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GEOLOGY OF THE CARRIZOZO QUADRANGLE, NEW MEXICO

Robert H. Weber

New Mexico Bureau of Mines and Mineral Resources,
New Mexico Institute of Mining and Technology
Socorro, New Mexico

INTRODUCTION

The results of detailed geologic mapping of the Carrizozo 15-minute quadrangle, summarized herein, are pertinent to both major regional features and local aspects of physiography, stratigraphy, petrology, and structure that will be viewed during the course of the 15th Annual Field Conference. The setting of the area in relationship to nearby geographic features is shown in figure 1. The geology has been highly generalized in the geologic map and section (fig. 2).

The mapped area includes segments of the Sacramento section of the Basin and Range Province and a western lobe of the Great Plains Province. It is bounded on the east by the Tertiary volcanic pile and intrusive complex of the northern Sierra Blanca, and by the western flanks of a series of domical intrusive bodies that extend northward outside the quadrangle into the Jicarilla Mountains. Sloping westward from the foot of the mountainous tract into the floor of the northern end of the Tularosa Valley, a closed intermontane basin, is a broad bajada that occupies most of the central part of the area. The bajada surface is breached near its eastern edge by a discontinuous chain of hills (Chaves Mountain, Cub Mountain, Willow Hill, etc.) capped by small intrusive bodies. Southeastward- to eastward-dipping Upper Cretaceous sandstones and shales, the beveled surface of which underlies most of the bajada, crop out in the slopes of these hills and in a narrow cuesta and scattered low hills near the foot of the slope. Recent basaltic flows of the Carrizozo Malpais mantle the floor of the valley, covering the trace of Triassic redbeds and the uppermost part of the Permian sequence. Permian strata are contorted by solution collapse and folding where they emerge from beneath the western edge of the malpais, rising in elevation northwestward onto the summit of Chupadera Mesa.

Elevations range from a minimum of about 5,000 feet on the floor of the Tularosa Valley to a maximum of 9,500 feet on the northern shoulder of Nogal Peak on the crest of the Sierra Blanca. Nogal Peak, with an elevation of about 10,000 feet, is in turn overshadowed by the 12,003-foot eminence of Sierra Blanca Peak (Cerro Blanco) 8.5 miles to the south.

Geologic mapping in the northeastern quarter of the quadrangle was contributed by Frederick J. Kuellmer. The writer was assisted briefly in the field by John H. Schilling. John E. Allen aided at the plane table during measurement of the Cub Mountain Formation type section. Line illustrations were drafted by Bob Price. Teri Ray provided editorial assistance. The geology of the area has been summarized recently by Griswold (1959), to whom the reader is referred for fuller coverage of the surrounding region of Lincoln County.

STRATIGRAPHY

Exposed rock units include Permian Yeso and San Andres Formations; local equivalents of Upper Cretaceous Dakota Sandstone, Mancos Shale, and Mesaverde Group; early Tertiary Cub Mountain Formation, volcanics of the Sierra Blanca, and a suite of intrusive rocks; late Tertiary to Recent valley fill, colluvium, landslides, and talus; and Recent basalt flows. Triassic rocks are concealed by the Carrizozo Malpais. An oil test (Standard of Texas No. 1 Heard-Federal), just outside the northwest corner of the quadrangle in sec. 33, T. 6 S., R. 9 E., provides additional stratigraphic control that includes Precambrian basement rock, a com-

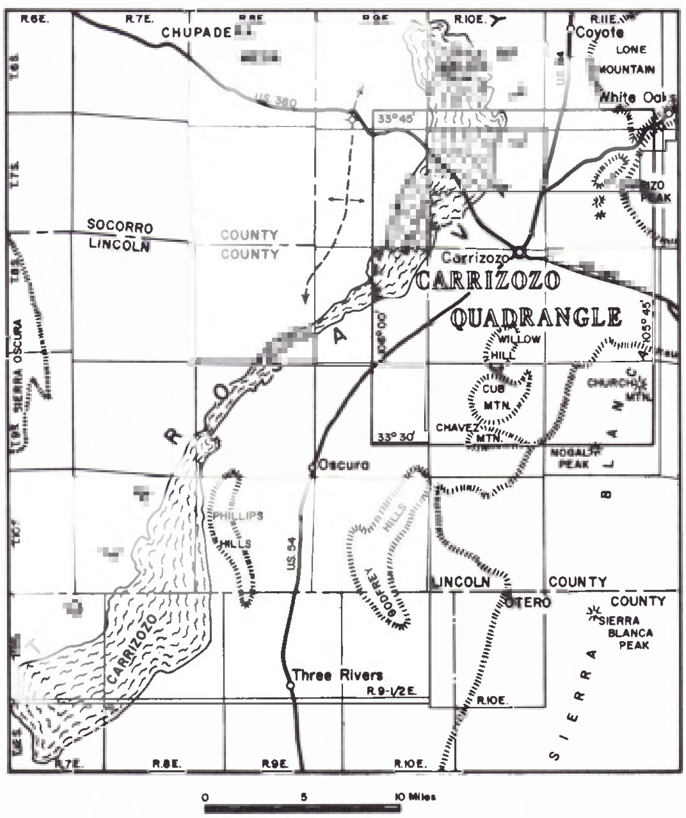

Figure 1. — Index map of Carrizozo quadrangle and vicinity, New Mexico.

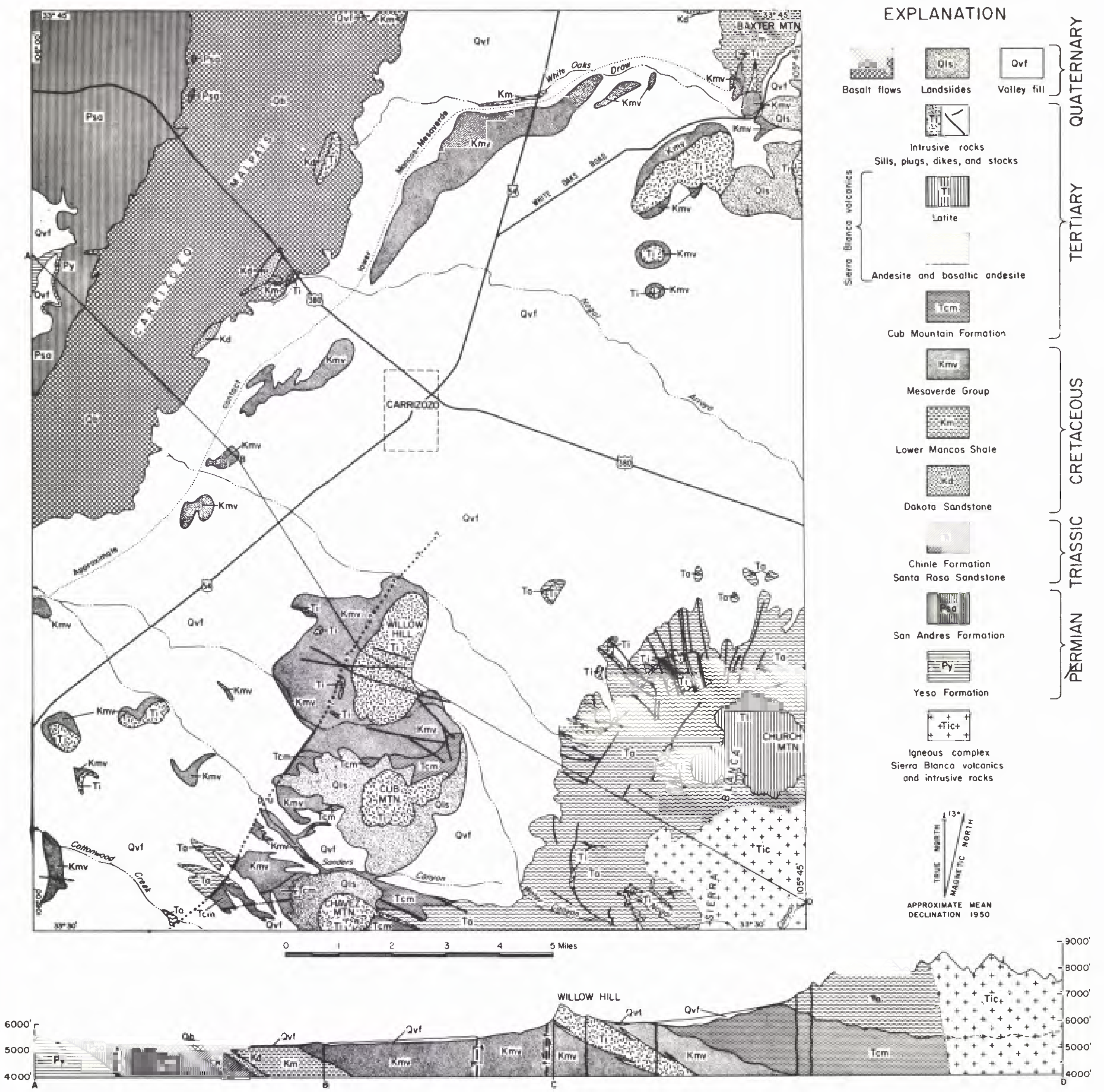

Figure 2. — Generalized geologic map and cross-section of the Carrizozo quadrangle, New Mexico.

plete section of the Pennsylvanian, and an abnormally thickened section of the Yeso Formation. Pre-Pennsylvanian Paleozoic rocks are lacking in this section, probably as a result of the combined effects of Devonian, Late Pennslyvanian, and Wolfcampian erosion, and nearness to the Pedernal landmass to the east (Kottlowski, 1963).

Precambrian Rocks

Although the southward projection of the Pedernal uplift lies only a short distance to the east (Foster and Stipp, 1961), there are no outcrops of Precambrian rocks within the Carrizozo quadrangle, nor in the immediate vicinity. The Heard test penetrated 310 feet of Precambrian gabbro with minor amounts of schist and gneiss underlying Pennsylvanian rocks below 7,740 feet. Core samples consist of a hypidiomorphic-granular aggregate of medium- to coarse-grained labradorite, augite, olivine rimmed with pyroxene and antigorite, and magnetite with local reaction rims of biotite.

The nearest outcrops of Precambrian rocks lie 30 miles west of the town of Carrizozo in the western slopes of the Sierra Oscura. Kottlowski (1953) described briefly the prevailing rock type near the northern end of the range as a muscovite leucogranite with intrusive relationships with small bodies of gray quartzite. Nearly equal proportions of quartz, potash feldspar (orthoclase and microcline), and oligoclase also permit designation as a sodic quartz monzonite. The high degree of variability in lithology of the Precambrian southward along the eastern front of the San Andres Mountains has been shown by Kottlowski and others (1956).

In the northern Sacramento Mountains near Bent, 34 miles south of Carrizozo, small outcrops of probable Precambrian rocks immediately underlie the Abo Formation. Granodiorite, quartzite, and possibly quartz diorite are represented, according to Foster (1959, p. 139) and Pray (1961, p. 25).

In the Gallinas Mountains, 40 miles north of Carrizozo, exposed basement rocks include aplitic granite and biotite gneiss, which are overlain by the Abo Formation (Kelley, 1949).

Pennsylvanian Rocks

The earliest Paleozoic rocks remaining in the Carrizozo area are of Pennsylvanian age. There are no outcrops of this sequence within the quadrangle, so the section cut in the Heard test provides the best available representation of the local stratigraphy. A maximum thickness of 1,745 feet and minimum thickness of 1,350 feet of Pennsylvanian rocks are represented, depending upon interpretation of the upper beds in this sequence as referable to the Pennsylvanian or to the early Wolfcampian Bursum Formation (Kottlowski, 1960, 1963).

As logged by R. W. Foster (*in* Griswold, 1959, p. 110), and including possible equivalents of the Bursum Formation, the total thickness is 1,700 feet in the interval between 6,040 and 7,740 feet. Dark gray shales and thin sandstones in the lower part are succeeded upward by gray to slightly reddish gray shales and claystones with interbeds of paler gray limestones and sandstones. The upper part contains large amounts of dark reddish gray to reddish brown mudstone interbedded with dark gray shale and claystone, arkosic sandstone, and limestone. Abundant arkosic beds in the Heard test have been cited by Kottlowski (1960, 1963) as indicating that the Pedernal landmass lay only a short distance to the east.

Pennsylvanian sequences in central New Mexico are commonly referred to the Magdalena Group, consisting of the Sandia Formation overlain by the Madera Formation. Faunal equivalents of the Morrow, Derry, Des Moines, Missouri, and Virgil Series have been recognized. The relatively thin section in the northern Sierra Oscura was subdivided by Thompson (1942) into 4 groups and 8 formations largely on the basis of fusilinid zones. Additional formational names have been applied to locally mappable lithologic units in the nearby San Andres and Sacramento Mountains (Kottlowski and others, 1956; Pray, 1961). Inasmuch as the problems of nomenclature, faunal ages, facies variations, and regional correlations have been discussed recently by Kottlowski (1960, 1963) a thorough review seems unwarranted in this paper.

Permian Rocks

Strata of Permian age crop out only in the extreme northwestern corner of the Carrizozo quadrangle, along the western edge of the Carrizozo Malpais, where they dip prevailingly eastward to southeastward beneath the basaltic flows. The exposed section includes only the uppermost part of the Yeso Formation and the lower part of the San Andres Formation. A complete section of the Yeso, underlying Abo Formation, and possible equivalents of the Bursum Formation were cut by the Standard of Texas No. 1 Heard-Federal oil test. The Bernal Formation may be present under the eastern part of the quadrangle.

Bursum(?) Formation

The possible equivalence in the Heard test of redbeds at the top of the Pennsylvanian section and the base of the Abo Formation to the Bursum Formation in the Sierra Oscura has been indicated by Kottlowski (1960, 1963) and Griswold and Foster (Griswold, 1959, p. 9, 110). Griswold assigned ". . . 230 feet of marine limestone interbedded with dark-red mudstone and arkosic conglomerate." in this interval to the Bursum. To the south, in the northern Sacramento Mountains, Bursum equivalents have been recognized by Otte (1959) under the term *Laborcita Formation.* Faunas of both Virgilian and Wolfcampian age have been identified from the Bursum and Laborcita Formations.

Abo Formation

The nearest outcrops of the Abo lie about 24 miles west of Carrizozo in the slopes extending eastward from the Sierra Oscura. Referring again to the Heard test, Foster (Griswold, 1959, p. 110) characterized the 1,560-foot Abo section (possibly including some Bursum), in the depth interval between 4,480 and 6,040 feet, as "Interbedded dark reddish-brown mudstone, claystone, and arkosic conglomerate. Mostly arkosic conglomerate in lower 700 feet." The 1,545-foot section in the Heard test assigned to the Abo by Kottlowski (1963, fig. 12) lies in a northward-trending prong of the Pennslyvanian Orogrande basin (Kottlowski's fig. 11), thinning rapidly eastward onto the Pedernal landmass.

Yeso Formation

Only the uppermost part of the Yeso is exposed along the contact of the overlying San Andres Formation at the northwestern edge of the quadrangle. A complete stratigraphic section was cut in the Heard test, but the Yeso was found to be anomalously thick as a result of folding and the presence of a thick salt sequence. Surface structure on the Carrizozo dome evidently is largely due to local thickening of the Yeso. How much of this is a product of close folding (of the type exposed in the Lincoln fold belt 30 miles ESE of Carrizozo), and how much may be a product of thickening by plastic flow of halite beds into the anticlinal axis is not clearly indicated.

As logged by Foster (Griswold, 1959, p. 110), the Yeso in the Heard test has a total thickness of 4,265 feet in the depth interval of 215 to 4,480 feet. The sequence consists of interbedded limestone, salt, gypsum, sandstone, and mudstone, of which salt beds comprise 900 feet. Deduction of the 900 feet of salt from the total thickness still leaves an abnormal thickness, as compared with the thickest nearby measured section of about 1,695 feet in T. 7 S., R. 7 E. (Wilpolt and Wanek, 1951).

Lacking a persistent Glorieta Sandstone horizon at the base of the San Andres Formation in the mapped area, the top of the Yeso Formation was arbitrarily established in outcrop at the base of a prominent (21 to 25 feet thick) gypsum bed that overlies yellowish orange to reddish brown friable siltsones and thin sandstones of typical Yeso lithology. The gypsum and overlying lenticular quartz sands and persistent silty dolomite are lithologically like those higher in the San Andres, and the contact is easily mappable in this area.

Marginal limits of the Yeso salt basin have not been determined inasmuch as the Heard test provides the only illustration of salt beds in this area. Solution effects probably would preclude outcrop of the halite. Surface drainage on the east side of the Carrizozo dome enters numerous solution cavities in gypsum and limestone beds along the west edge of the Carrizozo Malpais and, if circulation is deep enough in the upper Tularosa Valley, may be expected to have leached soluble salt beds. The high sodium chloride content of Malpais Spring, at the southern tip of the malpais, suggests active solution of salt deposits in groundwaters that received a major component of recharge from cavernous drainage in the Carrizozo area. Pray (1961) noted the presence of halite in the subsurface and a progressive northward increase in the abundance of redbeds and evaporites in the Yeso of the Sacramento Mountains.

There is no firm basis for dating the Yeso Formation in the Carrizozo quadrangle. Regional correlations indicate a Leonardian age (Pray, 1961).

San Andres Formation

Outcrops of the San Andres Formation are limited to the northwestern corner of the quadrangle, eastward from which it is buried beneath the Carrizozo Malpais. Only the lower part is exposed, permitting establishment of a mappable basal contact with the underlying Yeso Formation. The upper boundary is less certain. In the adjacent Little Black Peak quadrangle to the north, the San Andres is overlain by sandstone and shales referred to the Bernal Formation by Becker and others (Dane and Bachman, 1958) and Smith and Budding (1959). Absence of the Bernal west of Carrizozo, as shown by Kottlowski (1963, fig. 16, p. 70), suggests that post-Bernal Triassic beds directly overlie the San Andres in that area.

Basal beds consist of 21 to 25 feet of white to gray, mottled and banded gypsum with thin interbeds of gray dolomite and silty, gypsiferous limestone overlain by 21 to 39 feet of varicolored friable sandstone, then about 50 feet of yellowish gray silty dolomite and fossiliferous mottled limestone. Dolomites and limestones are interbedded with gypsum and lenticular quartz sandstones (possibly equivalent to the Glorieta Sandstone) upward in the section. Siliceous limestones and lenticular, brown-weathering chert zones are locally conspicuous.

Extensive collapse resulting from solution of gypsum and limestone has produced a chaotic variation in strikes and dips, with beds draped over the topography to an extent that makes the topographic map a fair approximation of a structural map. Dips range generally between 5 and 10 degrees, but locally steepen to as much as 65 degrees. The prevailing gentle eastward dip is apparent only in the profile of the general slope of ridge and hill crests. Recent damming of surface run-off in the Tularosa Valley by basalt flows of the Carrizozo Malpais has accelerated solution activity. Storm drainage from the western slopes pond against the edge of the basalt for a short time, then drains abruptly when the "plug is pulled" in tubular channelways in underlying gypsum beds. Recent collapse in the central part of the malpais has broken through 177 feet of basalt and underlying valley alluvium.

The partial section of the San Andres penetrated in the Heard test extended from the surface to a sample depth of 270 feet (215 feet, according to Foster *in* Griswold, 1959). To the north, Smith and Budding (1959) recorded an average thickness of 600 feet in the Little Black Peak quadrangle. A similar thickness of about 685 feet was reported by Allen and Jones (1951) in the Capitan quadrangle to the east.

Fossils are locally abundant in the carbonate beds and cherty zones, and include brachiopods, gastropods, bryozoa, pelecypods, echinoid spines, cephalopods, and corals. Specific identification has not been made of a small faunal collection from these beds, but it is expected that they are Leonardian inasmuch as they are from the lower part of the formation. Whether or not the upper beds include strata of Guadalupian age has not been determined.

Bernal Formation

Local sequences to the north and east of the Carrizozo quadrangle include post-San Andres redbeds that have been referred to the Triassic under the designation *Bernal Formation* (Allen and Jones, 1951; Smith and Budding, 1959) and to undifferentiated rocks of Guadalupian age that include equivalents of the Bernal, Grayburg, Queen, Seven Rivers, Yates, and Tansil Formations, or Whitehorse Group (Dane and Bachman 1958). Correlative beds do not crop out in the Carrizozo quadrangle. If present, they are buried beneath the Carrizozo Malpais. However, as shown by Kottlowski (1963, fig. 16, p. 70), the western edge of the Bernal probably lies along a north-south line passing through Carrizozo. In the Little Black Peak quadrangle, a few miles to the north, the Bernal consists variably of 200 to 300 feet of red to buff calcareous sandstone with silty partings and shale beds, overlain by redbeds of the Santa Rosa Formation (Smith and Budding, 1959).

Inasmuch as the Bernal was originally defined as representing the upper clastic member of the San Andres Formation in Mora County, and was believed to correlate with the Guadalupian Chalk Bluff Formation, (Bachman, 1953), it is similarly treated here as a part of the Permian System.

Triassic Rocks

Redbeds younger than the Bernal Formation and older than the Dakota Sandstone in the Capitan and Little Black Peak quadrangles have been correlated with the Santa Rosa Sandstone and Chinle Formation by Allen and Jones (1951) and Smith and Budding (1959). The trace of equivalent beds in the Carrizozo quadrangle probably extends southwestward under the eastern edge of the malpais, emerging a few miles to the southwest (in the southeastern corner of the Chihuahua Ranch quadrangle) in the western slope of Bull Gap Ridge. Triassic rocks pinch out southward in the vicinity of Mescalero. As a consequence, the Dakota(?) Sandstone rests directly on the San Andres Formation on the crest of the Sacramento Mountains (Pray and Allen, 1956).

Santa Rosa Sandstone

About 295 feet of light gray, buff, green, and red quartz sandstone, siltstone, and chert-pebble conglomerate have been correlated with the Santa Rosa sandstone in the Capitan quadrangle (Allen and Jones, 1951). The thickness averages 200 feet in the Little Black Peak quadrangle, where the Santa Rosa consists of red, micaceous, quartz sandstone with lenses of shale, siltstone, and quartz- and chert-pebble conglomerate in the upper part. In both areas, the Santa Rosa rests on the Bernal Formation, whereas west of Carrizozo it may rest directly on the San Andres Formation, as suggested by Kottlowski (1963).

Chinle Formation

Overlying the Santa Rosa sandstone in the Capitan quadrangle are 181 feet of red mudstone, siltstone, and claystone, with local limestone interbeds near the top. This sequence was correlated with the Chinle Formation by Allen and Jones (1951). A correlative sequence of redbeds, averaging 400 feet in thickness in the Little Black Peak quadrangle, consists of red to lavender quartz sandstone and mudstone (Smith and Budding, 1959). The uppermost part of the Chinle underlies the Dakota Sandstone in the kipuka near the eastern edge of the Carrizozo Malpais, 2.5 miles north of U.S. Highway 380, as indicated by patches of red soil. Exposures are otherwise lacking in this quadrangle.

Cretaceous Rocks

A thick succession of calcareous sandstones, shales, mudstones, and thin argillaceous limestones crops out discontinuosuly in a belt 7 to 8 miles wide extending southwestward across the central part of the quadrangle. Although a complete stratigraphic section is nowhere exposed, and broad covered intervals precluded detailed stratigraphic studies, equivalents of the Dakota Sandstone, Mancos Shale, and Mesaverde Group have been recognized. Undulations in attitude, displacement along both exposed and possible concealed faults, and thickening due to sill intrusion make thickness approximations of dubious value. The total thickness in the surrounding region is shown by Kottlowski (1963) to range from 1,460 to 1,850 feet, whereas Melhase (1927) estimated between 3,500 and 3,600 feet in the vicinity of Oscura. Faunal equivalents of the Greenhorn, Carlisle, and lower Niobrara were recognized by William A. Cobban (personal communication) during a very brief examination of a collection made during the course of the present study.

Dakota Sandstone

The basal unit of the Cretaceous sequence is a quartz sandstone whose lithologic features and stratigraphic position conform with those of the Dakota Sandstone of central New Mexico. Outcrops are scattered along a narrow arcuate belt extending from the south flank of Lone Mountain westward, then southwestward along the eastern margin of the Carrizozo Malpais. Several kipukas that project through the basalt flows strike northeasterly and dip 7 to 25 degrees southeasterly.

Basal contacts with the underlying Chinle Formation are not exposed but are probably close to the western edge of Dakota outcrops in the malpais. The lower beds are white, tan, pinkish buff, and yellow fine-grained to coarse-grained quartz sandstones. Small carbonized wood fragments are present locally. Fine bedding laminae, cross-laminations, and local ripple-marked surfaces become more prominent upwards. Weathered surfaces range from tan through dark brown to black, the darker hues resulting from a strong tendency toward the formation of desert varnish. Case-hardened surfaces are also common. Cementation by calcite varies from weak to very firm, with some tendency to increase upward. The upper contact is apparently gradational into the Mancos Shale, dark shales of the latter interfingering with sandstones of the Dakota.

The total thickness was not determined due to the lack of exposed contacts and complication by sill intrusions. Allen and Jones measured 134 feet of Dakota in the Capitan quadrangle, and Smith and Budding gave an average thickness of about 150 feet in the Little Black Peak quadrangle. Melhase reported 200 feet of Dakota in Bull Gap Ridge, where the upper part contains shaly coal and a coal bed.

Mancos Shale

Black to gray, fossiliferous, calcareous, pyritic shales, shaly to sandy limestone, and thin sandstones that overlie the Dakota Sandstone are correlated with the Mancos Shale on the basis of lithology and stratigraphic position. Outcrops are very sparse, of small lateral and vertical extent, and complicated by sill intrusions. Only the lower part is differentiated on the accompanying geologic map (fig. 2). Actually, however, dark gray calcareous shales containing abundant marine fossils intertongue with lenticular sandstones and gray to olive shales of the Mesaverde much higher in the section, extending southeastward high into the western slopes of Willow Hill. Under conditions of more continuous outcrop, some of these upper tongues probably could be differentiated on geologic maps of a mile-to-the-inch scale.

Incompetent shales of the Mancos were favorable hosts for sill intrusions. Local baking has so indurated them that they have been misinterpreted as limestones by some observers.

Faunal collections from highly fossiliferous beds in the Mancos have received only cursory examination. Pelecypods from the lower part are of Greenhorn aspect, whereas upper tongues contain forms indicative of the upper Carlisle (William A. Cobban, personal communication).

Mesaverde Group

Overlying and interfingering with tongues of the Mancos Shale is a thick sequence of marine and nonmarine sandstones, shales, and thin coal beds that is the local equivalent of the Mesaverde Group. Outcrops are scattered across the central part of the quadrangle in narrow cuestas and isolated hills, many of which are capped by sills. The broad bajada that forms the eastern slope of the Tularosa Valley is largely underlain at very shallow depths by an erosion surface that bevels prevailingly eastward- to southeastward-dipping beds of the Mesaverde. The section in all probability is repeated by faults, downthrown to the west, creating an exaggerated apparent thickness.

Yellowish gray to buff, massive to thin-bedded, fine- to medium-grained, lenticular, calcareous sandstones are particularly prominent in outcrops. Thin-bedded gray to yellowish brown siltstones, sandstones, gray to olive clays and shales, carbonaceous shales, and coal beds are usually covered. Cross-lamination is prevalent, and ripple marks were noted at several places. Fossiliferous marine sandstones and shales interfinger with sandstones containing silicified driftwood fragments and coaly shales. Weathered surfaces are prevailingly buff to brown; liesegang banding is locally prominent.

Three, possibly four, coal beds have been prospected in the section exposed on the west side of Willow Hill and the northwestern foot of Cub Mountain. Two of these at Cub Mountain have been mined, but the workings are now caved and inaccessible. Wegemann (1914, p. 424) reported a bed in the Conner and Smith mine 4 feet 10 inches thick, including four shale partings. The upper coal seam as measured by Melhase (1927) is 2 feet 6 inches thick.

Faunal equivalents of the upper Carlisle and lower Niobrara were tentatively identified in collections from marine sandstones of the Mesaverde in the western slopes of Willow Hill (William A. Cobban, personal communication).

Tertiary Rocks

Overlying the Mesaverde Group is a thick sequence of continental redbeds, the Cub Mountain Formation, succeeded upward by the andesitic pile of the Sierra Blanca, and latite. Widespread injection of dikes, sills, domed plugs, and stocks of granite, alkali syenite, monzonite, andesite, diorite, basalt, gabbro, and lamprophyre accompanied and followed volcanism. Although inadequately dated, these rocks are probably largely early Tertiary in age. Silts, sands, gravels, and their indurated equivalents of the valley fill in the eastern slope of the Tularosa Valley may include beds of late Tertiary age.

Cub Mountain Formation

The term *Cub Mountain Formation* was used by the writer to designate a thick interval of continental redbeds that rest on the Mesaverde Group in the slopes of Cub Mountain, T. 9 S., R. 10 E. (unpublished manuscript). Correlative beds in the Capitan coal field subsequently were described by Bodine (1956) under this term. Bodine had not intended that his paper serve as the type definition, as a typographically omitted footnote would have explained. The term has, however, been adopted, although handicapped by the lack of a formal definition and described type section.

Outcrops extend from the northern slopes of Cub Mountain southward into the Three Rivers drainage area in the Sierra Blanca Peak quadrangle. The western limits are along a northeast-trending fault west of Cub and Chaves Mountains. Eastern limits are marked by depositional contacts with younger rocks east of the two peaks. Pervasive landslide and intrusive activity obscure the section in the slopes of Cub Mountain. The type section accordingly was measured in the arroyo banks of Sanders Canyon, between Cub and Chaves Mountains, where outcrops extend in a very narrow band from the SW¼SW¼ sec. 16 to the SW¼SW¼ sec. 24, T. 9 S., R. 10 E., a distance of over three miles. Basal contacts with the Mesaverde are generally obscure, and appear locally conformable (although probably at least disconformable). The contact was mapped at the base of the lowest impure arkosic sandstone, or the base of the lowest red or variegated clayey to silty bed, whichever feature provided the most useful datum locally. The upper contact was placed at the base of the lowest bed of the Sierra Blanca volcanic pile, which in this area is pinkish gray to grayish red ash and lapilli tuff.

The sequence consists of white to gray and yellowish buff to brown, massive to thin-bedded, fine- to coarse-grained, poorly sorted arkosic sandstone beds (many of which are cross-laminated and show pronounced channeling at the base), interbedded with red, maroon, purple, brown, greenish gray, and variegated montmorillonitic claystone, mudstone, siltstone, and fine-grained sandstone. Thin lenses of conglomerate contain pebbles of quartzite, silicified rhyolite and latite(?), and minor amounts of chert, granite, and silicified wood. Coarser-grained beds higher in the section are characteristically gray to grayish red graywackes containing abundant mafic minerals, fragments of andesite and mud pellets. These beds probably reflect active volcanism in the source area, and provide criteria for subdividing the Cub Mountain Formation into lower and upper members. Seams and veinlets of gypsum are prevalent in fine-grained beds throughout most of the section.

The total thickness of the Cub Mountain in the type section is about 2,400 feet. The long traverse in the measured section, variations in attitude, and several apparently minor faults make this figure subject to correction. Nevertheless, it probably lies within the range of lateral variations in thickness.

Correlation with the Eocene(?) Baca Formation of central New Mexico (Wilpolt and others, 1946; Tonking, 1957) is strongly suggested by similarities in stratigraphic postion, lithology, and inferred depositional environment. It must be recognized that such a correlation does not imply complete synchronity in time nor continuity in basins of deposition of the Baca and Cub Mountain. Stratigraphic age limits for the Baca are post-Mesaverde Group and pre-Datil Formation. By tenuous extrapolation, a single potassium-argon age determination on the Spears Member of the Datil in the Socorro area, 37 m. y. (latest Eocene), may be grossly applicable to the upper member of the Cub Mountain (Burke and others, 1963; Weber, 1963).

Sierra Blanca Volcanics

Directly overlying the Cub Mountain Formation is a sequence of andesitic volcanic rocks that form the bulk of the northern Sierra Blanca. Small outcrops are also scattered along the western (downthrown) side of the fault extending northeastward near the western foot of Chaves and Cub Mountains. Local masses of younger latite are presented in and adjacent to Church Mountain and in Gaylord Peak in the Sierra Blanca. Similar latites are prominent to the south in the Godfrey Hills (Sierra Blanca Peak quadrangle), where they overlie andesitic rocks like those in the Sierra Blanca.

The basal contact with the Cub Mountain is poorly exposed, but lithologically distinguished by the abrupt appearance of pinkish gray to grayish red ash and lapilli tuff. The section above the contact is obviously of volcanic origin, whereas below are water-laid clastic sediments of the Cub Mountain. Andesite and basaltic andesite flow breccias, flows, tuff breccias, and lapilli tuffs of light to dark gray, bluish gray, purplish gray, and pink to red color, related intrusives, and minor volcanic conglomerate have a residual aggregate thickness of 3,500 feet or more in the higher parts of the Sierra Blanca. An unknown additional thickness has been stripped from the crest of the range by subsequent erosion. Textures range from aphanitic to highly porphyritic with random to flow-aligned phenocrysts of plagioclase and augite. Vesicular and amygdaloidal phases are prominent locally. Pervasive propylitic alteration of variable intensity is indicated by widespread development of epidote, chlorite, and calcite, accompanied by greenish alteration colors and local bleaching.

Light to dark gray, reddish gray, and brown porphyritic aphanites of latitic composition are responsible for the topographic prominence of Church Mountain. Similar rocks make up the main mass of Gaylord Peak. Possible correlatives in the foothills at the northern end of the Sierra Blanca have been highly altered to quartz, epidote, and chlorite. Sparse to abundant phenocrysts of saussuritized andesine, sanidine, clinopyroxene, and biotite set in a cryptocrystalline to fine-grained groundmass are distinguishing features of these rocks. Contact relationships with the adjacent andesites are obscurred by extensive talus and colluvium. Textural and structural features that include massive phases of considerable thickness, local low- to high-angular planar flow banding, welded tuffs, breccias, and an exposed thickness of over 1,400 feet suggest emplacement as a volcanic dome with associated intrusive elements.

Correlation of the Sierra Blanca volcanics with the better known volcanic assemblages that extend from the Socorro area westward across the Datil-Mogollon volcanic field is handicapped by 50 miles of separation. Lithologic similarities of the volcanic rocks and analogies in stratigraphic relationships of the Baca to the Datil volcanics, and of the Cub Mountain to the Sierra Blanca volcanics, led the writer to suggest a possible correlation of the latter with andesites in the lower part of the Datil Formation in Socorro County (Weber, 1963, p. 138). Depending upon the validity of so speculative a correlation, a frame of age reference that bounds the andesites of the Socorro area by potassium-argon ages of 37 m. y. for underlying latite of the Spears Member and 32 m. y. for overlying rhyolite of the Hell's Mesa Member (Burke and others, 1963; Weber and Bassett, 1963) may be grossly relevant to the age of the Sierra Blanca volcanics. Although the andesites and latities of the "lower volcanic group" in the Magdalena and San Mateo areas have been considered to be pre-Datil (Weber, 1963), later field observations strongly suggest that they may be assignable to the basal part of the Datil Formation.

Intrusive Rocks

An extensive series of small stocks, domed plugs, sills, and dikes cut all previously described rock units but are most prevalent in and adjacent to the Sierra Blanca. A wide range in composition is represented, from alkali syenite through monzonite to gabbro, and minor ultrabasic types. Soda- and potash-rich varieties are prominent, whereas oversaturated quartz-bearing rocks are relatively sparse within the limits of the quadrangle. The larger intrusive masses are prevailingly syenitic to monzonitic in composition. Characteristic mineral assemblages include sodic orthoclase, anorthoclase, albite, hornblende, augite, aegerite-augite, aegerite, biotite, analcime, nepheline, leucite, and sodalite, with calcic plagioclase in the normal monzonitic to gabbroic rocks. Late magmatic and deuteric soda and potash enrichment are prevalent in the alkalic varieties. Zeolites, especially thomsonite, are widely distributed late magmatic to hydrothermal minerals.

Both simple and compound dikes cut all rocks indiscriminately, except for thicker sills, locally forming swarms that are only partly indicated on figure 2. Sills were emplaced preferentially in incompetent shaly zones in the Mancos, Mesaverde, and Cub Mountain. They are also common in the Sierra Blanca volcanics, where controls of emplacement are less clear. Plugs and stocks also show little evident structural control, although their tendency toward alignment along northerly trends may have structural significance. The igneous complex in the southeastern corner of the quadrangle consists of a zone of Sierra Blanca volcanics so riddled by stocks, sills, and dikes as to preclude differentiation at the map scale. The largest stock in this complex is a normal hornblende-biotite monzonite that extends southward from Nogal Canyon into Bonito Canyon (syenodiorite of Griswold and Missaghi, 1964).

A belt of topographically prominent alkali syenite sills with associated feeder intrusives extends through Chaves and Cub Mountains and Willow Hill. Chaves Mountain is capped by a sill of porphyritic analcite syenite connected with a feeder dike on the east. Phenocrysts of orthoclase, and clusters of smaller crystals of augite rimmed successively by aegerite-augite and aegerite, are set in a felted matrix of highly altered albite(?). Analcite is abundant as an intergranular component. The core of Cub Mountain consists of a pluglike mass of similar composition with the addition of some nepheline. Mottled zones of pronounced orthoclasation are conspicuous on the crest of the peak. Sill offshoots contain more abundant intergranular nepheline. The Willow Hill sill, which reaches a thickness of 800 feet, differs in being largely homogenous, fine-grained leucosyenite containing sparse small glomerocrysts of albite and small amounts of aegerite-augite and biotite, set in a matrix of altered orthoclase. The regularity of jointing paralleling the sill walls results in a pseudo-bedded appearance.

Several large domed plugs lie just outside the northeast corner of the quadrangle. These have been considered by some observers to be laccoliths, but evidence is lacking that they are floored intrusives. Doming of peripheral sedimentary wall rocks is strikingly shown on aerial photographs of Lone Mountain and clearly indicated on the map by Smith and Budding (1959). Modes of this rock by Butler (1964) range from quartz syenite to granite. Carrizo Mountain has a similar topographic expression, but marginal relationships are obscured by landslides and alluvial fans. Modes indicate a biotite-hornblende-quartz syenite porphyry with local trachytic texture (Butler, 1964). Trachytic texture is a conspicuous feature of many of the syenite sills and dikes of the Carrizozo quadrangle, a number of which have a foliated appearance.

Dark-colored lamprophyric intrusives are associated with some of the syenites in the southern part of the quadrangle. Among the recognized varieties are biotite-rich kersantite, augite-rich spessartite or camptonite, and monchiquite. Possible extrusive equivalents may be represented in analcite-basanite breccias at the western foot of the Sierra Blanca.

Age relationships within the intrusive suite are obscure due to the scarcity of cross-cutting contacts. Compound dikes of diverse composition indicate considerable overlap by hazy contacts and local reversals of sequence of intrusion. Gradational boundaries between leucocratic and melanocratic syenites also suggest essential synchronicity. Alkali syenite sills, which appear to be relatively late, are cut locally by dikes of gabbroic composition.

Major intrusives of the Carrizozo area are tentatively considered to be early Tertiary in age, although positive criteria for dating are lacking. They are to a large extent younger than the Sierra Blanca andesites, but intrusive contacts with the latite of Church Mountain were not seen. Genetic relationships with alkalic intrusives of the Cornudas Mountains on the Texas-New Mexico line to the south (Warner and others, 1959) are suggested by strong petrologic similarities.

Quaternary Rocks

Three classes of rock units of Quarternary age have been differentiated on figure 2: valley fill, landslides, and basalt. Colluvium and talus have been omitted.

Valley Fill

Several locally differentiable units, the oldest of which may be late Tertiary in age, are included within the broad category of valley fill. Much of the bajada on the east side of the Tularosa Valley is underlain by a poorly exposed sequence of weakly cemented clayey muds, silts, and sands. These beds are overlain locally by a thin, coarse, caliche-cemented gravel composed largely of fragments of intrusive rocks like those in Chaves and Cub Mountains and Willow Hill. Younger unconsolidated sandy to clayey gravels thinly veneer most of the bajada surface, merging westward with Recent sandy to clayey alluvium that abuts the eastern edge of the Carrizozo Malpais. These younger beds extend upslope into a series of coalescent alluvial fans with apices at the mouths of the principal canyons along the mountain front. Mud-flow scallops are conspicuous on the higher parts of some of the fans.

Landslides

Scalloped slopes surrounding Cub and Chaves Mountains are landslide features. A narrow band along the western foot of Willow Hill and similar, though less conspicuous, features in the higher elevations of the Sierra Blanca have not been differentiated on figure 2. Incompetent clays and shales in the Mesaverde and Cub Mountain sequences are particularly prone to yield to gravitational slumping where exposed in steep slopes under the load of thick sills and sandstones.

Basalt Flows

The floor of the northern Tularosa Valley is mantled by a sheet of basaltic lavas, commonly known as the Carrizozo Malpais, that extends southwestward for a distance of about 44 miles, and ranges in width from half a mile to more than five miles. An areal extent of about 127 square miles and a volume of close to one cubic mile have been calculated by Allen (1951). The flows issued from a vent marked by a cluster of small cinder cones near the northern end of the malpais. Little Black Peak, the most prominent of these, is visible to the north from U.S. Highway 380 where it crosses the malpais.

The surface of the lava field is marked by ropy corrugations, pressure ridges, low tumuli, and collapse features typical of pahoehoe flows. Two major flow units totaling 162 feet in thickness are exposed in the walls of a sinkhole that collapsed through the lavas two miles south of the highway. The basal flow there consists of gray, massive, fine-grained olivine basalt 60 feet thick, with a thin vesicular to scoriaceous zone at the top. The upper flow is lithologically similar, has a local thickness of 102 feet, and bears a thicker vesicular zone at the top. Underlying the basal flow is valley-floor alluvium composed of pinkish gray, silty limestone gravels with an exposed thickness of 15 feet.

Lithologic characteristics include sparse to abundant small olivine phenocrysts set in a fine-grained intergranular to subophitic matrix of andesine-labradorite laths, augite, and olivine in the midsections of the flows, grading to glassy phases at the upper surface. A chemical analysis of the upper flow is as follows:

SiO_2	50.77%	Na_2O	3.50%
Al_2O_3	14.00	K_2O	1.51
Fe_2O_3	2.34	TiO_2	1.71
FeO	7.48	P_2O_5	0.34
MnO	0.16	H_2O-	1.72
MgO	6.96	H_2O+	0.07
CaO	9.08	CO_2	0.00

Three explosive episodes are indicated by cinder cones at the vent. The latest of these is Little Black Peak, which rises to a height of 85 feet with slopes of 25 degrees, and contains an intact crater 32 feet deep. Another older cone with a smaller crater lies at the north-northwestern foot of Little Black Peak. The earliest visible cone apparently had the largest crater; it is represented only by remnants of the northern rim that lie a little farther out to the north and northeast.

The freshness of surficial flow features, lack of erosional dissection, and intact conditions of the latest cone all point to Recent origin of these flows. Absolute age criteria have not been obtained, but an estimate of 1,000 to 1,500 years seems reasonable.

Older basaltic lavas that issued from vents marked by two cones at Broken Back Crater, 8 miles to the west-northwest, probably underlie the northwestern edge of the Carrizozo Malpais.

STRUCTURE

The Carrizozo quadrangle occupies the western limb of a broad north-northeastward-trending syncline approximately 40 miles long and 25 to 30 miles wide. Consequently, all rocks older than the valley fill dip prevailingly southeastward to eastward. Relatively minor cross folds, solution collapse structures, and intrusion domes are superimposed upon the larger structure.

Only one major fault is clearly indicated, and that trends northeast along the western foot of Chaves and Cub Mountains. It may continue farther northeastward along the western foot of Willow Hill, but its trace is concealed by landslides and alluvium. The downthrown side is on the west. Other parallel faults are suspected in the area to the west where extensive cover and lack of marker beds in Cretaceous rocks precluded positive recognition. Another northeastward-trending fault is inferred to lie just under the western edge of the malpais because beds of the San Andres exposed to the west are flexed sharply downward toward the east.

Trends of dike swarms offer additional structural implications, the significance of which is not clear. Although the trends range through all quadrants, there is a progressive clockwise rotation of dike sets when traced from west to east around the northern end of the Sierra Blanca. The radial pattern tempts speculation that the dike trends may be related to magmatic pressures active during emplacement of stocks in the Sierra Blanca.

Additional structural implications may be drawn from the northerly trend of major intrusive masses along the axis of the Sierra Blanca syncline. The west-northwesterly alignment of basaltic vents at Little Black Peak and Broken Back Crater with the prominent monzonite dike and flexure of the Jones Camp iron deposit also seems more than fortuitous. Paralleling this trend is a major transverse fault that crosses the Sierra Oscura and disappears under alluvium 16 miles west of Carrizozo (Dane and Bachman, 1961).

Structural features comparable with those of the Lincoln fold system east of the Sierra Blanca have not been recognized in the Carrizozo area, although folds in the subsurface Yeso in the Heard test may be related. Craddock (1960) ascribed the Lincoln folds and faults to eastward gravitational gliding (decollement), triggered by plutonic doming to the west.

All observed structures are of post-Mesaverde Group age. The Cub Mountain Formation may be a product of Laramide events in this area during which broad, open folding created sediment-source highlands and a depositional basin. The extent to which this basin coincided with the present limits of the Sierra Blanca syncline is unknown. Subsequent volcanism and igneous intrusion possibly were accompanied by increased downwarping of the synclinal trough, with attendant readjustment by faulting. Local doming was a product of igneous intrusion. High-angle basin-and-range block faulting then outlined major ranges and intervening basins such as the Tularosa Valley. According to Pray (1961, p. 124), uplift of the Sacramento Mountain block ". . . probably began in late Cenozoic time and appears to be still in progress." Inasmuch as the Sierra Blanca lie along a north-northeastward extension of the Sacramento Mountain block, Pray's interpretation may be expected to be applicable to the Carrizozo area.

MINERAL DEPOSITS

Griswold (1959) has provided thorough coverage of the mineral resources of the Carrizozo quadrangle and surrounding area of Lincoln County; therefore, only passing metion of these features will be made herein.

Except for small amounts of coal from the Mesaverde Group in the Willow Hill field, mineral production has been negligible, although districts with a significant history of mineral production (White Oaks, Nogal, Bonito) lie just outside the eastern and southern boundaries of the quadrangle. Narrow fissure veins containing calcite, siderite, iron oxides, barite, and quartz, with small amounts of oxidized iron, copper, lead, and zinc sulfide minerals have been explored to shallow depths in a number of prospects along the western margin of the Sierra Blanca (Schelerville district). Most of these veins are in or adjacent to sheared syenite and diorite dikes of westerly trend that cut andesitic volcanic rocks. Pyrite, molybdenite, and minor amounts of chalcopyrite are locally conspicuous in altered parts of the monzonite stock in Nogal Canyon. The geology of that area, and results of a geochemical survey, have been described by Griswold and Missaghi (1964).

Cuttings of the salt section in the Yeso Formation from the Heard test have been examined for potash minerals, but the known results have been negative. Gypsum beds in outcrops of the San Andres Formation show little promise for commercial exploitation when compared with known, and currently productive, deposits elsewhere in New Mexico.

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