specific localities), that are worth examining in detail (McKinstry, 1948). The general and specific guides are used to locate new districts and new targets in known districts, as well as to re-evaluate known targets. Many districts and localities, even in the most attractive areas, have not been examined in sufficient detail to disclose all the ore deposits they contain. The ore-bearing potentialities of such areas should not be overlooked, even though many have been considered barren of molybdenum mineralization. There are any number of localities where the second, third, or even a tenth look found ore.

Most favorable regions. The five most favorable regions for molybdenum exploration in New Mexico are the

(1) New Mexico mineral belt,
(2) Texas lineament,
(3) Grants uranium belt,
(4) Capitan cluster, and
(5) Santa Rita cluster.

These are described under *Geographic Distribution.*

The Santa Rita cluster in southwest New Mexico at the intersection of the Texas lineament and the New Mexico mineral belt is a particularly favorable region because the features of both belts are present, and the localities worth exploring are more numerous and closely spaced than anywhere else in the state. Of course, this region has been more intensively examined than other parts of New Mexico, which at least partly offsets its attractiveness.

Other favorable regions. The parts of the Rocky Mountains (north-central New Mexico), Basin and Range (southwestern, central, and south-central New Mexico), and the Datil Plateau (west-central New Mexico) that are not included above also warrant exploration. These regions (fig. 7) are considered less favorable, but only because regional guides and trends are lacking or vague and advantageous environments are fewer and farther between. Here, it is first necessary carefully to evaluate the regional setting before concentrating on finding targets (Jerome, 1959). As new geologic data and better maps become available, the use of lineaments in defining favorable regions should be increasingly fruitful as well as controversial. Mayo has described a number of probable lineaments that traverse New Mexico.

UNFAVORABLE REGIONS

Several large areas in the state lack features suitable for molybdenum mineralization.

Great Plains. The Great Plains, or eastern third of New Mexico, are by far the least favorable region (fig. 7). Molybdenum occurrences, hydrothermal ore deposits, and granitic intrusive rocks are absent. There are large areas of postore (Late Tertiary—Quaternary) cover, but no indication that there are any hidden favorable environments. It is unlikely that future technological developments will open up new possibilities in this region.

San Juan Basin. The San Juan Basin, encompassing most of the northwest quarter of New Mexico, contains only molybdenum deposits of the bedded uranium type. Granitic intrusive rocks and molybdenum occurrences of the quartz-vein, porphyry, contact-tungsten, and oxidized-lead types are absent, and there are only a few, relatively small areas of postore cover.

Thick cover. In many other areas of the state, postore cover (Late Tertiary—Quaternary) is so thick that deeply buried ore deposits would be extremely hard to find and profitable mining would be impossible under current conditions. Until new techniques such as leaching in place make deeper mining possible, such areas obviously are unattractive for exploration. Unfortunately, the areas of thick versus thin cover have not been delineated except in the roughest way. Much of the Datil Plateau or west-central part of the state; the basins of the Basin and Range, which include the southwestern and south-central parts of the state; and the Rio Grande trough, which extends north-south through the southern Rocky Mountains and Basin and Range, are mantled by thick cover (pl. 2).

OTHER CONSIDERATIONS

It is not enough that those involved in mineral exploration be competent geologists; they must also be practical mineral economists. Changing technology and market patterns, new uses and substitutes, and the political climate all (Ridge, 1962) have just as great an effect on what can be mined at a profit as do the grade, tonnage, distribution, and mineralogy of the molybdenum in the ground. If a molybdenum deposit is particularly large or high grade, it should not be ignored because it can not be exploited under present conditions. Nor is it always enough to gain and retain possession of a deposit in the vague hope that a technological break-through or increased demand will make mining profitable; it may be worthwhile to develop whatever new techniques or markets are needed. The huge Climax deposit could not be mined until extensive and expensive research developed a market for molybdenum. Men make mines.

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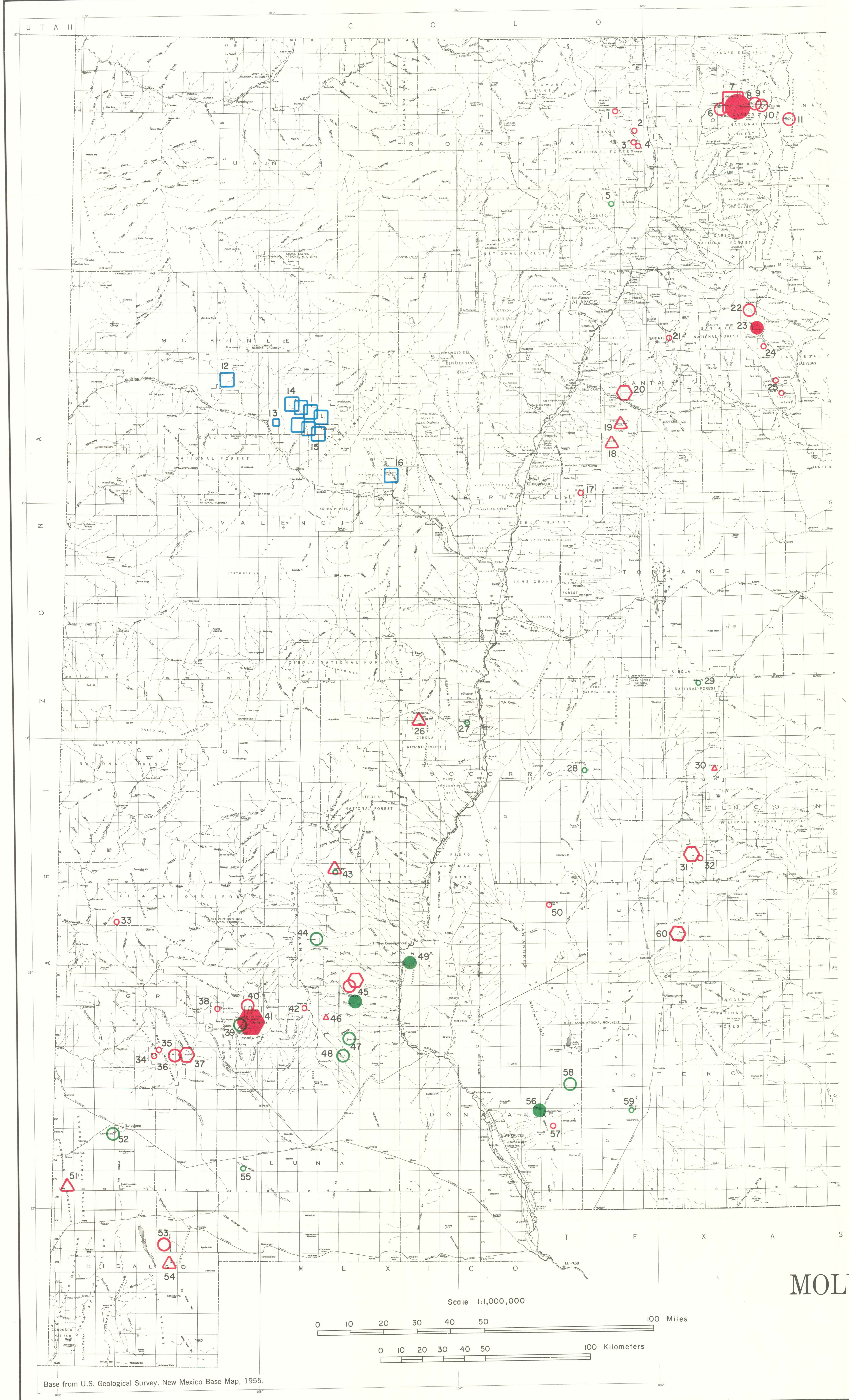


EXPLANATION

Quartz Veins (and Pegmatites)

- mineral locality (molybdenite and/or ferrimolybdite)
- small deposit, no molybdenum production
- small deposit, molybdenite production less than a million pounds
- large deposit, molybdenite production more than 10 million pounds

Porphyry-Molybdenum Deposits

- large deposit, no molybdenum production

Porphyry-Copper Deposits

- large copper deposit containing little molybdenum; or small deposit with no molybdenum production
- large deposit, molybdenite production more than 10 million pounds

Contact-Tungsten Deposits

- mineral locality (powellite, molybdenite, and/or molybdian scheelite)
- small deposit

Oxidized Lead-Zinc Deposits

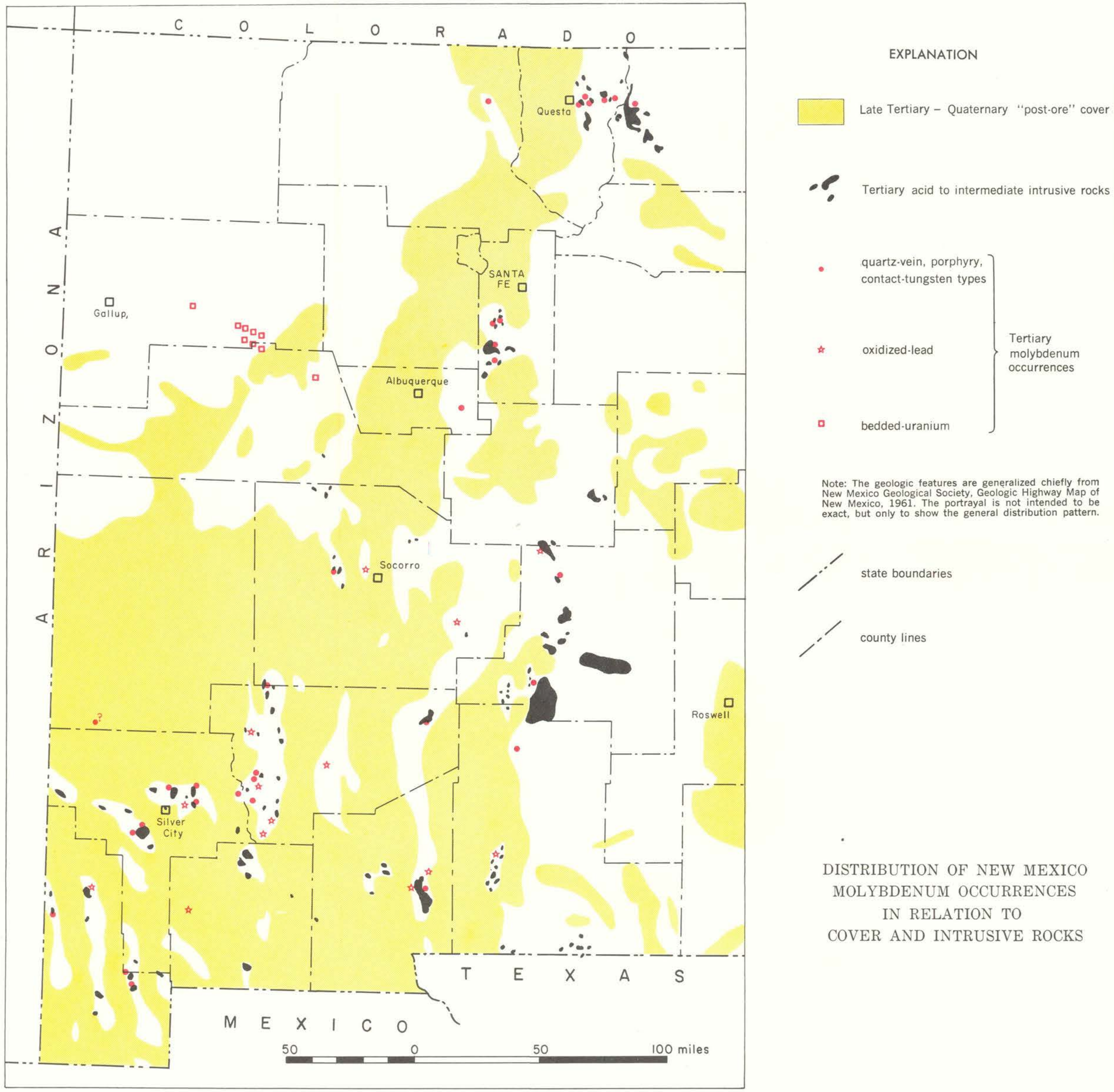
- mineral locality (wulfenite and/or molybdenite)
- deposit, no wulfenite production
- deposit, small wulfenite production

Bedded Uranium Deposits

- mineral locality (jordisite and/or ilsemannite)
- deposit, no molybdenum production

1 BROMIDE DISTRICT
2 KIAWA MOUNTAIN
3 POSO SPRING
4 RUSSIAN RANCH
5 NEAR EL RITO
6 LOG CABIN CANYON
BEAR CANYON PROSPECT
7 QUESTA PORPHYRY-COPPER DEPOSIT
BJB PROSPECTS
HERCULES PROSPECTS
8 QUESTA MINE VEIN DEPOSIT
BERNHARDT PROSPECT
9 COPPER KING MINE — Red River-Twinning
GRANITE PROSPECT
10 JACKS AND SIXES PROSPECT
11 BALDY TUNNEL
12 SMITH LAKE DISTRICT
13 HAYSTACK BUTTE
14 AMBROSIA LAKE TREND } GRANTS DISTRICT
15 POISON CANYON TREND
16 LAGUNA DISTRICT
17 HELLS CANYON SUBDISTRICT
18 SAN PEDRO MINE
19 CUMMINGTON HILL
20 CERRILLOS PORPHYRY-COPPER DEPOSIT
MINA DEL TIRO
21 SANTA FE DISTRICT
22 AZURE-RISING SUN MINE
23 ROMERO MINE, PORVENIR DISTRICT
24 OTHER LOCALITIES, PORVENIR DISTRICT
25 TECOLOTE DISTRICT
26 MAGDALENA DISTRICT
27 SOCORRO PEAK DISTRICT
28 HANSONBURG DISTRICT
29 GALLINAS MOUNTAINS DISTRICT
30 JICARILLA DISTRICT
31 RIALTO PROSPECT
32 ~~WATER DOG PROSPECT~~
33 SCHWARZ CABIN
34 ECCLES CANYON
35 PACEMAKER PROSPECT — Burros
36 BEAUMONT MINE
BOLTON & WILSON PROPERTY
37 TYRONE PORPHYRY-COPPER DEPOSIT
38 PORTLAND MINE — Piños Altos
39 BAYARD AREA
40 FIERRO IRON DEPOSITS
41 SANTA RITA PORPHYRY-COPPER MINE
42 GRANDVIEW MINE
43 IRON MOUNTAIN DISTRICT — ?
44 HERMOSA DISTRICT
45 HILLSBORO DISTRICT
46 SILVER TAIL PROSPECT — Tierra Blanca
47 LAKE VALLEY DISTRICT
48 MACHO DISTRICT
49 PALOMAS GAP DISTRICT
50 SALINAS PEAK DISTRICT
51 HILLTOP MINE
BAKER-STANDARD PROSPECT
SCHEELITE PROSPECT
52 LORDSBURG DISTRICT
53 SANTA MARIA TUNNEL
FARIA SHAFT
54 EAGLE POINT PROSPECT
CACTUS PROSPECT
55 IRISH ROSE MINE
56 STEVENSON-BENNETT MINE
57 TEXAS CANYON MINE
58 BEAR CANYON DISTRICT
59 OROGRANDE DISTRICT
60 TULAROSA DISTRICT

MOLYBDENUM OCCURRENCES IN NEW MEXICO



DISTRIBUTION OF NEW MEXICO MOLYBDENUM OCCURRENCES IN RELATION TO COVER AND INTRUSIVE ROCKS