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GEOLOGIC FRAMEWORK OF TERTIARY INTRUSIONS OF THE CORNUDAS MOUNTAINS, SOUTHERN NEW MEXICO

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Abstract—The Cornudas Mountains in southern New Mexico are underlain by Eocene to Oligocene syenite and phonolite that intrude the Permian Hueco Formation, an anomalously thin Yeso Formation, the San Andres Formation and the Lower Cretaceous Cox, Campagrande, Mesilla Valley, and Muleros Formations. The alkaline intrusions rose along pre-Permian faults near and at the edge of the Pedernal uplift, and moved laterally along the unconformity between Precambrian rocks and the base of the Permian and along the disconformity between the Permian San Andres and overlying Cretaceous rocks. The present-day level of erosion exposes a variety of intrusive forms. Intrusions caused a series of continuous anticlines and synclines and local sags and uplifts in the Permian rocks. Cretaceous rocks occur only in patches along the edges of the resistant intrusions and are remnants of a mostly eroded section that once covered the area. Cretaceous rocks are preserved in and beneath Quaternary landslides that slid off Alamo, San Antonio, Chattfield, and Black Mountains.

INTRODUCTION

The Cornudas Mountains alkaline intrusions at the border of New Mexico and Texas stand out in stark contrast to the plains where most geology is known from subsurface drilling. Exploration for beer-bottle-quality glass derived from syenite brought a request from the U.S. Bureau of Land Management for the U.S. Geological Survey to study the area. About 120 mi^2 of the Cornudas Mountains of New Mexico were mapped to extend the work of theses by Clabaugh (1941), Timm (1941), and Zapp (1941). Our observations and conclusions are based on the resultant 1:24,000-scale map (O'Neill and Nutt, 1998) and on correlation of map data with subsurface data.

GEOLOGIC SETTING

Regional

The Cornudas Mountains are in the easternmost part of the Rio Grande province of southern New Mexico. The area is located near the center of the Otero-Diablo platform, which separates areas of Tertiary and Quaternary faulting of the Rio Grande rift on the west from the Salt Basin graben and the adjacent Guadalupe Mountains on the east (Fig. 1). The Cornudas Mountains include late Eocene to early Oligocene alkaline intrusive rocks that are part of the Tertiary Trans-Pecos magmatic belt (Barker, 1977). The predominantly alkaline intrusive rocks of the Cornudas Mountains give way to calc-alkaline intrusions of the Hueco Mountains, about 30 mi to the west (Fig. 1). The Cornudas Mountains lie above the faulted, western edge of the buried Pennsylvanian Pedernal uplift; alkaline rocks apparently intruded along the pre-Permian faults and invaded Paleozoic sedimentary rocks lying unconformably on the uplifted Precambrian basement (Black, 1975).

TABLE 1. Igneous rocks of the Cornudas Mountains. Ages are K-Ar on biotite from Barker et al. (1977). Modified from Clabaugh (1941), Zapp (1941), Timm (1941), Barker et al. (1977), Barker and Hodges (1977), McLemore and Guilinger (1993), Schreiner (1994), and McLemore et al. (1996).

Locality	Rock type and description	Age
Wind and Deer Mtns	Nepheline syenite: medium- to light-gray, mostly coarse-grained, equigranular to slightly porphyritic, weakly to strong foliated	31.6 Ma at Deer Mtn
upper part of Wind Mtn	Syenite porphyry: fine-grained	
Black and San Antonio Mtns	Nepheline syenite: dark-gray-green, porphyritic fine- to medium-grained, euhedral anorthoclase as long as 1 in.	
Corundas Mtn	Quartz-bearing syenite: medium-gray, weakly foliated, granoblastic to porphyritic with conspicuous tabular and euhedral anorthoclase	33.9 Ma
Chattfield and Alamo Mtns, Flat Top	Phonolite: medium-gray-green, aphanitic, with well developed flow foliation	36 Ma at Alamo Mtn
Chess Draw	Nepheline-bearing syenite: poorly exposed	36.9 Ma

Cornudas Mountains

The Cornudas Mountains are underlain by Permian limestone, dolomite, gypsum, and shale; Cretaceous sandstone and shale; and late Eocene to early Oligocene alkaline intrusive rocks. The igneous rocks form the major peaks of the Cornudas Mountains that are, from east to west, Black, Cornudas, Wind, Chattfield, San

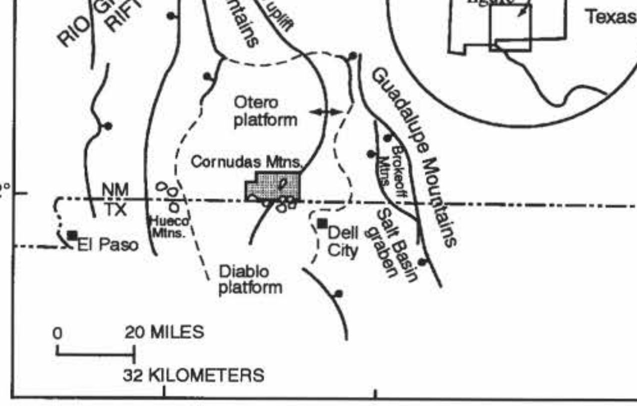


FIGURE 1. Generalized tectonic map of south-central New Mexico and adjacent Texas. Modified from Woodward et al. (1975) and King and Harder (1985).

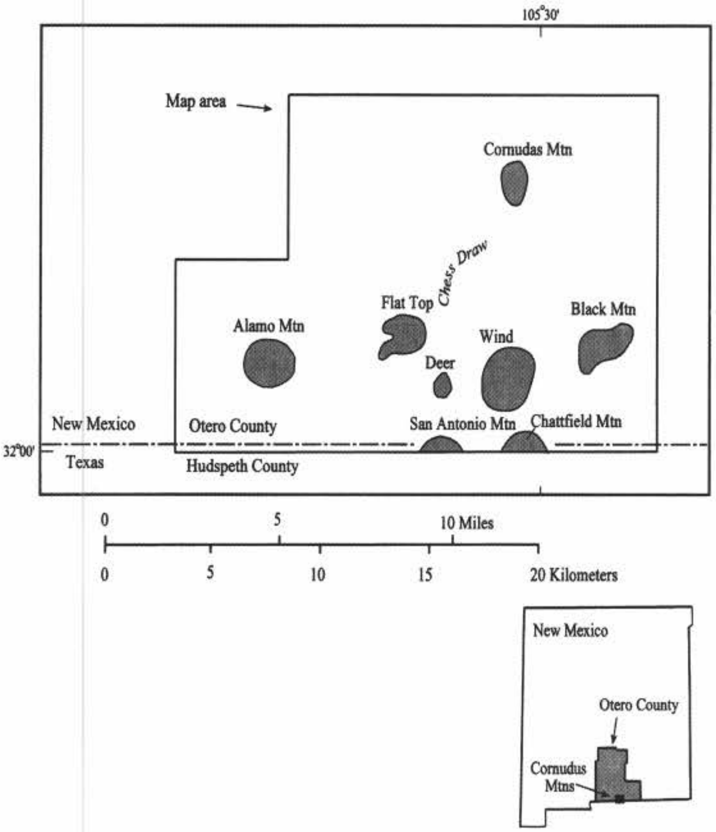


FIGURE 2. Locality map showing the Cornudas Mountains in southern New Mexico, the peaks and Chess Draw referred to in the text, and the map area of Figure 4.

Antonio, Deer Mountains, Flat Top, and Alamo Mountain (Fig. 2). The igneous rocks are described in Table 1 and the Permian and Cretaceous succession is shown on Figure 3.

Permian sedimentary strata, the oldest exposed rocks in the study area, make up the gently rolling hill and plain topography around the Cornudas Mountains. Three distinct Permian units are mapped in the Cornudas Mountains (Figs. 3 and 4). The lowermost limestones exposed in the map area are likely equivalents of the Hueco Formation (Ph) (Kottlowski, 1963). The Hueco is in sharp contact with an overlying, anomalously thin section of gypsum, green and red shale, and pale-gray limestone of the Yeso Formation (Py). The Yeso has not been reported south of Cornudas and appears to pinch out abruptly southward. The Yeso is overlain by a marine, near-shore, shallow-water deposit of carbonate rocks and sandstone that grade upward into thin- to medium-bedded dolomitic limestone and dolomite that we correlate with the San Andres Formation (Psa). The San Andres in the western part of the map area grades laterally into Leonardian limestones, probably the Bone Springs Limestone (King, 1934) of the Diablo platform; on the east, the formation appears to grade into the Victorio Peak carbonates, the bank-ramp facies of the Capitan reef complex (Pray, 1988).

Cretaceous sedimentary rocks (Fig. 3; Ku on Fig. 4) are exposed only where they are overlain by or adjacent to resistant igneous bodies at Alamo, San Antonio, Chattfield, and Black Mountains. Cretaceous rocks are remnants of a sedimentary section that once covered the area. The thickness of the lowermost Cretaceous Campagrande Formation and Cox Sandstone is variable and suggest that the pre-Cretaceous depositional surface was locally irregular. Areas of Cretaceous outcrop are coincident with landslide deposits (Qls) and suggest that during late Tertiary erosion of the southern Otero platform, the less resistant Cretaceous strata slumped along the edges of the more resistant igneous rocks.

Quaternary surficial deposits are common in the map area and consist mainly of calcium-carbonate-cemented colluvium, alluvial and fluvial deposits, and ephemeral stream channel deposits shown as Qu on Figure 4. Talus (Qt) and landslide deposits near intrusive bodies are shown in Figure 4. Perched gravels of probable Pliocene-Pleistocene age are preserved adjacent to many of the peaks of the Cornudas Mountains.

The intrusive bodies vary considerably in their shape and form, as discussed below. Flow foliation is common in all intrusive rocks and is particularly well developed near contacts with adjacent sedimentary rocks. Intrusive bodies range from sills where foliation is subparallel to the enclosing, nearly flat-lying sedimentary rocks (Flat Top, Black, San Antonio, and Chattfield Mountains), to plug-like bodies where foliation is steep (Deer and Wind Mountains), to irregularly shaped intrusive complexes with variable foliation where the level of erosion has exposed both feeder bodies and off-shooting sills (Cornudas and Alamo Mountains). Magnetic data (Nutt et al., 1997) indicate a major, buried intrusive body northwest of Wind Mountain and in the Chess Draw area at a depth of about 2200 ft (Fig. 2).

Contacts between intrusive and sedimentary rock are surprisingly sharp, and the lack of anything more than irregular and local metamorphism and alteration is striking. The Chess Draw area in the central part of the map area is the one small area of altered rock that has been prospected for metallic mineral resources.

SYN-INTRUSIVE STRUCTURES

Folds and intrusive forms

Rocks that underlie the Otero platform are deformed by gentle folds and minor faults (Black, 1975; Woodward et al., 1975). The relatively undeformed character of the platform rocks changes dramatically in the vicinity of the Cornudas Mountains, where a complex series of gently to steeply dipping, locally asymmetric folds

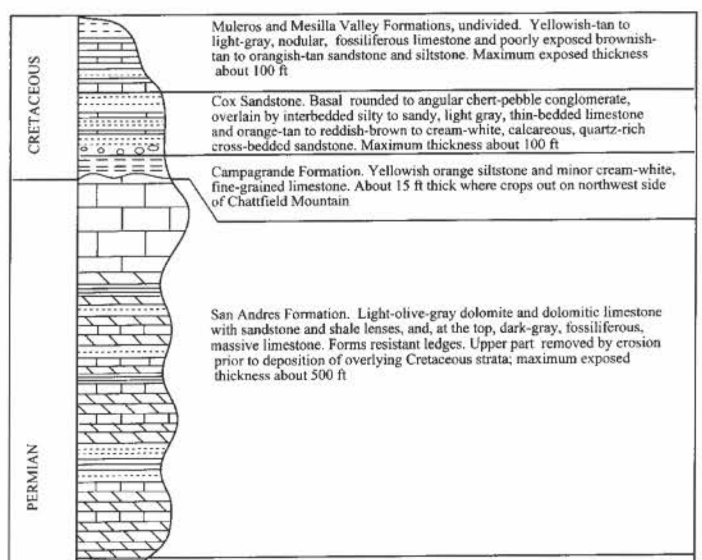
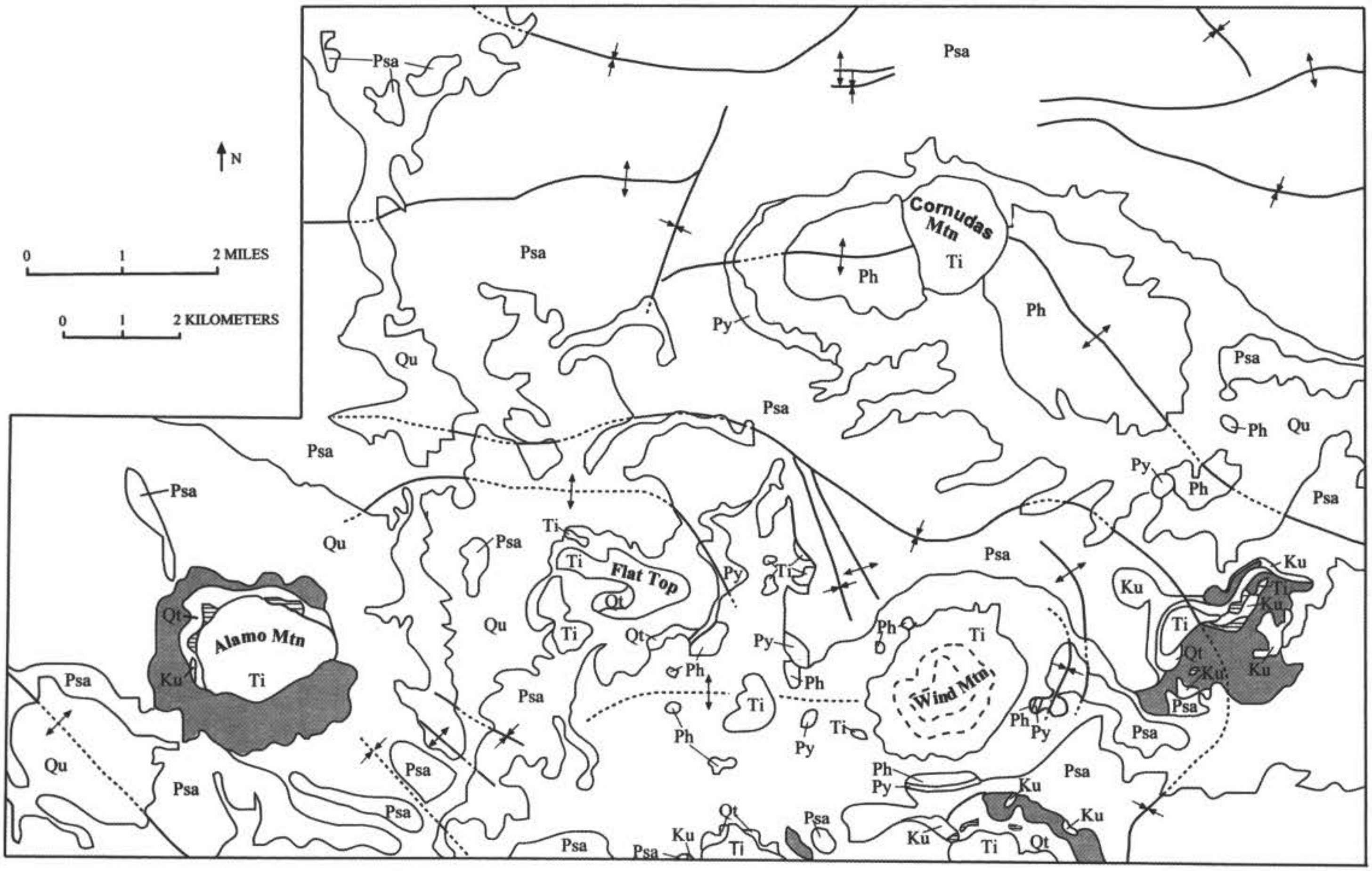


FIGURE 3. Stratigraphic description of the Permian and Cretaceous rocks in the Cornudas Mountains.



EXPLANATION

Qt	Quaternary talus
Qu	Quaternary to Pleistocene alluvium, undifferentiated, includes stream and fan alluvium and colluvium
	Pleistocene landslides
	Pleistocene to Pliocene pediment alluvium
Ti	Oligocene to Eocene intrusive rocks, undifferentiated
Ku	Cretaceous Muleros, Mesilla Valley, and Campagrande Formations, and Cox Sandstone, undivided
Psa	Permian San Andres Formation
Py	Permian Yeso Formation
Ph	Permian Hueco Formation
	Contact, dashed on Wind Mountain to show zoned composition of that intrusion
	Anticline, dotted where concealed
	Syncline, dotted where concealed

FIGURE 4. Simplified geologic map modified from O'Neill and Nutt (1998). Locality of map area shown on Figure 2.

appear to be related to intrusion of the igneous rocks. Elongate domes or anticlines are centered on Cornudas Mountain and on Wind Mountain; two additional anticlines lacking exposed igneous rocks in their cores are present north of Flat Top and southwest of Alamo Mountain. Between the anticlines are a series of subparallel to obliquely trending synclines or structural sags. The most pronounced syncline can be traced along the east side of Wind Mountain where sedimentary rocks dip as much as 60° away from the peak. The traces of the axial planes of folds in the Cornudas Mountains define complex, locally merging and curvilinear patterns. These patterns bear a strong similarity to folds associated with laccolithic intrusives so well described by Hunt (1953) in the Henry Mountains, Utah.

In the north, Cornudas Mountain sits astride an anticline that can be traced for 12 mi completely across the map area; the Hueco Formation is well-exposed in the axial portion of the fold centered on the intrusive rocks. The anticlinal axis trends northwest on the east and folded Hueco limestones appear to extend beneath the east side of Cornudas Mountain. On the west, the fold deforms Hueco limestones that overlie the intrusion. The fold axis trends west in this area but is displaced about 1 mi to the north where it merges with a north-trending structural sag. The association of the fold axis and the Cornudas Mountain intrusive suggest that an elongate intrusive body underlies the entire anticlinal fold and that the exposed Cornudas intrusive is an odd-shaped, sill-like body that plunges gently west, yet is bulgingly discordant on the east (Fig. 5). Hunt (1953) might have termed this apophysis of the underlying intrusion a sphenolith.

Wind Mountain is the core of a dome in which the enclosing sedimentary rocks of the Hueco Formation locally dip more than 60°. A structural sag appears to separate Deer Mountain on the west from the main dome; however, the Deer Mountain intrusive also invaded the Hueco and is structurally in the core of a west-trending anticlinal flexure that is a part of the Wind Mountain dome (Fig. 3). The Wind Mountain dome cannot be traced east. The Wind Mountain intrusive has been interpreted as a laccolithic intrusion (McLemore et al., 1996), but newly mapped geologic and geophysical relations (Nutt et al., 1997) suggest an alternative interpretation. There is no evidence that sedimentary rocks floor the intrusion; all sedimentary host rocks are strongly deformed adjacent to the intrusion and dip steeply away from the peak. Foliation within the Wind Mountain intrusion defines a circular pattern that is mimicked by the enclosing sedimentary rocks. The aeromagnetic signature at Wind Mountain is the strongest, most prominent magnetic anomaly in the Cornudas Mountains (Nutt et al., 1997). Other topographically similar peaks are floored by sedimentary rocks and, based on their magnetic signature, lack the mass of Wind Mountain. The Wind Mountain intrusion appears to be a steep-sided plug that extends downward to its intersection with a parent intrusive body that underlies the combined Wind and Deer Mountains anticlinal flexure. Hunt (1953) described intrusive forms similar to Wind Mountain as bysmaliths.

An anticlinal, convex-northward upwarp is present north of Flat Top. The fold plunges west and terminates near Alamo Mountain; on the east it merges with the Wind and Deer Mountains anticline. A second anticlinal flexure is mapped southwest of Alamo Mountain; the fold can be traced southeast at least 7 mi into Texas. Based on the direct correlation of anticlinal flexures and doming with known intrusive rocks, we suggest that these two additional upwarps are also cored by igneous rocks.

Synclines mapped in the Cornudas Mountains appear to be related to igneous intrusions as well. They occur as partial ring structures around Wind Mountain, as structural sags between buried intrusions, and as parts of paired anticline-syncline accommodation folds formed in response to dilation of intruded sedimentary rocks.

Peaks in the map area other than Cornudas Mountain and Wind Mountain do not appear to be associated with strongly deformed sedimentary rocks. Alamo Mountain, San Antonio Mountain, Chattfield Mountain, Black Mountain, and Flat Top are similar to one another in that they are concordant and sills or laccoliths. Unlike Wind and Cornudas Mountains, the sills and laccoliths were injected into sedimentary host rocks at or directly above the Permian-Cretaceous disconformity (Fig. 5). San Antonio Mountain, perhaps the only true laccolith of the Cornudas Mountains and only partly exposed in the south-central part of the map area, is floored by basal Cretaceous rocks (Kues and Lucas, 1993). Chattfield Mountain, at least on the north where exposed in the map area, also is underlain by flat-lying Cretaceous strata. Black Mountain, a multiple sill complex east of Wind Mountain, was emplaced in part directly above the disconformity as well as

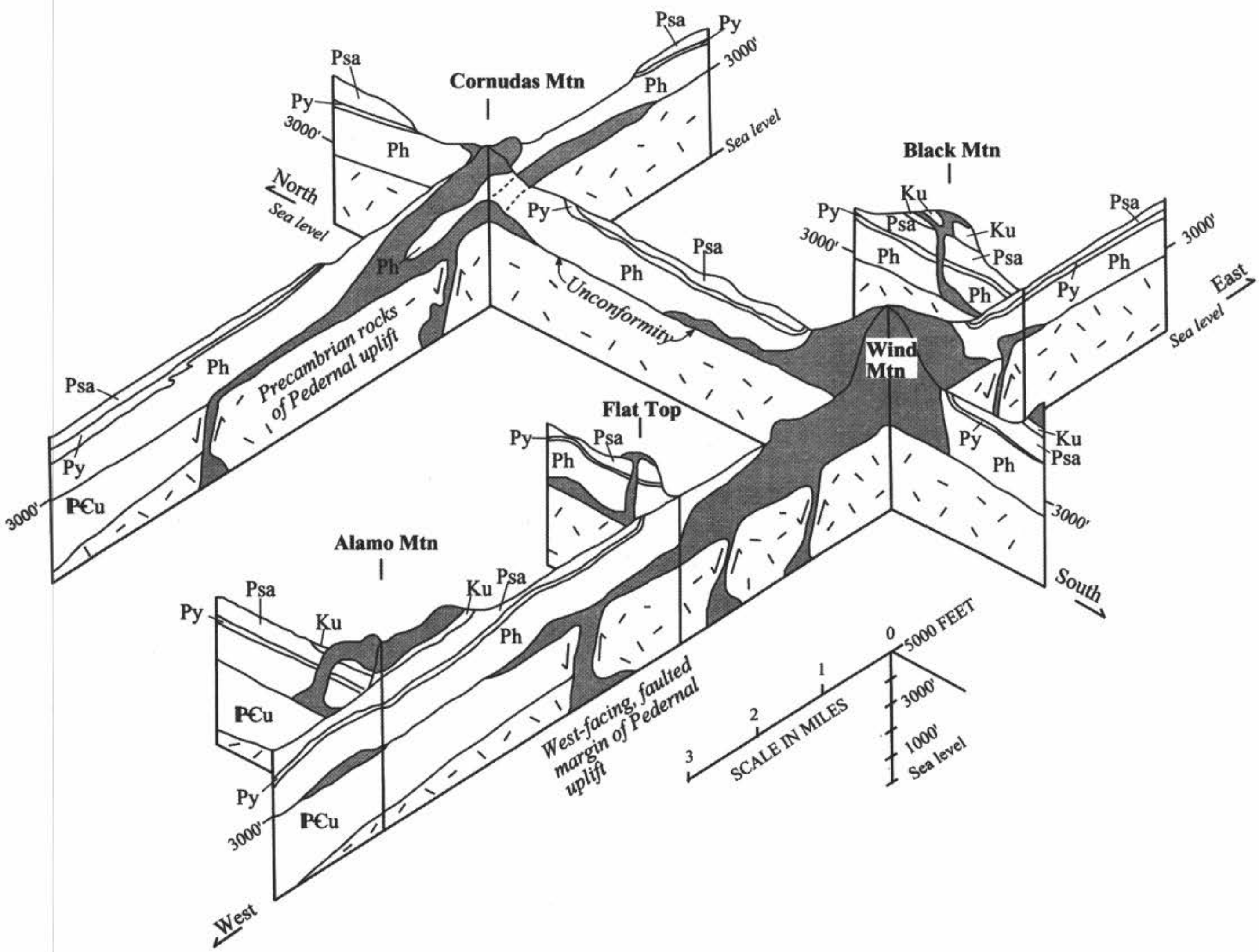


FIGURE 5. Schematic fence diagram showing stratigraphic, structural, and intrusive relationships discussed in texts. PЄ: Pennsylvanian through Cambrian rocks; Ph: Hueco Formation; Py: Yeso Formation; Psa: San Andres Formation; Ku: Cretaceous sedimentary rocks, undivided; pattern: Precambrian rocks of the Pedernal uplift; stipple: Oligocene to Eocene alkaline intrusions.

higher in the Cretaceous section. The Flat Top sill is underlain by the San Andres Formation; no Cretaceous rocks were observed on this peak. The stratigraphic position of the disconformity east of Flat Top (north of Wind Mountain) as well as on the west (beneath Alamo Mountain) relative to the statigraphy at Flat Top suggests that the Flat Top sill was intruded along or very near the Permian-Cretaceous disconformity.

The Alamo intrusion is perhaps the most complex of the stratigraphically higher intrusions (Fig. 5). The intrusive body is discordant on the north where it probably intruded gently west-dipping limestones of the San Andres. Along the south and west base of the peak, Cretaceous rocks are exposed. Flow foliation within the intrusion is complex. On the north flank, foliation dips steeply north; midway between the north flank and the crest of the peak, foliation is gently inclined to the north. Directly beneath the crest of the peak, the foliation steepens whereas, at the crest, the attitude of the foliation again becomes nearly flat lying. The contemporary morphology of the peak, as viewed from the northwest, reflects the abrupt changes of foliation attitude. Hornfelsic Cretaceous rocks rest on the intrusion on its north side (shown as Ku) suggesting that the present exposed upper surface of the igneous rocks probably represents the exhumed upper contact of the intrusion. As such, Alamo Mountain appears to represent a steeply inclined, thick, east-trending dike on the north where it intruded Permian strata. When the dike encountered the Permian-Cretaceous disconformity, it spread laterally to the south as a concordant intrusion before it bulged, thickened, and folded overlying Cretaceous rocks; it then concordantly invaded Cretaceous strata farther to the south before abruptly terminating at its present location. In a crude way, Alamo Mountain appears to represent an incompletely formed laccolith with its northern half undeveloped (Fig. 5). Hunt (1953) did not describe an intrusive form quite like Alamo Mountain although he does suggest, following Daly (1914), that such an intrusive form could be called a chonolith.

Faults

The Cornudas Mountains are near the western edge of the Salt Basin graben (Fig. 1), which is the easternmost structure related to Rio Grande rift tectonism and shows evidence of Quaternary fault movement (Goetz, 1980). In contrast, the Cornudas Mountains are cut by rare faults in which the offset is typically 15 ft or less and are not shown on the simplified map of Figure 4. Apparently the Cornudas Mountains are within a stable block bounded by segments of the late Cenozoic Rio Grande rift to the west and east. Several of the small faults are intruded by dikes related to the larger intrusions of the area. We interpret the faults to have formed mainly in response to deformation of host sedimentary rocks during intrusion of alkaline rocks.

PRE-PERMIAN FAULTS

In Pennsylvanian time, New Mexico and adjacent Texas and Colorado were the sites of numerous uplifted intracratonic basement blocks of the ancestral Rocky Mountains (Kluth and Coney, 1981). Most of these uplifts and adjacent basins in New Mexico trended north; one of the larger crustal blocks, the Pedernal uplift, can be traced on the surface from central New Mexico southward into the Sacramento Mountains in eastern Otero County (Fig. 1). From the Sacramento Mountains southward, the uplift is buried beneath Permian rocks that now underlie the Otero platform. Basement faulting, stratigraphic pinchouts, and syntectonic sedimentary deposits associated with the uplift are best exposed in the Sacramento Mountains near Alamogordo (Pray, 1959; Kottlowski,

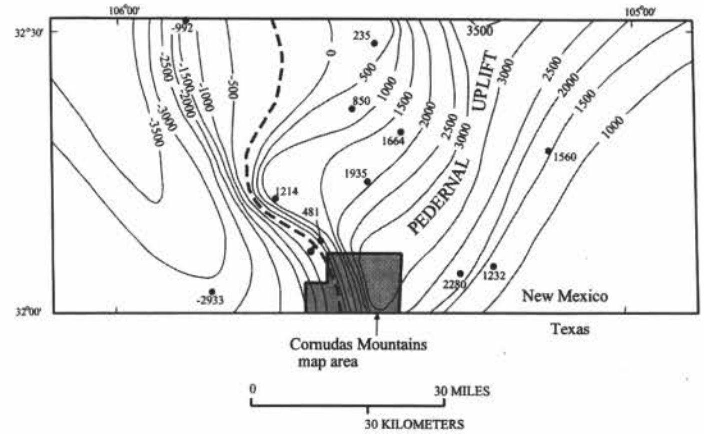


FIGURE 6. Structure contour map drawn on top of Precambrian basement showing location of buried Pedernal uplift with respect to Cornudas Mountains (modified from King and Harder, 1985). Contour interval 500 ft; datum is mean sea level.

1963; Bauer and Lozinsky, 1991). To the south, similar geologic features associated with the uplift have been detected in exploratory oil wells drilled on the Otero platform (Black, 1975).

Structure contours drawn on the top of the buried Precambrian of the Otero platform indicate that the Cornudas Mountains are located near the western edge of the buried Pedernal uplift (Woodward et al., 1975; Foster, 1978; King and Harder, 1985). Geologic cross sections drawn across the Otero platform by Black (1975), particularly his section C–C' drawn through the northern part of the Cornudas Mountains, show the beveled top of the buried pre-Permian uplift. In Black's section C–C', the well drilled east of the Cornudas bottomed in Permian strata resting directly on Precambrian rocks at 2280 ft above sea level; the well on the west penetrated Permian as well as older Paleozoic rocks and encountered Precambrian basement nearly 2000 ft lower, at an elevation of 481 ft (King and Harder, 1985). The faulted, western edge of the Pedernal uplift, as shown by Black, is located between these two wells; in this cross section the Cornudas Mountains are shown as laccolithic intrusions localized along a minor fault located about 2 mi west of the faulted edge of the uplift.

Geologic mapping and geophysical investigations conducted by Nutt et al., (1997) suggest that the western, faulted edge of the Pedernal uplift lies beneath or west of the Cornudas Mountains. Geologic evidence for the location of the buried uplift margin is derived from regional variations in the thickness of the Permian Yeso Formation. In the Cornudas Mountains, the Yeso is only 100 ft thick. In cross sections constructed by Black (1975, C–C') exploratory oil wells drilled 10 mi east and 5 mi northwest of the Cornudas encountered a much thicker Yeso: about 850 ft thick on the east and nearly 900 ft thick on the west (King and Harder, 1985). The explanation for this anomalously thin Yeso section is unclear. The Yeso is exposed only as upturned strata between the Hueco and San Andres around the Wind and Deer Mountains and Cornudas Mountain intrusive centers. Given that gypsum flows at the slightest provocation and is also quite soluble, it is possible that the thinness of the formation is the result of deformation related to intrusion and/or dissolution due to magmatic fluids. Arguing against such an interpretation is the noticeable lack of strong disharmonic folding, contorted bedding, and brecciation of the Yeso and the overlying San Andres and the paucity of evidence of magmatic fluids. Alternatively, thinning of the Yeso to about 100 ft in the Cornudas Mountains may likely be due to abrupt gradation and intertonguing with the overlying San Andres (see Black, 1975, p. 328–329). Equally likely is the possibility that the formation pinches out against, over, and across the uplifted Pedernal highland. Abrupt thickening of the Yeso to the west, and the fact that the entire Cambrian through Pennsylvanian section (encountered in the wildcat well) rests directly on Precambrian rocks that are nearly 2000 ft deeper than to the east of the Cornudas Mountains, suggest that the major west-bounding fault of the Pedernal uplift is more correctly interpreted to be located west of or beneath the Cornudas Mountains.

Geophysical evidence for an abrupt change in the character of the subsurface rocks lies in aeromagnetic anomalies and audiomagnetotelluric (AMT) soundings conducted across the Cornudas Mountains (Nutt et al., 1997). The intrusive rocks in the subsurface of the Cornudas Mountains appear to be concentrated at or near the unconformity between the sedimentary rocks and the underlying Precambrian crystalline basement. That unconformity is interpreted from the aeromagnetic data to be about 2200 ft beneath the surface and at an elevation of about 3000 ft above sea level. Similarly, AMT soundings detected highly resistive rocks directly east of the Cornudas Mountains that contrast markedly with a layered rock sequence detected on the west. The interpretation offered here is that the Precambrian basement is much nearer the surface directly east of the Cornudas Mountains than on the west.

In their basement structure contour map of the Otero Platform, King and Harder (1985) have drawn a major fault in the area of the Cornudas Mountains. Projection of that fault to the surface places it between Alamo and Wind Mountains. We would amend their structure contour map only by extending the 1500-, 2000-, and 2500-ft basement contours farther south, beneath the Cornudas Mountains and into Texas, as shown in Figure 6. We would amend Black's cross section C–C' to show elevated Precambrian basement directly beneath the Cornudas Mountains and suggest that the intrusion of these rocks, rather than being controlled by a relatively minor fault, was controlled by a major fault or fault system located along the western margin of the Pedernal uplift (Fig. 5).

DISCUSSION

The series of domes, laccoliths, and sill complexes that make up the Cornudas Mountains are surface expressions of magmatic intrusion along the faulted edge of the Pedernal uplift. The concordant to partially concordant form of the exposed intrusions is the result of lateral magma movement along the unconformity between the base of the Permian section and underlying Precambrian rocks and at the disconformity between Permian and Cretaceous rocks. A complex series of folds in the Permian rocks adjacent to igneous intrusive rocks probably formed during intrusion and suggest unexposed igneous intrusions in the cores of the folds.

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