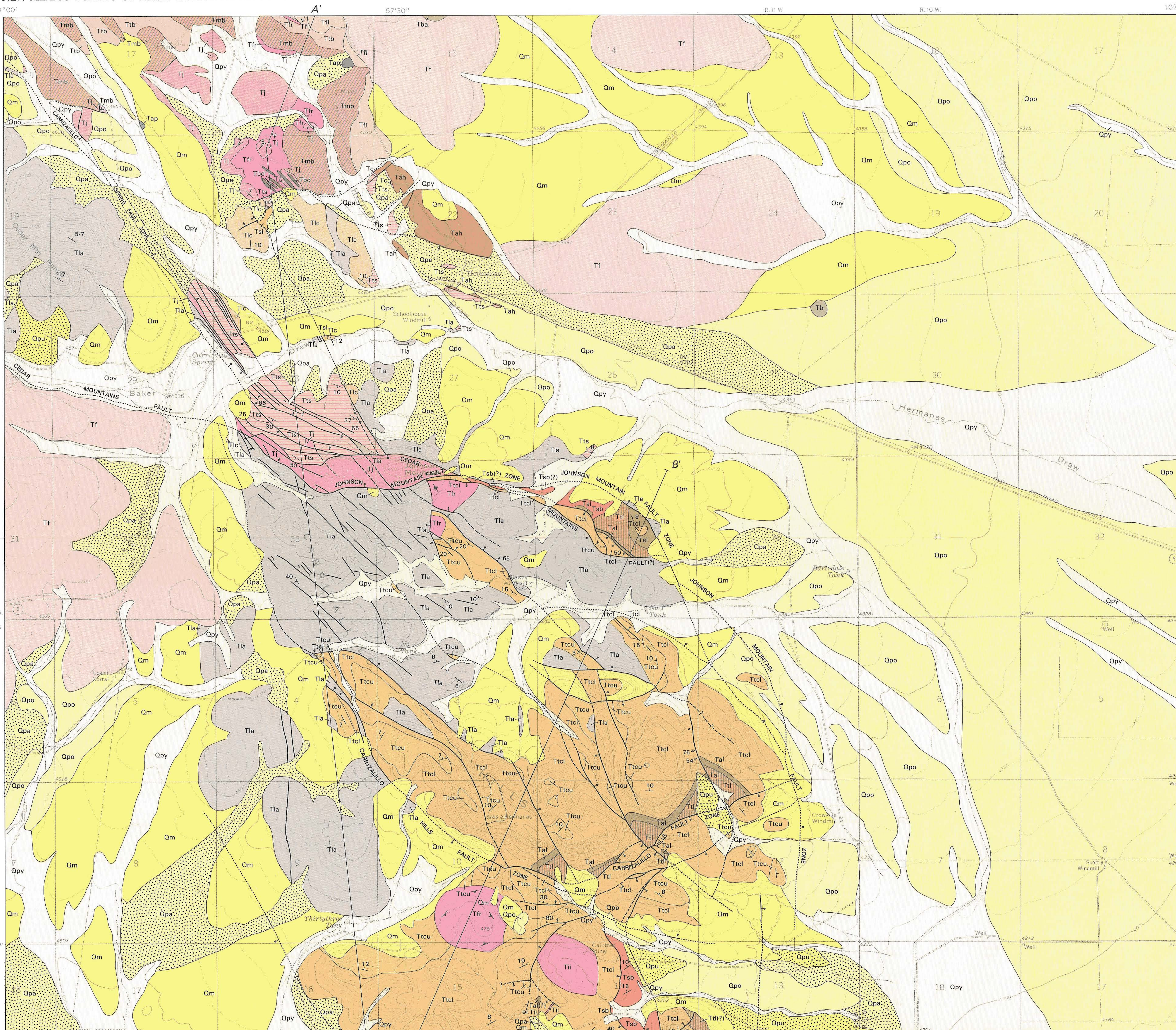
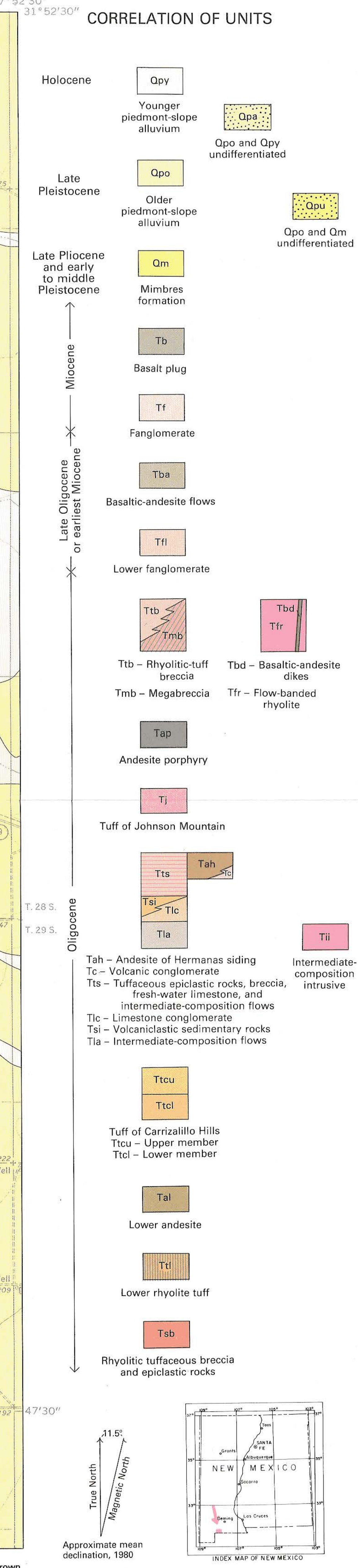
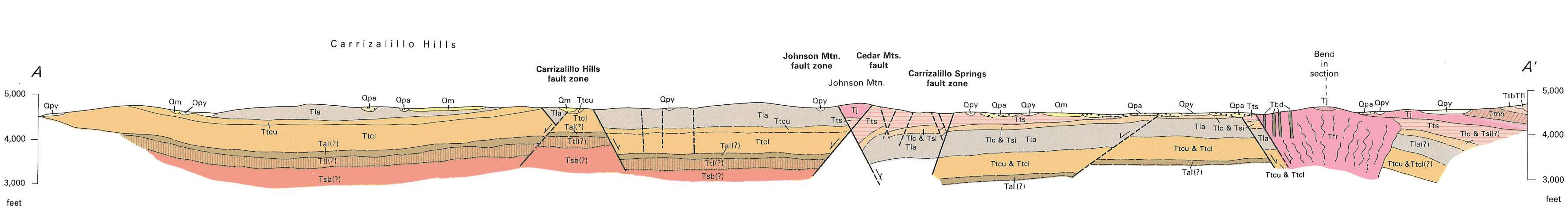
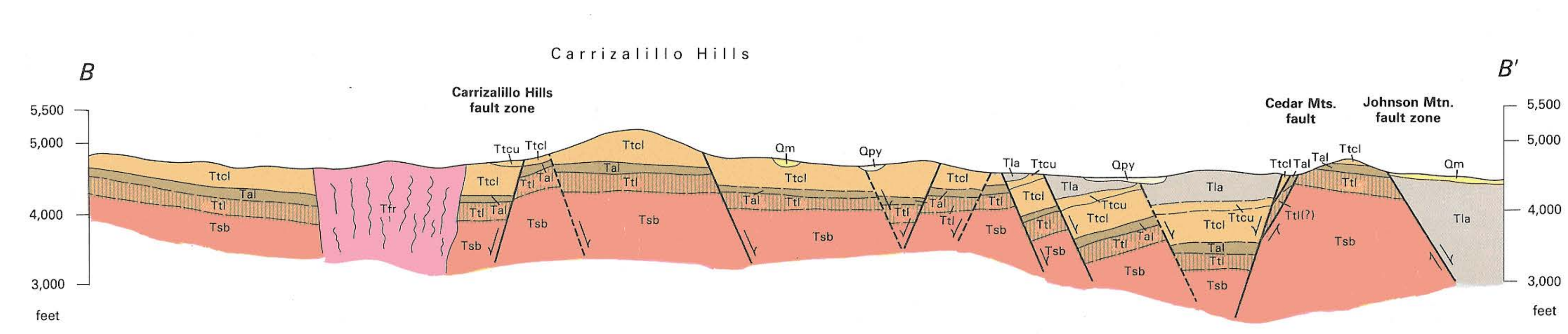




Base from U.S. Geological Survey
Geology by W. R. Seager, 1983–1984

Drafting and layout by K. Doherty and M. Brown
Editing by J. C. Love





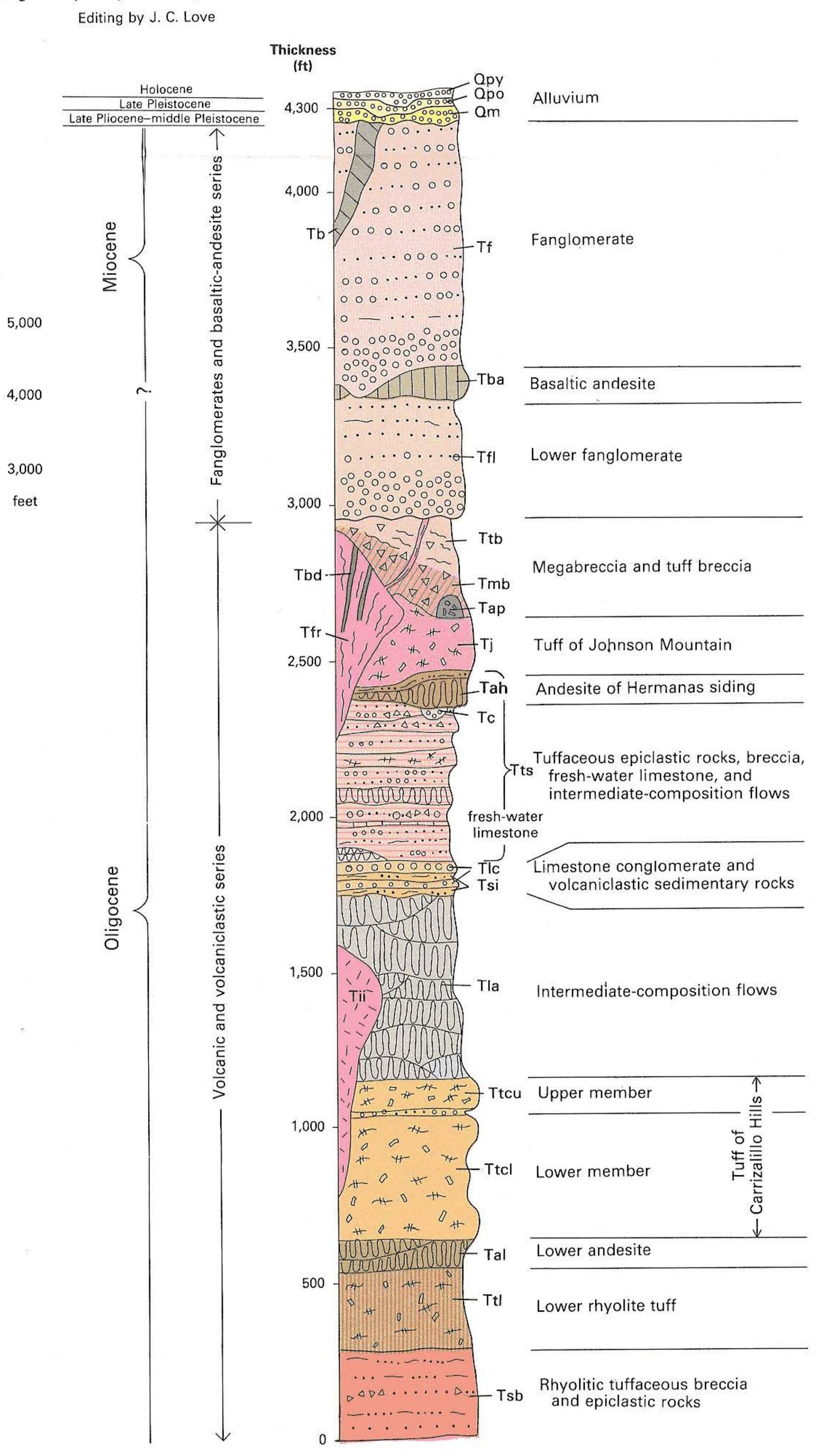


FIGURE 3—Composite stratigraphic column.

Geology of Hermanas quadrangle, Luna County, New Mexico

by William R. Seager and Russell E. Clemons, 1988

scale 1:24,000

INTRODUCTION

Adjoining the State of Chihuahua, Mexico, the Hermanas quadrangle is located in Luna County approximately 30 mi south-southwest of Deming, New Mexico (Fig. 1). NM–9 traverses the center of the quadrangle, providing principal access. The highway connects Columbus, New Mexico, to the east with Hachita, New Mexico, to the west. Mining roads, ranch roads serving stock tanks, and an improved gravel road from Hermanas to Deming allow further access to most parts of the quadrangle.

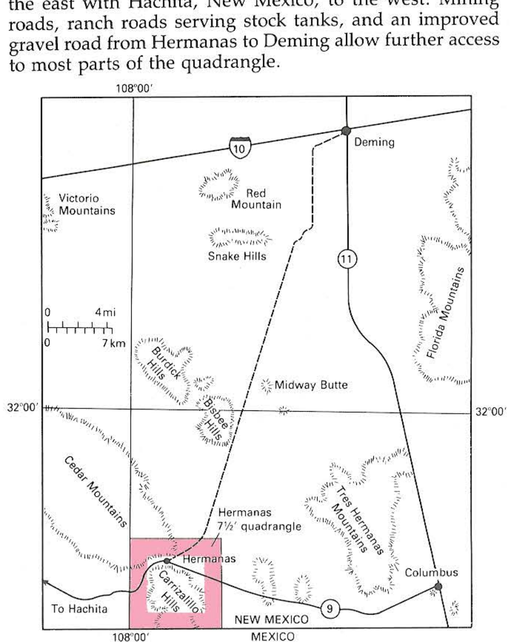


FIGURE 1—Index map showing location of Hermanas quadrangle in Luna County, New Mexico.

Diagonally bisecting the quadrangle is the southeastern terminus of the Cedar Mountains, which, south of NM–9, are known as the Carrizalillo Hills. Upland topography in these hills and low mountains consists of rounded hills and cuestas with local relief less than 800 ft (Fig. 2). Except for scattered juniper on some hills and mesquite or desert willow trees along sandy washes, vegetation is scant and limited to grass, sotol, yucca, cactus, and low bushes, mostly creosote and mesquite.

There are few published accounts of the geology of the Hermanas quadrangle. Darton (1916) briefly described rocks in the Cedar Mountains and Carrizalillo Hills and noted that a small shipment of rich copper ore with gold had been made from a mine in the northwestern Carrizalillo Hills. Griswold (1961) also briefly described the rocks of the Carrizalillo Hills, as well as weak mineralization in several prospects. Prior to the present study, the only published geologic map of the area, at a scale of 1:62,500, was made by Bromfield and Wrucke (1961). Gates' (1985) Master's thesis addressed the geology of the Carrizalillo Hills.

This study of the Hermanas quadrangle in 1982, 1983, and 1984 was an outgrowth of Seager's mapping of the Las Cruces and El Paso 1° × 2° sheets. During the course of that study, detailed mapping of the quadrangle revealed complexly faulted and altered volcanic rocks, and it also

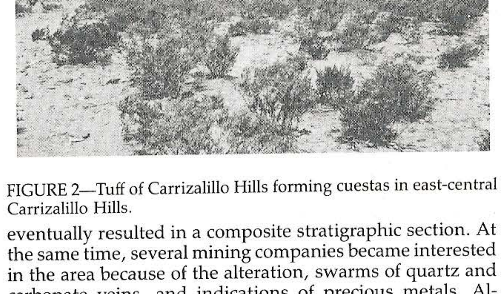


FIGURE 2—Tuff of Carrizalillo Hills forming cuestas in east-central Carrizalillo Hills.

eventually resulted in a composite stratigraphic section. At the same time, several mining companies became interested in the area because of the alteration, swarms of quartz and carbonate veins, and indications of precious metals. Although the present study is not focused on economic geology, we hope that the geologic map, composite section, and account of the petrology of the volcanic section will provide a useful base for further exploration. The mapping was done by Seager, whereas petrographic descriptions of more than 120 thin sections were contributed by Clemons.

ACKNOWLEDGMENTS—We are grateful to Joe Kapler, consulting geologist, Englewood, Colorado, for sharing with us his first-hand knowledge of the geology of the Carrizalillo Hills and for his helpful criticism of the map and text. Lynn Brandvold kindly provided us with chemical analyses, and Jacques Renault determined mineral norms, various oxide ratios, mass-balance calculations, and rock classification with his computer program. The New Mexico Bureau of Mines and Mineral Resources supported this study, and we especially thank Frank E. Kottlowski, Director, for his continuing encouragement and support of our geologic studies in southern New Mexico.

STRATIGRAPHY

General

The stratigraphic section in the Hermanas quadrangle consists of three distinct series of rocks or sediments (Fig. 3). The older series is approximately 3,000 ft thick and consists almost entirely of faulted volcanic and volcaniclastic rocks of silicic to intermediate composition (including ash-flow tuffs). Small subvolcanic domes, plugs, and dikes also are present, as is a peculiar sequence of limestone–granite conglomerate, which is interbedded in the volcanic section. The volcanic and volcaniclastic rocks form most of the upland areas of the quadrangle. Unconformably overlying the volcanic series is a sequence of homoclinally tilted fanglomerate many hundreds of feet thick, at least, which is derived from local volcanic rocks. The fanglomerate contains flows of basaltic andesite near the base and a small plug of basalt near the top. The youngest stratigraphic units in the map area are several generations of alluvial-fan and arroyo sediments, which mantle modern piedmont slopes and fill the extensive bolsons between upland areas. Generally a few tens of feet thick in surface exposures, these deposits may be considerably thicker in the subsurface of major basins.

None of the rocks or sediments in the Hermanas quadrangle have been dated, so their age is inferred from physical correlation with better-dated sections in other parts of southern New Mexico. We presume that the basal series of volcanic and volcaniclastic rocks is Oligocene as are similar sequences of ash-flow tuff, flow-banded rhyolite, and intermediate-composition lava in southern New Mexico, such as those in the Black Range (Elston, 1957; Seager et al., 1982). The overlying fanglomerate is generally correlative with the Santa Fe Group of the Rio Grande region and the Gila(?) Group of the Mogollon–Datil Plateau (Balk, 1962). Undated basaltic-andesite flows near the base of the fanglomerate are probably late Oligocene–earliest Miocene and correlative with the Bear Springs Basalt and Uvas Basaltic Andesite of the Black Range–Sierra de las Uvas region. A basaltic plug near the top of the fanglomerate section appears similar to Pliocene dikes, plugs, and flow remnants in the nearby Palomas volcanic field (Seager et al., 1984). Modern alluvial fans are mostly Quaternary, although the oldest parts of the oldest generation may range into late Pliocene.

Descriptions of map units that follow are grouped into the three main rock series, from oldest to youngest: volcanic and volcaniclastic series, fanglomerate and basaltic-andesite series, and Quaternary deposits. Chemical data for selected rocks are presented in Table 1, and a summary of petrographic data is presented in Tables 2 and 3.

Volcanic and volcaniclastic-rock series

One of the most important features of the basal series of volcanic and volcaniclastic rocks is the extensive alteration, especially in the Carrizalillo Hills south of NM–9. The alteration, dominated by potassic metasomatism, which is revealed in both thin sections and chemical analysis, has precluded dating of many of these rocks. Apparently centered on swarms of quartz- and carbonate-filled faults in the northwestern part of the Carrizalillo Hills, the metasomatism has affected a variety of rock types and has altered pervasively rocks southward to the Mexican border. To the north and northwest of NM–9, in different fault blocks, effects of alteration appear to be essentially absent, or, at least, far less severe. Potassium metasomatism, such as that described here, has also been reported in the Rio Grande rift (Chapin et al., 1978); in various other parts of the southern Basin and Range province (Clemons, 1982b; Chapin and Glazner, 1983; Chapin and Lindley, 1985); in numerous ore districts, such as Bodie, California (O'Neil et al., 1973), and Mogollon, New Mexico (Ferguson, 1927; Bornhorst and Kent, 1975); and from caldera environments (Fenner, 1936; Ratté and Steven, 1967).

RHYOLITIC TUFFS, TUFFACEOUS BRECCIA, AND EPICLASTIC ROCKS (*Tsb*)—The oldest exposed rocks in the Hermanas quadrangle are a sequence of rhyolitic, tuffaceous sandstone, mudstone, and fine- to medium-grained breccia, perhaps containing a few pumiceous air-fall beds. Pale purple or maroon, gray to pink, or cream in color, the strata are siliceous and bleached in patches or along fractures. Locally, limonite is a heavy stain. At most, a few hundred feet are exposed. The unit forms a narrow horst within the tuff of Carrizalillo Hills at the Mexico–United States border, and the contacts with adjacent rocks are faults.

LOWER RHYOLITE TUFF (*Ttl*)—Light-gray rhyolite tuff, at least 250 ft thick, is exposed at the base of a section of predominantly ash-flow tuff in the central and southern Carrizalillo Hills. The base of the tuff is not exposed, but it is overlain successively by a thin andesite flow and the tuff of Carrizalillo Hills, the latter unit being the major ash-flow tuff sheet in the quadrangle. In hand specimens the tuff is distinguished by conspicuous andesitic-lithic fragments and by biotite phenocrysts rendered bronze in color by oxidation. The lithic–vitric tuff contains xenocrysts of perthite, microcline, and oligoclase, which are intensely altered to carbonates and clay, and andesitic-lithic fragments. Xenocrysts and xenoliths total approximately 37% of the rock. The tuff also contains approximately 5% quartz, 1% sanidine, and 2% intensely oxidized biotite in a cryptocrystalline to microcrystalline matrix. The shard-poor part of the matrix is stained easily with sodium cobaltinitrite, indicating its high potassium content. Interstitial patches and pore fillings of carbonate are common. Minor spherulitic zones show some devitrification of the matrix. A chemical analysis of this altered rock is included in Table 1.

LOWER ANDESITE (*Tal*)—An andesitic flow, approximately 60–100 ft thick, overlies the lower rhyolite tuff and underlies the tuff of Carrizalillo Hills in the central and southern Carrizalillo Hills. The dark-gray to reddish-gray lava flows contain approximately 14% stout and blocky feldspar (probably sanidine) phenocrysts and 12% microcrystalline (0.01–0.05 mm) anhedral-equant quartz patches and veins(?) in a matrix of small (0.05–0.3 mm) plagioclase laths, iron oxides, and quartz. Feldspar phenocrysts appear to have a faint perthitic texture, but they are replaced extensively by clay and sericite. Most are surrounded by a dark corona of aligned plagioclase laths and iron oxides. The very high K_2O content (11.27%) and low Na_2O content (0.30%) in this rock indicate severe potassium metasomatism (Table 1). The high K_2O content results in classification of this rock as a trachybasalt, but originally it was probably an andesite (Table 1; Fig. 4).

TUFF OF CARRIZALILLO HILLS (*Ttcl* and *Ttcu*)—The tuff of Carrizalillo Hills is one of the thickest and most widespread volcanic units in the Hermanas quadrangle. It forms the higher hills and cuestas in the central and southern Carrizalillo Hills (Fig. 2) but also typically weathers to brown, boulder-strewn slopes, rounded hills, or local cliffs. The unit extends southward several miles into Mexico.

Two cooling units (members) of the tuff of Carrizalillo Hills, which are separated by a few feet of conglomerate and sandstone, were recognized. The lower member (*Ttcl*), a compound cooling unit, is approximately 450 ft thick and contains alternating zones of poorly welded to moderately welded tuff, which weather to a succession of three to four alternating cliffs and slopes. The unit is crystal rich and weathers to various shades of brown. The upper member (*Ttcu*) is a simple cooling unit of densely welded, pinkish- to reddish-gray-weathering, crystal-rich tuff approximately 60–100 ft thick.

Thin-section studies show the lower tuff to be a vitric-crystal, rhyolitic ash-flow tuff containing prominant xenocrysts—though less abundant than in the lower rhyolite tuff (*Ttl*). Crystal content includes 5–11% quartz, 8–17% sanidine, and approximately 1.5% biotite. Lithic fragments comprise less than 1% of the rock and include andesite, perthite, sandstone, and arkose. Abundant large axiolitic shards in a holocrystalline–microcrystalline or microcrystalline to cryptocrystalline matrix characterize the groundmass. Spherulitic zones are more common in the cryptocrystalline matrix. Potassium-feldspar xenocrysts are argillized and partly replaced with carbonate and kaolin(?), and carbonate also occurs as small, irregular patches in the cryptocrystalline groundmass. Flattened shards in some samples show compaction and flowage around crystals. In less welded samples shards are loosely packed, curved, or oval.

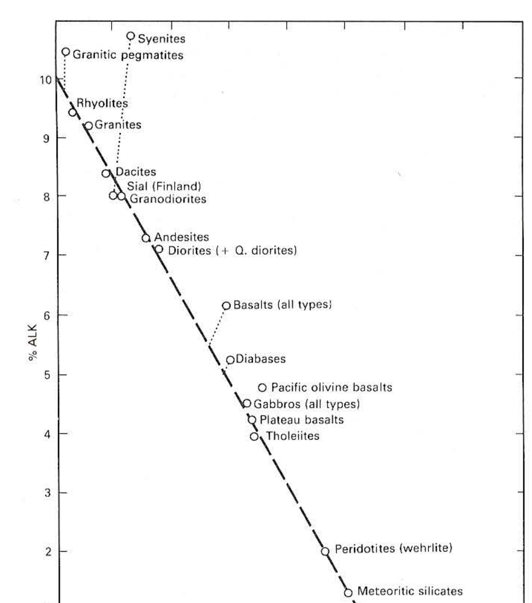


FIGURE 4—Partial composition of the more abundant igneous rock types, plotted as ALK (%Na_2O + K_2O. . .) versus CFM (%CaO + FeO + MgO + MnO. . .), when the rock composition is recast to ALK + CFM + SIL (%SiO_2) = 100%. The heavy broken line illustrates the nearly linear relation between the compositions of rocks in the normal (calc-alkaline) sequence. The lighter dotted lines are projections from the SiO_2 corner to the above line to obtain normalized values. Plots of ALK vs. CFM for altered rocks shown in Table 1 will give an estimate of original, unaltered rock (modified from F. Gordon Smith, PHYSICAL GEOCHEMISTRY, © 1963, Addison-Wesley, Reading, Massachusetts. Figure 15-3. Reprinted with permission).

Petrographically, the upper member is similar to the lower member, except the upper member appears to contain less quartz (2–4%) and sanidine (3–8%). Consequently, some samples of the upper tuff member are best described as vitric ash-flow tuffs containing less than 10% crystals.

In terms of SiO_2, TiO_2, and CaO content, the lower and upper members appear to form a chemically zoned unit (Table 1). Silica content ranges from approximately 76% at the base to less than 70% at the top, decreasing rather steadily upward. TiO_2 and CaO also show a consistent trend by their steady upward increase from the basal lower member tuff to the upper member. These trends suggest progressive evacuation of a magma chamber from the silica-rich top downward, but mineralogical trends indicate such a scheme may be oversimplified.

For example, total crystal content steadily decreases upward in the lower member (22–14%) but increases more than twofold at the top of the lower member (35%), only to fall off to lower values (9–20%) in the upper member. Sanidine and quartz likewise decrease steadily upward in the lower member (12–8% and 10–5%, respectively), only to dramatically increase (14–17% and 7–10%, respectively) at the top of the lower member and fall back to 3–7% in the upper member. These relationships suggest that the initial eruption tapped progressively more aphyric magma down to a certain level, below which crystals, especially sanidine and quartz, were growing in abundance and were erupted as the last part of the lower member. Subsequent eruption of the upper tuff was from a more aphyric and somewhat more mafic upper magma chamber, following a period of partial or whole reequilibration of and, perhaps, new thermal input into the magma chamber. Other schemes to account for the mineral and chemical variations are possible.

Some oxides, particularly sodium and potassium, have no apparent trends. However, K/Na ratios for every sample of tuff of Carrizalillo Hills are anomalously high, typically 8:<1 (Table 1). These anomalous ratios almost certainly reflect extensive potassium metasomatism, which also was revealed in thin sections.

INTERMEDIATE-COMPOSITION FLOWS (*Tla*)—Overlying the tuff of Carrizalillo Hills is a series of intermediate-composition lava flows 600 or more ft thick. These are widely exposed in the Carrizalillo Hills, where they are extensively altered, faulted, and locally mined for quartz and carbonate. A similar section of lavas overlies the tuff of Carrizalillo Hills in the Cedar Mountains, 108°01′–108°06′ longitude and 31°50′–31°52′ latitude (Bromfield and Wrucke, 1961). These rocks are in a separate fault block from those in the Carrizalillo Hills and are relatively unfaulted and unaltered. Consequently, we will describe the unaltered rocks first and then comment on the altered, but probably correlative, flows in the Carrizalillo Hills.

The lava flows in the Cedar Mountains are aphyric to slightly porphyritic andesite, hornblende andesite, hornblende-augite andesite, and dacite. SiO_2 content ranges from 57 to 59.5%. Many of the flows have a distinctly basaltic appearance, so the field term basaltic andesite may apply in general. Flow thicknesses range from 50 to 100 ft, and whereas some flows seem to persist along strike for miles, others are decidedly short and stubby. Seven samples analyzed petrographically (Table 3) contain practically no clay, carbonate, or hematite-limonite, typical alteration of the same rocks in the Carrizalillo Hills. Cedar Mountains andesites are largely nonporphyritic, hypocrystalline, vesicular rocks. Larger plagioclase crystals (to 1 mm) range in composition from andesine (An_{45}) to labradorite (An_{52}), averaging An_{49}. They are typically euhedral, progressively and oscillatorily zoned, and fresh. Euhedral oxyhornblende microphenocrysts (to 2.5 mm), present in some samples, have thin, dark, oxidized rims, but the interiors are pleochroic light brown to red brown and have extinction angles of approximately 15°. Augite and orthopyroxene content ranges from 2 to 18%, with the equant crystals varying in size from microlites to 1 mm. Magnetite content varies from 1 to 4%. Hypocrystalline groundmass textures include intersertal, intergranular, hyalophilitic, and pilotaxitic types. Carbonate and minor zeolites(?) fill some vesicles.

Intermediate-composition flows in the Carrizalillo Hills (*Tla*) are correlatable with *Tla* flows in the Cedar Mountains because of their general lithologic similarity and stratigraphic position above the tuff of Carrizalillo Hills. The main difference between the units in the two areas is the locally higher phosphorus content and widespread alteration of the Carrizalillo Hills rocks. Although alteration of

text continued on back

the flows is extensive, the most intense alteration is restricted to areas of closely spaced fractures, such as those adjacent to Johnson Mountain, or to narrow envelopes marginal to isolated fractures.

In thin section the lavas of the Carrizalillo Hills are microporphyritic, typically containing 18–25% plagioclase phenocrysts (to 1.5 mm long), 7–11% hornblende phenocrysts (to 1.5 mm long), and approximately 1.5% biotite(?) phenocrysts. These are in a hyalopilitic–pilotaxitic or intersertal matrix. The plagioclase is progressively and oscillatorily zoned, but it is so altered to clays, carbonate, sericite(?), and epidote(?) that its original composition is obscure. The mafic minerals are intensely oxidized, and typically their former presence is indicated only by hematite–magnetite ghosts outlining the euhedral crystals. One thin section contains small (0.2–0.8 mm) equant phenocrysts without apparent cleavage, which may be olivine. They, too, have been altered to aggregates of magnetite, carbonate, and microcrystalline quartz. Groundmass consists of tiny (0.005–0.05 mm) plagioclase microlites and laths in a cloudy, cryptocrystalline to glassy material largely replaced by carbonate, iron oxides, clays, and some microcrystalline quartz. A few nonporphyritic rocks are composed chiefly of pilotaxitic–hyalopilitic plagioclase laths averaging 0.01–0.03 mm wide. Hornblende ghosts are ubiquitous in trace amounts as are clay and carbonate alteration products.

Comparison of chemical analyses of lavas from the Cedar Mountains and Carrizalillo Hills reveals the extent to which the latter rocks have been altered (Table 1). Unaltered Cedar Mountains andesites consistently exhibit K/Na ratios near 1.5:4, typical of calc-alkaline andesites. Two samples of andesites from the Carrizalillo Hills, however, show perturbed ratios of 10:1 and 7:3. Clearly the alteration revealed in thin sections has involved extensive addition of K_2O and removal of Na_2O in the Carrizalillo Hills rocks. Although these altered rocks plot as trachybasalt or alkali basalt in Irvine–Baragar classification schemes, their original composition was closer to dacite (Fig. 4).

At the Calumet mine in the southeastern Carrizalillo Hills a pluglike mass of andesite, possibly correlative with intermediate-composition flows (*Tla*), transects the tuff of Carrizalillo Hills. Labeled *Tii* on the geologic map, the greenish to purplish-gray andesite is intensely altered. Potassium-feldspar(?) and plagioclase phenocrysts, which once constituted 10% of the rock, have been changed almost completely to kaolin and carbonate; amphibole(?) phenocrysts are now aggregates of magnetite, as is minor biotite. Locally, spotty epidote alteration gives the rock a greenish color. The nearly oval-shaped plug is approximately 0.4 mi long and exhibits chilled contacts with surrounding tuff, although the western margin may be a fault.

LIMESTONE CONGLOMERATE AND VOLCANICLASTIC SEDIMENTARY ROCKS (*Tlc* and *Tsi*)—Overlying the lavas just described, (*Tla*), is a sequence of conglomerate, sandstone, and mudstone several hundred feet thick. Exposed poorly and discontinuously from Johnson Mountain northward across NM–9, the sequence is notable for its content of limestone and granite clasts derived from Paleozoic, Lower Cretaceous(?), and Precambrian rocks. Permian brachiopods and foraminifera were identified from some clasts (J. J. Kapler, written communication 1985). The source of these clasts is unknown.

Two lithologies, mapped separately, are present: limestone–granite cobble–boulder conglomerate (*Tlc*) and andesitic mudstone, sandstone, and cobble conglomerate (*Tsi*). Age relationships between these are unclear. At least locally they may intertongue. Both units represent deposits of stream-channel systems.

The limestone–granite conglomerate is best exposed in two patches north of NM–9. Whether these two outcrops represent two beds or a single unit repeated by faulting is not clear, although a fault appears to separate the two outcrops. At any rate, the conglomerate primarily consists of cobble- to boulder- size clasts of Paleozoic and Lower Cretaceous(?) rocks, as well as coarse-grained, red Precambrian granite and substantial amounts of andesitic detritus. Clasts range up to approximately 20 inches in diameter and are well rounded and grain supported. In general, the conglomerate and conglomeratic sandstone weather to low, boulder-strewn hills. Rare exposures reveal a reddish-brown color owing to abundant Precambrian detritus. In spite of the poor outcrops the conglomerate and conglomeratic sandstone are moderately well cemented by calcite.

Andesitic sandstone and conglomerate locally underlies and is interbedded in the limestone–granite conglomerate in exposures in Baker Draw, 1 mi west–southwest of Hermanas siding. Pink, pale-maroon, tan, pale-lavender, and gray mudstone, sandstone, and conglomeratic sandstone derived from andesitic volcanic rocks characterize the volcaniclastic rocks. Exploration trenches, open in summer of 1985 near the middle of sec. 21, T28S, R11W, revealed similar volcaniclastic rocks either overlying or faulted against the limestone–granite cobble conglomerate.

The section of limestone–granite conglomerate and associated volcaniclastic rocks is clearly underlain by intermediate-composition lava flows (*Tla*) in sec. 21, T28S, R11W. In sec. 22, T28S, R11W, the conglomerate is overlain by rhyolitic and andesitic sedimentary rocks. Near Johnson Mountain, *Tla* lavas are succeeded upward by similar limestone–granite conglomerate and volcaniclastic rocks containing air-fall tuff and breccia, as well as two interbedded andesitic flows. Consequently, the limestone–granite conglomerate appears to mark a change from predominantly lava-flow emplacement (*Tla*) to deposition of volcaniclastic rocks and relatively minor air-fall tuffs and andesite flows (*Tts* and *Tah*).

TUFFACEOUS EPICLASTIC ROCKS, BRECCIA, FRESH-WATER LIMESTONE, AND INTERMEDIATE-COMPOSITION FLOWS (*Tts*)—A varied suite of rhyolitic to andesitic volcaniclastic rocks with interbedded andesite flows and thin vitric ash-flow tuff (*Tts*) overlies the limestone–granite conglomerate (*Tlc*) and intermediate-composition lavas (*Tla*). The unit crops out most extensively in the highly faulted, veined, and altered region just northwest of Johnson Mountain, as well as in the low hills just northeast of Carrizalillo Springs and south of Hermanas. Assembling a stratigraphic section from these outcrops proved difficult, so the section of *Tts* on the composite stratigraphic column (Fig. 3) is tentative and somewhat diagrammatic. Total thickness may be 400–600 ft.

The *Tts* map unit includes the following lithologies: brownish-red to brick-red, tuffaceous rhyolitic sandstone, breccia, and mudstone; gray to yellow, coarse-grained, tuffaceous rhyolitic sandstone; gray to purplish andesitic sandstone and conglomeratic sandstone; beds of rhyolitic air-fall(?) tuff and breccia; aphyric or slightly porphyritic andesite flows; rhyolitic ash-flow(?) tuff; and, near the base of the section, a fresh-water limestone bed 2–3 ft thick. The andesitic flows are distinguishable from those of the *Tla* map unit and are shown on the columnar section interbedded in *Tts*. One of the flows, andesite of Hermanas siding (*Tah*), was locally differentiated on the map.

Except for outcrops near Hermanas, nearly all of the rocks in this sequence are thoroughly altered, especially in the area immediately northwest of Johnson Mountain. In some instances, the type and composition of the original rock is in doubt. Thin sections reveal that all mafic minerals are extensively oxidized to limonite, hematite, magnetite, and chlorite. Feldspars are argillized and replaced by anhedral, granular, microcrystalline potassium feldspar or sericite. Lithic fragments, some originally andesitic, others rhyolitic, are saturated with microcrystalline potassium feldspar and quartz in the ratio of 2:1. Groundmasses of original flow rocks are altered to kaolin or patchy sericite. Delassite, celadonite, and calcite are also part of the alteration assemblage (J. J. Kapler, written communication 1985). Thus, thin sections indicate that potassium metasomatism of these flows and sedimentary rocks is as severe as that affecting the underlying intermediate-composition flows (*Tla*).

ANDESITE OF HERMANAS SIDING (*Tah*)—Interbedded near the top of the volcaniclastic and lava-flow section just described (*Tts*) is a distinctive andesitic flow that crops out in the hills just north of Hermanas siding. This flow was mapped separately and named andesite of Hermanas siding. Near Hermanas siding (Hermanas), the flow overlies rhyolitic epiclastic rocks, mainly tuffs and breccia, of the *Tts* map unit. Locally, a channel-form volcanic cobble conglomerate (*Tc*), a few feet thick, underlies the andesite. Quaternary alluvium overlies the andesite near Hermanas siding. The andesite of Hermanas siding is also present in outcrops of *Tts* northwest of Johnson Mountain but was included there in the *Tts* map unit. Radiolarian-bearing lacustrine clastic rocks and air-fall tuff overlie the andesite at this locality (J. J. Kapler, written communication 1985).

At least 100 ft thick, the dark-gray to purplish-gray andesite of Hermanas siding contains less than 5% euhedral plagioclase phenocrysts (to 1.5 mm) clustered in a very dense hyalopilitic groundmass of tiny (to 0.1 mm) plagioclase laths and magnetite(?) microlites. Larger plagioclase crystals are argillized and partly replaced with carbonate.

TUFF OF JOHNSON MOUNTAIN (*Tj*)—Named for Johnson Mountain in the northwestern part of the Carrizalillo Hills, the tuff of Johnson Mountain was originally a widespread unit, the second important ash-flow tuff sheet in the Hermanas quadrangle. Besides Johnson Mountain, the tuff crops out in scattered low hills and valley sideslopes along the northeastern flank of the Cedar Mountains in the northwestern Hermanas quadrangle. Our mapping has revealed only faults or intrusive contacts at the base of the unit, although mapping by J. J. Kapler (personal communication 1984) revealed a small area near Johnson Mountain where the tuff depositionally overlies andesitic volcaniclastic rocks of the *Tts* map unit. Approximately 250 ft thick, the tuff is crystal rich, medium grained, and generally reddish gray in color. It is extensively altered in outcrops on or near Johnson Mountain.

Crystal content and ratios vary considerably in this tuff owing, perhaps in part, to hydrothermal alteration or lack of it, to proximity to flow-banded rhyolite masses (*Tfr*), and perhaps to original compositional zoning. Total crystal content varies from approximately 40 to 55% of the tuff, averaging approximately 45% (Table 2). Partly resorbed and embayed euhedral to subhedral fragments (0.1–4.0 mm) of quartz (0–6%), sanidine (1–9%), plagioclase (22–48%), and biotite (1.5–3.5%) comprise the crystal population. An anomalous rock, thought to be tuff of Johnson Mountain but in intrusive contact with flow-banded rhyolite (*Tfr*; NE¼NW¼NW¼ sec. 21, T28S, R11W), contains 27% sanidine and no plagioclase. The rock is extremely altered, however. The groundmass in the tuff of Johnson Mountain is a cryptocrystalline to microcrystalline mosaic of minute crystal fragments, magnetite–hematite, glass, and scarce, visible shards. Spherulitic zones are common. Xenocrysts in the tuff have been altered to clays and carbonate or are empty cavities outlined by thin, black, oxidized (magnetite–hematite) rims.

FLOW-BANDED RHYOLITE (*Tfr*)—Three sizable flow-banded rhyolite domes or plug domes intrude rocks as young as the tuff of Johnson Mountain in the Hermanas quadrangle. Two plugs of rhyolite, one 0.4 mi in diameter and the other 0.2 mi in diameter, transect the tuff of Carrizalillo Hills in the southern and central Carrizalillo Hills, respectively. North of NM–9 a third intrusion has domed the tuff of Johnson Mountain, which still remains as roof pendants and flanking cuestas above the rhyolite. Also preserved on the flanks of this dome are tuff breccia (*Ttb*) and megabreccia beds (*Tmb*) interpreted to be the remains of a tuff cone. They are described in the next section. The rhyolite in these intrusions is delicately to coarsely flow banded, locally stony or spherulitic, and ranges in color from gray to brown to yellow gray. The dome north of NM–9 is transected by a series of basaltic-andesite dikes (*Tbd*).

MEGABRECCIA (*Tmb*) AND TUFF BRECCIA (*Ttb*)—The rhyolite dome north of NM–9 is surrounded on the east, north, and northwest by a complex megabreccia (*Tmb*) and tuff breccia (*Ttb*) unit interpreted to be the remnants of a tuff cone created by the explosive emplacement of the rhyolite dome. The megabreccia overlies the tuff of Johnson Mountain and is unconformably overlain in the Hermanas quadrangle by a basal fanglomerate (*Tfl*) of Gila(?) or Santa Fe type. Numerous dikes and irregular masses of flow-banded or devitrified stony rhyolite, presumably satellite bodies to the central rhyolite dome, invade the megabreccia. Agate-bearing rhyolite masses, either intrusive or fragmented blocks, also comprise part of the megabreccia, and some of these have been quarried extensively for their semiprecious stones.

The megabreccia consists mainly of cobble- to room-size blocks of tuff of Johnson Mountain and flow-banded rhyolite embedded in a matrix of finer-grained, pumiceous tuff breccia. Locally, the matrix appears to be massive rhyolitic glass or devitrified rhyolite glass, which may be welded pumice masses or small intrusives, weathering yellowish green to gray to cream. In places the matrix of tuff breccia is relatively free of large blocks and is mapped simply as tuff breccia (*Ttb*). In general, bedding is lacking or, at least, is not obvious in the limited exposures of matrix. Locally, crude bedding dips away from the central rhyolite dome. The megabreccia usually crops out as low hills or ridges studded with boulders or blocks of every size and orientation with finer-grained matrix material obscured by slope wash.

The origin of the megabreccia seems clearly related to the rise and emplacement of the central rhyolite dome. We visualize disruption of the tuff of Johnson Mountain, as well as upper parts of the rhyolite intrusion itself, as the dome rose explosively toward the surface. Although some of the larger blocks may have slid to their present position in the megabreccia cone, much of the megabreccia was emplaced as proximal air-fall material and, subsequently, was invaded irregularly from the side or from below by satellite masses of rhyolite.

ANDESITE PORPHYRY (*Tap*)—Two outcrops of andesite porphyry are surrounded by megabreccia. Whether these outcrops are blocks within the megabreccia, intrusives into it, or remnants of the pre-megabreccia "basement" is not known. The porphyry is unlike any of the volcanic section cropping out below the tuff of Johnson Mountain. It is composed of 2% andesine phenocrysts (to 5 mm), 2% hornblende phenocrysts (to 2 mm), 2% biotite phenocrysts (to 1 mm), and 1% augite and orthopyroxene phenocrysts (to 4 mm) in a felted, holocrystalline matrix. The matrix contains andesine laths, magnetite, enstatite granules, and abundant unidentified mafic microlites. Plagioclase is progressively zoned, and many appear "wormy." Biotite books are ragged and oxidized, which produced much of the magnetite.

Fanglomerate and basaltic-andesite series

Unconformably overlying the andesite porphyry (*Tap*), megabreccia (*Tmb*), and, in quadrangles to the north, various other rock units is a sequence of fanglomerate, interbedded basaltic-andesite flows, basaltic plugs, cinder cones, and dikes. The basaltic-andesite flows (*Tba*) occur near the base of the sequence. Fanglomerate below the flows is labeled *Tfl* on the geologic map; fanglomerate above or within the flows is identified by *Tf*. Basalt plugs transecting *Tf* are noted by *Tb*.

The lower fanglomerate (*Tfl*) consists of a basal boulder conglomerate several hundred feet thick derived from immediately underlying volcanic rocks, as well as from older volcanic rocks exposed elsewhere in the quadrangle. Boulders to 5 ft in diameter embedded in a sandy to gravelly matrix are not uncommon. These rocks are the products of mudflow or debris-flow deposition on ancient piedmont slopes. Upward, coarse conglomerate gives way to light-gray to light-tan, tuffaceous, volcaniclastic sandstone, siltstone, and conglomeratic siltstone, also a few hundred feet thick. This, in turn, is overlain by or interfingers with basaltic-andesite flows (*Tba*).

Exposed only in one area in the Hermanas quadrangle, the basaltic-andesite flows farther northwest in the Cedar Mountains are extensive and several hundred feet thick. There they consist of a series of black, gray, red, or brown vesicular to platy andesite to basaltic flows. One thin section reveals microphenocrysts (0.05–1.0 mm) of olivine, mostly replaced with iddingsite, in an intersertal matrix of labradorite–andesine laths, pyroxene(?), olivine, magnetite, and glass. The fresh, slender, plagioclase laths are aligned in an excellent fluidal texture. Calcite fills most of the small (0.1–0.8 mm) vesicles and forms a few interstitial patches. Chemical analysis of this rock (Table 1) yields 52% SiO_2 and falls in the tholeiite field of Irvine and Baragar (1971).

Above the basaltic andesite a sequence of volcanic fanglomerate, conglomeratic sandstone, and sandstone (*Tf*), probably 500–1,000 ft thick, dips gently northeastward off the Cedar Mountains. These rocks are derived from the basaltic andesite, as well as from all older local volcanic rocks. Unfortunately, they are poorly exposed except in a few gully bottoms, but to the north in the Hermanas NW quadrangle exposures are better and more frequent.

A small plug(?) of basalt (*Tb*) apparently cuts the *Tf* fanglomerate in the northeastern part of the map area. The plug contains sparse microphenocrysts (0.2–0.5 mm) of pyroxene, plagioclase, and oxidized hornblende in an intersertal, vesicular groundmass of plagioclase, pyroxene, magnetite, and pale-brown glass. The blocky plagioclase laths are sodic labradorite. Pyroxene phenocrysts are predominantly hypersthene, whereas the groundmass pyroxene appears to be mostly clinopyroxene. Hornblende phenocrysts may be xenocrysts, because they are partly resorbed and have thick oxidized borders of iron oxides. Minor carbonate fills a few vesicles.

The basaltic-andesite flows (*Tba*) between *Tfl* and *Tf* are petrographically and chemically similar to upper Oligocene–lower Miocene lavas (29–26 m.y.) of the Uvas Basaltic Andesite and Bear Springs Basalt (Elston, 1957; Clemons and Seager, 1973; Clemons, 1979; Seager et al., 1982). Furthermore, the basaltic andesite of the Hermanas quadrangle is located near the base of a thick basin-fill sequence, as are the Uvas Basaltic Andesite (lower Santa Fe Group) and Bear Springs Basalt (Gila Conglomerate). Consequently, we believe that the basaltic andesite of the southeastern Cedar Mountains is roughly time correlative with the Uvas Basaltic Andesite and Bear Springs Basalt. Furthermore, we correlate *Tfl* and *Tf* with the bulk of the lower Santa Fe Group and Gila Conglomerate, as did Balk (1962) in his mapping of the Tres Hermanas Mountains area. The basaltic plug that cuts *Tf* may be correlative with plugs, dikes, and cinder cones that crop out in the Tres Hermanas Mountains and Palomas basalt field a few miles east of the Hermanas quadrangle. These latter rocks are 2.9–5 m.y. old (Seager et al., 1984), and they indicate that the bulk of *Tf* basin fill is pre-Pliocene. *Tfl* may range in age from late Oligocene to earliest Miocene, whereas *Tf* is largely, if not entirely, Miocene.

We interpret the *Tfl* fanglomerates and *Tba* basaltic rocks to record the onset of vigorous late Tertiary extension in the Hermanas quadrangle and the *Tfl* and *Tf* fanglomerates to be the fill of a broad extensional basin that is no longer part of the landscape. Uplift of the modern ranges, such as the Cedar Mountains, Tres Hermanas Mountains, and other fault blocks, segmented the earlier basins and piedmont slopes, incorporating parts of them into the modern uplifts. Exactly when this segmentation took place is not clear from relationships in the Hermanas quadrangle but is thought to have taken place in the last 7–9 m.y. in the southern Rio Grande rift (Chapin and Seager, 1975; Seager et al., 1984).

Quaternary deposits

Several generations of alluvial fans have been deposited adjacent to the Carrizalillo Hills and Cedar Mountains during the Quaternary.These are distinguished from one another primarily by their geomorphic position and degree of soil development.

The oldest fans (*Qm*) are assigned to the Mimbres formation of Clemons (1982a). On upper piedmont slopes these fans are topographically highest and are deeply trenched by arroyo systems; younger fans are inset below them. Petrocalcic horizons up to 3 ft thick typically cement uppermost *Qm* fan deposits. On middle and lower piedmont slopes, however, *Qm* deposits are generally buried by younger fans. *Qm* deposits are up to 50 ft thick on piedmont slopes and typically consist of coarse gravelly alluvium grading downslope to gravelly sand or loam. Except for petrocalcic horizons the deposits are either weakly cemented or uncemented. Correlation with better-dated fans of the Camp Rice Formation in the Rio Grande valley (Gile et al., 1981) suggests that the Mimbres fan deposits are older than about 0.4 m.y., and the oldest parts may range into latest Pliocene.

Qpo fans are similar in composition, thickness, cementation, and distribution to Mimbres fans, but the former are inset below the Mimbres fans on upper piedmont slopes and exhibit weaker petrocalcic horizons. They are, however, geomorphically above modern arroyo floors by several feet to several tens of feet. On middle and distal piedmont slopes *Qpo* fan deposits underlie broad stable fan surfaces and exhibit well developed, reddish, clay-rich soil suitable for irrigated crops. *Qpo* fan deposits and surfaces are generally late Pleistocene (0.4–0.1 m.y.) based on correlation with similar, better-dated fans in the Rio Grande valley (Gile et al., 1981).

Youngest deposits (*Qpy*) in the Hermanas quadrangle include fans at the mouths of currently or recently active drainage systems, as well as the deposits on modern arroyo floors. These deposits are inset below all older fan remnants on upper piedmont slopes but have buried older deposits and surfaces on middle to distal piedmont slopes. Petrocalcic horizons are weak or absent, but weak, clayey B horizons and A horizons may be present. Deposits range from coarse gravel to loam or even clay depending on their position on the fan or in the arroyo system. In general, *Qpy* deposits are less than 15 ft thick. Based on charcoal dates from correlative deposits in the Rio Grande region, *Qpy* sediments are less than 15,000 yrs old.

STRUCTURE

General

High-angle normal faulting dominates the structural features of the Hermanas quadrangle, and the two principal upland regions, the Cedar Mountains and Carrizalillo Hills, are products of this faulting. The Cedar Mountains, a northwest-trending fault block, are bounded on the southwest and northeast by faults: the Cedar Mountains fault and Carrizalillo Springs fault zone, respectively. Rocks in this horst dip homoclinally northeastward approximately 10°. Farther south, the Carrizalillo Hills consist of faulted rocks dipping generally northward approximately 10°, although there are also broad folds. The horstlike, lozenge-shaped Carrizalillo Hills uplift is bordered by two curved fault zones striking generally northwest: the Carrizalillo Hills fault zone on the southwest and the Johnson Mountain fault zone on the northeast. The four major fault zones that outline the Cedar Mountains and Carrizalillo Hills converge and intersect west of Johnson Mountain, creating a zone of intensely broken ground approximately 1 mi². Faults and fractures at this intersection are filled with quartz and carbonate, and adjacent rocks are thoroughly altered and tilted at angles of 15–90°. Locally, veins approach 50 ft in width; these have been the focus of precious-metal exploration in recent years.

Although less intensely fractured compared to the four-fault intersection area, the Carrizalillo Hills block is thoroughly dismembered by a pervasive fault system. The pattern of faulting is one of branching and anastomosing fractures so that the whole system exhibits a braided pattern. Faults typically enclose lozenge-shaped horst and graben blocks whose long axis may range from a fraction of a mile to several miles. Whereas the overall trend of the braided fault system is N45°W, many segments of curved faults trend easterly or even northeasterly.

In plan view the geometry of the fault system is typical of strike-slip systems (Wilcox et al., 1973; Reading, 1980). However, strike-slip faults are typically vertical or at least steep, whereas fault surfaces in the Cedar Mountains and Carrizalillo Hills dip 50–80°. We found no evidence in the form of drag features, second-order folds or faults, slickensides, or offset rock bodies that might indicate more than a small component of strike slip. The faults in the map area all seem to be essentially dip-slip, high-angle normal faults. A Neogene age is based on the fact that the faults cut all Oligocene(?) volcanic units, and some displace basal parts (*Tfl*) of the overlying fanglomerate series.

Cedar Mountains fault

The Cedar Mountains fault zone borders the Cedar Mountains on the southwest where it has juxtaposed upper Tertiary fanglomerate (*Tf*) on the southwest against Oligocene lavas (*Tla*) on the northeast. Exposures of the fault are common in quadrangles west of the Hermanas quadrangle. Stratigraphic separation may be approximately 2,500 ft in this area, with downthrow to the southwest. Farther east, the Cedar Mountains fault enters the complex junction of the four major fault zones and is not easily identified. We regard the major down-to-the-south faults on the northern side of Johnson Mountain and on the southern side of the structurally high block centered on sec. 35, T28S, R11W as the probable continuation of the fault zone into the Carrizalillo Hills. Stratigraphic separation on these faults is 1,000 ft or less, the decrease in throw relative to the more westerly segment of the fault being a product of the intersection of the Cedar Mountains fault with the Carrizalillo Hills fault zone.

Carrizalillo Springs fault zone

The Carrizalillo Springs fault zone strikes northwesterly through volcanic rocks along the northeastern flank of the Cedar Mountains. Although the zone consists of faults with opposing dips and direction of downthrow, the major fault in the zone seems to be downthrown to the northeast. Thus, the main structural block (*Tla*) between this fault zone and the Cedar Mountains fault zone is a horst. Stratigraphic separation is less than 1,000 ft.

From Carrizalillo Springs southward, the fault zone widens, consisting of a major down-to-the-northeast fault dipping northeast and numerous antithetic faults dipping southwest. Most of the faults are filled with thick, prominent veins of quartz and carbonate, making the system conspicuous as it crosses NM–9 and Baker Draw. As the system approaches the Cedar Mountains fault zone west of Johnson Mountain, it appears to bend eastward into semiparallelism with that zone. This region of convergence of the two zones contains the most altered and fractured ground in the quadrangle and has been the site of extensive exploration for precious metals in 1983, 1984, and 1985.

Carrizalillo Hills fault

Bordering the Carrizalillo Hills on the south and west, the Carrizalillo Hills fault zone is one of the best exposed fault zones in the quadrangle and is a good example of the curving fault zones that border large lozenge-shaped structural blocks. The faults in the zone dip moderately to steeply south or southwest, and the zone steps structural blocks down to the south or southwest. Tuff of Carrizalillo Hills (*Ttcl*), lower rhyolite tuff (*Ttl*), or lower andesite flow (*Tal*) commonly form the footwall block at the surface, whereas higher parts of *Ttcl* or the overlying lava flows (*Tla*) form the hanging wall. Stratigraphic separation is generally 400–800 ft. Approximately 1.2 mi southwest of the Carrizalillo Hills fault, another fault, unnamed and projected into the quadrangle from exposures in Mexico, steps the volcanic section down again. Thus, the Carrizalillo Hills volcanic rocks are stepped down by at least two major fault zones into the basin that forms the southwestern corner of the Hermanas quadrangle.

Johnson Mountain fault zone

The curved Johnson Mountain fault zone, downthrown to the north, northeast, and east, bounds the lozenge-shaped Carrizalillo Hills block on the north and east. Poorly exposed on the south side of Johnson Mountain, the major fault can be traced eastward where it seemingly crosses the Cedar Mountains fault zone in the NE¼ sec. 34, T28S, R11W and, then, is exposed on the northern edge of the hills in the center of sec. 35, T28S, R11W. From there, the fault zone is buried but apparently bends south truncating the east-trending cuestas of the central and southern Carrizalillo Hills. One possible piedmont scarp, 0.2 mi long, which cuts a Mimbres fan (*Qm*), indicates that this zone has been active in the Quaternary. Other scarps along the zone are also present in Mexico.

Potassic alteration and normal faulting relationship

Recent papers have pointed out the widespread geographic correspondence between tilted rocks, low-angle normal faults, and potassic alteration in the Rio Grande rift and southern Basin and Range (Chapin and Glazner, 1983; Lindley et al., 1983; Bartley and Glazner, 1985; Chapin and Lindley, 1985). Bartley and Glazner (1985) show how hydrothermal systems, the delivery system for potassic alteration, could modify regional stress trajectories in such a way that low-angle normal faults are initiated rather than high-angle ones. According to Bartley and Glazner (1985), high pore pressure combined with a surface slope are required for the formation of low-angle faults, the high pore pressure resulting from sealed geothermal systems.

Although potassic alteration is well developed and widespread across the Carrizalillo Hills, the associated normal faulting is high angle without exception (>50°), and, except very locally, rocks are not strongly rotated (<15°). Thus, there is no one to one relationship between regions of potassic alteration, strong stratal rotation, and low-angle normal faulting. Regions of extension characterized by high-angle faulting may also be the sites of potassic alteration and their associated geothermal systems. In such areas, however, the geothermal systems may not be sealed so that high fluid pore pressures are precluded, or surface slopes may be negligible, or both. In any case, the Carrizalillo Hills rocks and structures argue against the notion that every region of potassic alteration is also the likely site of highly rotated rocks and low-angle faults.

ECONOMIC GEOLOGY

Although considerable prospecting in the Cedar Mountains, and especially Carrizalillo Hills, was done in the early part of the century, very little ore was ever shipped. Darton (1916) notes that a small shipment of copper-rich ore with associated gold was made from a vein in the northwestern part of the Carrizalillo Hills. Griswold (1961) provides the latest and best summary of mineral deposits in the Carrizalillo Hills. He describes chrysocolla, malachite, and azurite associated with quartz, carbonate, and breccia veins in the broken region northwest of Johnson Mountain; gold prospects located "just east of Hermanas and north of the highway," which produced a few shipments of ore; and the copper-bearing andesite at the Calumet mine in the southern Carrizalillo Hills.

In the early to middle 1980's renewed interest in the district was triggered by favorable prices for precious metals. The intensely veined and altered rocks at the intersection of the four major fault zones were examined in detail by several companies. Trenches were dug, samples analyzed, detailed geologic maps prepared, and in 1984–1985 target areas drilled. Apparently the results of these investigations were encouraging as exploration continued into the summer of 1985.

Alteration is a clear aid for mineral exploration in the Hermanas quadrangle. The area of most intense alteration and focus for precious-metal exploration is centered northwest of Johnson Mountain in the area where the four major fault zones converge. Rock units in this region are segmented by closely spaced faults, which apparently created ground permeable enough to localize the core of a geothermal–hydrothermal system. Alteration and quartz–carbonate veining is most intense, widespread, and pervasive in this region, although somewhat weaker alteration of andesite and ash-flow tuff persists southward to the Mexican border. The dominant alteration is potash metasomatism as revealed in whole-rock chemical analysis and thin sections. In addition to potassium feldspar, the alteration assemblage includes clays, sericite, chlorite, celadonite, quartz, calcite, and various iron oxides (J. J. Kapler, written communication 1985). The age of alteration is clearly younger than the tuff of Johnson Mountain and may be younger than flow-banded rhyolite masses, as J. J. Kapler (written communication 1985) reports quartz–carbonate veins cutting basaltic–andesite dikes (*Tbd*) within the rhyolite dome north of NM–9.

REFERENCES

Balk, R., 1962, Geologic map of Tres Hermanas Mountains: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 16, scale 1:48,000.

Bartley, J. M., and Glazner, A. F., 1985, Hydrothermal systems and Tertiary low-angle normal faulting in the southwestern United States: Geology, v. 13, no. 8, pp. 562–564.

Bornhorst, T. J., and Kent, G. R., 1985, Geochemistry of host-rock alteration at the Eberle mine, Mogollon mining district, southwestern New Mexico; *in* Eggleston, T. L. (ed.), Epithermal deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 199, pp. 7–15.

Bromfield, C. S., and Wrucke, C. T., 1961, Reconnaissance geologic map of the Cedar Mountains, Grant and Luna Counties, New Mexico: U.S. Geological Survey, Mineral Investigations Field Studies Map MF–159, scale 1:62,500.

Chapin, C. E., Chamberlin, R. M., Osburn, G. R., Sanford, A. R., and White, D. W., 1978, Exploration framework of the Socorro geothermal area, New Mexico, *in* Chapin, C. E., and Elston, W. E. (eds.), Field guide to selected cauldrons and mining districts of the Datil–Mogollon volcanic field, New Mexico: New Mexico Geological Society, Special Publication 7, pp. 115–130.

Chapin, C. E., and Glazner, A. F., 1983, Widespread K_2O metasomatism of Cenozoic volcanic and sedimentary rocks in the southwestern United States (abs.): Geological Society of America, Abstracts with Programs, v. 15, no. 5, p. 282.

Chapin, C. E., and Lindley, J. I., 1985, Potassium metasomatism of volcanic and sedimentary rocks in rift basins, calderas, and detachment terranes; *in* Papers presented to the conference on heat and detachment in crustal extension on continents and planets: Lunar and Planetary Institute, Contribution 575, pp. 25–31.

Chapin, C. E., and Seager, W. R., 1975, Evolution of the Rio Grande rift in the Socorro and Las Cruces areas: New Mexico Geological Society, Guidebook to 26th Field Conference, pp. 297–321.

Clemons, R. E., 1979, Geology of Good Sight Mountains and Uvas Valley, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 169, 32 pp., 2 sheets, scale 1:48,000.

Clemons, R. E., 1982a, Geology of Massacre Peak quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 51, scale 1:24,000.

Clemons, R. E., 1982b, Geology of Florida Gap quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 52, scale 1:24,000.

Clemons, R. E., and Seager, W. R., 1973, Geology of Souse Springs quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 100, 31 pp., 1 sheet, scale 1:24,000.

Darton, N. H., 1916, Geology and underground water of Luna County, New Mexico: U.S. Geological Survey, Bulletin 618, 188 pp.

Fenner, C. N., 1936, Bore-hole investigations in Yellowstone Park: Journal of Geology, v. 44, pp. 225–315.

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 38, 86 pp., 4 sheets, scale 1:48,000.

Ferguson, H. G., 1927, Geology and ore deposits of the Mogollon mining district, New Mexico: U.S. Geological Survey, Bulletin 787, 100 pp.

Gates, E. E., 1985, The geology of the Carrizalillo Hills, Luna County, New Mexico: M.S. thesis, University of Texas (El Paso), 133 pp., 1 sheet, scale 1:12,000.

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico—Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222 pp.

Griswold, G. B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 72, 157 pp., 10 sheets.

Irvine, T. N., and Baragar, W. R. A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, pp. 523–548.

Lindley, J. I., D'Andrea–Dinkelman, J. F., Glazner, A. F., and Osburn, G. R., 1983, Chemical and mineralogic variations associated with potassium metasomatism of Tertiary volcanic rocks from the Rio Grande rift and Mojave Desert (abs.): Geological Society of America, Abstracts with Programs, v. 15, no. 5, p. 282.

O'Neil, J. R., Silberman, M. L., Fabbi, B. P., and Chesterman, C. W., 1973, Stable isotope and chemical relations during mineralization in the Bodie mining district, Mono County, California: Economic Geology, v. 68, pp. 765–784.

Ratté, J. C., and Steven, T. A., 1967, Ash flows and related volcanic rocks associated with the Creede caldera, San Juan Mountains, Colorado: U.S. Geological Survey, Professional Paper 524–H, 58 pp.

Reading, H. G., 1980, Characteristics and recognition of strike- slip fault systems; *in* Ballance, P. F., and Reading, H. G. (eds.), Sedimentation in oblique-slip mobile zones: International Association of Sedimentologists, Special Publication, v. 4, pp. 7–26.

Seager, W. R., Clemons, R. E., Hawley, J. W., and Kelley, R. E., 1982, Geology of northwest part of Las Cruces 1° × 2° sheet (scale:1:125,000), New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 53.

Seager, W. R., Shafiqullah, M., Hawley, J. W., and Marvin, R., 1984, New K–Ar dates from basalt and the evolution of the southern Rio Grande rift: Geological Society of America, Bulletin, v. 95, no. 1, pp. 87–99.

Smith, F. G., 1963, Physical geochemistry: Addison–Wesley, Reading, Massachusetts, 624 pp.

Wilcox, R. E., Harding, T. P., and Seely, D. R., 1973, Basic wrench tectonics: American Association of Petroleum Geologists, Bulletin, v. 57, pp. 74–96.

TABLE 1—Chemical analyses of selected volcanic rocks from the Hermanas quadrangle.

	Ttl	Tal	Ttcl (base)	Ttcl (middle)	Ttcl (top)	Ttcu	Ttcu
Sample no.	84WS16	84WS17	84WS7	84WS9	84WS10	84WS11	84WS22
Location	Carrizalillo Hills Center sec. 35, T28S, R11W	Carrizalillo Hills Center sec. 35, T28S, R11W	Carrizalillo Hills NW¼NE¼ sec. 11, T29S, R11W	Carrizalillo Hills NW¼NE¼ sec. 11, T29S, R11W	Carrizalillo Hills NW¼NE¼ sec. 11, T29S, R11W	Carrizalillo Hills Center SE¼, sec. 11, T29S, R11W	Carrizalillo Hills Center NW¼ sec. 2, T29S, R11W
Irvine–Baragar class.	tristanite*	trachybasalt*	rhyolite*	rhyolite–dacite*	rhyolite*	dacite–andesite*	rhyolite*
SiO_2	53.79(+2.53)	57.94(+8.99)	76.02(+13.31)	71.42(−5.49)	71.49(−1.59)	70.59(−3.51)	69.85(−8.90)
TiO_2	0.56	0.89	0.20	0.23	0.23	0.28	0.37
Al_2O_3	12.05	13.26	12.12	13.97	13.30	13.72	15.06
Fe_2O_3	3.13	5.06	0.10	1.18	0.48	0.40	1.44
FeO	0.64	1.08	1.48	0.76	1.56	1.70	1.51
MnO	0.29(+0.34)	0.17(+0.20)	0.02(+0.02)	0.04(+0.04)	0.03(+0.03)	0.03(+0.03)	0.03(+0.03)
MgO	0.82(−0.55)	0.33(−2.72)	0.29(−0.21)	0.76(+0.43)	0.36(+0.03)	0.41(+0.02)	0.21(−0.37)
CaO	10.20(+8.24)	5.65(+1.13)	0.22(−1.52)	0.25(−1.30)	0.30(−1.27)	1.14(−0.55)	0.16(−1.65)
Na_2O	2.03(−0.37)	0.30(−2.57)	0.68(−2.99)	0.47(−3.24)	1.28(−2.44)	0.84(−2.78)	1.28(−2.59)
K_2O	6.49(+4.17)	11.27(+10.55)	7.89(+4.81)	8.42(+3.66)	9.23(+4.97)	7.86(+3.39)	10.21(+5.23)
P_2O_5	0.16	0.32	0.06	0.08	0.06	0.08	0.09
LOI	8.45	4.28	0.61	1.38	0.61	2.05	0.60
H_2O+	0.43	0.10	0.43	0.78	0.41	0.26	0.32
total	99.04	100.65	100.12	99.74	99.34	99.36	101.13
SIL	81.7	76.45	86.83	87.51	87.41	87.16	86.75
CFM	10.04	16.35	3.76	2.94	3.06	3.36	3.86
ALK	8.31	7.20	9.41	9.55	9.53	9.48	9.39
Estimated precursor rock	dacite	andesite	rhyolite	rhyolite	rhyolite	rhyolite	rhyolite

	Tla	Tla	Tla	Tla	Tla	Tla	Tla	Tj
Sample no.	84WS43	84WS44	84WS45	84WS46	84WS48	84WS14	84WS24	84WS19
Location	Cedar Mountains NE¼NW¼ sec. 29, T28S, R11W	Cedar Mountains NE¼NE¼ sec. 30, T28S, R11W	Cedar Mountains SE¼SE¼ sec. 19, T28S, R11W	Cedar Mountains SE¼SE¼ sec. 19, T28S, R11W	Cedar Mountains NW¼SE¼ sec. 19, T28S, R11W	Carrizalillo Hills SW¼SE¼, sec. 35, T28S, R11W	Carrizalillo Hills SW¼NW¼ sec. 2, T28S, R11W	Carrizalillo Hills NE¼NW¼ sec. 34, T28S, R11W
Irvine–Baragar class.	andesite	andesite	dacite	andesite	andesite	alkali basalt*	trachybasalt	trachyte*
SiO_2	57.92	56.83	57.83	59.50	59.23	59.10(−17.53)	53.08(−12.40)	63.32(−3.91)
TiO_2	0.75	0.91	0.72	0.78	0.96	0.60	1.10	0.74
Al_2O_3	18.20	17.18	18.28	16.47	16.41	17.02	17.28	15.68
Fe_2O_3	4.35	4.26	3.49	1.40	3.13	3.35	1.62	3.14
FeO	1.20	1.52	2.33	4.14	2.36	0.71	1.73	1.98
MnO	0.09	0.09	0.09	0.09	0.10	0.11(−0.09)	0.16(+0.14)	0.06(+0.06)
MgO	3.96	3.02	3.97	2.66	2.11	1.11(−0.21)	0.57(−2.44)	0.61(−1.41)
CaO	6.45	6.45	6.72	5.46	6.37	3.00(−0.15)	7.91(+2.07)	0.56(−3.04)
Na_2O	4.37	3.92	4.02	3.70	4.80	0.56(−2.80)	2.96(−0.35)	0.71(−2.66)
K_2O	1.58	1.97	1.55	2.74	2.62	10.23(+4.78)	6.68(+3.28)	12.67(+9.08)
P_2O_5	0.20	0.27	0.17	9.25	0.45	0.19	0.22	0.24
LOI	0.99	2.34	0.78	1.77	0.85	3.41	4.38	0.74
H_2O+	1.12	1.04	0.23	0.10	0.39	0.89	0.22	0.25
total	101.18	99.80	100.18	99.06	99.78	100.28	97.91	100.70
SIL						84.33	77.51	81.71
CFM						6.79	15.07	9.97
ALK						8.88	7.42	8.32
Estimated precursor rock						dacite–rhyolite	andesite	dacite

*Rocks determined from petrographic studies to be altered, especially by potassium metasomatism. Mass-balance calculations of altered rocks relative to hypothetical unaltered precursor rocks that have the same Al_2O_3/Al_2O_3 + total Fe (as Fe_2O_3) have been made. Parenthetical numbers in table are weights in grams that would have to be added or subtracted from the precursor rock to give the analyzed rock. Note particularly how alteration has involved removal of Na_2O and addition of K_2O. SIL, CFM, and ALK of bottom line are ternary end members SiO_2, CaO + FeO + MgO, Na_2O + K_2O, which describe the precursor. The name of the precursor can be estimated by locating CFM and ALK on the compositional trend of Fig. 4.

TABLE 2—Modal analyses of ash-flow tuffs; average from 500 points counted on each of two thin sections.

Description	Sample number	Quartz	Sanidine	Plagioclase	Biotite	Total crystals	Xenocrysts	Rock fragments	Matrix	Shards
Tuff of Johnson Mountain (Tj)	84WS14	3.0	8.4	15.2	2.6	29.2	0.7	1.6	68.5	scarce
	84WS19		1.0	44.0	5.0	50.0	2.7		47.3	scarce
	84WS34	6.5	26.7		1.8	35.0	7.8	tr	57.2	scarce
	84WS35	3.2	0.7	22.2	1.5	27.6	9.5	tr	62.9	scarce
	84WS37	5.7	5.9	28.3	4.1	44.0	0.8		55.2	none
	84WS38	4.5	9.1	21.5	3.7	38.8			61.2	scarce
	84WS39	0.2	0.1	48.2	1.3	49.8	5.2		45.0	none
	84WS50	2.0	2.4	0.4	2.0	6.8	5.0	0.1	88.1	scarce
Tuff of Carrizalillo Hills (upper member; Ttcu)	84WS11	2.9	5.7		1.4	10.0	0.2		89.8	abundant
	84WS22	1.8	6.6		1.4	9.8	10.6		79.6	common
	84WS22A	4.0	8.2		1.6	13.8	8.2		78.0	abundant
	84WS23	1.4	3.2		1.0	5.6	3.4		91.0	abundant
	84WS56	2.7	4.2		2.5	9.4	6.4		84.2	common
Tuff of Carrizalillo Hills (lower member; Ttcl)										
base	84WS7	9.6	11.8		0.8	22.2	tr		77.8	abundant
	84WS8	5.6	8.5		1.7	15.8		0.3	83.9	common
	84WS9	5.2	7.6		1.5	14.3		0.2	85.5	abundant
top	84WS10	6.5	16.5		1.6	24.6	8.6		66.8	abundant
upper part	84WS13	10.0	13.8		1.1	24.9	11.6	tr	63.5	abundant
base	84WS18	11.2	8.9		0.7	20.8	3.1	0.3	75.8	abundant
base	84WS55	9.6	14.2		0.6	24.4	2.3	0.2	73.1	abundant
Lower rhyolitic ash-flow tuff (Ttl)	84WS16	4.5	0.9		2.3	7.7	37.4	tr	54.9	none

TABLE 3—Petrographic analyses of andesitic and basaltic rocks. Textures are: 1—intergranular, 2—intersertal, 3—pilotaxitic, 4—hyalopilitic, 5—felted, and 6—vesicular. Asterisk * denotes plagioclase(?), which may have been sanidine originally.

Description		Sample number	Phenocrysts % Plagioclase	Biotite	Hornblende	Pyroxene	Olivine	Total	Matrix composition Quartz	Plagioclase	Biotite	Hornblende	Pyroxene	Olivine	Fe-oxides	Carbonate	Alteration	Textures
Basalt (Tb) near top of Tf		84WS66								x		x	x		x		none	2,6
Basaltic andesite (Tba) between Tf and Tfl		84WS52					1.2	1.2		x			x	x	x		trace	2,3,6
Andesite porphyry (Tap)		84WS40	23.2	1.6	2.3	0.5		27.6		x	x	x	x		x		trace	1
		84WS65	15.0	3.0		0.6		18.6		x	x		x		x		trace	1
Basaltic-andesite dike (Tbd) cutting rhyolite (Tfr)		84WS36							x	x					x		trace	2,4,5
Andesite of Hermanas siding (Tah)		84WS41	0.5					0.5		x					x	x	moderate	2,4
		84WS54	3.9					3.9		x					x		moderate	2,4
Intermediate-composition flows (Tla) above Tlc, Carrizalillo Hills		84WS28	0.4		0.5			0.9		x					x	x	intense	5
		84WS29	4.0					4.0		x					x	x	intense	5
		84WS31			7.4			7.4	x	x		x	?	?	x	x	intense	2,6
		84WS32			?		?	5.4	x	x					x	x	intense	1,3
		84WS33		?	?			8.8	x	x					x	x	intense	2,4
Intermediate-composition flows (Tla) below Tlc, Carrizalillo Hills		84WS14	21.0	1.2	11.2			33.4		x	x				x	x	intense	3
		84WS15	25.0	1.0	7.4			33.4		x					x	x	intense	3
		84WS21	18.6	1.6	8.0			28.2		x					x	x	intense	3
		84WS24			1.0			1.0									very intense	4,5
		84WS25	0.8		2.6			3.4	x	x					x	x	intense	2,4,6
		84WS26	1.0		1.0			2.0	x	x					x	x	intense	2,4
		84WS30	0.2		10.8			11.0		x					x	x	intense	2,4
		84WS53	4.0				5.0	9.0	x	x					x	x	very intense	2,4
		84WS57	22.4		8.6			31.0	x	x					x	x	intense	1,3
Intermediate-composition flows (Tla), southeastern Cedar Mountains	oldest	84WS43	1.4			0.1		1.5		x		x	x		x		trace	1,3
		84WS44	?		?			4.6		x		x	x		x	x	trace	1,3,6
		84WS45	26.0			1.5		27.5		x			x		x		trace	1,3
		84WS46	1.4			0.8		2.2		x			x		x		trace	4,6
		84WS47								x					x		trace	2,5,6
		84WS49	1.2			2.0		3.2		x			x		x		none	2,4,6
	youngest	84WS48	4.1		5.2			9.3		x		x			x		trace	3
Lower andesite (Tal)		84WS17	13.8					13.8	x	x*					x	x	intense	4