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THE CARRIZO MOUNTAIN STOCK AND ASSOCIATED INTRUSIONS, LINCOLN COUNTY, NEW MEXICO

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Abstract—The Carrizo Mountain stock in the Sacramento Mountains of south-central New Mexico is a steep-sided, partly fault-bounded intrusion of rhyolite and quartz monzonite. Sills associated with the intrusion occur along the north and northwest sides. Associated plugs and dikes occur on the northwest and southeast sides where their emplacement was facilitated by pre-existing fault zones. Dikes trend N20°E to N70°E and consist of rhyolite and several types of diabase. The diabase dikes are petrographically similar to the dikes of the adjacent Capitan dike swarm. Field and petrographic study has delineated an interior zone of porphyritic equigranular quartz monzonite partially enclosed in a thin shell of rhyolite. The presence of sanidine-rimmed plagioclase in the quartz monzonite suggests that differentiation of a granitic magma may be responsible for the observed variation, although the possibility of multiple intrusions cannot be ruled out.

INTRODUCTION

Location

Carrizo Mountain is in the northern portion of the Sacramento Mountains of south-central New Mexico. It is the most prominent topographic feature in the study area, rising abruptly more than 900 m above the surrounding plain. Deep canyons and steep talus-covered slopes are common. Carrizo Mountain is flanked by numerous intrusive bodies; the largest intrusion is the Bald Hills, 3 km northwest of Carrizo Mountain (Fig. 1).

Previous work

Within the vicinity of Carrizo Mountain more than 60 intrusive bodies have been mapped. These include the Capitan, Gallinas and Jicarilla Mountains and Lone, Patos and Vera Cruz Mountains. These have been variously described as stocks and laccoliths (Kelley, 1971, p. 35), with associated dikes and sills.

Previous work in the vicinity of Carrizo Mountain includes a paper on the Lone Mountain area to the northwest (Smith, 1964) and theses on Patos Mountain to the northeast (Haines, 1968) and the Jicarilla Mountains to the north (Ryberg, 1968). A report on the geology of the Carrizozo quadrangle (Weber, 1964, p. 107) referred to Carrizo Mountain as a domed plug, but Carrizo Mountain was also described as a probable laccolith (Kelley and Thompson, 1964, p. 115; Kelley, 1971, p. 35) and simply as a "steep-sided intrusion" (Elston and Snider, 1964, p. 143). Petrographically, the Carrizo Mountain intrusion is reportedly a hornblende-quartz syenite porphyry (Butler, 1964) and also a rhyolite and kalialaskite (Elston and Snider, 1964). Previous geologic mapping of the Carrizo Mountains is limited to a geologic map of the Carrizozo quadrangle at a scale of 1:177,408 (Weber, 1964), a tectonic map of the Ruidoso-Carrizozo region at 1:253,440 (Kelley and Thompson, 1964) and the New Mexico state geologic map at 1:500,000 (Dane and Bachman, 1965).

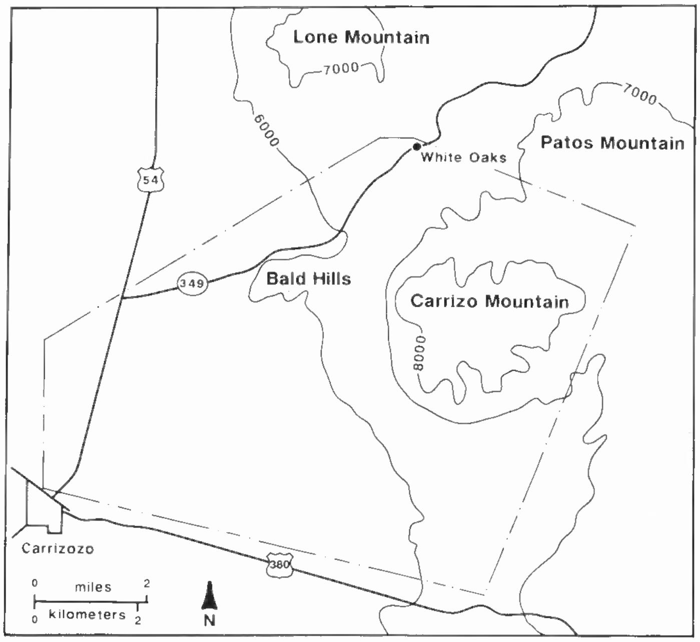

FIGURE 1. Location of study area, showing major topographic features in the vicinity of Carrizo Mountain, south-central New Mexico.

Purpose and methods

The main purpose of this study was to map the Carrizo Mountain area which had not previously been mapped in detail. The relationships of the intrusive bodies to the surrounding sedimentary units were examined in an attempt to describe the nature of the intrusive complex. In addition, the igneous rocks of the various intrusive bodies were studied and described.

Fieldwork for this study was conducted during the summer of 1983. Mapping of the area was done from aerial photographs at scales of 1:27,000 and 1:24,792. Data were then transferred to a topographic base, compiled from the White Oaks South and Carrizozo East, U.S. Geological Survey 7.5-min quadrangles, at a scale of 1:24,000.

Samples of the igneous rocks were collected during the fieldwork, and 25 were selected for detailed petrographic examination. The thin-sections were stained with saturated sodium cobaltnitrite and rhodizonate reagent to distinguish between alkali and plagioclase feldspar (Bailey and Stevens, 1960). Plagioclase compositions were estimated using the Michel-Levy method as outlined by Kerr (1977, p. 293–298). All igneous rocks were classified according to the IUGS Classification.

DESCRIPTION OF CARRIZO MOUNTAIN INTRUSIVE COMPLEX

Carrizo Mountain is the most prominent topographic feature in the northern part of the Sacramento Mountains, reaching an elevation of 2924 m (9650 ft). The intrusive body is circular in plan and covers an area of 35 km^2 (14 mi^2). It is flanked by intrusive bodies which are most numerous northwest and southeast of the mountain (Fig. 2). Faults bound the stock to the north, northwest and possibly to the southeast. Exposures of the Cretaceous Mancos Shale and the Mesaverde Formation surrounding the stock have a gentle southeasterly regional dip, except where the beds have been disturbed by the intrusion.

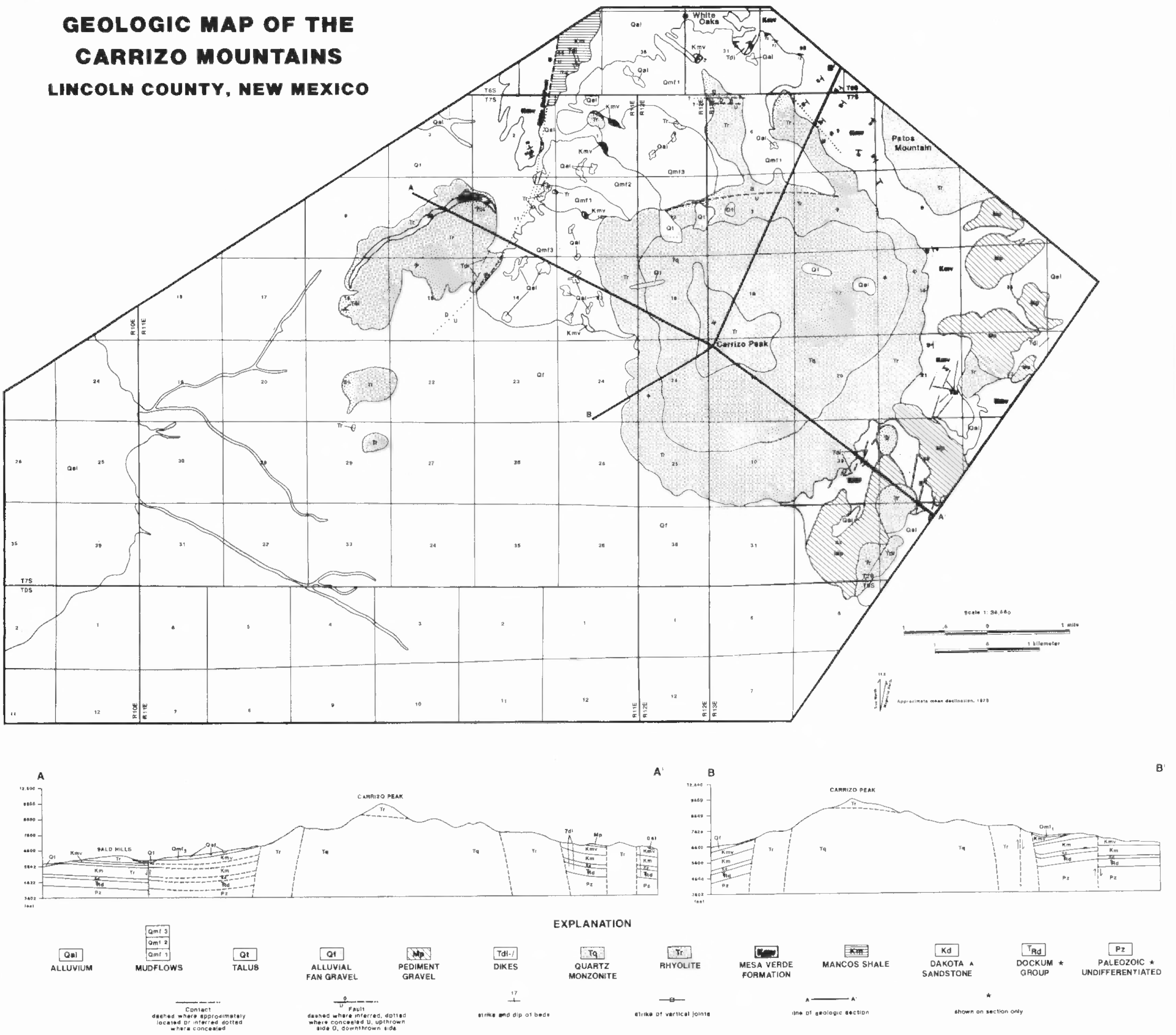

FIGURE 2. Geologic map of the Carrizo Mountain area.

Igneous rocks

Introduction

The Carrizo Mountain stock is composed of rhyolite and quartz monzonite and is surrounded by several rhyolitic sills and plugs. The quartz monzonite is best exposed on the south side of the intrusion, where it forms rounded outcrops up to 9 m (30 ft) high. The igneous bodies were not observed in direct contact with one another due to cover by talus and vegetation, but a gradational contact is inferred.

Diabase and olivine-diabase porphyry dikes are concentrated southeast of the intrusion and also occur locally northwest of the Carrizo stock. Most exhibit a northerly trend; some are oriented east-west. The dikes are most likely related to the Capitan dike swarm (Elston and Snider, 1964, p. 140).

Rhyolite

Rhyolite is exposed on Carrizo Mountain up to approximately 2454 m (8100 ft) and above 2727 m (9000 ft). It forms the entire periphery of Carrizo Mountain, the Bald Hills sill and all outlying intrusive bodies, including Patos Mountain to the northeast (Haines, 1968). The rhyolite in these intrusive bodies is texturally and mineralogically indistinguishable from the rhyolite of the main Carrizo Mountain intrusion. The contact between the surrounding Mesaverde Formation and the rhyolite is rarely observed due to cover by float or vegetation. Where contacts are observed, contact metamorphism of the Mesaverde Formation is limited to slight induration and bleaching.

Contacts between the rhyolite and quartz monzonite were also rarely observed due to cover by talus and vegetation. Based on limited observations at the contact and the positions of outcrops of monzonite and rhyolite, the contact between the two rock types appears to be vertical.

Megascopically, the rhyolite is very light gray and aphanitic. Locally, sanidine and biotite phenocrysts are present and may contain as much as 3 to 5% of the rock. The sanidine phenocrysts commonly weather out of the rock, leaving small euhedral cavities. In weathered outcrop the rhyolite is very pale orange to moderate orange-pink. Vertical jointing has produced platy, weathered fragments 15 to 30 cm (6 to 12 in.) in diameter. Liesegang banding and coatings of desert varnish are common.

Microscopically, the rhyolite is microcrystalline with an equigranular trachytic groundmass (0.1 to 0.2 mm) composed primarily of feldspar microlites. Phenocrysts of alkali feldspar and locally biotite are common. Porphyritic textures predominate, although non-porphyritic types commonly occur. Other minerals in the groundmass include sanidine, plagioclase, quartz, biotite, opaques and possibly hornblende (Fig. 3).

Quartz monzonite

Quartz monzonite crops out on Carrizo Mountain at elevations between 2364 and 2727 m (7800 and 9000 ft). The outcrops are vertically jointed, although jointing is not as pronounced as in the rhyolite. Flow banding is common in outcrops on the south side of the intrusion and appears to be the result of the magmatic segregation of light- and dark-colored minerals.

Megascopically, the quartz monzonite is very light gray and has a porphyritic texture. The rock contains phenocrysts of sanidine (up to 2 mm) and biotite in a fine-grained groundmass of quartz and of sanidine(?) commonly altered to clay minerals. Weathering of the quartz monzonite produces light-gray, blocky, angular boulders up to 0.6 m (2 ft) in diameter.

Microscopically, the quartz monzonite is porphyritic to equigranular and hypidiomorphic. Porphyritic samples contain phenocrysts of plagioclase and sanidine in a matrix of plagioclase, sanidine, quartz, biotite and locally, hornblende. Equigranular varieties exhibit the same mineralogy, lacking only the phenocrysts. The larger sanidine and biotite grains are parallel to subparallel in some samples but trachytic textures are uncommon (Fig. 4).

Dikes

Dikes in the vicinity of Carrizo Mountain are similar to those described by Elston and Snider (1964) and Cepeda (1990) in the Capitan area. Age relations between the dikes are based on crosscutting and chill- and bake-zone relationships and are, in order of intrusion: (1) diabase porphyry, (2) olivine diabase porphyry, (3) fine-grained diabase, including hornblende and biotite bearing varieties, (4) rhyolite, (5) latite and trachyte, and (6) tephrite (Elston and Snider, 1964; Cepeda, 1990). Twenty dikes were mapped southeast of the intrusion. In this area they trend N10°E to N73°E, with dips ranging from 71° to 81°SE. Varieties present in the Carrizo Mountain area include diabase porphyry, fine-grained diabase, rhyolite and possibly trachyte. All have intruded the Mesaverde Formation and generally are 0.9 to 2 m wide and may be up to 600 m long in outcrop. All are steeply dipping.

Diabase porphyry

Megascopically, the olivine diabase porphyries are medium dark gray. Phenocrysts of plagioclase occur in a fine-grained to aphanitic groundmass of pyroxene and plagioclase (0.05 to 0.2 mm). In weathered outcrop, the rocks are medium dark gray to grayish black and moderate brown. Microscopically, the rocks are hypidiomorphic and generally equigranular; however, phenocrysts of plagioclase and pyroxene (0.1 to 1 mm) are locally significant. The plagioclase in the groundmass defines a rather trachytic texture.

Plagioclase may occur as tabular to blocky phenocrysts (up to 1 mm) and as felted masses in the groundmass (0.05 to 0.2 mm). Carlsbad-albite twinning and normal zoning are common. Composition of the plagioclase phenocrysts ranges from An39 to An36. Two generations of plagioclase phenocrysts are evident in some samples. Subhedral plagioclase is oriented at 90° to generally anhedral, ragged plagioclase grains. The subhedral grains are often embayed by the anhedral grains.

Augite, hypersthene and enstatite form phenocrysts (to 0.4 mm) and scattered grains in the samples. The grains are blocky and euhedral to subhedral, often occurring in glomerophyric clusters. Alteration to sheaths of chlorite along grain margins and on grain surfaces is common.

Olivine occurs as subhedral to anhedral grains and phenocrysts (0.2 to 1 mm). Sinuous fractures filled with iddingsite are common. The grains are distinguished by curved, ragged edges. Accessory minerals include brown, chloritized biotite, zircon, acicular apatite and opaques.

Olivine diabase

Megascopically, the diabases are very light gray to grayish black and aphanitic to medium grained. Pyroxene, biotite and plagioclase are visible in the medium-grained samples. Weathered outcrops are greenish gray to grayish black and moderate brown. Microscopically, the diabases are characterized by hypidiomorphic, trachytic textures. Parallel, acicular plagioclase crystals form a felted groundmass that includes pyroxene and biotite. Some samples are porphyritic, containing plagioclase phenocrysts up to 4 mm in length (Fig. 5).

Plagioclase, whether in the groundmass or as phenocrysts, forms tabular, euhedral crystals. The crystals exhibit Carlsbad-albite twinning, with compositions ranging from An50 to An32. Normal and reverse zoning are evident; however, Ca-rich cores appear to be slightly more numerous. Alteration to sericite and chlorite, leaving skeletal crystals, is common.

Pyroxene (0.02 to 0.2 mm) occurs as subhedral to anhedral grains of light-green augite, enstatite and hypersthene. The grains are badly fragmented and skeletal. Grain contacts are sutured. Fractures filled with iddingsite(?) are locally significant.

Green or brown biotite (0.05 to 0.2 mm) occurs as euhedral to

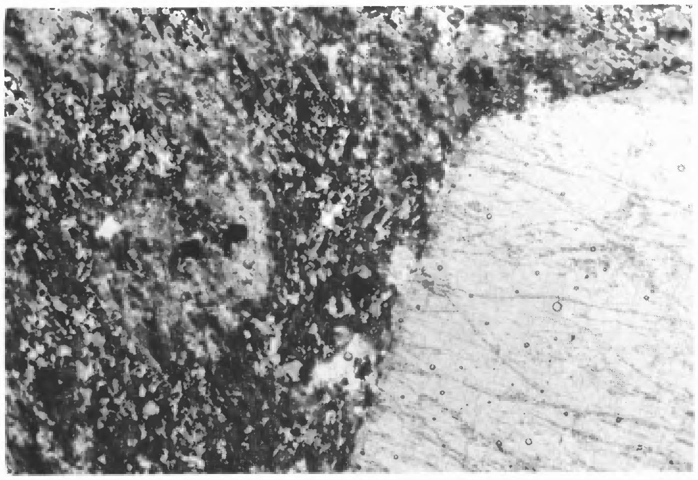

FIGURE 3. Photomicrograph of Carrizo Mountain rhyolite. Portion of sanidine phenocryst visible in right half of photograph. Field of view is 4 mm by 2.5 mm.

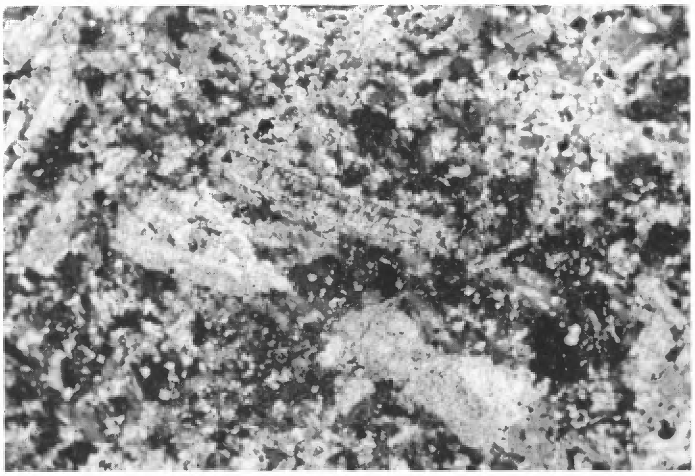

FIGURE 4. Photomicrograph of Carrizo Mountain quartz monzonite showing euhedral to subhedral plagioclase phenocrysts (center) in a groundmass of plagioclase, quartz and sanidine. Field of view is 4 mm by 2.5 mm.

FIGURE 5. Photomicrograph of diabase dike showing plagioclase laths and equidimensional grains of olivine and clinopyroxene. Field of view is 4 mm by 2.5 mm.

anhedral, tabular grains. The crystals are ragged and chloritized. Accessory minerals include zircon associated with biotite, apatite needles and euhedral to subhedral opaques.

Rhyolite

Rhyolite dikes are common in the Lone Mountain area (Fig. 1). The occurrence of these dikes may be related to the silicic intrusive bodies of Lincoln County (Elston and Snider, 1964, p. 142; Smith, 1964, p. 96). One rhyolite dike occurs in N$^1/_2$ SE$^1/_4$ sec. 35, T6S, R11E. The dike trends N30°W and is exposed along a hillside where it has cut the Mancos Shale. Paralleling the rhyolite dike are three diabase dikes. The rhyolite dike is approximately 0.3 m (1 ft) wide and may be traced for nearly 12 m (40 ft) up the hillside.

Megascopically, the rhyolite dike is pale yellowish orange. The rock is entirely aphantic and closely resembles the rhyolite exposed in the Carrizo Mountain area. Microscopically, the dike has a trachytic texture, with plagioclase microlites (0.1 to 0.2 mm) forming a felted groundmass. The plagioclase may also form euhedral phenocrysts (0.5 to 1.5 mm) exhibiting Carlsbad twinning. Composition of the plagioclase is approximately An35. Alteration to sericite is most pronounced in the groundmass.

Age of the dikes

The dikes in the study area are petrographically similar to those in the Capitan area. Based on field evidence, Elston and Snider (1964, p. 140) designated the labradorite-olivine diabase to be the oldest dike type, followed in age by the olivine diabase porphyry. They believed the olivine diabase to be chemically representative of the parent magma. However, Cepeda (1990) noted that the fine-grained diabase more closely approximates a parental magma, and the porphyritic varieties represent cumulates derived from various levels in the magma chamber. The dikes adjacent to Carrizo Mountain appear to be part of the Capitan swarm, based on their mineralogical similarities and proximity to this dike swarm. Thompson (1966) assigned a late Oligocene age to intrusion and volcanism in the Sierra Blanca area, 10 km to the south. Moreover, K-Ar dating of an olivine diabase porphyry dike collected southeast of Carrizo Mountain, gives an age of 35.1 ± 0.7 Ma. Therefore, it seems probable that the dikes of the Capitan dike swarm are related to volcanic activity in the Sierra Blanca area 35 to 26 Ma ago (Thompson, 1972).

ECONOMIC GEOLOGY

The White Oaks mining district is approximately 2 km (1 mi) northwest of White Oaks village (Fig. 1). Mining operations were most active at the turn of the century but decreased shortly thereafter (Griswold, 1959, p. 28, table 5). Gold was the most important economic mineral and operations centered on five mines in the Lone and Baxter Mountain areas. The gold occurs in northerly trending, vertical fractures and breccia zones in association with silver and tungsten. Gold production from the White Oaks mining district reached 143,000 oz between 1879 and 1903. Total production through 1956 was 152,373 oz (Griswold, 1959).

Iron ore was produced from the area around Lone Mountain during the early 1900s. It occurs as hematite, with subordinate magnetite and specularite in the San Andres Formation. Approximately 23,636 mt (26,000 t) of iron ore were mined (Griswold, 1959).

Coal was mined from Coal Dump Canyon, southeast of White Oaks village, beginning around 1880. The principal demand was to supply fuel for the gold mining operations in the White Oaks mining district. By 1885 the coal deposits near Capitan, New Mexico, were being mined and together with the White Oaks production, ranked third in total production for the state. The Capitan deposits were difficult to mine due to faulting and intrusion by numerous dikes, and operations ceased in 1906. White Oaks continued to supply local coal demands until 1939 (Griswold, 1959, p. 105). The White Oaks coal deposits occur in the middle unit of the Mesaverde Formation. The coal seams are thin (less than 8 cm or 3 in) and may be interbedded with shale. Mining operations were hampered by the lack of adequate exposures and the discontinuous nature of the seams.

One prospect pit was found during the course of the field investigation. However, these is little evidence of mineralization adjacent to the Carrizo stock or the intrusive bodies which surround it. Reasons for the lack of mineralization immediately adjacent to the stock are unknown. The apparent low water content of the magma resulted in little, if any, late-stage ore-bearing hydrothermal activity. The anhydrous nature of the magma is deduced from the lack of significant water-bearing minerals in the Carrizo rocks.

ORIGIN OF THE CARRIZO MOUNTAIN INTRUSIVE COMPLEX

Carrizo Mountain has been described as a domed plug (Weber, 1964, p. 107), a steep-sided intrusion (Elston and Snider, 1964, p. 143) and a laccolith (Kelley and Thompson, 1964, p. 115; Kelley, 1971, p. 35). The details of the relationship of the Carrizo intrusion to surrounding strata are obscured by alluvial fans on the south and southwest sides of the intrusion, and by mudflows that mantle much of the north and northwest slopes. However, field investigation during this study, especially on the north and east sides of the intrusion, indicates the relations with the surrounding Mesaverde Formation are more suggestive of a stock. The Mesaverde commonly dips gently toward the intrusion and is dragged upward within several hundred meters of the intrusive contact (Elston and Snider, 1964, p. 143). Although the contact between the Mesaverde and the intrusive body is obscured, dip reversals occur within 90 to 600 m (300 to 2000 ft) of the inferred contact.

In addition, Carrizo Mountain is partly fault bounded. A fault along the north flank of the stock forms a linear scarp along the mountain front and is probably related to the intrusive episode. The presence of this fault indicates strong upward movement of the igneous body, rather than lateral movement through the surrounding sedimentary units suggestive of a laccolith.

Finally, laccolithic arching of the strata surrounding the Carrizo stock was not detected. Possibly the viscosity of the magma inhibited the formation of laccolithic structures in Carrizo Mountain while favoring irregular intrusive bodies. Paige (1913) and Hunt (1953) recognized the effects of marginal cooling on the viscosity of magma in their studies of laccolithic intrusions. Their work indicates marginal cooling may increase the viscosity along the edges of the intrusive body, resulting in greater vertical push of the magma. Based on previously discussed evidence of a strong vertical thrust of the Carrizo intrusive body (faulting) and the effects of marginal cooling on the viscosity of magma, it seems probable that marginal cooling played an important role in the formation of the Carrizo stock. Aphanitic textures in the Carrizo rhyolites suggest rapid cooling during the intrusive episode. The cooling of the magma against the country rock and the subsequent increase in viscosity inhibited lateral movement of the magma body. The result was greater upward thrusting of the magma and the formation of the Carrizo stock.

It is interesting to speculate on the relationship between the Carrizo stock and the Patos laccolith. The two intrusions lie within 600 m (2000 ft) of one another. The igneous rock which makes up the Patos laccolith occupies an area of 20 km^2 (8 mi^2) and has a maximum relief of 454 m (1500 ft). Haines (1968) believed the Patos laccolith to be mushroom-shaped in cross section, and composed entirely of rhyolite. Flow layering in the rhyolite occurs at oblique angles to their contact with the intruded strata, indicating lateral intrusion of the Patos magma body (Haines, 1968, p. 33). Haines was unable to determine the total thickness of the body, but believed it to be thicker on the north side. He found the exposed part of the Patos laccolith to be intruded wholly into the Mesaverde Formation and noted that "The roof of the laccolith has been removed, but on the south and west the sandstones are dipping gently away from the intrusion and may be projected over the top of the mountain . . ." (Haines, 1968, p. 18).

Based on the dip of the strata toward the Carrizo stock, the similarity of rhyolite lithology and the close proximity of the two igneous bodies, it seems probable that the Patos laccolith is directly related to the Carrizo stock (Fig. 6). In the Coal Dump Canyon area, northeast of Carrizo Mountain, the middle unit of the Mesaverde Formation conformably overlies the lower sandstone unit of the Mesaverde. Both units exhibit the same general strike and southwesterly dip, and no evidence of intrusion through the shale unit is apparent. Hunt (1953, p. 142–143) found that the largest number of laccoliths occur in the least coherent strata in the Henry Mountains of Utah, whereas irregular bodies were most likely to occur in thick competent strata. Therefore, based on Hunt's observations and the size of the Patos laccolith, we believe that the Mancos Shale is the more likely stratigraphic horizon of laccolith formation. The thick Mancos Shale sequence (approximately 182 m or 600 ft), overlain by the lower sandstone of the Mesaverde Formation and underlain by the Dakota Sandstone, would form an ideal horizon for potential intrusion. Movement of the magma upward from the Mancos through the middle unit of the Mesaverde was probably facilitated by the opening of joints as the strata were arched into laccolithic form. This allowed the magma to intrude into the Mesaverde Formation as observed by Haines (1968).

SILLS

Five sills, mapped on the north, northwest and southwest sides of the Carrizo stock, form flat-topped structural features. The largest is the Bald Hills sill, which occupies an area of approximately 5 km^2 (2 mi^2) northwest of the Carrizo stock. The sill dips approximately 10° to the south-southeast, reflecting the 14° southerly dip of the intruded Mesaverde strata. The sill is composed of vertically jointed rhyolite. The spacing of the joint planes ranges from approximately 8 cm to 0.3 m (3 in. to 1 ft). Observed outcrops of the rhyolite vary from 0.3 to 4 m (1 to 12 ft) in thickness. The total thickness of the sill is at least 30 m (100 ft); however, this estimate includes approximately 15 m (50 ft) of Mesaverde Formation, which has been enveloped and surrounded by the invading rhyolitic magma.

The remaining sills occur southwest, northwest and north of the Carrizo stock. All are rhyolitic in composition and have intruded the Mesaverde Formation, based on exposures of the unit along arroyos cut into the flank of the sills. Contact metamorphic effects are limited to slight baking of the sedimentary unit along its contact with the intruding body.

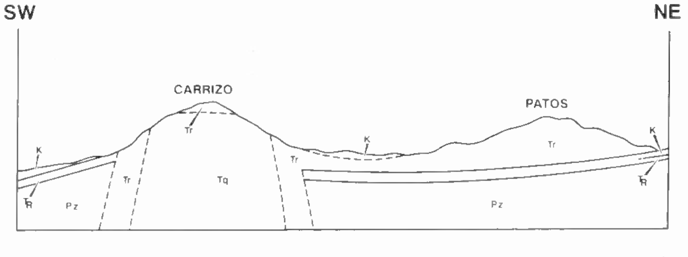

FIGURE 6. Diagrammatic southwest to northeast cross section across Carrizo and Patos Mountains illustrating Patos Mountain as a laccolith formed during the intrusion of the Carrizo stock. K, Cretaceous sedimentary rocks; Tr, Triassic rocks; Pz, Paleozoic rocks; Tr, Tertiary rhyolite; Tq, Tertiary quartz monzonite.

ZONING WITHIN THE CARRIZO MOUNTAIN INTRUSION

The Carrizo stock is a reversely zoned intrusive body, based on its increasily mafic coreward (rhyolite to quartz monzonite) composition. The formation of reversely zoned intrusive bodies appears to be the result of differences in the density and rates of flow between mafic and felsic portions of the magma body. According to Blake (1981), the magma chamber becomes reversely zoned as magma flows toward a conduit in its roof. Due to its low viscosity, mafic portions of the melt flow toward the conduit more quickly. Restratification of the remaining magma by density between intrusive events allows mafic magma to sink and silicic magma to migrate to open areas near the margins of the intrusion (Fridrich and Mahood, 1984).

The igneous bodies were not commonly observed in direct contact with one another due to cover by talus and vegetation. Therefore, an overall gradational contact is inferred. The relationship between the bodies remains unclear, but, based on our work we believe the rhyolite once formed a continuous shell around the periphery of the magma body. The shell insulated the remaining melt, resulting in a slower rate of crystallization and the coarser texture of the quartz monzonite (Fig. 7). This hypothesis explains the rhyolite to quartz monzonite coreward compositional change observed in the Carrizo stock. The rhyolite is therefore interpreted to be an erosional remnant of a once-continuous shell that formed the periphery of the magma body.

It is also possible that the Carrizo stock is the result of two intrusive phases. An initial rhyolitic phase may have resulted in the intrusion of the periphery of the stock and all satellitic intrusive bodies. Intrusion of the quartz monzonite within the rhyolite shell may have occurred in

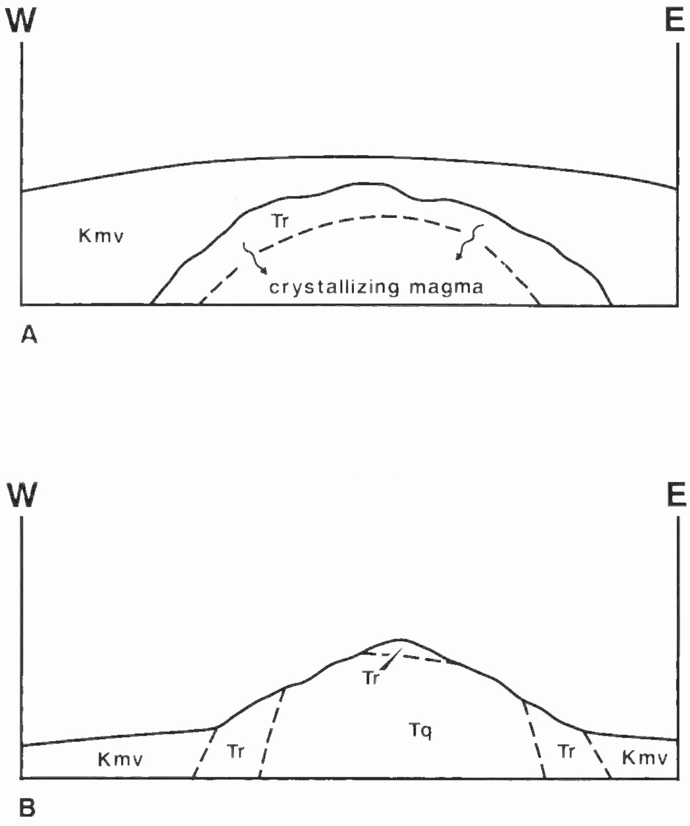

FIGURE 7. Diagrammatic east-west cross section across Carrizo Mountain, illustrating the possible evolution of the stock into a zoned magma body. Kmv, Cretaceous Mesaverde Formation: Tr, Tertiary rhyolite; Tq, Tertiary quartz monzonite.

a subsequent intrusive phase. However, sharp contacts and crosscutting relationships that would support this hypothesis are lacking with the Carrizo stock.

ACKNOWLEDGMENTS

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View to west across the high railroad bridge and roadway toward the Tularosa Basin. The bridge remains standing today, unlike all others on this line. From the postcard collection of Spencer Wilson.