Circular 158 1978

Geology of central Peloncillo Mountains, Hidalgo County, New Mexico

by A. K. Armstrong, M. L. Silberman,
V. R. Todd, W. C. Hoggatt, and R. **B. Carten**

New Mexico **Bureau of Mines & Mineral Resources**

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Prepared in cooperation with the Geological Survey
United States Department of the Interior

SOCORRO 1978

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First printing, 1978

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63-1-
Pinted by University of New Mexico Printing Plant, June, 1978

Available from New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801 Price $5.00

Preface

Numerous reports on the geology of the central Peloncillo Mountains—including studies of the sedimentary and igneous rocks, structure, and mineral resources—have been published over the last 120 years (Antisell, 1856; Gilbert, 1875; Lindgren and others, 1910; Jones, 1904; Darton, 1928). Gillerman (1958) published a geologic map and detailed descriptions of the igneous and sedimentary rocks, metamorphism, and mineral deposits. His discussion of the various mines and prospects in the area is excellent and represents the most complete work on the area to date.

Our objectives were to provide a more detailed geologic map of the central Peloncillo Mountains than was previously available, to determine the age of the igneous rocks, to study the geochemistry of the igneous rocks and ore deposits, and to attempt to assess the future mineral potential of the region. Included are a geologic map (in pocket) and detailed descriptions of the petrography of the igneous and sedimentary rocks. We summarize the major-element chemistry of the igneous rocks and their K-Ar ages as well as the history of the region. Detailed geochemical anomaly maps and assessment of mineral potential by Silberman and others (1974) and Carten and others (1974) are summarized within. Todd and others (1975) summarized parts of the minor-element geochemistry of the igneous rocks. Rb-Sr results and detailed discussions of the geochemistry of the igneous rocks will be presented subsequently.

ACKNOWLEDGMENTS—This work was done in cooperation with the New Mexico Bureau of Mines and Mineral Resources; we appreciate the support and encouragement received. R. K. Hose and F. E. Kottlowski read earlier versions of this manuscript; their comments and suggestions were valuable. Discussions in the field with Wolfgang Elston of the University of New Mexico were helpful. We thank the Southwestern Research Station of the American Museum of Natural History, Portal, Arizona, and particularly Vincent Roth, the Director, for providing laboratory and other facilities during field work.

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Menlo Park
January 24, 1978

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(in pocket)

Abstract

The central Peloncillo Mountains consist of a broken, faulted arch of Precambrian to middle Tertiary extrusive and intrusive igneous rocks and sedimentary rocks overlain to the north and south by middle Tertiary and younger extrusive volcanic rocks. Paleozoic carbonate rocks and Mesozoic clastic rocks with a large proportion of carbonates underlie most of the mountains. The Paleozoic and Mesozoic sedimentary rocks and the Precambrian granite are intruded and metamorphosed by four groups of igneous rocks: 1) an 8- sq-km outcrop at Granite Gap, yielding 30-33-m.y.-old K-Ar ages; 2) granite porphyry dikes and sills, which give 31-32 m.y. old K-Ar ages; 3) fine-grained porphyritic to felsitic rhyolite dikes, probably related to the granite porphyry; and 4) quartz-latite porphyry dikes and sills, which give 26-28-m.y.-old K-Ar ages and intrude all of the other igneous and sedimentary rocks. In the northern part of the area studied, a thick sequence of altered, dominantly andesitic volcanic rocks overlies the Paleozoic sedimentary rocks and most of the Mesozoic sedimentary rocks as well. Sills and irregular dikes of andesite, probably related to the extrusive pile, cut the layered sedimentary rocks. The andesite extrusives are cut by the granite porphyry and quartz-lathe porphyry dikes and sills. Thrust faulting and folding have deformed the sedimentary strata. The present structure reflects dominance of high-angle normal faulting. Steep northeast- and northwest-trending faults controlled the emplacement of many of the granite porphyry, rhyolite, and quartz-latite porphyry dikes and sills. Contact metamorphic aureoles in the sedimentary rocks surround these dikes and sills and exhibit anomalous concentrations of the trace metals, copper, lead, zinc, silver, molybdenum, bismuth, and tungsten.

Description of rocks

Precambrian metamorphic rocks

Precambrian amphibolite is exposed in the lower plate of a thrust at Granite Gap. Another outcrop, too small to indicate on the geologic map (in pocket), is located in the east-central part of sec. 25, T. 25 S., R. 21 W., south of US-80, 1,950 m (6,400 ft) in a direction 97.5 ° from the top of Preacher Mountain at an elevation of 1,397 m (4,420 ft). At this site Tenneco Oil Company drilled a test hole. The amphibolite at Granite Gap is medium grained, containing green amphibole, feldspar (albite?) now largely sericitized, quartz, minor chert and iron oxides, and thin (less than 1 mm) stringers of calcite and K-feldspar. The smaller outcrop is very fine grained amphibolite, consisting of green amphibole, feldspar, quartz pyroxene, and disseminated sulfides. Precambrian granite porphyry intrudes the metamorphic rocks in both localities.

Sedimentary rocks

The sedimentary rocks within the mapped area were first described in detail by Gillerman (1958). The following descriptions are based in part on Gillerman's work, modified by results of our study.

The Silurian is the only system of the Paleozoic not represented by marine sedimentary rocks.

CAMBRIAN—The unconformable contact between the Precambrian granite porphyry and the Cambrian Bliss Sandstone can be seen in the N1/2 sec. 22 and SW'/ sec. 23 and is well exposed in the NW 1/4 sec. 8, SW'/ sec. 9, and NW'/ sec. 16, T. 25 S., R. 21 W. The granite porphyry is deeply weathered for 2-3 m below the contact. The base of the Bliss Sandstone consists of reworked Precambrian regolith in the form of rounded cobbles and pebbles of granite porphyry, feldspar, and quartz. The overlying part of the Bliss is arkosic and orthoquartzitic sandstone 18-20 m thick. No fossils were found. Sabins (1957a) reported Late Cambrian trilobites in the temporally correlative Bolsa Quartzite 22 km to the west at Blue Mountain in the Chiricahua Mountains of Arizona.

ORDOVICIAN—The Ordovician section was measured in the SW 1/4 sec. 23, T. 25 S., R. 21 W. and is represented by the Lower Ordovician El Paso Limestone, which is 180 m thick. It consists of a lower 44 m of arenaceous, argillaceous dolomite, with some nodular chert, overlain by 51 m of fossiliferous wackestone and packstone with echinoderm, brachiopod, algae, trilobite, and gastropod fragments. The final 85 m consists of crystalline, gray dolomite with molds of brachiopods and echinoderm fragments.

Gillerman (1958, p. 24) reported (with some doubt) the Montoya Dolomite in secs. 22 and 24, T. 25 S., R. 21 W.; however, we did not find the Montoya in any of the outcrops. Hayes (1975) reported only the El Paso Limestone from the Peloncillo Mountains. Sabins (1957a, p. 473) reported 218 m of El Paso Limestone beneath the Devonian rocks at Portal, Arizona, in the Chiricahua Mountains, about 20 km southwest of the Peloncillo Mountain outcrops. Zeller (1965) described the El Paso Limestone in the Big Hatchet Mountains, about 55 km to the southeast, as being over 300 m thick beneath the Cable Canyon Sandstone Member of the Montoya Dolomite. The Ordovician section in the Peloncillo Mountains is relatively thin compared to adjacent outcrops, suggesting that it was eroded before the Devonian rocks were deposited.

DEVONIAN—The Percha Shale (Late Devonian) is about 70 m thick and consists of the Ready Pay Member, of black fissile shale, overlain by fossiliferous, interbedded nodular limestone and calcareous shale of the Box Member. In many areas the Percha Shale is metamorphosed to light-gray to brown hornfels in the vicinity of granite porphyry, rhyolite, and quartz-latite porphyry dikes.

MISSISSIPPIAN—The Mississippian System is represented by the Escabrosa Group and the Paradise Formation. The Escabrosa Group is divided into two formations. The Keating Formation (Early Mississippian) is 111 m thick and disconformably overlies the Percha Shale. Its lowest beds are about 24 m of oolitic packstone overlain by 15 m of dolomite and 16 m of coralliferous wackestone; the upper 56 m of the formation is cherty, gray, peloid-crinoid wackestone. The Hachita Formation (Early and Late Mississippian) is a 44-m-thick, massive, gray to light-gray unit composed of crinoid-bryozoan-wackestone-packstone. The Paradise Formation (Late Mississippian) is 13-37 m thick, composed of alternating beds of light-gray to light-olive-gray, oolitic-arenaceous-micritic wackestone to grainstone with interbedded shale, siltstone, and sandstone.

PENNSYLVANIAN—The Pennsylvanian System is represented by the Horquilla Limestone, of Early, Middle, and Late Pennsylvanian age, the lowest formation in the Naco Group. Accurate measured sections of the Horquilla at Blue Mountain in secs. 3, 10, 11, and 14, T. 25 S., R. 21 W. are difficult to obtain because of extensive faulting. Bedding-plane faults and quartz-latite porphyry cut the Horquilla at all outcrops. A minimum of 450 m of Lower, Middle, and Upper Pennsylvanian carbonate rocks is present. The Horquilla Limestone unconformably overlies the Paradise Formation. The lower 75 m of the Horquilla Limestone is composed of peloid-echinoderm-brachiopod-foraminiferal wackestone to packstone. A persistent zone of *Chaetetes* sp. and rugose corals occurs 30-50 m above the base. The remainder of the Horquilla Limestone is medium- to thick-bedded, cherty, foraminiferal-echinoderm brachiopod wackestone with smaller amounts of packstone.

PERMIAN—The Permian System is represented by the Earp Formation, the Colina Limestone, the Scherrer Formation, and the Concha Limestone, all within the Naco Group. The Earp Formation (Early Permian Wolfcampian) has a gradational contact with the underlying Horquilla Limestone. The contact between the two formations is difficult to pick and is based upon the greater abundance of terrigenous clastic material in the Earp Formation. The Earp consists of alternating beds of foraminiferal-peloid-echinoderm packstone-wackestone with brownish-red calcareous siltstone and quartz sandstone grains 50-200 µm in size. All outcrops of Earp are in structurally complex terrane or thermally metamorphosed areas, and accurate measures are difficult. The Earp Formation is probably more than 600 m thick.

The Colina Limestone conformably overlies the Earp Formation and consists of dark-olive-gray to dark-gray micritic limestone and dolomite, with minor thin sandstone beds. The dolomite is composed of dolomite rhombs 10-25 µm in size. Algal mats, gypsum pseudomorphs, mud cracks, and bird's-eye structures are common; in the middle of the unit are beds with pelecypods. Within the area of outcrop in the Peloncillo Mountains, the Colina Limestone was deposited in a subtidal to supratidal environment.

The Scherrer Formation is 30-35 m of thin-bedded pale-reddish-brown siltstone, argillaceous sandstone, thick interbeds of olive-gray sandstone, and a few interbeds of 0.3-0.5-m-thick dolomite composed of 5-gm rhombs of dolomite.

The Concha Limestone, at least 76 m thick, is massive light-gray marine crinoid-bryozoan-brachiopod wackestone and packstone with gray-red chert nodules. In areas of outcrop adjacent to the granite of Granite Gap, the Concha is a coarse-grained white marble containing wollastonite. According to Sabins (1975a) and Sabins and Ross (1963), the Concha Limestone is of Early Permian age.

CRETACEOUS—The Cretaceous System is represented by the Bisbee Group (Early Cretaceous). The basal unit, McGhee Peak Formation, named by Gillerman (1958, p. 45-47), rests with marked unconformity on an irregular Paleozoic surface. At McGhee Peak, here designated its type locality, the McGhee Peak Formation rests on the lower half of the Permian Earp Formation; and 3-4 km to the southwest it rests on the intervening Concha Limestone. The McGhee Peak Formation is 150-225 m thick and is composed of limestone, chert, quartz pebbles and cobbles, and alternating beds of shale, sandstone, and argillaceous limestone. The 75-100-m-thick Carbonate Hill Limestone, named by Gillerman (1958, p. 47-50), is composed of argillaceous, arenaceous packstone and wackestone with abundant molluscan remains alternating with thin silty gray shale. The overlying sandstone, shale, and siltstone of Gillerman (1958, p. 50-53), the Still Ridge Formation, and the Johnny Bull Sandstone are 250-350m-thick, tan to brown well-cemented subgraywacke. Gillerman (1958) reported a large Early Cretaceous megafossil fauna from the Carbonate Hill Limestone.

Igneous rocks

The igneous rocks of the central Peloncillo Mountains range in age from Precambrian to middle Tertiary and in composition from intermediate to felsic. Both extrusive and intrusive igneous rocks are present. Coarse-to medium-grained, largely porphyritic granites and quartz latites occur as plutonic masses, and dikes and sills are present throughout the range.

A thick sequence of extrusive andesitic volcanic rocks crops out in the northern part of the map area. Rhyolite to quartz-latite ash flows and other volcanic rocks crop out from about 2 km south of Granite Gap to the southern limit of the map area.

Extrusives

ANDESITE—Andesite and associated dacite are present largely in the northern part of the map area as a thick sequence, exceeding 1,100 m, of extrusive flows, breccias, and tuffs (Gillerman, 1958). The dominant lithology is pyroxene andesite. Pervasive propylitic alteration, with dominant replacement of pyroxenes, plagioclase, and groundmass by epidote, has affected the andesitic volcanic rocks. Chlorite, sericite, and kaolinite are also present, and disseminated pyrite is common in many areas. Minor irregular andesitic intrusive rocks, petrographically similar to the extrusive andesite, cut the older sedimentary sequence in isolated places, notably in the low hills northwest of Wood Canyon. Gillerman (1958) described the andesite sequence in considerable detail, and we do not discuss it further here. Most of the area between the northern limit of the map area and US-80, 6 km to the north, is underlain by andesite. Alteration was too pervasive to allow an isotopic age to be determined on the andesite.

Gillerman (1958) assigned a Late Cretaceous or Tertiary age to these rocks because they seem to be at least partly interbedded with a conglomerate unit, the Bobcat Hill Conglomerate of that age (Gillerman, 1958) to the north of the map area. Granite porphyry dikes and sills and quartz-latite porphyry dikes intrude the andesite, indicating a minimum pre-Middle Tertiary age.

VOLCANIC ROCKS, UNDIFFERENTIATED—Other volcanic rocks crop out approximately 2 km south of Granite Gap and thicken to the south. These include rhyolite tuffs, minor andesite intrusive rocks, and tuffs and ignimbrites of Gillerman's (1958) Weatherby Canyon Ignimbrite—the most voluminous volcanic unit in the southern part of the map area. Gillerman (1958) described this unit in detail. W. E. Elston (written communication, 1974) determined a K-Ar age of 25 m.y. on the Weatherby Canyon Ignimbrite. The volcanic rocks south of Granite Gap are being studied by W. E. Elston and associates of the University of New Mexico and are not discussed here.

Intrusives

PRECAMBRIAN GRANITE PORPHYRY—An elongate, faulted mass of Precambrian granite porphyry, unconformably overlain by sedimentary rocks ranging in age from Cambrian through Early Cretaceous, is exposed in the northern part of the area, largely southwest of the northwest-trending Wood Canyon fault. Several smaller outcrops are scattered south of the prominent east-west-striking Preacher Mountain fault. The rock is typically dark green or gray with irregular, oblong, pink K-feldspar phenocrysts. It is slightly foliated owing to subparallel alignment of lenticular quartz and K-feldspar grains. The large (3-5 cm) K-feldspar and quartz phenocrysts occur in a holocrystalline, fine-grained groundmass of smaller, highly sericitized plagioclase phenocrysts (3-4 mm) and irregular aggregates of secondary chlorite, epidote, quartz, sphene, and calcite. Biotite generally is replaced by muscovite, in thin-bladed radiating masses, and opaque iron oxide. Quartz lenticles and feldspar grains show evidence of minor crushing (pervasive fractures, undulose extinction, and deformation twins), and secondary epidote and chlorite are localized along these fractures. Graphic granite relicts and dark-brown, fine- to medium-grained, equigranular rock occur in the granite porphyry and are identical to it in mineralogy and advanced alteration of plagioclase and biotite.

BASALT—Small irregular dikes of basalt intrude the Precambrian granite porphyry in several areas north of the Preacher Mountain fault. Most outcrops are small, only a few meters across or less, and are not shown on the geologic map. An exception is the irregular dike of altered basalt in Wood Canyon in the northwest part of sec. 22, T. 25 S., R. 21 W. These grayish-green rocks range in texture from very fine grained porphyritic to medium grained and granulitic. Alteration of these rocks is pervasive but varies in intensity. Most of the localities have been affected by propylitization. Olivine, which was common in the basalts, is replaced by iron oxides; chlorite commonly replaces the matrix and occurs with epidote and sericite after feldspar. Amphibole commonly replaces the matrix or pyroxene(?) and is itself partially replaced by chlorite. Disseminate pyrite and iron oxides are common.

Despite the variety of textures and degrees of alteration, all of these dike rocks are assigned a Precambrian age because they are only found cutting the Precambrian granite porphyry and are not known to intrude any of the younger sedimentary or igneous rocks. The only other basic rock that occurs in the vicinity of the map area is a Quaternary(?) basalt flow just off the southeast edge of the geologic map area in Animas Valley (Gillerman, 1958). The basalt dikes are very minor in extent and were not studied in detail.

GRANITE OF GRANITE GAP—A pluton of granite approximately 8 sq km in outcrop area intrudes and thermally metamorphoses Paleozoic and Mesozoic sedimentary rocks in the vicinity of Granite Gap. The granite is white to pink or pinkish gray in weathered outcrop with abundant pink, subhedral K-feldspar phenocrysts up to 2 cm long. The rock is medium to coarse grained, hypidiomorphic granular with a color index ranging from 2-7 percent and typically less than 5 percent. Biotite occurs in aggregates of anhedral 1-mm grains. Larger biotite grains are interstitial to other minerals. Quartz (3-5 mm) and K-feldspar are subequal in amount; K-feldspar is typically twice as abundant as plagioclase. Euhedral oligoclase laths (1-2 mm) show both oscillatory and normal zoning, and early synneusis aggregates are common. Plagioclase is marginally replaced by interstitial quartz and K-feldspar. Locally, biotite is replaced by chlorite, rutile, muscovite, and opaque iron oxide. Accessory minerals are allanite, sphene, colorless zircon, magnetite, and apatite.

TERTIARY GRANITE PORPHYRY—Large dikes and sills of porphyritic granite and granite porphyry intrude the granite of Granite Gap and are in many ways petrographically and geochemically similar to it. Dikes and sills occur throughout the range but are concentrated in the area north of Granite Gap. The granite porphyry typically has a light-gray, aphanitic groundmass with phenocrysts of both white and pale-pink K-feldspar, gray quartz, whitish plagioclase, and euhedral biotite books that are weathered to reddish brown. Like the granite of Granite Gap, the porphyry is commonly poor in mafic minerals, with color index ranging from 2-4 percent.

K-feldspar occurs as orthoclase in euhedral fresh grains up to 2 cm long and in synneusis aggregates of grains 1 mm or less; perthite and interpenetrant twins are common. Quartz phenocrysts are euhedral and subhedral, ranging from 0.5-4 mm, showing embayed, partly resorbed forms. Sodic andesine clouded by fine-grained epidote and calcite occurs as euhedra 2-3 mm in size; cores are more altered. Synneusis clots of 3-4 plagioclase grains are common. The rock has glomeroporphyritic texture in which quartz, K-feldspar, and plagioclase phenocrysts are subequal in amount and groundmass is slightly more abundant than phenocrysts. K-feldspar makes up about 45-50 percent of the groundmass, which is holocrystalline and equigranular with interdigitating grain boundaries; quartz is second in abundance.

Mafic minerals are biotite euhedra less than 0.5 mm long and typically replaced by pale-green chlorite, muscovite, sphene, opaque iron oxide, and—in some samples—early pyroxene in euhedral prisms (0.25-1 mm) and synneusis aggregates, commonly with resorbed margins and replacement biotite. Zircon, allanite, sphene, and apatite are accessories. In samples adjacent to ore deposits, plagioclase and biotite are replaced by epidote, calcite, chlorite, and muscovite.

RHYOLITE AND FELSITE—Associated with Tertiary granite porphyry (probably a late stage) are dikes of rhyolite and felsite generally occurring in northwest-striking faults. Crystal-poor rhyolite porphyry is light tan to white and greenish in color with phenocrysts, less than 1 mm long, of sanidine, plagioclase, quartz, and oxidized mafic minerals in a felsitic groundmass. A few feldspar phenocrysts are 2-4 mm long. Quartz phenocrysts are euhedral with resorbed outlines; white sanidine crystals are subhedral, and two- and three-grain intergrowths of these two minerals are common. Plagioclase laths are clouded by fine-grained sericite and carbonate and commonly occur in aggregates. Pseudomorphs of muscovite, opaque iron oxide, carbonate, and minor chlorite replace euhedral biotite grains (0.75-2 mm long). Euhedral magnetite phenocrysts up to 4 mm across form dark spots in hand sample. The groundmass consists chiefly of K-feldspar grains 0.1-0.2 mm long. Granophyre is common, particularly adjacent to coarser intergrowths of K-feldspar and quartz. Secondary minerals are chiefly sericite and calcite, with minor epidote and chlorite. The rhyolite was not dated by the K-Ar method but is younger than the granite porphyry and is cut by the quartz-latite porphyry sills and dikes.

QUARTZ-LATITE PORPHYRY—The youngest intrusive unit consists of quartz-latite porphyry, porphyritic latite, and latite porphyry sills and dikes, many localized along northwest-trending faults. The rocks are dark grayish brown, the color of the holocrystalline ground-mass, with weathered white, yellowish, and pinkish plagioclase phenocrysts up to 1.5 cm across and fresh, black biotite phenocrysts. Intermediate andesine with oscillatory zoning occurs as euhedral grains averaging about 5 mm long, commonly in glomeroporphyritic texture with other plagioclase grains and with biotite. Quartz and K-feldspar phenocrysts are rare. Biotite phenocrysts are euhedral and subhedral, 1-3 mm long; grain margins are locally resorbed. The groundmass consists of abundant subhedral K-feldspar, euhedral to subhedral plagioclase, reddish-brown biotite, magnetite, and interstitial quartz in grains 0.2-0.3 mm long. Some samples show a groundmass of elongate plagioclase grains in matted array with the other minerals. Accessories in quartz-latite porphyry are apatite and zircon. At most localities the quartz-latite porphyry has undergone propylitic alteration, with introduction of calcite, epidote, chlorite, and sericite in the groundmass replacing the phenocrysts of biotite and plagioclase. Altered quartz-latite porphyry is greenish.

CHEMICAL AND NORMATIVE COMPOSITIONS—The chemical and normative compositions of typical specimens of the above units are given in table 1 and figs. 1 and 2. Triangular diagrams showing the relative proportions of normative quartz, Ab and An, Or, and Or, Ab, An are shown in fig. 1.

As the tables and diagrams show, the intrusive rocks are granite to quartz monzonite or quartz latite in composition. The granitic rocks are similar in composition, and their major-element contents have overlapping ranges (figs. 1 and 2). The rocks are all highly differentiated, with Thornton and Tuttle's differentiation indices of 80 to over 95, and are characterized by low concentrations of iron, magnesium, and calcium. Normative orthoclase and albite are roughly subequal, with albite usually slightly higher than Or, except in the Precambrian granitic rocks. The Precambrian granite porphyry contains generally lower SiO_2 and Na_2O and higher K_2O (fig. 2) than the younger granitic rocks. The Precambrian granite porphyry is generally more variable in major-element content than are the other rocks—most probably the effect of greater alteration. No completely unaltered sample of the Precambrian granite porphyry was found. The youngest igneous rock—the latite porphyry—has lower SiO_2, approximately equivalent K20 and Na20, and higher values of iron oxides, MgO, and CaO than does the granite porphyry (fig. 2), in keeping with its higher concentration of plagioclase and mafic minerals, principally biotite. Trace-metal analyses of the igneous rocks (Todd and others, 1975; M. L. Silberman and V. R. Todd, unpublished data) indicate that the Precambrian granite porphyry is anomalously high in thorium relative to the other granitic rocks. The latite porphyry has less rubidium, thorium, and uranium and more strontium than the granitic rocks.

K-AR AGE OF THE INTRUSIVE IGNEOUS ROCKS—Twelve samples of igneous rock have been dated by the K-Ar method (Todd and others, 1975)—three quartz-latite porphyry dikes, four samples of Tertiary granite porphyry, three samples of granite from Granite Gap, a pegmatite south of Granite Gap, and one sample of Precambrian granite porphyry (table 2). Sample locations, with two exceptions north of the mapped area, are shown on the geologic map. Two samples of granite porphyry, one near the Silver Hill mine (loc. 4) and another north of the geologic map area, were hydrothermally altered. Biotite was recrystallized to muscovite in one sample (loc. 3) and to a mixed-layer intergrowth of muscovite and chlorite in the other (loc. 4). The K-Ar ages, with the exception of microcline and muscovite from the pegmatite at Granite Gap (loc. 9) and K-feldspar from the Precambrian granite porphyry (loc. 10), are all middle Tertiary.

The quartz-latite porphyry (table 2, locs. 1, 2, and 11) was emplaced 26-27 m.y. ago; the mean age is 26.8 m.y. Tertiary granite porphyry (table 2, locs. 3, 4, 5, and 6) was emplaced between 31 and 32 m.y. ago; the mean age is 31.6 m.y. Concordant results of the different minerals, biotite, orthoclase, and muscovite, indicate that emplacement and alteration were nearly contemporaneous and that the results give a good estimate of the age of crystallization of this unit. The granite of Granite Gap (table 2, locs. 7, 8, and 12) yielded nearly the same K-Ar ages as the Tertiary granite porphyry. Only biotites were dated from the first two samples, and biotite, plagioclase, and K-feldspar were dated from the third. The concordant biotite and plagioclase results indicate that crystallization probably occurred in the mid-Tertiary. The younger K-feldspar age may have been partially reset during latite intrusion. Overall geochemical and petrographic similarity would allow the granite of Granite Gap and the granite porphyry to have similar ages and perhaps even suggests that they do. Lacking confirmation by alternate geochronological methods, however, the age of this unit is not yet definitely specified.

The pegmatite (table 2, loc. 9) south of Granite Gap, from an isolated outcrop in the alluvium, gave discordant ages of 70 and 55 m.y., respectively, from muscovite and microcline. It was thought originally to be related to the granite of Granite Gap because small pegmatitic segregations and veins of quartz and microcline are common in the granite. If this is true, then the granite of Granite Gap may be of Laramide age. The coarse-grained mica of the pegmatite would be much more resistant to argon loss from subsequent heating than the fine-grained mica and feldspars in the granite of Granite Gap would be. Microcline was dated, despite its poor argon retentivity, because it was also extremely coarse grained. Its known Ar leakage characteristics would make its K-Ar age a minimum estimate. The microcline also gave a Mesozoic (although discordant) age—further evidence for at least some plutonism of that age in the area.

Muscovite, which appears to be an alteration product of biotite in the Precambrian granite porphyry (table 2, loc. 10), gives an age of 34.4 m.y.—obviously not the age of crystallization for the rock. Microcline from the same rock gave an early Tertiary age of 58 m.y. Enough middle Tertiary igneous activity in the area occurred to explain these anomalously young ages by differential loss of argon from the mica and feldspar during reheating.

In summary, major intrusive igneous activity occurred in the central Peloncillo Mountains in middle Tertiary time. The granite of Granite Gap is possibly of Laramide age, but geochemical similarity with the well-dated granite porphyry indicates that it may be middle Tertiary in age. Geochemical and K-Ar data indicate that the quartz-latite porphyry dikes represent a stage of intrusion later than the granite, and we suggest they have a different magmatic source. K-Ar geochronology has not been able to completely resolve the age relations of all the igneous rocks because of the complex and multiple nature of intrusion of different units. Application of other isotopic techniques, particularly Rb-Sr geochronology and Sr-isotopic studies, should clarify the petrogenetic and age relations.

beneath the Cable Canyon Sandstone Member of the Montoya Dolomite. The Ordovician section in the Peloncillo Mountains is relatively thin compared to adjacent outcrops, suggesting that it was eroded before the Devonian rocks were deposited.

DEVONIAN—The Percha Shale (Late Devonian) is about 70 m thick and consists of the Ready Pay Member, of black fissile shale, overlain by fossiliferous, interbedded nodular limestone and calcareous shale of the Box Member. In many areas the Percha Shale is metamorphosed to light-gray to brown hornfels in the vicinity of granite porphyry, rhyolite, and quartz-latite porphyry dikes.

MISSISSIPPIAN—The Mississippian System is represented by the Escabrosa Group and the Paradise Formation. The Escabrosa Group is divided into two formations. The Keating Formation (Early Mississippian) is 111 m thick and disconformably overlies the Percha Shale. Its lowest beds are about 24 m of oolitic packstone overlain by 15 m of dolomite and 16 m of coralliferous wackestone; the upper 56 m of the formation is cherty, gray, peloid-crinoid wackestone. The Hachita Formation (Early and Late Mississippian) is a 44-m-thick, massive, gray to light-gray unit composed of crinoid-bryozoan-wackestone-packstone. The Paradise Formation (Late Mississippian) is 13-37 m thick, composed of alternating beds of light-gray to light-olive-gray, oolitic-arenaceous-micritic wackestone to grainstone with interbedded shale, siltstone, and sandstone.

PENNSYLVANIAN—The Pennsylvanian System is represented by the Horquilla Limestone, of Early, Middle, and Late Pennsylvanian age, the lowest formation in the Naco Group. Accurate measured sections of the Horquilla at Blue Mountain in secs. 3, 10, 11, and 14, T. 25 S., R. 21 W. are difficult to obtain because of extensive faulting. Bedding-plane faults and quartz-latite porphyry cut the Horquilla at all outcrops. A minimum of 450 m of Lower, Middle, and Upper Pennsylvanian carbonate rocks is present. The Horquilla Limestone unconformably overlies the Paradise Formation. The lower 75 m of the Horquilla Limestone is composed of peloid-echinoderm-brachiopod-foraminiferal wackestone to packstone. A persistent zone of *Chaetetes* sp. and rugose corals occurs 30-50 m above the base. The remainder of the Horquilla Limestone is medium- to thick-bedded, cherty, foraminiferal-echinoderm brachiopod wackestone with smaller amounts of packstone.

PERMIAN—The Permian System is represented by the Earp Formation, the Colina Limestone, the Scherrer Formation, and the Concha Limestone, all within the Naco Group. The Earp Formation (Early Permian Wolfcampian) has a gradational contact with the underlying Horquilla Limestone. The contact between the two formations is difficult to pick and is based upon the greater abundance of terrigenous clastic material in the Earp Formation. The Earp consists of alternating beds of foraminiferal-peloid-echinoderm packstone-wackestone with brownish-red calcareous siltstone and quartz sandstone grains 50-200 µm in size. All outcrops of Earp are in structurally complex terrane or thermally metamorphosed areas, and accurate measures are difficult. The Earp Formation is probably more than 600 m thick.

The Colina Limestone conformably overlies the Earp Formation and consists of dark-olive-gray to dark-gray micritic limestone and dolomite, with minor thin sandstone beds. The dolomite is composed of dolomite rhombs 10-25 m in size. Algal mats, gypsum pseudomorphs, mud cracks, and bird's-eye structures are common; in the middle of the unit are beds with pelecypods. Within the area of outcrop in the Peloncillo Mountains, the Colina Limestone was deposited in a subtidal to supratidal environment.

The Scherrer Formation is 30-35 m of thin-bedded pale-reddish-brown siltstone, argillaceous sandstone, thick interbeds of olive-gray sandstone, and a few interbeds of 0.3-0.5-m-thick dolomite composed of 5-gm rhombs of dolomite.

The Concha Limestone, at least 76 m thick, is massive light-gray marine crinoid-bryozoan-brachiopod wackestone and packstone with gray-red chert nodules. In areas of outcrop adjacent to the granite of Granite Gap, the Concha is a coarse-grained white marble containing wollastonite. According to Sabins (1975a) and Sabins and Ross (1963), the Concha Limestone is of Early Permian age.

CRETACEOUS—The Cretaceous System is represented by the Bisbee Group (Early Cretaceous). The basal unit, McGhee Peak Formation, named by Gillerman (1958, p. 45-47), rests with marked unconformity on an irregular Paleozoic surface. At McGhee Peak, here designated its type locality, the McGhee Peak Formation rests on the lower half of the Permian Earp Formation; and 3-4 km to the southwest it rests on the intervening Concha Limestone. The McGhee Peak Formation is 150-225 m thick and is composed of limestone, chert, quartz pebbles and cobbles, and alternating beds of shale, sandstone, and argillaceous limestone. The 75-100-m-thick Carbonate Hill Limestone, named by Gillerman (1958, p. 47-50), is composed of argillaceous, arenaceous packstone and wackestone with abundant molluscan remains alternating with thin silty gray shale. The overlying sandstone, shale, and siltstone of Gillerman (1958, p. 50-53), the Still Ridge Formation, and the Johnny Bull Sandstone are 250-350m-thick, tan to brown well-cemented subgraywacke. Gillerman (1958) reported a large Early Cretaceous megafossil fauna from the Carbonate Hill Limestone.

Igneous rocks

The igneous rocks of the central Peloncillo Mountains range in age from Precambrian to middle Tertiary and in composition from intermediate to felsic. Both extrusive and intrusive igneous rocks are present. Coarse-to medium-grained, largely porphyritic granites and quartz latites occur as plutonic masses, and dikes and sills are present throughout the range.

A thick sequence of extrusive andesitic volcanic rocks crops out in the northern part of the map area. Rhyolite to quartz-latite ash flows and other volcanic rocks crop out from about 2 km south of Granite Gap to the southern limit of the map area.

Extrusives

ANDESITE—Andesite and associated dacite are present largely in the northern part of the map area as a thick sequence, exceeding 1,100 m, of extrusive flows, breccias, and tuffs (Gillerman, 1958). The dominant lithology is pyroxene andesite. Pervasive propylitic alteration, with dominant replacement of pyroxenes, plagioclase, and groundmass by epidote, has affected the andesitic volcanic rocks. Chlorite, sericite, and kaolinite are also present, and disseminated pyrite is common in many areas. Minor irregular andesitic intrusive rocks, petrographically similar to the extrusive andesite, cut the older sedimentary sequence in isolated places, notably in the low hills northwest of Wood Canyon. Gillerman (1958) described the andesite sequence in considerable detail, and we do not discuss it further here. Most of the area between the northern limit of the map area and US-80, 6 km to the north, is underlain by andesite. Alteration was too pervasive to allow an isotopic age to be determined on the andesite.

Gillerman (1958) assigned a Late Cretaceous or Tertiary age to these rocks because they seem to be at least partly interbedded with a conglomerate unit, the Bobcat Hill Conglomerate of that age (Gillerman, 1958) to the north of the map area. Granite porphyry dikes and sills and quartz-latite porphyry dikes intrude the andesite, indicating a minimum pre-Middle Tertiary age.

VOLCANIC ROCKS, UNDIFFERENTIATED—Other volcanic rocks crop out approximately 2 km south of Granite Gap and thicken to the south. These include rhyolite tuffs, minor andesite intrusive rocks, and tuffs and ignimbrites of Gillerman's (1958) Weatherby Canyon Ignimbrite—the most voluminous volcanic unit in the southern part of the map area. Gillerman (1958) described this unit in detail. W. E. Elston (written communication, 1974) determined a K-Ar age of 25 m.y. on the Weatherby Canyon Ignimbrite. The volcanic rocks south of Granite Gap are being studied by W. E. Elston and associates of the University of New Mexico and are not discussed here.

Intrusives

PRECAMBRIAN GRANITE PORPHYRY—An elongate, faulted mass of Precambrian granite porphyry, unconformably overlain by sedimentary rocks ranging in age from Cambrian through Early Cretaceous, is exposed in the northern part of the area, largely southwest of the northwest-trending Wood Canyon fault. Several smaller outcrops are scattered south of the prominent east-west-striking Preacher Mountain fault. The rock is typically dark green or gray with irregular, oblong, pink K-feldspar phenocrysts. It is slightly foliated owing to subparallel alignment of lenticular quartz and K-feldspar grains. The large (3-5 cm) K-feldspar and quartz phenocrysts occur in a holocrystalline, fine-grained groundmass of smaller, highly sericitized plagioclase phenocrysts (3-4 mm) and irregular aggregates of secondary chlorite, epidote, quartz, sphene, and calcite. Biotite generally is replaced by muscovite, in thin-bladed radiating masses, and opaque iron oxide. Quartz lenticles and feldspar grains show evidence of minor crushing (pervasive fractures, undulose extinction, and deformation twins), and secondary epidote and chlorite are localized along these fractures. Graphic granite relicts and dark-brown, fine- to medium-grained, equigranular rock occur in the granite porphyry and are identical to it in mineralogy and advanced alteration of plagioclase and biotite.

BASALT—Small irregular dikes of basalt intrude the Precambrian granite porphyry in several areas north of the Preacher Mountain fault. Most outcrops are small, only a few meters across or less, and are not shown on the geologic map. An exception is the irregular dike of altered basalt in Wood Canyon in the northwest part of sec. 22, T. 25 S., R. 21 W. These grayish-green rocks range in texture from very fine grained porphyritic to medium grained and granulitic. Alteration of these rocks is pervasive but varies in intensity. Most of the localities have been affected by propylitization. Olivine, which was common in the basalts, is replaced by iron oxides; chlorite commonly replaces the matrix and occurs with epidote and sericite after feldspar. Amphibole commonly replaces the matrix or pyroxene(?) and is itself partially replaced by chlorite. Disseminate pyrite and iron oxides are common.

Despite the variety of textures and degrees of alteration, all of these dike rocks are assigned a Precambrian age because they are only found cutting the Precambrian granite porphyry and are not known to intrude any of the younger sedimentary or igneous rocks. The only other basic rock that occurs in the vicinity of the map area is a Quaternary(?) basalt flow just off the southeast edge of the geologic map area in Animas Valley (Gillerman, 1958). The basalt dikes are very minor in extent and were not studied in detail.

GRANITE OF GRANITE GAP—A pluton of granite approximately 8 sq km in outcrop area intrudes and thermally metamorphoses Paleozoic and Mesozoic sedimentary rocks in the vicinity of Granite Gap. The granite is white to pink or pinkish gray in weathered outcrop with abundant pink, subhedral K-feldspar phenocrysts up to 2 cm long. The rock is medium to coarse grained, hypidiomorphic granular with a color index ranging from 2-7 percent and typically less than 5 percent. Biotite occurs in aggregates of anhedral 1-mm grains. Larger biotite grains are interstitial to other minerals. Quartz (3-5 mm) and K-feldspar are subequal in amount; K-feldspar is typically twice as abundant as plagioclase. Euhedral oligoclase laths (1-2 mm) show both oscillatory and normal zoning, and early synneusis aggregates are common. Plagioclase is marginally replaced by interstitial quartz and K-feldspar. Locally, biotite is replaced by chlorite, rutile, muscovite, and opaque iron oxide. Accessory minerals are allanite, sphene, colorless zircon, magnetite, and apatite.

TERTIARY GRANITE PORPHYRY—Large dikes and sills of porphyritic granite and granite porphyry intrude the granite of Granite Gap and are in many ways petrographically and geochemically similar to it. Dikes and sills occur throughout the range but are concentrated in the area north of Granite Gap. The granite porphyry typically has a light-gray, aphanitic groundmass with phenocrysts of both white and pale-pink K-feldspar, gray quartz, whitish plagioclase, and euhedral biotite books that are weathered to reddish brown. Like the granite of Granite Gap, the porphyry is commonly poor in mafic minerals, with color index ranging from 2-4 percent.

K-feldspar occurs as orthoclase in euhedral fresh grains up to 2 cm long and in synneusis aggregates of grains 1 mm or less; perthite and interpenetrant twins are common. Quartz phenocrysts are euhedral and subhedral, ranging from 0.5-4 mm, showing embayed, partly resorbed forms. Sodic andesine clouded by fine-grained epidote and calcite occurs as euhedra 2-3 mm in size; cores are more altered. Synneusis clots of 3-4 plagioclase grains are common. The rock has glomeroporphyritic texture in which quartz, K-feldspar, and plagioclase phenocrysts are subequal in amount and groundmass is slightly more abundant than phenocrysts. K-feldspar makes up about 45-50 percent of the groundmass, which is holocrystalline and equigranular with interdigitating grain boundaries; quartz is second in abundance.

Mafic minerals are biotite euhedra less than 0.5 mm long and typically replaced by pale-green chlorite, muscovite, sphene, opaque iron oxide, and—in some samples—early pyroxene in euhedral prisms (0.25-1 mm) and synneusis aggregates, commonly with resorbed margins and replacement biotite. Zircon, allanite, sphene, and apatite are accessories. In samples adjacent to ore deposits, plagioclase and biotite are replaced by epidote, calcite, chlorite, and muscovite.

RHYOLITE AND FELSITE—Associated with Tertiary granite porphyry (probably a late stage) are dikes of rhyolite and felsite generally occurring in northwest-striking faults. Crystal-poor rhyolite porphyry is light tan to white and greenish in color with phenocrysts, less than 1 mm long, of sanidine, plagioclase, quartz, and oxidized mafic minerals in a felsitic groundmass. A few feldspar phenocrysts are 2-4 mm long. Quartz phenocrysts are euhedral with resorbed outlines; white sanidine crystals are subhedral, and two- and three-grain intergrowths of these two minerals are common. Plagioclase laths are clouded by fine-grained sericite and carbonate and commonly occur in aggregates. Pseudomorphs of muscovite, opaque iron oxide, carbonate, and minor chlorite replace euhedral biotite grains (0.75-2 mm long). Euhedral magnetite phenocrysts up to 4 mm across form dark spots in hand sample. The groundmass consists chiefly of K-feldspar grains 0.1-0.2 mm long. Granophyre is common, particularly adjacent to coarser intergrowths of K-feldspar and quartz. Secondary minerals are chiefly sericite and calcite, with minor epidote and chlorite. The rhyolite was not dated by the K-Ar method but is younger than the granite porphyry and is cut by the quartz-latite porphyry sills and dikes.

QUARTZ-LATITE PORPHYRY—The youngest intrusive unit consists of quartz-latite porphyry, porphyritic latite, and latite porphyry sills and dikes, many localized along northwest-trending faults. The rocks are dark grayish brown, the color of the holocrystalline ground-mass, with weathered white, yellowish, and pinkish plagioclase phenocrysts up to 1.5 cm across and fresh, black biotite phenocrysts. Intermediate andesine with oscillatory zoning occurs as euhedral grains averaging about 5 mm long, commonly in glomeroporphyritic texture with other plagioclase grains and with biotite. Quartz and K-feldspar phenocrysts are rare. Biotite phenocrysts are euhedral and subhedral, 1-3 mm long; grain margins are locally resorbed. The groundmass consists of abundant subhedral K-feldspar, euhedral to subhedral plagioclase, reddish-brown biotite, magnetite, and interstitial quartz in grains 0.2-0.3 mm long. Some samples show a groundmass of elongate plagioclase grains in matted array with the other minerals. Accessories in quartz-latite porphyry are apatite and zircon. At most localities the quartz-latite porphyry has undergone propylitic alteration, with introduction of calcite, epidote, chlorite, and sericite in the groundmass replacing the phenocrysts of biotite and plagioclase. Altered quartz-latite porphyry is greenish.

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Metamorphism

Metamorphism was widespread in the central Peloncillo Mountains. Three types can be distinguished: 1) propylitization, chiefly of igneous rocks; 2) production of skarn zones along contacts of igneous intrusive bodies; and 3) hornfelsification and recrystallization of sedimentary rocks at a distance from intrusions (Gillerman, 1958; Carten and others, 1974).

Propylitization characterized by epidote, calcite, quartz, and albite is the primary metamorphic effect in the igneous rocks. Epidote occurs in the groundmass and partly or wholly replaces grains of pyroxene, biotite, and calcium-plagioclase in many of the igneous rocks. Calcareous sedimentary rocks throughout the region also show signs of epidote formation (Gillerman, 1958).

Skarn zones are produced at the contacts of limestone with granite porphyry, rhyolite dikes and sills, the granite of Granite Gap, and latite porphyry dikes and also at faults near such contacts. The best examples are the skarn along the rhyolite dikes on Silver Hill and Carbonate Hill and the granite porphyry dike emplaced along the Preacher Mountain fault. Garnet of andradite-grossularite composition is the most abundant constituent of the skarn and is accompanied by wollastonite, epidote, calcite, and quartz. At several localities, metallic sulfides have been introduced into the skarn. Farther away from the intrusive bodies, the limestone is recrystallized, with an increase in grain size.

Hornfelsification of the Percha Shale and interbedded siltstone of other sedimentary sequences is also common. The hornfels is fine grained and flintlike and occurs as far away as 3-5 km from any exposed intrusive body. It is difficult to tell hornfels from felsite in the field at many locations. Sparse phenocrysts in the felsite or rounded quartz sand grains in the hornfels are the only distinguishing features and are not everywhere present.

The metamorphism was associated with the igneous intrusions of Late Cretaceous or middle Tertiary age. Little or no regional metamorphism of the rocks occurred. More complete descriptions of the effects of metamorphism can be found in Gillerman (1958), and the extent of the metamorphic aureoles is depicted by Armstrong and Silberman (1974).

Structure

Gillerman (1958) describes the structural geology of the central Peloncillo Mountains. The Peloncillo Mountains and adjacent valleys are part of the Basin and Range province and show the characteristic dominance of faulting and tilting of the strata.

The stratigraphy of the Peloncillo Mountains indicates that from late Precambrian to Permian the region was a stable platform marked by periodic shallow-marine transgression and regression.

The massive McGhee Peak Formation in the Peloncillo Mountains and the temporally equivalent Glance Conglomerate to the east in the Chiricahua Mountains (Sabins, 1957b, p. 1323) and in most of the Basin and Range province of southeastern Arizona and New Mexico unconformably overlie older rocks with an angular discordance (Hayes, 1970). The older rocks were elevated in a series of uplifts throughout the region and provided detritus for the Glance Conglomerate. The distribution of Paleozoic rock beneath the Glance Conglomerate was controlled by pre-Cretaceous structure and topography.

Late Mesozoic and/or Cenozoic orogeny caused thrusting, folding, and strike-slip faulting. The best example of thrusting is found south of US-80, on the southwest side of Granite Gap, in the NW 1/4 sec. 3, T. 26 S., R. 21 W., where the Earp Formation of Permian age is thrust over Precambrian granite porphyry. The thrust surface was then steeply folded into a north- trending anticline, and the thrust faults and folds were cut by high-angle, north-trending normal faults, which then controlled localization of granite porphyry, rhyolite, and quartz-latite porphyry dikes and sills.

Gillerman (1958) has shown that the central Peloncillo Mountains are part of a broken arch, whose axial plane trends northwest. High-angle faults that postdate the thrusting and folding occupy the axial part of the arch, parallel to its axis, and strike northwest. Gillerman (1958, pl. 14) named the major faults from northeast to southwest the Johnny Bull fault, Goatcamp fault, Wood Canyon fault, and Fluorite fault *(see geologic map).*

Two major faults that trend east-northeast are the Preacher Mountain fault and Granite Gap fault.

Metamorphism

Metamorphism was widespread in the central Peloncillo Mountains. Three types can be distinguished: 1) propylitization, chiefly of igneous rocks; 2) production of skarn zones along contacts of igneous intrusive bodies; and 3) hornfelsification and recrystallization of sedimentary rocks at a distance from intrusions (Gillerman, 1958; Carten and others, 1974).

Propylitization characterized by epidote, calcite, quartz, and albite is the primary metamorphic effect in the igneous rocks. Epidote occurs in the groundmass and partly or wholly replaces grains of pyroxene, biotite, and calcium-plagioclase in many of the igneous rocks. Calcareous sedimentary rocks throughout the region also show signs of epidote formation (Gillerman, 1958).

Skarn zones are produced at the contacts of limestone with granite porphyry, rhyolite dikes and sills, the granite of Granite Gap, and latite porphyry dikes and also at faults near such contacts. The best examples are the skarn along the rhyolite dikes on Silver Hill and Carbonate Hill and the granite porphyry dike emplaced along the Preacher Mountain fault. Garnet of andradite-grossularite composition is the most abundant constituent of the skarn and is accompanied by wollastonite, epidote, calcite, and quartz. At several localities, metallic sulfides have been introduced into the skarn. Farther away from the intrusive bodies, the limestone is recrystallized, with an increase in grain size.

Hornfelsification of the Percha Shale and interbedded siltstone of other sedimentary sequences is also common. The hornfels is fine grained and flintlike and occurs as far away as 3-5 km from any exposed intrusive body. It is difficult to tell hornfels from felsite in the field at many locations. Sparse phenocrysts in the felsite or rounded quartz sand grains in the hornfels are the only distinguishing features and are not everywhere present.

The metamorphism was associated with the igneous intrusions of Late Cretaceous or middle Tertiary age. Little or no regional metamorphism of the rocks occurred. More complete descriptions of the effects of metamorphism can be found in Gillerman (1958), and the extent of the metamorphic aureoles is depicted by Armstrong and Silberman (1974).

Structure

Gillerman (1958) describes the structural geology of the central Peloncillo Mountains. The Peloncillo Mountains and adjacent valleys are part of the Basin and Range province and show the characteristic dominance of faulting and tilting of the strata.

The stratigraphy of the Peloncillo Mountains indicates that from late Precambrian to Permian the region was a stable platform marked by periodic shallow-marine transgression and regression.

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Mineral deposits

Signs of early prospecting and mining activity are everywhere present in the central Peloncillo Mountains. The primary commodities mined were copper, lead, zinc, and silver. Gillerman (1958) reported production worth more than $2 million, mostly in lead and zinc from the Carbonate Hill mine and the mines at Granite Gap. Accurate production figures are scarce, but most activity occurred prior to 1920. Gillerman (1958) provided detailed descriptions of the mineral deposits.

The ore deposits are found both in pyrometasomatic (contact-metasomatic) deposits and hydrothermal veins; both have a similar mineralogy and occur primarily in limestone. In the contact metasomatic deposits, which are most abundant, replacement of limestone by calcium silicate minerals (largely garnet but including quartz, calcite, and wollastonite) has occurred adjacent to dikes and sills of granite porphyry, rhyolite, and quartz-latite porphyry. The development of skarn mineralogy was accompanied by the introduction of galena, sphalerite, and chalcopyrite. Some deposits fill fissures. The larger contact-metasomatic deposits occur at the Johnny Bull (copper), Silver Hill (lead-zinc), and Carbonate Hill (lead-zinc-silver) mines (Carten and others, 1974). Near the Silver Hill mine, southwest of McGhee Peak, ore deposits occur in skarn zones adjacent to a conspicuous granite porphyry sill and rhyolite dikes that are believed to be related to the sill. At the Carbonate Hill mine, east of McGhee Peak, ore is found in a contact zone near a large propylitized felsite dike. Tungsten is present in skarn-bearing rocks at the Ward mine north of the Preacher Mountain fault.

Hydrothermal vein deposits also occur in limestone, principally at Granite Gap and at the Crystal mine. Fissure filling was the dominant process, accompanied by some replacement. The primary ore minerals are sphalerite, galena, and chalcopyrite with some tetrahedrite. Pyrite, quartz, and calcite occur as gangue minerals. At Granite Gap, the sulfides have been almost completely oxidized to limonite and manganese oxides. No metamorphism of the highly fractured and thrust-faulted limestone is visible, but felsite dikes mentioned in an earlier report by Lindgren and others (1910) were found in the area.

Most likely, the contact-metasomatic deposits developed nearer main sources of heat (the various intrusive bodies nearby), and the hydrothermal vein deposits formed at lower temperatures some distance from these bodies. Fluid inclusion and stable-isotope studies of the deposits would help to clarify the relations between the two types of ore deposits.

Metamorphism of the sedimentary rocks, alteration of the intrusive rocks, and deposition of the ore metals resulted from solutions generated during emplacement of the Cretaceous(?) and/or middle Tertiary intrusive rocks—the granite of Granite Gap, the Tertiary granite porphyry, and the quartz-latite porphyry dikes and sills. In general, the metamorphic aureoles adjacent to areas where only the quartz-latite porphyry dikes and sills are present do not contain mineral deposits, but in some places trace-metal anomalies are present.

Trace-element anomalies

A sampling program was conducted during five weeks in October and November 1974 by Silberman, Armstrong, and Carten. Sampling was concentrated along faults at the contact zones of igneous rocks with limestone and other sedimentary lithologies. About 900 rock samples were taken at approximately 500 locations (Carten and others, 1974; Silberman and others, 1974). The Johnny Bull-McGhee Peak area was sampled in greater detail than the rest of the region because an earlier ground reconnaissance had indicated that this area showed base-metal zoning similar to that found in the vicinity of porphyry-type copper deposits. Barren, unmineralized units were collected to determine background values, and mineralized or altered rocks were collected to enhance the detection of areas of anomalous trace-metal content and zoning patterns. Most of these latter samples came from skarn, fault and shear zones, brecciated units, and veins. Anomaly maps for the base metals and several other trace elements have been published (Silberman and others, 1974).

Anomalous concentrations of copper, lead, zinc, and silver are present within garnet-bearing metamorphic rocks adjacent to dikes emplaced along the northwest-trending Johnny Bull fault and associated parallel faults on the eastern side of the mountains (fig. 3). Similar anomalies are present in the wall rocks of dikes along the Preacher Mountain fault, particularly at the intersections with several northwest-trending faults. Lower, but still anomalous, metal concentrations were found in the igneous rocks themselves. Anomalous concentrations of these four elements are also associated with lead-zinc replacement deposits near McGhee Peak. The distribution of these deposits is controlled by northeast-trending rhyolite dikes branching from a granite porphyry sill. Farther east, an anomalous zone of lead, zinc, and silver was identified at the Carbonate Hill mine within and adjacent to another felsite dike. At Granite Gap, anomalous concentrations of base metals and silver occur in small, largely oxidized, hydrothermal sulfide veins in highly fractured limestone (fig. 3). North of Granite Gap, localized zones of copper, lead, and zinc are present where granite porphyry and quartzlatite porphyry dikes intruded and metamorphosed the sedimentary rocks of the central Peloncillo Mountains (Silberman and others, 1974).

Trace-element ratio maps indicate a well-defined zoning pattern in the McGhee Peak area; copper/total base-metal values are higher along and adjacent to the Johnny Bull fault and decrease eastward to the Carbonate Hill mine. Similar zoning patterns are found elsewhere along the Johnny Bull and Preacher Mountain faults (Carten and others, 1974; and fig. 4).

Geologic history

After deposition of the Paleozoic and Mesozoic sedimentary rocks and a period of erosion, the following sequence of events occurred:

1) Intrusion of the granite of Granite Gap metamorphosed adjacent Paleozoic and Mesozoic rocks into hornfelses and marbles in Late Cretaceous or Middle Tertiary time.

2) Unmetamorphosed Lower Permian shelf carbonate rocks were thrust over Precambrian igneous rocks and metamorphosed Mississippian and lower Paleozoic carbonate rocks; the thrust is now exposed only in the Granite Gap vicinity. The thrusting must have taken place after emplacement of the granite of Granite Gap since the thrusting juxtaposed unmetamorphosed rocks over metamorphosed rocks. The age of emplacement of the granite, however, is not yet conclusively demonstrated to be either Cretaceous or middle Tertiary.

3) The region was folded into broad north-south-trending anticlines and synclines.

4) High-angle, normal block faulting began in middle Tertiary and has continued into Holocene time.

5) Dikes, plugs, and sills of granite porphyry were intruded along northwest- and northeast-trending faults.

6) Dikes and sills of rhyolite and felsite were intruded along northwest- and northeast-trending faults and fractures, probably as a late stage in evolution of the granite porphyry magma.

7) Throughout much of the range, dikes of quartzlatite porphyry were intruded along northwest-trending faults.

Faulting continued during stages 5 through 7, as indicated by brecciation and reintrusion of the igneous bodies along the faults. Mineralization accompanied stages 5, 6, and 7 as indicated by hydrothermal alteration and mineralization of all of the igneous rocks. The onset of Basin and Range faulting at least 30 m.y. ago agrees with Christiansen and Lipman's (1972) proposal that crustal extension of this region began at approximately this time, but does not substantiate the suggestion of McKee and Noble (1974) that crustal extension began throughout the Basin and Range province between 17 and 20 m.y. ago—at least for southwestern New Mexico.

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TABLE 1—Representative chemical and normative analyses of igneous rocks, central Peloncillo Mountains (method of analysis was a single-solution procedure, Shapiro, 1967; analyst: L. Artis). Q, quartz; C, corundum; Or, orthoclase; Ab, albite; An, anorthite; Wo, wollastonite; En, enstatite; Fs, ferrosilite; Mt, magnetite; Hm, hematite; Il, ilmenite; Ru, rutile; Ap, apatite; Cc, calcite; D.I., differentiation index.

	Precambrian granite porphyry		Granite of Granite Gap			Tertiary granite porphyry		Rhyolite	Quartz latite porphyry	
Oxide	NP4	NP18	NP2	NP12	S136	NP5	S254	NP8	NP6	S193
SiO_2	73.2	67.0	73.0	76.9	76.0	74.5	74.6	75.7	62.6	67.7
Al_2O_3	14.1	16.9	14.8	13.3	12.7	14.2	13.7	13.1	16.9	15.9
Fe_2O_3	.12	3.3	.81	.41	.56	.09	.30	.55	2.9	1.9
FeO	.40	.64	.72	.16	.20	.24	1.00	.20	1.10	.96
MgO	.30	.49	.37	.00	.09	.33	.41	.32	1.20	.79
CaO	1.20	.56	1.20	.28	.68	1.20	1.50	.39	2.70	2.00
Na_2O	3.70	.16	3.80	4.00	3.40	3.20	3.50	2.80	3.80	4.20
K_2O	4.60	7.50	4.20	4.30	4.50	5.00	4.50	4.60	4.60	5.20
$H_2O\pm$	.70	1.42	.50	.57	.44	.44	.49	1.20	1.30	.91
TiO_2	.08	.82	.06	.01	.03	.11	.07	.06	.86	.27
P_2O_5	.10	.17	.09	.02	.03	.07	.05	.04	.35	.24
MnO	.07	.07	.07	.05	.07	.04	.05	.08	.06	.06
CO_2	.40	.02	.02	.02	.03	.04	.07	.06	.62	.81
Total	99.0	99.1	99.6	100.0	98.7	99.5	100.2	99.1	99.0	100.9
					Normative minerals					
Q	32.5	36.3	31.8	36.7	38.1	34.1	32.7	41.1	18.2	20.6
C	2.04	8.03	2.09	1.65	1.16	1.61	.63	3.07	3.07	2.16
Or	27.5	44.7	24.9	25.4	26.9	29.7	26.5	27.4	27.5	30.4
Ab	31.6	1.37	32.3	33.8	29.1	27.2	29.5	23.9	32.5	35.2
An	2.80	1.56	5.26	1.13	3.03	5.27	6.66	1.31	7.26	3.20
Wo										
En Di	.76	1.23	.93		.23	.83	1.02	.80	3.02	1.95
Fs	.64		.69	.03		.26	1.56			
Mt	.18		1.18	.59	.80	.13	.43	.74	1.27	2.48
Hm		3.33			.02			.05	2.06	.17
Il	.15	1.52	.11	.02	.06	.21	.13	.12	1.65	.51
Ru		.03								
Ap	.24	.41	.21	.05	.07	.17	.11	.10	.84	.56
Cc	.92	.04	.05	.05	.07	.09	.16	.14	1.42	1.83
D.I.	91.6	82.4	89.0	95.9	94.1	91.0	88.8	92.5	78.1	86.3

TABLE 2—K-AR AGES OF INTRUSIVE IGNEOUS ROCKS, CENTRAL PELONCILLO MOUNTAINS (analytical data, Hoggatt and others 1977).

Loc. No.	Sample No.	Mineral	K-Ar age (m.y.)[1]
		Quartz latite porphyry	
1	S-37A	Biotite	27.4±0.8
2	S-193	Biotite	27.7±0.8
		Plagioclase	25.8±0.8
11[2]	73NP-23	Biotite	27.0±0.8
		K-feldspar	26.1±0.8
		Tertiary granite porphyry (dikes and sills)	
3[2]	73NV-4*	Muscovite	31.4±0.9
4	73NP-7*	Muscovite/chlorite	31.7±1.0
5	73NP-5	Orthoclase	31.0±0.9
6	S-254	Biotite	32.2±1.0
		Granite of Granite Gap	
7	73NP-12	Biotite	30.3±0.9
8	73NP-2	Biotite	32.5±1.0
12	S-136	Biotite	31.8±1.0
		Plagioclase	32.1±1.0
		K-feldspar	29.8±0.9
		Pegmatite (graphic granite, feldspar, muscovite)	
9	73NP-19A	Microcline	55.3±1.7
		Muscovite	69.9±2.1
		Precambrian granite porphyry	
10	73NP-18	Muscovite	34.4±1.0
		K-feldspar	57.8±1.7

*Altered rock

[1] Constants used in calculation of age:

$$\lambda_\beta = 4.963 \times 10^{-10}\ \mathrm{yr}^{-1}$$
$$\lambda_e = 0.572 \times 10^{-10}\ \mathrm{yr}^{-1}$$
$$\lambda_{e'} = 8.78 \times 10^{-13}\ \mathrm{yr}^{-1}$$
$$K^{40}/K_{total} = 1.167 \times 10^{-4}\ \text{(mole/mole)}$$

[2] Not shown on map; located north of map area.

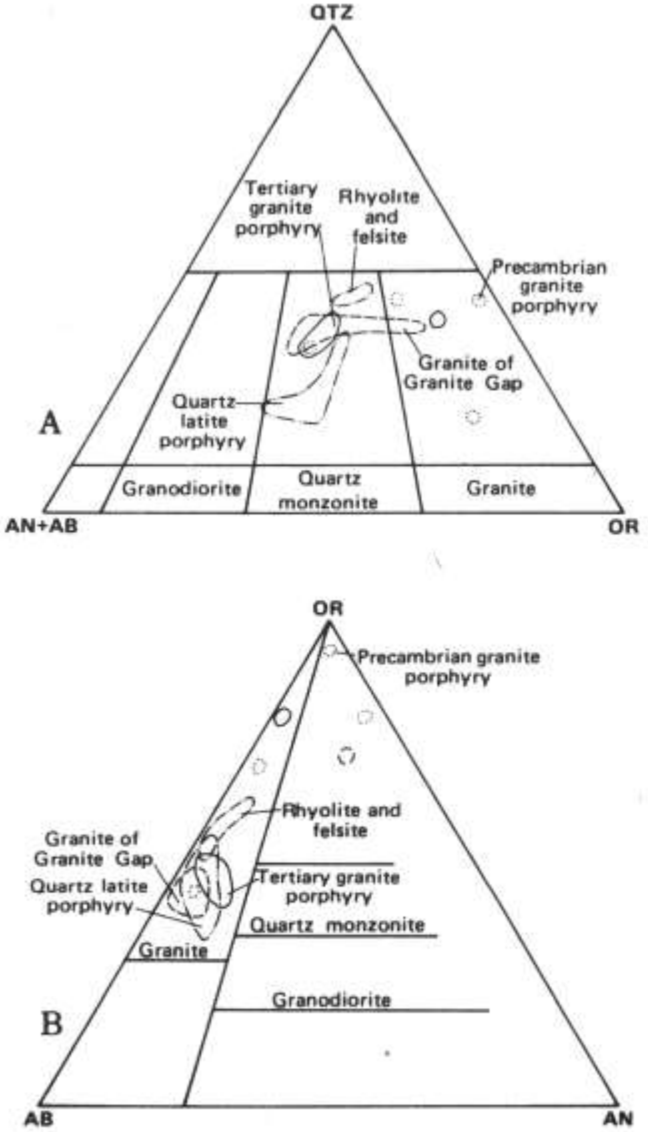

FIGURE 1—NORMATIVE DIAGRAMS FOR IGNEOUS ROCKS OF CENTRAL PELONCILLO MOUNTAINS. **A)** Normative quartz, anorthite + albite, orthoclase. **B)** Normative orthoclase, albite, anorthite.

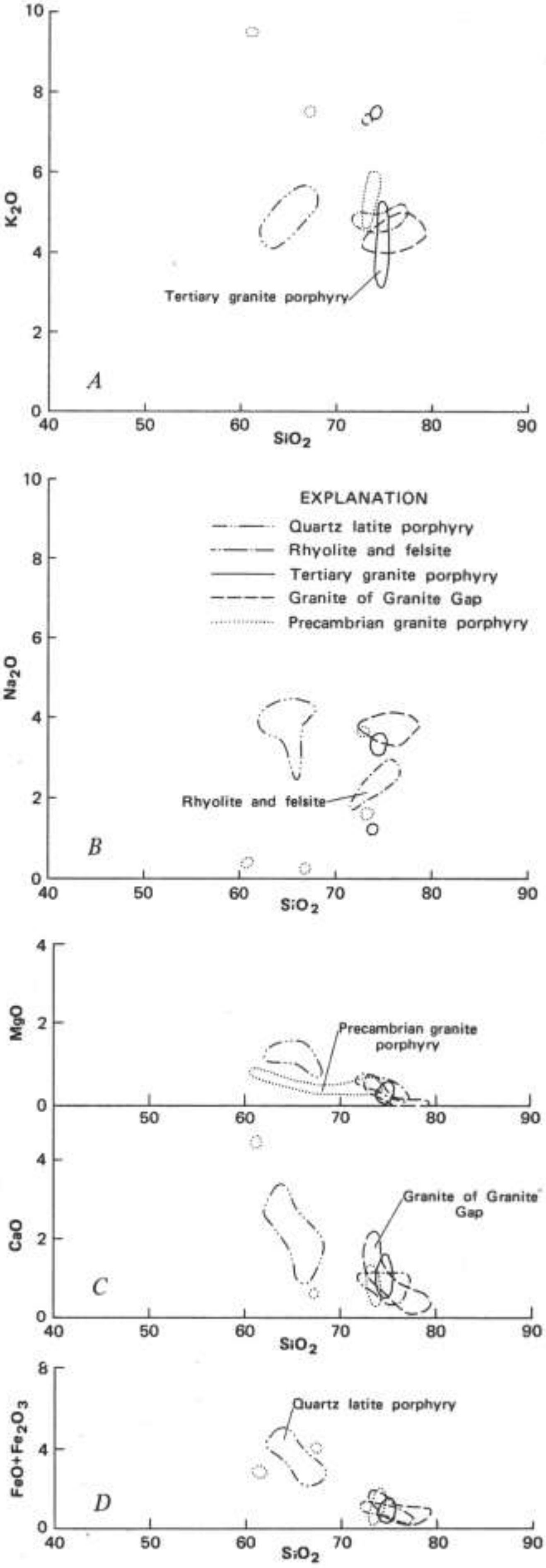

FIGURE 2—VARIATION DIAGRAMS FOR IGNEOUS ROCKS OF CENTRAL PELONCILLO MOUNTAINS. **A)** SiO_2, K_2O variation diagram. **B)** SiO_2, Na_2O variation diagram. **C)** SiO_2, CaO and SiO_2, MgO variation diagrams. **D)** SiO_2, FeO + Fe_2O_3 variation diagram.

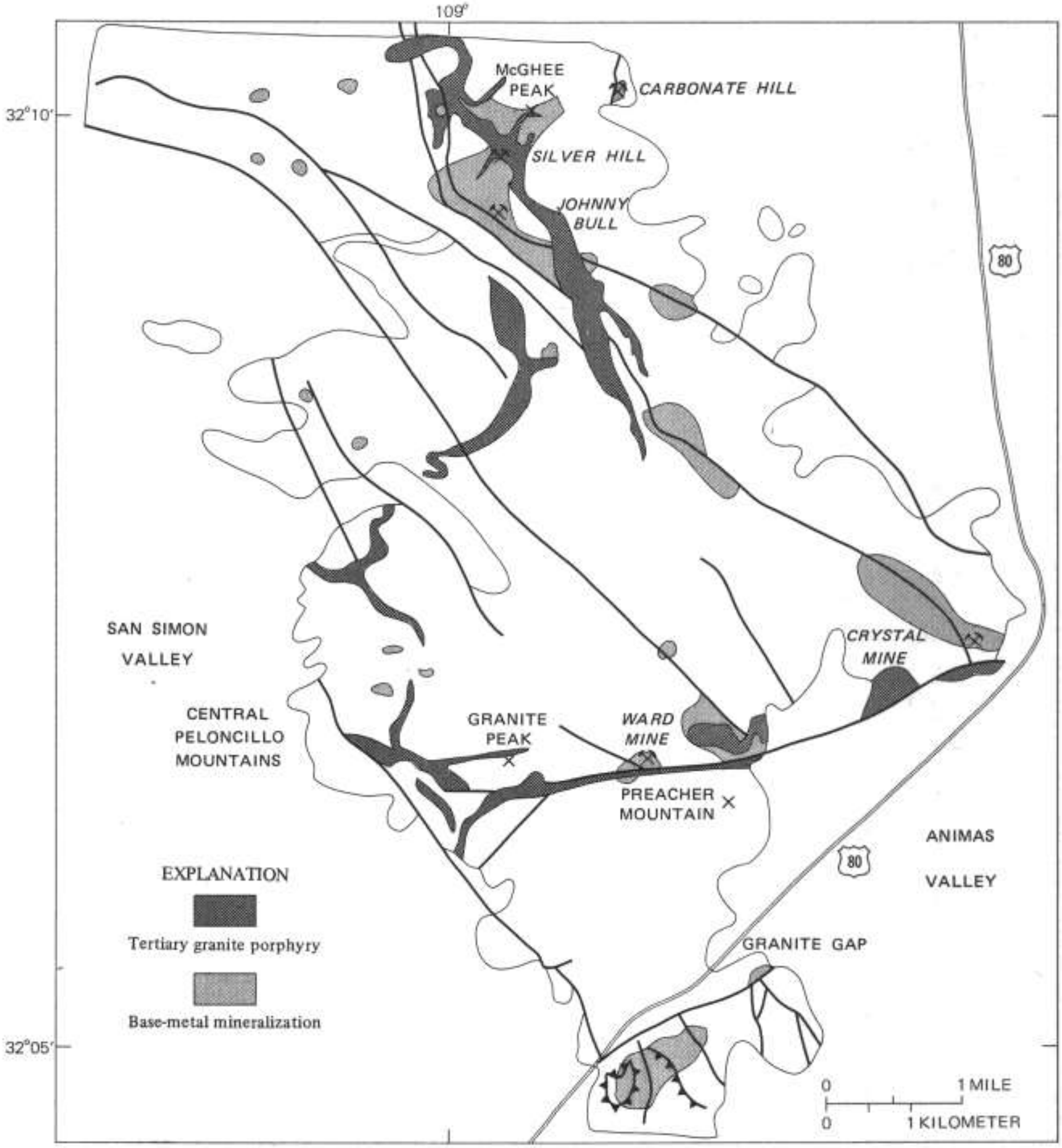

FIGURE 3—Structure map showing distribution of major high-angle normal faults, Tertiary granite porphyry dikes and sills, and areas of base-metal mineralization.

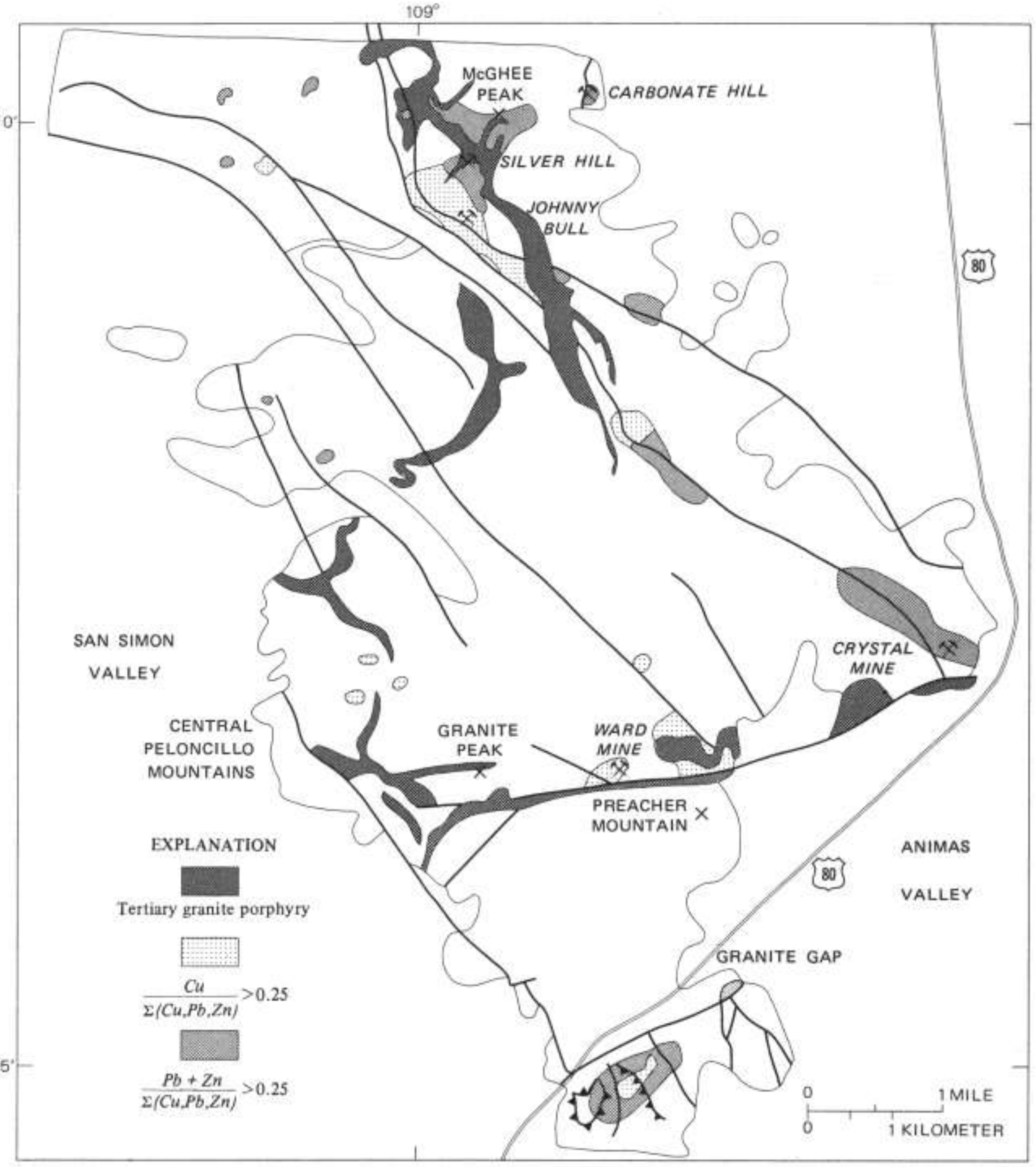

FIGURE 4—Structure map showing distribution of major high-angle normal faults, Tertiary granite porphyry dikes and sills, and areas of enrichment of copper and lead-zinc mineralization.

Type faces: Text in 10-pt. English Times, leaded two points
References in 8-pt. English Times, leaded one point
Display heads in 24-pt. English Times bold

Tables: Camera-ready copy furnished by NM Bureau of Mines & Mineral Resources

Presswork: Miehle Single Color Offset
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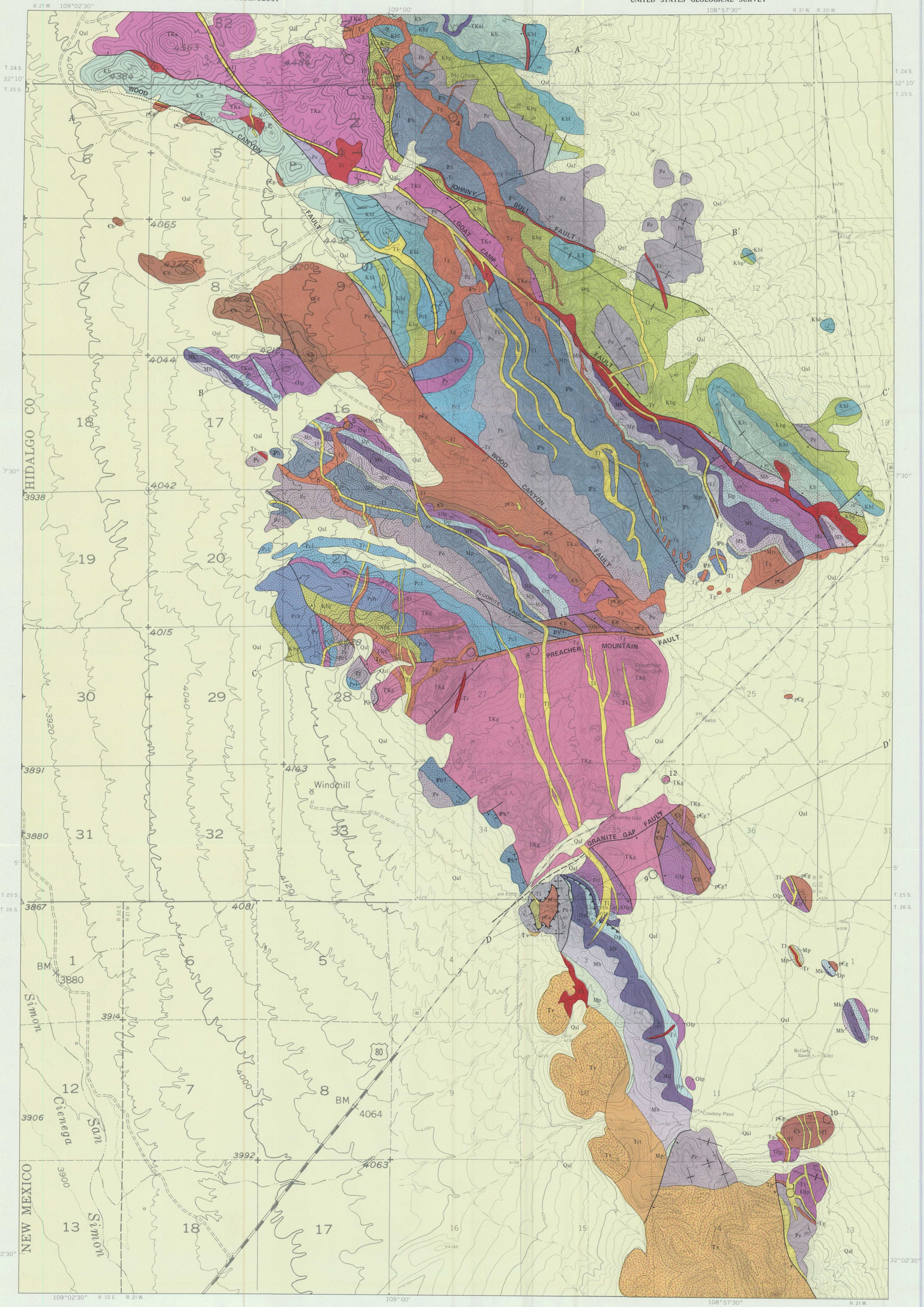
Text on 60 lb. White Offset

Ink: Cover—PMS 282
Text—Black

NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES
A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Prepared in cooperation with the
UNITED STATES GEOLOGICAL SURVEY

CIRCULAR 158
GEOLOGIC MAP



Base from U.S. Geological Survey
Vanar, 1950, 1:62,500; Steins, 1965,
and Cotton City, 1964, 1:24,000

APPROXIMATE MEAN DECLINATION, 1977

SCALE 1:24,000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVALS 10, 20, AND 40 FEET
DATUM IS MEAN SEA LEVEL

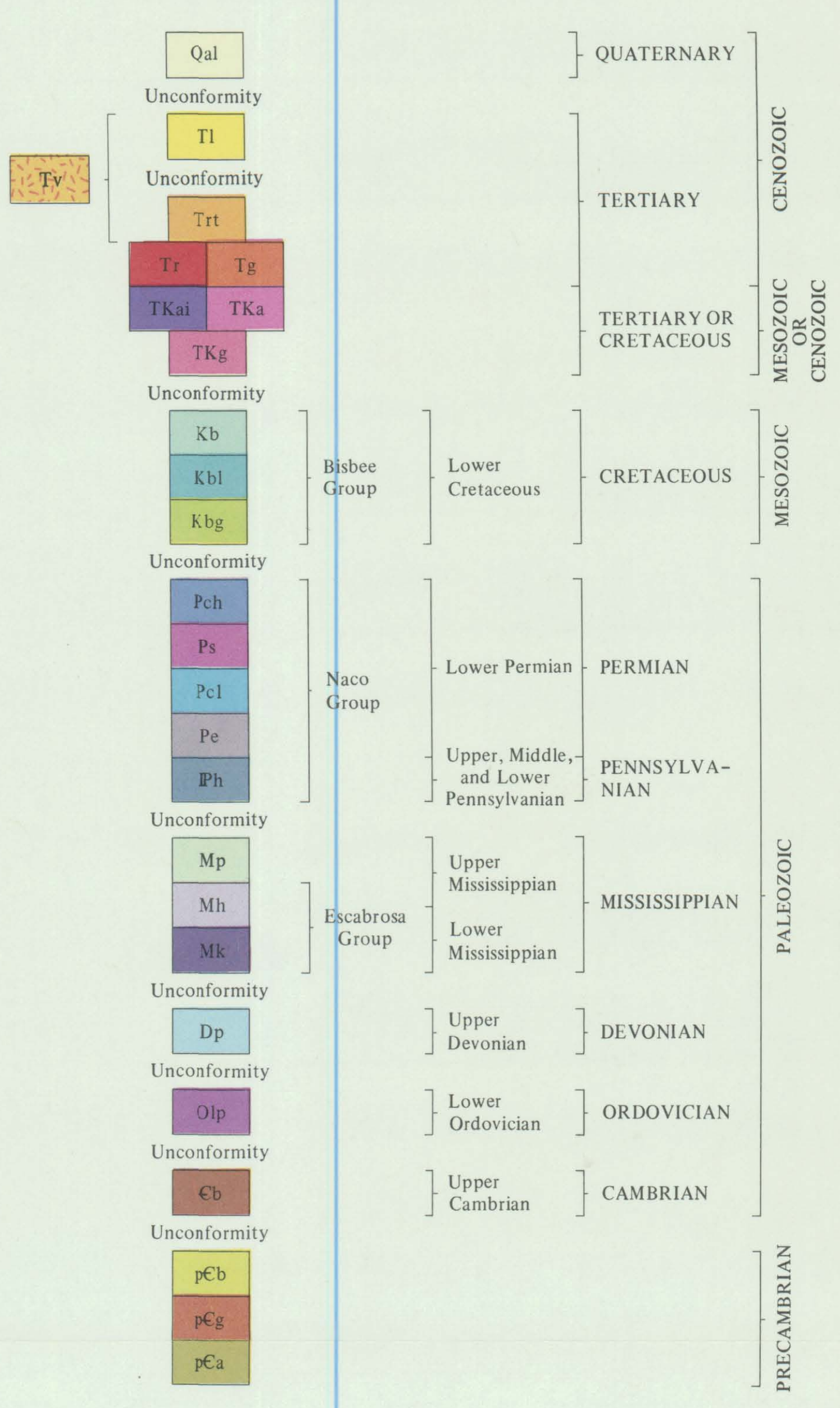
INDEX MAP OF NEW MEXICO

Geology by A. K. Armstrong, 1970–72
and A. K. Armstrong and M. L. Silberman, 1973

Acknowledgments. – Southwestern Research Station of the American Museum of Natural History, Portal, Arizona, for support in 1970–74

Frank Kottlowski, Director, New Mexico Bureau of Mines and Mineral Resources, aided materially in the completion of the project

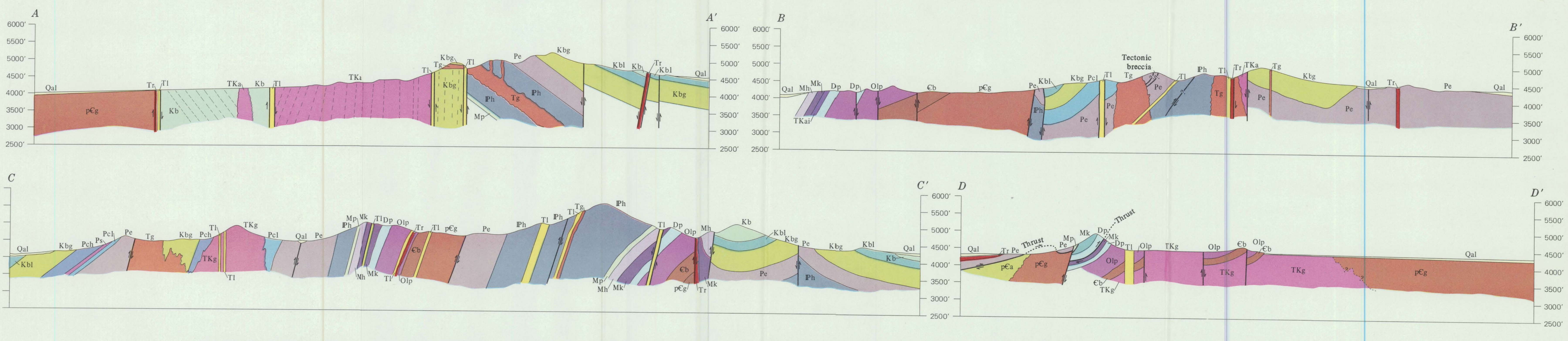
CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qal	ALLUVIAL AND LACUSTRINE DEPOSITS (Quaternary) – Coarse gravel, silt, sand, and lake-bed deposits on east side of map area
Tl	QUARTZ LATITE PORPHYRY (Tertiary) – Labradorite, orthoclase, and biotite
Tv	VOLCANIC ROCKS, UNDIFFERENTIATED (Tertiary) – Include Weatherby Canyon Ignimbrite of Gillerman (1958)
Trt	RHYOLITE TUFF (Tertiary) – White, light-gray
Tr	RHYOLITE AND FELSITE (Tertiary)
Tg	GRANITE PORPHYRY (Tertiary)
TKai	INTRUSIVE ANDESITE (Tertiary or Cretaceous)
TKa	ANDESITE (Tertiary or Cretaceous)
TKg	GRANITE OF GRANITE GAP (Tertiary or Cretaceous)
	BISBEE GROUP (Lower Cretaceous)
Kb	**JOHNNY BULL SANDSTONE and Still Ridge** Formation – Sandstone, shale, and marl
Kbl	**CARBONATE HILL LIMESTONE** – Arenaceous limestone
Kbg	**McGHEE PEAK FORMATION** – Conglomerate, shale, and sandstone
	NACO GROUP (Pennsylvanian and Lower Permian)
Pch	CONCHA LIMESTONE (Lower Permian) – Gray cherty crinoidal limestone
Ps	SCHERRER FORMATION (Lower Permian) – Maroon shale, siltstone, and sandstone
Pcl	COLINA LIMESTONE (Lower Permian) – Gray micritic limestone
Pe	EARP FORMATION (Lower Permian) – Gray limestone, shale, and siltstone
IPh	HORQUILLA LIMESTONE (Lower, Middle, and Upper Pennsylvanian) – Gray cherty limestone
Mp	PARADISE FORMATION (Upper Mississippian) – Gray to brown micrite, oolitic limestone, shale, and siltstone
	ESCABROSA GROUP (Lower and Upper Mississippian)
Mh	HACHITA FORMATION (Lower and Upper Mississippian) – Light-gray crinoidal limestone
Mk	KEATING FORMATION (Lower Mississippian) – Gray limestone and cherty limestone
Dp	PERCHA SHALE (Upper Devonian) – Calcareous black shale
Olp	EL PASO LIMESTONE (Lower Ordovician) – Light-gray dolomite and limestone
€b	BLISS SANDSTONE (Upper Cambrian) – Arkosic to quartzitic quartzite
p€b	BASALT (Precambrian)
p€g	GRANITE PORPHYRY (Precambrian)
p€a	AMPHIBOLITE (Precambrian)

—	Contact – Dashed where approximately located; dotted where concealed
60	Fault, showing dip – Dashed where approximately located; dotted where concealed; bar and ball on downthrown side
▲▲▲▲	Thrust fault – Sawteeth on upper plate
↕	Anticline – Showing crestline
┼	Syncline – Showing troughline
	Strike and dip of beds
55	Inclined
┼	Overturned
┼	Vertical
▨	Approximate outline of metamorphic halo
○4	Location of sample dated by K–Ar method



GEOLOGIC MAP OF THE CENTRAL PELONCILLO MOUNTAINS, HIDALGO COUNTY, NEW MEXICO

By

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1977