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# Precambrian metallic mineralization in New Mexico

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"Geologists may write extravaganzas, But only God can make bonanzas." (J. E. Spurr, 1927).

The purposes of this report are to describe briefly the known metallic mineral deposits of probable Precambrian age in New Mexico, to suggest a genetic classification for these deposits, to place them in a regional lithologic framework, and to note the implications for mineral exploration. Because of the lack of detailed geologic maps and lithologic descriptions for much of the Precambrian terrane in New Mexico, along with the scarcity of reliable radiometric dates, this synthesis is somewhat speculative. However, in view of the current interest in mineral exploration in Precambrian rocks in New Mexico, this synthesis may provide new ideas for exploration.

Precise correlations of metasedimentary and metavolcanic units from one major Precambrian terrane to another in New Mexico are difficult because of discontinuity of outcrops and paucity of reliable radiometric dates. Accordingly, we have grouped the Precambrian outcrops into several major regions (fig. 1) having broad similarities. Numerous unresolved problems exist within each major region concerning stratigraphic relations because of lack of data on directions of younging and complications resulting from folding and faulting. Therefore, the generalized stratigraphic and lithologic sequences are subject to revision as more detailed work is done. Many of the mineral deposits are not precisely dated; although we interpret the mineralization to be Precambrian, some deposits could be younger. Mineral deposits described in the text are shown as numbered localities on fig. 1. An annotated bibliography and mapping index of the Precambrian of New Mexico is available as Bull. 103 of the New Mexico Bureau of Mines and Mineral Resources (Robertson, 1976).

### Lithologic framework

Precise correlations of Precambrian rocks throughout New Mexico have not been achieved; however, several major regions have distinct lithologic assemblages (fig. 1).

Region A (fig. 1) includes the Tusas–Brazos and Sangre de Cristo uplifts where a thick sequence of metasediments has been interpreted to be overlain by a dominantly metavolcanic sequence (Montgomery, 1953). All of these supracrustal rocks are intruded by granitic plutons. Barker (1958) described a stratigraphic sequence in the Tusas–Brazos uplift consisting of 14,000–20,000 ft of metaquartzite overlain by several thousand feet of mafic metavolcanic rocks (Moppin metavolcanic series) that are overlain in turn by quartzose metasediments with minor interbedded mafic metavolcanics. Metarhyolites are interbedded with both the metasediments and the mafic metavolcanics. Pegmatites and granitic rocks are intrusive into the metamorphic rocks. The metarhyolite has been radiometrically dated at 1,750–1,800 m.y.; the granodiorite intrusive into the mafic metavolcanics has an age of 1,700–1,750 m.y.; trondhjemite is dated at 1,724 ± 34 m.y. (Barker and Friedman, 1974). Gresens and Stensrud (1974) suggested that the stratigraphic sequence consists of metavolcanics overlain by metasediments, the inverse order of that described by Barker (1958). Grade of metamorphism is upper greenschist to middle amphibolite facies. Two episodes of isoclinal folding have been followed by open folding.

Condie (1979) suggested that a metasedimentary sequence in the Taos Range in the northern part of the Sangre de Cristo uplift consisting of locally graphitic gneiss and quartzite that totals at least 4,900 ft thick, is overlain by metavolcanic rocks at least 16,000 ft thick. Felsic metavolcanics are dominant, with interbedded minor mafic metavolcanics. Tonalite-trondhjemite and granite are intrusive into the metamorphic rocks and are interpreted by Condie (1979) to be mostly syntectonic. Pegmatites, quartz veins, and diabase dikes also are present. Metamorphism reached the amphibolite facies; two periods of folding are recognized.

Montgomery (1953) described a metasedimentary sequence (Ortega formation) in the Picuris Range, approximately 6,600 ft thick, that he thought was overlain by a partly metavolcanic sequence (Vadito Formation) that is approximately 4,500 ft thick and contains rhyolitic and basaltic protoliths. J. F. Callender (personal communication, 1980) interprets the stratigraphic succession to be reversed; that is, the metasediments are thought to overlie the metavolcanics. The metavolcanics and metasediments are intruded by the Embudo Granite that Long (1974) considered to be composed of several intrusions ranging in age from 1,700 to 1,400 m.y. Metamorphism reached the upper amphibolite facies. Two episodes of isoclinal folding were followed by two periods of open to tight folding.

In the area of Truchas Peak in the central part of the Sangre de Cristo uplift a thick sequence of metasediments, mostly pure metaquartzite and metapelitic rocks, is overlain by interbedded metavolcanic and metasedimentary rock (Grambling, 1979). The metavolcanics form a bimodal suite with amphibolites of basaltic parentage and felsic schists derived from rhyolitic tuffs. These metamorphic rocks in the Truchas area are correlated with the metamorphics in the Picuris Range, although the two terranes are separated by a major strike-slip fault (Miller and others, 1963). Grambling (1979) suggested that the rocks in the northern part of the Truchas area were deposited in a stable-shelf environment, but correlative rocks to the south were deposited in a deep-water basin. The grade of metamorphism reached the middle amphibolite facies. Oldest folds are tight to isoclinal, and later folds are open.

The deep basin proposed by Grambling (1979) appears to be the site of a thick sequence of subaqueous metamorphosed basalt and locally important felsic metavolcanics along with metasediments, including iron formation, that has been called the Pecos greenstone belt (Robertson and Moench, 1979). Metavolcanics are dominant in the southern and western parts of the belt, but interbedded metasediments increase in abundance to the northeast. The greenstone sequence is interpreted by Robertson and Moench (1979) to overlie an older quartzite sequence, but J. A. Grambling (personal communication, 1980) reports that in the Rio Mora area primary sedimentary structures indicate that the quartzite stratigraphically overlies the metavolcanics in an inverted section. Robertson and Moench (1979, p. 171) suggest that the felsic metavolcanics may be approximately 1,710–1,720 m.y. old based on model lead ages from associated ore deposits. Two suites of intrusive rocks are present: a coeval, subvolcanic complex of amphibolite, quartz ☞

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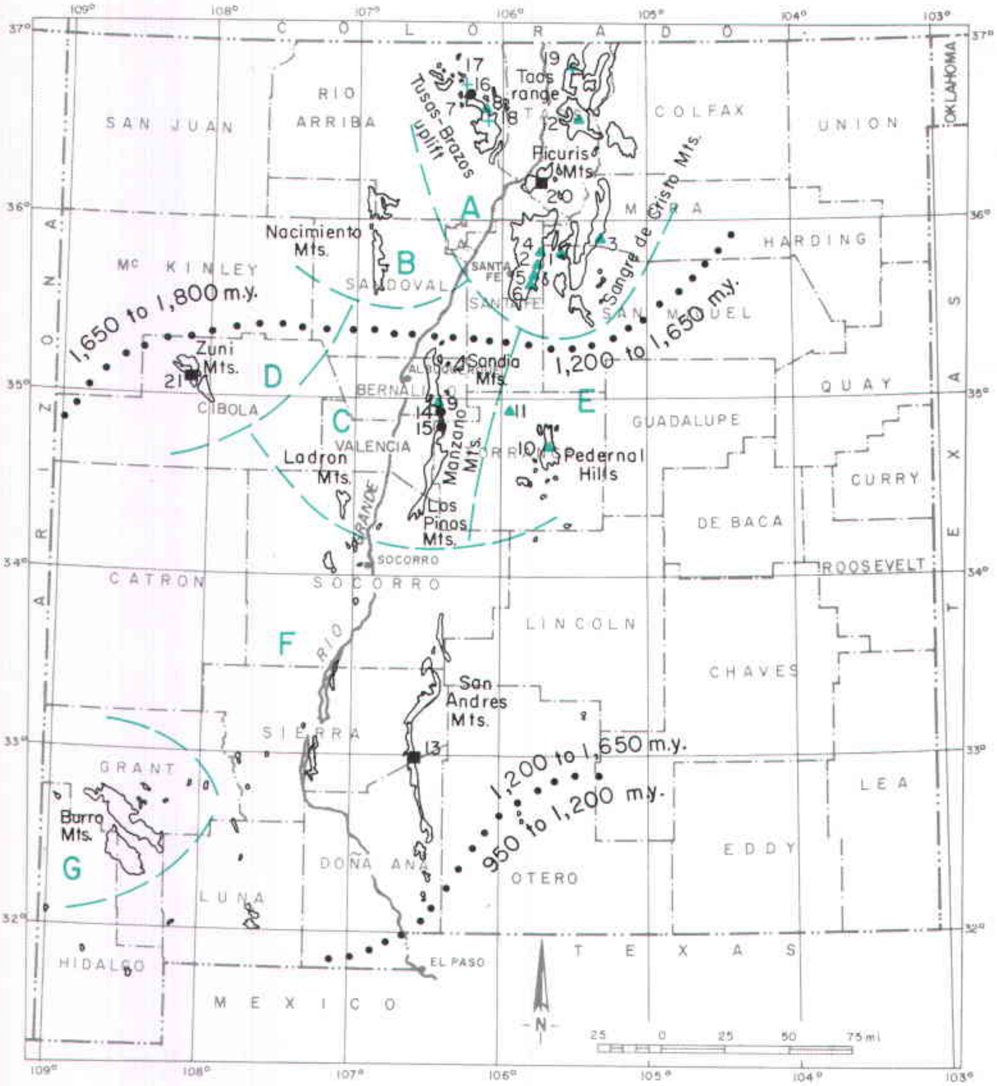


▲ Volcanogenic polymetallic sulfide deposits
● Greenstone exhalative-fumarolic gold-(copper) deposits
+ Iron-bearing chemical sedimentary deposits
■ Deposits of uncertain origin
— — — Boundary between lithologic-tectonic regions
• • • • • • Boundary between radiometric age provinces, with ages in millions of years (m.y.)

FIGURE 1—PRECAMBRIAN OUTCROPS AND RADIOMETRIC AGE PROVINCES IN NEW MEXICO. Numbered localities and lettered lithologic-tectonic regions are discussed in text.

diorite, trondhjemite, quartz porphyry, and minor metamorphosed ultramafics, and a younger plutonic complex of tonalite, granodiorite, and granite. Quartz diorite west of the Pecos greenstone has been dated at approximately 1,650 m.y. (Stacey and others, 1976). Metamorphism is of upper greenschist to upper amphibolite facies. At least one episode of isoclinal folding exists; younger folds are open.

Region B (fig. 1) consists of Precambrian outcrops in the Nacimiento uplift. Descriptions are mainly from the summaries by Woodward and others (1974, 1977). The oldest rocks are metasediments and metavolcanics that occur principally as inclusions or roof pendants in granitic intrusions. In the northern Nacimiento uplift, these rocks are intruded by variably foliated tonalite, quartz diorite, and granite plutons. Minor ultramafic, gabbroic, and dioritic bodies have been partially assimilated by the granitic rocks. Pegmatitic and mafic dikes cut the granitic bodies. In the southern part of the Nacimiento uplift, the plutonic rocks include foliated quartz diorite, quartz monzonite, and granodiorite that are cut by nonfoliated granite and quartz monzonite. Dikes of aplite, pegmatite, and granite cut the other rocks. Silicic metavolcanics in the northern part of the region have been radiometrically dated at 1,800 ± 50 m.y. (Brookins, 1974). A large quartz monzonite pluton, also in the northern part of the region, has an age of 1,720 ± 30 m.y. (L. T. Silver, personal communication, 1972). The grade of metamorphism in the Nacimiento area probably reached the upper greenschist facies.

Region C (fig. 1) includes the Sandia, Manzano, Los Piños, and Ladron Mountains. The most complete sequence of surface-accumulated rocks is found in the northern Manzano Mountains (Reiche, 1949; Woodward and others, 1979), where the basal unit consists of approximately 1,900 ft of metasediments, mostly phyllite with subordinate metaquartzite. These metasediments are overlain by approximately 4,500 ft of mafic metavolcanics (Tijeras–Hell Canyon greenstone) with minor cherty iron formation and silicic metavolcanics. Above the greenstone are more metasediments (maximum thickness of 9,500 ft) that are mostly phyllites and metaquartzites. Locally, a rhyodacite crystal-rich tuff 2,000 ft thick, containing abundant lithic fragments, unconformably overlies the greenstone. The uppermost unit is metarhyolite with subordinate metabasaltic sills with maximum thickness of about 5,000 ft in the Manzano Mountains (Stark, 1956). At least two episodes of folding occurred here. Grade of metamorphism reached the greenschist facies.

In the southern Manzano and Los Piños Mountains only the upper sequence of metasediments and the overlying metarhyolite are exposed. Metamorphism reached lower amphibolite facies and the rocks are isoclinally folded. Metasediments and overlying metavolcanics in the Ladron Mountains (Condie, 1976) may be broadly equivalent to those supracrustal units exposed in the southern Manzano Mountains. In the Ladron Mountains metamorphism was of greenschist to lower amphibolite facies.

Granitic rocks are intrusive into the metasediments and metavolcanics noted above. The Sandia Mountain Granite is reported to be approximately 1,500 m.y. old by Brookins (1974). The Ojito quartz monzonite and Priest Granite in the Manzano Mountains and the Los Piños pluton in that

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range intrude the supracrustal rocks. Condie (1976) reported that granite and quartz monzonite plutons occur in the Ladron Mountains.

Region D (fig. 1) consists of the Zuni Mountains where little detailed information is available. The most useful work is a map and report by Goddard (1966) that is the basis for the following interpretation. Pelitic metasediments and quartzite appear to be the oldest rocks. Plutonic igneous rocks ranging from quartz monzonite to granite were emplaced and are now strongly gneissic. Metavolcanic rocks, mostly rhyolitic, are next youngest and are slightly gneissic to well foliated. Biotite granite was emplaced next, followed by basaltic dikes that are now amphibolites. Monzonite and diorite dikes seem to be the youngest Precambrian rocks there. The oldest plutonic rocks (quartz monzonite and granite) have been radiometrically dated at 1,490 ± 90 m.y.; the silicic metavolcanics were dated at 1,380 ± 30 m.y. (Brookins and others, 1978). Metamorphism appears to have reached the upper greenschist or lower amphibolite facies. At least one episode of isoclinal folding probably took place.

Region E (fig. 1) consists of Precambrian rocks of the Pedernal Hills, divided by Gonzalez and Woodward (1972) into five major rock units: 1) metaquartzite; 2) a heterogeneous unit containing micaceous phyllite and schistose rocks along with subordinate augen gneiss, metaquartzite, epidiorite, greenstone, and amphibolite; 3) granitic gneiss; 4) intrusive granite; and 5) cataclastic rocks. Detailed stratigraphic relations between the metaquartzite, heterogeneous rocks, and granitic gneiss have not been determined. The metaquartzite contains quartz-specularite schist that may have been derived from chemically precipitated iron formation (iron-rich metachert). Although Gonzalez (1968) reported the heterogeneous unit to be mostly metasedimentary, unpublished mapping in 1979 by Fulp revealed a highly differentiated metavolcanic-metasedimentary terrane consisting of protoliths of mafic, intermediate, and felsic volcanics, epiclastic sediments, and intermediate conglomerates, agglomerates, and breccias. Metavolcanic rocks have been dated at 1,493 ± 30 m.y. and granite at 1,416 ± 100 m.y. by Rb-Sr whole-rock methods (D. G. Armstrong, personal communication, 1980). The grade of metamorphism reached the middle greenschist facies. Early isoclinal folding was followed by open folding.

Region F (fig. 1) consists mostly of Precambrian granite and granite gneiss in south-central New Mexico. Minor schist, quartzite, and phyllite are present in the San Andres Mountains and include a talc deposit (Fitzsimmons and Kelley, 1980). The granitic rocks range in age from 1,300 to 1,570 m.y. (Muehlberger and others, 1967). Metamorphism reached the lower amphibolite facies and isoclinal folds may be present.

Region G (fig. 1) in southwestern New Mexico is underlain mostly by the composite Burro Mountains batholith of Precambrian age that is intrusive into metasediments. According to Hewitt (1959), two metasedimentary sequences that consist of clastics and carbonate-rich clastics are found here. The older sequence, at least 2,300 ft thick, was intruded by leucogranite and regionally metamorphosed to quartz-feldspar gneiss and hornblende gneiss prior to deposition of the younger metasediments. The younger sequence, approximately 5,900 ft thick, was metamorphosed to serpentine-carbonate rocks, hornfels, quartzite, phyllite, and schist. Anorthosite and diabase were injected into the metamorphic rocks prior to emplacement of the batholith. K-Ar and Rb-Sr dating of granitic gneiss of the presumably older metasedimentary sequence gives ages of 1,550 and 1,270 m.y. (Hedlund, 1978a, b) that probably represent the time of metamorphism. Hedlund also reported a K-Ar date on a biotite granite from the Burro Mountains batholith that gives a model age of 950 m.y.

SUMMARY—Greenstone terranes characterized by subaqueous metavolcanics with intercalated, dominantly pelitic metasediments occur in the Tusas Range (Moppin metavolcanic series), Pecos area, Tijeras Canyon–Hell Canyon area, Pedernal Hills, Picuris Range (Vadito Formation), and the Taos Range. Also, a remnant of a greenstone sequence may occur in the northern Nacimiento Mountains where intrusive rocks have mostly engulfed the older metasediments and metavolcanics. In southern New Mexico, mainly in the Burro and San Andres Mountains, a thin sequence of shelf sediments including clastics, carbonate-rich clastics, and carbonates is present. Intrusive granitic rocks are present throughout the Precambrian of New Mexico, but are especially widespread in regions F and G. Radiometric dates indicate these rocks are increasingly younger toward the south (fig. 1).

## Mineralization

Metallic mineralization of probable Precambrian age is subdivided into four categories: 1) volcanogenic polymetallic sulfide deposits; 2) greenstone exhalative gold with or without copper deposits; 3) iron-bearing chemical deposits; and 4) deposits of uncertain genesis and minor occurrences of various origins. Each category is described with regard to geologic characteristics and followed by a compilation of known deposits and prospects.

### Volcanogenic polymetallic sulfide deposits

Volcanogenic zinc-lead-copper deposits that commonly contain economic values of precious metals are of great exploration interest in New Mexico. They occur within the greenstone terranes, and host rocks are generally felsic metavolcanics (proximal ores) or epiclastic metasediments (distal ores) with associated iron-bearing metacherts. Ore mineralogy is generally simple, consisting of pyrite and/or pyrrhotite, with subordinate but variable amounts of sphalerite, galena, chalcopyrite, and magnetite. Distinguishing characteristics of these deposits are their occurrence in highly differentiated, complex, metavolcanic-metasedimentary piles and their stratiform or stratabound configuration that reflects syngenetic, hydrothermal deposition (Sangster, 1972). Every recognized greenstone sequence in New Mexico contains prospects of this type, although only one such deposit has been productive.

The Pecos greenstone of the southern Sangre de Cristo Mountains is a recently recognized volcanogenic massive-sulfide province (Giles, 1974; Riesmeyer and Robertson, 1979). The Pecos mine (locality 1, fig. 1) near Terrero produced 2.3 million tons of ore, averaging 12.9 percent zinc, 4.0 percent lead, 0.78 percent copper, 3.4 oz/ton silver and 0.11 oz/ton gold during 1927–1939. Up to 1963 this remarkable orebody accounted for nearly 20 percent of the state's total zinc and lead production and 8 percent of its gold and silver (U.S. Geological Survey, 1965). At today's prices, the value would be at least $600 million. Riesmeyer (1978) interpreted the host rocks to be chloritized metarhyolite tuffs associated with a proximal breccia dome.

The Jones Hill deposit (locality 2, fig. 1) is a recent discovery by Conoco, Inc. in the Macho–Indian Creek area 4 mi southwest of the Pecos mine. Host rocks and mineralization appear to be time-stratigraphic equivalents of the Pecos deposit with both proximal and distal ore lenses; the deposit resembles the Flin Flon deposit of east-central Manitoba (P. J. Sterling, personal communication, 1980). Several other prospects are known in the region including the Rociada district (locality 3, fig. 1), where small copper-lead-zinc occurrences are found in amphibolites, felsic schists, and marble lenses; the Doctor Creek area (locality 4, fig. 1), where a differentiated, metamorphosed volcano-sedimentary sequence contains abundant cherty iron formation and minor copper; the Dalton Canyon area (locality 5, fig. 1), where intense, stratiform copper mineralization occurs in metagraywackes and metapelites, with indications of a buried zinc-lead deposit in metarhyolite and felsic metatuffs (Fulp, 1981); and Wild Horse Canyon (locality 6, fig. 1), where minor chalcopyrite-pyrite mineralization is noted in quartzites and metafelsites intercalated with metabasalt.

In addition to the aforementioned areas of obvious economic potential, other occurrences of base and precious metals include: Mikado prospects along the Santa Fe River, Penacho Peak southeast of Santa Fe, Aspen Mountain, Ruiz Canyon area in the Glorieta district, Gallinas–Hollinger Canyon area, Tecolote district, and the western slope of the Rincon Range (Harley, 1940; Anderson, 1957). Grambling (1979) reported zinc-bearing staurolite and gahnite in metasediments intercalated with metavolcanics in the Truchas Range. Anomalous tungsten and bismuth occur in stream sediments in the Pecos belt, and anomalous tin occurs in streams draining areas underlain by two-mica granite west of the Glorieta Baldy area (Moench and Erickson, 1980). The Barillas Ridge area has a small cobalt-nickel-chromium-copper prospect in an ultramafic xenolith in granite, and a substantial ultramafic terrane is present at Cow Creek (Wyman, 1980).

The Moppin greenstone terrane of the Tusas–Brazos Mountains of north-central New Mexico also hosts polymetallic sulfide deposits. The Hopewell district (locality 7, fig. 1) consists of numerous patented claims, mostly placer gold operations, worked sporadically from the late 1870's to the 1960's. Lode prospects include narrow stratabound copper-lead-zinc lenses and quartz-sulfide veins in sheared greenschist and metarhyolite. Mineralized lenses, consisting of concentrated sulfide cores decreasing outward to disseminated pyrite zones and then unmineralized country rock suggest a syngenetic origin. Prospects in the Bromide district (locality 8, fig. 1) resemble those of the Hopewell district to the north. Host rocks, mineralogy, and mode of occurrence are generally the same except for the presence of argentiferous tetrahedrite in the Bromide mines, molybdenite in the Tampa mine, and lower gold values. Mining activity commenced in the 1880's with 35 patented claims, but by 1910, activity had ceased. The Bromide mine reopened and operated during 1956–57 (Bingler, 1968), and renewed interest in both these districts occurred in the 1970's with much exploration and drilling but no announced discoveries.

The Tijeras–Hell Canyon greenstone complex of the Manzanita and northern Manzano Mountains contains one known volcanogenic, polymetallic sulfide deposit at the York mine (locality 9, fig. 1). The deposit is a small, stratiform copper-lead-zinc body occurring in a cherty-iron-marble lens. Host rocks are tuffaceous metasediments within a terrane dominated by greenstone and mafic metasediments. Numerous copper occurrences are reported in the greenstone between Tijeras Canyon and Hell Canyon (Reiche, 1949; Elston, 1967).

The Pedernal schist belt of east-central New Mexico (locality 10, fig. 1) also is a greenstone terrane. Although there are only sparse secondary copper occurrences in the complex, the lithologic sequence (including felsic pyroclastics) is indicative of an environment of deposition favorable for volcanogenic massive sulfides. A similar lithologic sequence occurs to the northwest in the Lobo Hill horst (locality 11, fig. 1). Although outcrops of Precambrian rock are rare, rocks similar to the Pedernal terrane including metagraywacke, felsic gneiss, chlorite schist, and meta-agglomerate are exposed in several prospect pits with minor chalcopyrite and malachite. A large quartzite body (metachert?) crops out southeast of the sequence described above.

The Twining (Rio Hondo) district (locality 12, fig. 1) of the Taos Range includes a 200-ft-wide shear zone that can be traced for at least 2.5 mi in a northeasterly direction and is conformable with the metamorphic foliation. Several mines and prospects have been developed along the shear zone including the Frazer, Bull-of-the-Woods (Highline), and Comstock. The country rock is amphibolite, but talc, sericite, and chlorite schists are present in the shear zone. Mineralization consists of pyrite, copper sulfides, secondary copper minerals, and gangue along fractures and as disseminations in the sheared schist. Precious-metal values have been reported. To the north several prospects are found in other parallel shears including the Silver Star lead-zinc, the Iron Dyke specularite schist, and the Commodore copper occurrences. The mineralization is interesting because it is associated with amphibolite, chlorite-talc-sericite-quartz schist (sheared and altered metarhyolite?), and specularite schist (sheared iron formation?) that may be a differentiated metavolcanic sequence. Restrepo (1972), in a detailed study of the area, favored a volcanogenic massive sulfide origin for the deposits with remobilization and redistribution during subsequent events.

### Greenstone exhalative gold with or without copper deposits

Also of major exploration interest in the greenstone terranes are the exhalative gold with or without copper deposits. These orebodies are generally found in metamorphosed mafic volcanic sequences with interlayered cherty-iron or iron-carbonate-facies chemical precipitates. The orebodies are believed to be syngenetic, hot-spring deposits in submarine environments, with the metals leached from underlying flows and pyroclastics and redeposited by late-stage hydrothermal activity. Remobilization by later metamorphic processes may concentrate and redistribute the ore, and the deposits thus may occur in concordant stratabound horizons, in vein systems, in shear zones, or in saddle reefs. The most common assemblage includes gold-quartz-pyrrhotite-arsenopyrite and may include ankerite, siderite, pyrite, chalcopyrite, graphite, and scheelite. Cummingtonite schist is commonly the host rock in medium-grade metamorphic rocks. Alteration of host rocks to talc and chlorite schist or serpentine is common (Sawkins and Rye, 1974; D. L. Giles, personal communication, 1979).

Three deposits of this type are known in New Mexico. In Tijeras Canyon, the Great Combination and Mary M mines (locality 14, fig. 1) consist of a few small pits and adits in sheared greenstone with abundant quartz veinlets. Mineralization consists of malachite, chalcopyrite, pyrite, magnetite, and gold; small shipments of ore have been reported (Kelley and Northrop, 1975). In the Hell Canyon area to the south, the Milagros mine and adjacent Star shaft (locality 15, fig. 1) are deposits that occur in sintery quartz veins and metachert in sheared greenstone and metasediments. The deposits are within the zone of oxidation and consist of copper carbonates, iron oxides, minor native copper, gold, and silver. The mines produced gold and copper in the 1880's and early 1900's; in 1975–76 the Milagros mine was operated as an open pit and produced over $300,000 of gold and silver (Woodward and others, 1978). The Moppin greenstone of the Hopewell district (locality 16, fig. 1) hosts numerous quartz-siderite-pyrite-gold veins in greenschist. The presence of abundant siderite and pyrite in the remobilized veins suggests a precursor of cherty-iron exhalite. They are the probable source of the placer gold found in the area (Bingler, 1968). A small amount of gold is reported to occur in an iron formation at Iron Mountain (locality 17, fig. 1) (Lindgren and others, 1910).

### Iron-bearing chemical deposits

There are two principal types of banded iron formations: the Lake Superior type, which is strictly sedimentary and forms by chemical precipitation in tectonically stable basins with restricted circulation; and the Algoma type, which is volcanogenic and forms by exhalative processes during quiescent periods in volcanic cycles (Sims, 1976). The vast majority of the world's iron-ore reserves are of the Lake Superior type. However, the Algoma-type deposits may contain gold that may be concentrated by silica leaching, metamorphic differentiation, and structural deformation.

Two small Algoma-type deposits occur in the Moppin greenstone complex. The Iron Mountain area (locality 17, fig. 1) north of Hopewell Lake consists of two layers of magnetite-quartz-chlorite schist averaging 40 percent iron. The deposits are 10–20 ft thick with a strike length of several hundred feet (Bingler, 1974). In the Cleveland Gulch area (locality 18, fig. 1) of the Bromide district a similar body occurs and is traceable by magnetometer for 3,000 ft along strike. Two iron-rich samples ran 29.7 and 37.7 percent iron (Harrer and Kelly, 1963). In the Cabresto Creek area (locality 19, fig. 1) of the Taos Range, magnetite-hematite-ilmenite-rich bands of uncertain origin are common in quartzite, gneiss, and schist. Richer concentrations range up to 25 percent iron and are up to 50 ft thick (Schilling, 1960). In addition, numerous small lenses and bodies of metamorphosed cherty iron formation occur throughout the greenstone terranes of New Mexico. They are of economic interest, however, because of their common association with volcanogenic mineralization.

### Deposits of uncertain genesis and minor occurrences of various origins

In the Copper Hill–Copper Mountain district (locality 20, fig. 1) in the Picuris Range, mineralization consists of secondary copper carbonates, silicates, and oxides and minor secondary uranium minerals along fracture planes in massive Ortega Quartzite and sheared schists. Gold and silver values are also reported (Lindgren and others, 1910). The deposits were developed in the early 1900's and extensively drilled in the late 1960's and early 1970's. A medium-size, low-grade copper deposit is present at Copper Hill but is subeconomic. The secondary, remobilized copper minerals are of interest because of proximity to the Vadito Formation, thought to be correlative with the Pecos greenstone which hosts massive sulfide deposits.

In the Copperton, Diener Canyon, and Montezuma areas of the Zuni Mountains (locality 21, fig. 1), copper sulfides, pyrite, secondary copper minerals, gold, and silver occur in shear zones and as disseminations in metarhyolites and hypabyssal granitic rocks. Some of these prospects occur with potassic

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and phyllic alteration and may represent Precambrian porphyry-type copper deposits (M. Seay, personal communication, 1980). In the Hagen Creek–Glorieta Canyon area of the southern Santa Fe Range, chalcopyrite-pyrite disseminations occur in Precambrian granite (D. G. Armstrong, personal communication, 1980).

In the central San Andres Mountains (locality 13, fig. 1) two small prospects have been described that may be of syngenetic origin. In Sulphur Canyon, high-grade copper-iron ore consisting of chrysocolla, malachite, and specularite is associated with a massive chlorite lens that shows a very sharp contact with enclosing sericite schist. To the south in Grandview Canyon, sheared greenstone, altered to chlorite and calcite but showing original igneous texture, contains pods and veinlets of chalcopyrite, malachite, and calcite near a contact with quartzite (Lasky, 1932). Condie and Budding (1979) included the sheared rock in a schist and phyllite unit with thick, conformable metadiabase sills.

Base and/or precious metal prospects in Precambrian host rocks are reported from nearly every county with Precambrian rock exposures and are listed below:

- Bernalillo County—Tijeras Canyon, gold-quartz veins (Elston, 1967);
- Colfax County—Hematite Creek and West Moreno areas in the Elizabethtown-Baldy district, gold-quartz veins (Clark and Read, 1972);
- Doña Ana County—Gold Camp (gold-copper-quartz veins) and Mineral Hill (gold-quartz veins) in the Organ Mountains (Dunham, 1935);
- Grant County—Gold Hill district in the Burro Mountains, gold-silver-lead-zinc-quartz veins (Lindgren and others, 1910; Gillerman, 1964);
- Hidalgo County—Little Hatchet Mountains, copper (Zeller, 1970);
- Luna County—Stenson mine in the Florida Mountains, copper-quartz veins and disseminated copper (Griswold, 1961);
- Mora County—Rio de la Casa, Lujan Creek prospects, gold-quartz veins (Harley, 1940);
- Sandoval County—Nacimiento district prospects, disseminated copper in schist, diabase dikes with gold, base and precious metals in shear zone (Lindgren and others, 1910; Woodward and others, 1972);
- Sierra County—Shandon (Pittsburg) district, gold-quartz veins (Harley, 1934);
- Socorro County—Ladron Mountains, copper-quartz veins (Condie, 1976); Corkscrew Canyon prospect, zinc-copper in shear zone (Lasky, 1932); and
- Taos County—Cabresto Creek (base metals), Columbine Creek (lead-zinc-copper disseminations), San Cristobal Creek (copper in shear zone), Enderman prospect (gold in shear zone), Golden Goose prospect (gold-quartz in shear zone) in the Questa–Red River areas (Schilling, 1960; Clark and Read, 1972); Picuris Range, copper-quartz in veins and shears (Montgomery, 1953).

Several molybdenum- or tin-bearing pegmatites of minor importance are known from the northern part of the state (U.S. Geological Survey, 1965). Minor tungsten with or without bismuth prospects occur in several scattered localities. Most of these prospects are pegmatite or quartz vein occurrences containing scheelite and minor wolframite. Some appear to be skarnlike deposits of scheelite-quartz-hornblende-epidote assemblages in schist and amphibolite that are probably derived from marly sediments. Tungsten prospects (Dale and McKinney, 1959) include:

- Grant County—Bullard Peak, Gold Hill, Rice–Graves area in the Burro Mountains;
- San Miguel County—El Porvenir district in the Las Vegas Range;
- Sierra County—Grandview prospect in the San Andres Mountains; and
- Taos County—Tungsten (Wichita) mine in the Picuris Range.

Moench and Erickson (1980) proposed a stratabound volcanogenic origin for scheelite in the Pecos greenstone terrane although the scheelite-quartz-hornblende-epidote association with amphibolites is analogous to skarn prospects described by Hewitt (1959) in the Burro Mountains.

## Implications for exploration

Greenstone basins are volcano-sedimentary terranes characterized by subaqueous differentiated metavolcanics with intercalated, predominantly pelitic metasediments. The association of polymetallic massive sulfides and exhalative gold with or without copper deposits with greenstone terranes makes the following areas prime targets for mineral exploration: Pecos greenstone, Moppin metavolcanics, Tijeras–Hell Canyon greenstone, and the Pedernal schist belt. Of lesser importance are the Vadito Formation of the Picuris area and the relatively unknown Taos Range metamorphics.

Because of the tendency for massive sulfide deposits to occur in clusters and the fact that the Pecos area contains two discovered deposits, additional occurrences are likely. Of particular interest are the central and southwest parts of the belt where there are major felsic metavolcanic centers, including Willow Creek, Macho Canyon–Jones Hill, Doctor Creek, and Dalton Canyon and surrounding areas.

The other greenstone terranes contain stratiform base-metal prospects, but none has produced significant tonnages. However, the most important criteria in massive sulfide evaluation are the lithologic associations and environments of deposition, not the grade or tonnage of outcropping prospects. Because outcropping major ore deposits will probably not be found, exploration must focus on minor prospects and buried, even blind, targets. The most effective prospecting method is reconnaissance mapping followed by an airborne electromagnetic and magnetometer survey. Panned heavy minerals and bulk sediment stream sampling are often employed with good success. After broad targets are delineated, the successful exploration program will employ thorough geologic mapping, coupled with ground geophysics and geochemical prospecting.

The potential for economic exhalative gold with or without copper deposits is also deemed very high in New Mexico. Because of their known gold occurrences, the Tijeras–Hell Canyon and Moppin terranes are assigned the greatest potential. The exploration program should involve recognition of suitable rock types (iron-bearing metachert within metavolcanic sequences) coupled with geophysical surveys and extensive geochemical sampling using pathfinder elements such as arsenic, mercury, and tungsten. Recognition of fold styles and geometry is important as these ore bodies tend to be concentrated in dilatant zones and noses of folds.

Iron formations in New Mexico probably will not be of economic interest in the near future for their iron content because of low reserves and/or grade combined with distance from a market. The Algoma-type iron formations, however, can be useful in prospecting for gold deposits as they are in some cases related to exhalative deposits containing gold. Magnetic geophysical methods and geochemical investigation for pathfinder elements in the iron formations could lead to definition of targets.

Of undetermined economic importance are the numerous minor prospects scattered throughout the Precambrian rocks of New Mexico. Most are small and low grade; however, any of the gold-bearing veins and shears could have potential for a large disseminated deposit. Metamorphic and structural processes and geologic history are important in that differentiation, remobilization, and concentration of slightly anomalous or even background values of gold in country rocks could produce an orebody in suitable host rocks.

The occurrence of Precambrian porphyry-type copper prospects merits further exploration in the granitic stocks and plutons throughout the state. Also, some potential must be assigned to the tin and tungsten anomalies reported in the southern Santa Fe Range, primarily because their existence has been reported only recently and they have not been evaluated. More investigation of the two-mica granites in that area is warranted, as these kinds of rocks are hosts for most of the world's tin. The possibility of volcanogenic or skarn-type scheelite bodies in metabasalts also deserves further investigation.

Considerable economic mineral potential exists in the Precambrian rocks of New Mexico. Discovery of major deposits, however, will require long-range exploration programs with field geologists experienced in structurally complex metamorphic terranes, sophisticated geophysical and geochemical techniques, and a persevering and dedicated management.

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## Mine Health, Safety, and Training Institute scheduled

The Seventh Institute of Mine Health, Safety, and Training will be held at the Colorado School of Mines in Golden, CO, on November 4–6, 1981. The institute, established to provide a forum for the mining community to focus upon mine health and safety concerns, is sponsored by the Colorado School of Mines, Mine Safety and Health Administration, U.S. Bureau of Mines, Colorado Mining Association, and Colorado Safety Association. For information on registration and fees, contact Robert T. Reeder, Program Institute Chairman, Associate Professor, Mining Engineering Department, Colorado School of Mines, Golden, CO 80401.