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GEOLOGY OF SOUTHWESTERN NEW MEXICO

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Abstract—Rocks exposed in southwestern New Mexico range from Precambrian to Recent, with all systems except Triassic and Jurassic represented. Maximum thicknesses of the Cambrian-Quaternary sedimentary sections range from about 3700 m near Deming to 11,000 m in the extreme southwestern corner of the state. The majority of the section in the northeast part of this area is of Cenozoic age; upper Paleozoic and Mesozoic sections thicken southwestward into the Pedregosa basin.

Precambrian, Paleozoic, Laramide and middle to late Tertiary deformations are documented in the region. The Precambrian and Laramide episodes were compressional involving folding and uplift. The Laramide event may have had associated wrench faulting. Cambro-Ordovician alkalic plutonism probably had contemporaneous regional uplift. Subsequent Paleozoic deformational events are evidenced by regional wedging out of units and unconformities or missing stratigraphic units on the Burro-Florida uplift. Middle to late Tertiary deformation has been large scale cauldron volcanism followed by Basin and Range extensional faulting.

Southwestern New Mexico is part of the Mexican Highland Section of the Basin and Range Physiographic Province. The region is dominated physiographically and structurally by north-trending basins and ranges formed by late Tertiary normal faulting. The Gila Conglomerate is composed of alluvium shed from the uplifted fault blocks into closed or nearly closed basins since early Miocene time. Relatively large, shallow lakes occupied parts of the Animas and Playas Valleys and possibly the Hachita Valley during the Pleistocene.

Most of the mining districts of southwestern New Mexico were discovered and developed following the Civil War in the late 1800s. Just about every mountain range has at least one mining district or group of prospects. Early prospecting concentrated on gold and silver, but when the railroads came in the 1880s interest increased in prospecting for other materials. Copper, lead, zinc and manganese have been produced in significant quantities. Minor production of fluorite, barite, tungsten and bismuth are recorded. Most mining and development are dormant at this time but exploration continues sporadically, especially for the precious metals. Oil and gas exploration has been intermittent with the most recent activity ending in 1985.

INTRODUCTION

The New Mexico Geological Society visited parts of southwestern New Mexico on its 4th field conference in 1953, and again in 1965. The Society ventured into the region south and southwest of Deming for the first time in 1970 to utilize the then-current mapping projects of Corbitt (1971) in the Florida Mountains and Zeller (1965, 1970) in the Big and Little Hatchet Mountains. The Society's 29th field conference into southeastern Arizona in 1978 originated in Lordsburg and included many articles on the geology of southwestern New Mexico; especially the volcanic rocks.

This paper is intended as a geological overview of the area covered by this conference. The area extends westward to Arizona from the Florida Mountains and includes the approximately 12,400 km^2 of New Mexico adjacent to and south of I-10 (Fig. 1). Recent and current geologic investigations in the Florida, Big Hatchet, Little Hatchet, Peloncillo and Animas Mountains and Klondike Hills, as well as several exploration wells drilled since 1980 provided incentive to update the geology of southwestern New Mexico.

STRATIGRAPHY

Precambrian

Precambrian rocks can be seen in only a few small, poorly exposed outcrops south of the Big Burro Mountains. Outcrop locations are shown by Foster and Stipp (1961) and Woodward (1970). Although Condie and Budding (1979) did not include details of Precambrian rocks of southwestern New Mexico, they indicated the area was underlain by granitic-metamorphic terrane 1200–1650 my. Most of the outcrops are coarse-crystalline granite or quartz monzonite. The rocks are so deeply weathered and/or altered, detailed petrographic study has not been attempted. Granitic and hornblende gneisses north of Capitol Dome in the Florida Mountains have been described by Clemons (1984, in press). Gneiss is also poorly exposed at the southeast end of Fluorite Ridge (Clemons, 1982a). Gneiss, schist and micaceous quartzite have been reported in cuttings from several exploration wells in southwestern New Mexico that bottomed in Precambrian.

Stacey and Hedlund (1983) reported U/Pb zircon ages of 1450–1650 my for granite and diabase in the Burro Mountains. Evans and Clemons (1987, in press) determined an age of 1550–1570 my for zircons from the granite gneiss at Capitol Dome. The following Rb/Sr ages were determined by the Laboratory of Isotopic Geochemistry at the University of Arizona for Marathon Oil Company: altered granite and aplite from the Central Peloncillo Mountains, 776–1262 my; deeply weathered gneissic granite from the Klondike Hills, 1390 my; weathered aplite and granite from Chaney Canyon in the Big Hatchet Mountains, 950 my; deeply weathered, and probably altered, granite from the northern Animas Mountains, 1190 my (M. Shafiqullah, written commun. 1983).

Cambrian-Ordovician

Alkali syenite and granite form a major part of the Florida Mountains. The mineral compositions of the alkali-feldspar granites, quartz syenite and syenites are the same except for quartz content. Braid and string perthite is the predominant mineral; up to 36% quartz is present in the granites; mafic minerals are predominantly hastingsite and biotite (Clemons, 1982b). These rocks were mapped as Precambrian by Darton (1916, 1917), as Precambrian and Mesozoic by Corbitt (1971) and Precambrian by Clemons (1984, 1985) and Clemons and Brown (1983). Brookins (1974a, 1974b, 1980a, 1980b), Brookins and Corbitt (1974) and Matheney and Brookins (1983) obtained Rb/Sr ages ranging from 371 to 1600 my on these rocks. Evans and Clemons (1987, in press) reported U/Pb zircon ages of 503 my for the granite and 523 my for the syenite. There appears to be little doubt that this alkalic suite of rocks was emplaced during the Cambrian or earliest Ordovician time. Clemons (1985, in press) presented evidence that the granite and syenite represent a shallow pluton that was unroofed prior to deposition of the Bliss Formation. Ballman (1960), Hayes (1975) and Flower (1953) reported Late Cambrian trilobites in the Bliss at Werney Hill, 55 km northwest of the Florida Mountains, and at San Diego Mountain, 75 km to the northeast. No age-diagnostic fossils have been reported in the Bliss in the Florida Mountains. Considering the 32 my uncertainty on the 505 my Ordovician-Cambrian boundary there appears to have been time to unroof a shallow pluton.

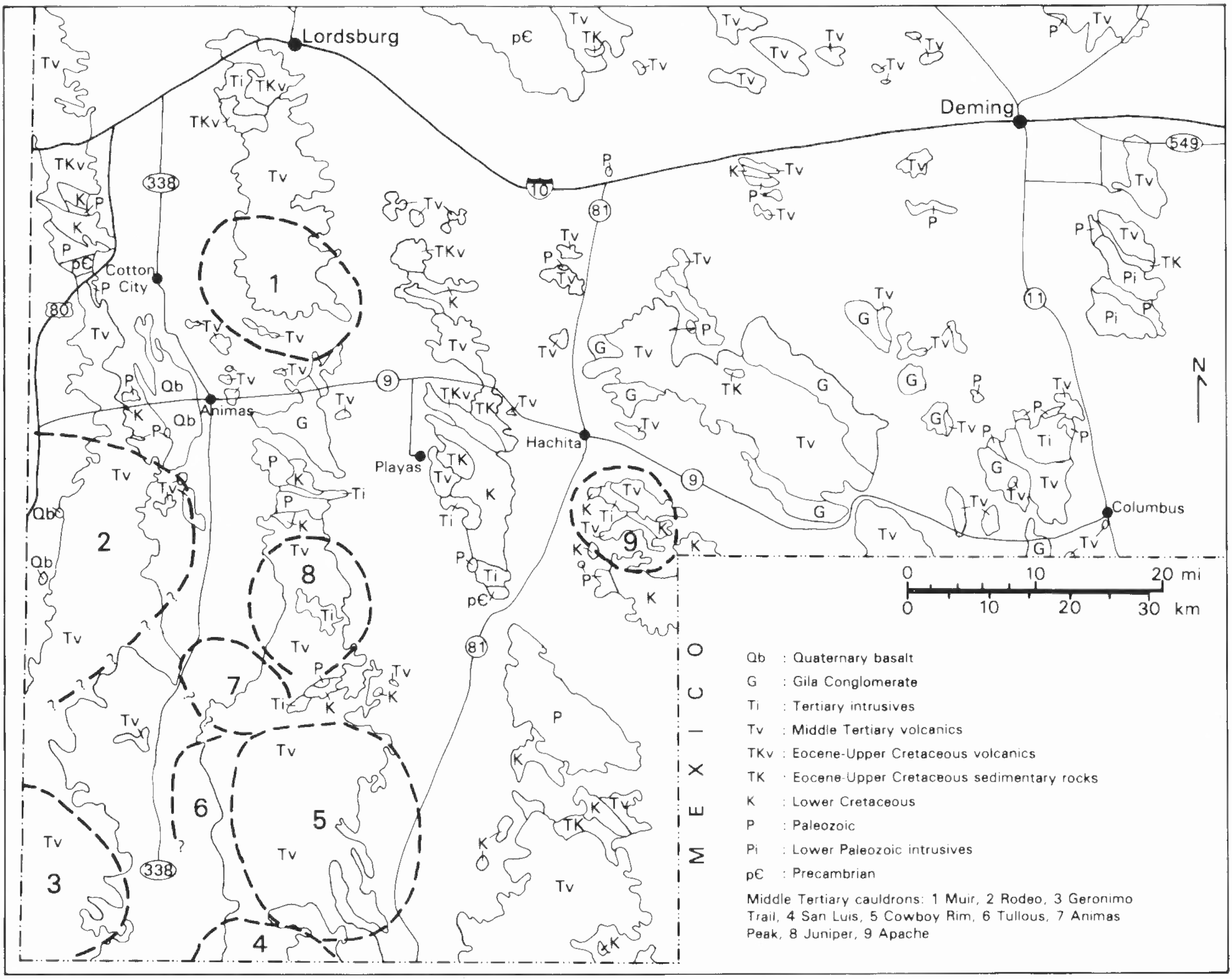

FIGURE 1. Generalized geologic map of southwestern New Mexico, modified from NMGS highway Geologic Map.

Initial Paleozoic sedimentation in the region is represented by the Bliss and El Paso Formations (Fig. 2). The Bliss contains 35–120 m of slightly fossiliferous, medium- to coarse-grained sandstone with local minor interbeds of dolostone and limestone (Ballman, 1960; Clemons and Brown, 1983; Clemons, 1984; Gillerman, 1958; Hayes, 1975; Hedlund, 1978d; Kottlowski, 1963; Zeller, 1965). Cephalopods and *Nuia* are common in the limestone beds near Capitol Dome. The sandstone typically is arkosic at the base and grades upward to a quartz arenite. Thompson and Potter (1981) indicated that the Bliss consists mostly of tidal deposits with minor beach, fluvial and deltaic deposits. Lochman-Balk (1971) and Hayes (1975) tended to favor interpreting the Bliss and correlative Coronado Sandstone and Bolsa Quartzite, to the west, as beach deposits. Stageman (1987) distinguished eight facies in the Bliss, all of which he interpreted as shallow marine to intertidal deposits.

The Bliss Formation is conformably and gradationally overlain by the El Paso Formation. Stratigraphic nomenclature of El Paso has been discussed in detail by Hayes (1975), Clemons (1985, in press) and Clemons and Osburn (1986). Current mapping in southern New Mexico treats the El Paso as a formation containing four members, in ascending order the Hitt Canyon, Jose, McKelligon, and Padre.

The Hitt Canyon Member is composed of medium-gray, silty limestone with prominent, irregularly reticulated laminae (mostly stylolite insoluble residue). Silt content decreases upward. The upper part contains stromatolite carbonate-mud mounds (Fig. 3) in the Big Hatchet Mountains, northern Florida Mountains and Klondike Hills but are scarce or absent at most other locales in southwestern New Mexico. Thickness of the Hitt Canyon ranges from 50 m in the southern Florida Mountains to 170 m in the Victorio Mountains. The overlying Jose Member is only 4–14 m thick, but it is a very distinctive unit. The Jose contains more dark-gray bioturbated limestone than the rest of the El Paso. It is generally thinner-bedded, more friable and contains prominent oolitic zones (Fig. 4). It typically contains rounded carbonate allochems and silt to medium sand-sized quartz. The McKelligon Member is light-gray, medium- to thick-bedded limestone. Sponge-*Calathium* and stromatolite mounds common in the southern Caballo Mountains and in the type section occur sporadically throughout the region. The McKelligon Member ranges in thickness from about 155 m in the Big Hatchet Mountains to 170 m in the Florida Mountains. The upper part of the Padre Member has been eroded at most locales but up to 67 m are preserved beneath the Montoya Formation in the Florida Mountains.

The El Paso Formation is quite fossiliferous, but whole fossils are extremely difficult to extract from the carbonate host rock. Planispiral and conospiral gastropods, cephalopod siphuncles, lithistid sponges and *Calathium* can commonly be seen in the outcrops. *Calathium*, a problematical organism, is now considered a receptaculitid (Nitecki, 1986).

System	Series	Southeastern Arizona	Southwestern New Mexico	South-Central New Mexico
Q		Ft. Lowell Fm & equivalents	Gila Cgl & basalts	Santa Fe Gp & basalts
T	P			
	M	Rillito Fm & equivalents	Pothook volcanics & equivalent cauldron sequences	Bell Top Fm & equivalents
	O	Pantano Fm & equivalents		
	E		Rubio Peak Fm Lobo Fm Hidalgo volcanics;	Palm Park Fm equivalents
	P	Gringo Gulch Fm	Ringbone, Little Hat Top Fms	Love Ranch Fm
K	U	Ft. Crittenden Fm	Colorado Fm	Mancos Sh Dakota Ss
	L	Bisbee Gp: Cintura Fm Mural Fm Morita Fm Glance Cgl	Mojado/Sarten/ Beartooth Fms U-Bar Fm Hell-to-Finish Fm	Mojado Fm U-Bar Fm Hell-to-Finish Fm
		Bathtub Fm Temporal Fm		
J				
TR				
P	U	Rainvalley Ls Concha Ls	Concha Ls	San Andres Fm
	L	Scherrer Fm Epitaph Fm Colina Ls Earp Fm	Naco Gp Scherrer Fm Epitaph Fm Colina Ls Earp Fm	Yeso Fm Abo/Hueco Fms
P	U	Horquilla Fm	Horquilla Fm	
	M	Black Prince Ls		Magdalena Gp
M	U	Paradise Fm Hachita Fm	Paradise Fm Hachita Fm	Helms Fm Rancheria Fm
	L	Keating Fm	Escabrosa Gp Keating Fm	Lake Valley Fm
D	U	Swisshelm-Portal Fm	Percha Sh	Percha Sh
	M	Martin Fm	Oñate Fm?	
	L			
S	U			
	M		Fusselman Dol	Fusselman Dol
	L			
O	U		Montoya Fm	Montoya Fm
	M			
	L		El Paso Fm	El Paso Fm
C	U	Abrigo Fm	Bliss Ss	Bliss Ss
	M	Bolza Quartzite	granite & syenite	
	L			

FIGURE 2. Generalized stratigraphic correlation chart for southwestem New Mexico.

FIGURE 3. Stromatolite mound in basal McKelligon Member in Klondike Hills. (Photo by Mike Rupert)

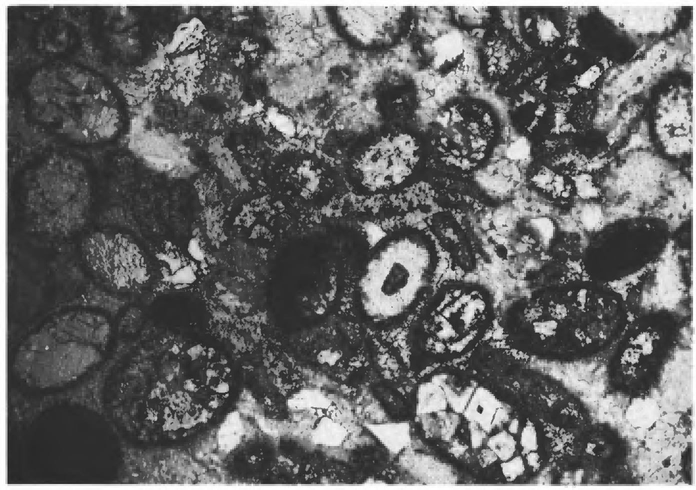

FIGURE 4. Photomicrographs of ooids replaced by dolomite from the Jose Member of the El Paso Formation in the Florida Mountains. Several quartz grains are present in the top center and left center. Largest ooids are 1.5 mm diameter.

Nuia, another problematical organism that has come to be widely recognized in Lower Ordovician carbonate rocks during the past 20 years, is common in the Hitt Canyon and McKelligon Members but scarce in the Jose and Padre Members. Ostracods have been reported only in the Padre. Intrasparite lenses, probably representing storm deposits, are common in all El Paso sections. Echinoderm, trilobite and spicule fragments are abundant in most thin sections.

The El Paso Formation of southwestern New Mexico is considered to be a platform carbonate deposit, mostly of shallow subtidal and intertidal origin (Clemons, 1987; Hayes, 1975). Dolostone is less abundant in the El Paso of southwestern New Mexico than farther east, and there is little or no evidence of supratidal deposition. Much of the dolostone is probably of hydrothermal origin (Clemons, 1988).

The Montoya Formation unconformably overlies the El Paso Formation as far west as the northern Animas Mountains but is absent by erosion in extreme southwestern New Mexico. The Montoya is generally considered to be of late Middle through Late Ordovician age (Flower, 1965; Hayes, 1975). There has been a debate about stratigraphic nomenclature of the Montoya for the past 40 years. Most current mapping treats the Montoya as a formation containing four members, in ascending order the Cable Canyon, Upham, Aleman and Cutter. Hayes (1975) considered the Cable Canyon and Upham to be members of the second Value Dolomite along with the Aleman and Cutter Formations of the Montoya Group.

The Cable Canyon consists of medium- to coarse-grained dolomitic sandstone that weathers dark brown. Its thickness varies regionally from zero to 18 m. The overlying Upham, Aleman and Cutter Members appear to have been deposited as limestone, but have since been irregularly dolomitized (Kottlowski, 1963) and are predominantly dolostone and dark chert, except in the Cooke's Range and Florida Mountains. The lower part of the Upham is a fossiliferous limestone in the Cooke's Range. Elsewhere it is a massive, medium- to coarse-crystalline, dark-brownish-gray dolostone about 15 m thick. The basal part is typically sandy and the upper part contains dark-gray chert nodules. Locally, the Upham contains abundant recognizable fossils in spite of its intense dolomitization. These include massive colonial corals, large gastropods, *Receptaculites*, crinoids and cephalopods. The Aleman consists of about 25–50 m of ribboned, fine- to medium-crystalline dolostone and dark-gray chert (Fig. 5). Silicified brachiopods, solitary corals and bryozoans are common in some sections. The Cutter Member is composed of fine-crystalline, medium-gray dolostone with scattered medium-gray chert nodules. The Cutter ranges in thickness from 30 to 80 m in the area. The well exposed Aleman and Cutter sections in the southern Florida Mountains contain much limestone. Thin sections of these rocks contain

FIGURE 5. Aleman Member of Montoya Formation in southern Florida Mountains.

abundant bryozoa, echinoderm, trilobite, brachiopod and coral fragments (Fig. 6) and minor ostracods and sponge spicules.

The Montoya Formation has not received much attention in recent years except for a study of the Aleman cherts in southwestern New Mexico (Geeslin and Chafetz, 1982), a regional study from southwestern New Mexico to west Texas by Measures (1985) and an M.S. thesis in the Sacramento Mountains by Brimberry (1984). Hayes (1975) indicated the Montoya carbonates were deposited in a warm, well aerated, shallow subtidal environment.

Silurian

The Fusselman Dolomite is the only Silurian unit in southern New Mexico. Regionally, the dolostone generally is medium to coarse crystalline, medium gray and contains little chert (Kottlowski, 1957). The Fusselman in the southern Florida Mountains contains six distinctive alternating dark and light units (Fig. 7) totaling 451 m. The 180-m-thick section in the Victorio Mountains contains only the three lower units and the 73-m-thick section in the Cooke's Range contains only the two lower units. The Fusselman does not crop out west of the Klondike Hills but it may be present in the subsurface as far west as The Saltys (see Second-Day Road Log, this guidebook). Dolomitization has destroyed most fossil material but silicified corals are abundant (Fig. 8) in the Florida Mountains. These include solitary cup corals, *Halysites, Favosites, auloporid*-like and *Syringopora*-like corals (Clemons, in press). Brachiopod-rich zones prominent in the Fusselman to the east and north have not been reported south or southwest of the Silver City area.

FIGURE 6. Photomicrograph of Cutter Member of Montoya Formation in southern Florida Mountains. Width of photo about 7 mm.

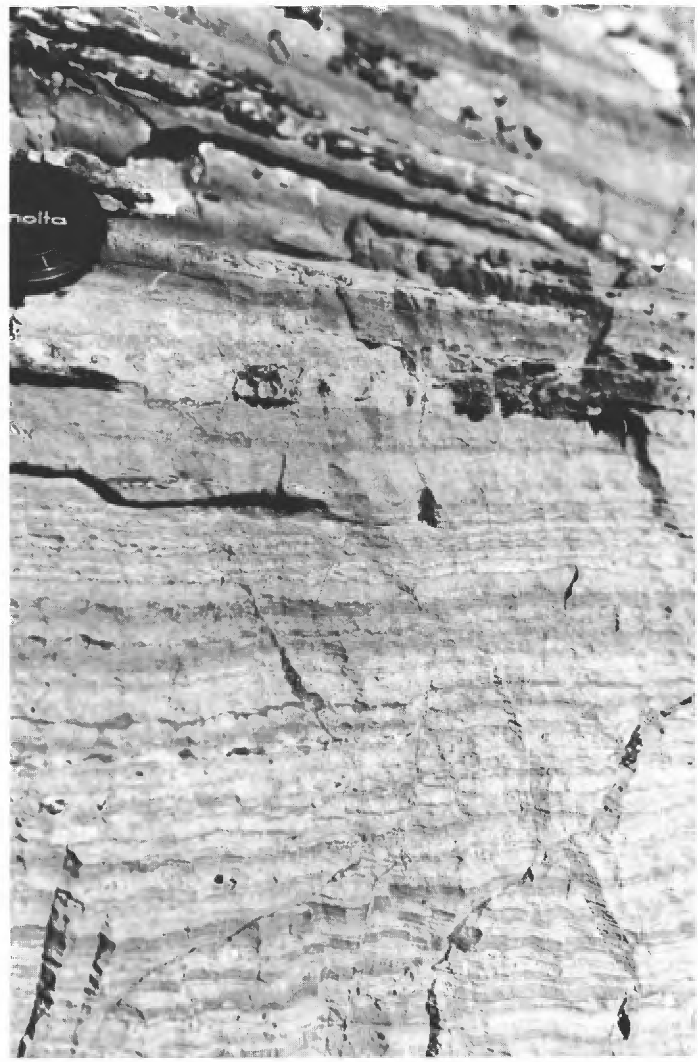

FIGURE 7. Upper "varved" part of lower dark unit of Fusselman Dolomite in southern Florida Mountains.

Devonian

Upper Devonian Percha Shale crops out in many of the ranges, but typically is poorly exposed. The Percha has been subdivided into two units: a lower Ready Pay Member, consisting of olive-gray to black fissile shale, and an upper Box Member, consisting of gray calcareous shale and nodular limestone interbeds. A few meters of shale are exposed in the southern Klondike Hills (Thorman and Drewes, 1981; Rupert, 1986). Armstrong (1970) reported about 30 m of the Box Member in the northern Klondike Hills. Zeller (1965, 1975) reported about 100 m of Percha in the Big Hatchet Mountains. There, the predominantly shale section contains a basal sandstone and the upper part contains limestone nodules and thin nodular limestone beds. Gillerman (1958) measured 70 m of Percha in the central Peloncillo Mountains where about 25% of the unit is limestone. Clemons and Brown (1983) mapped 76 m of Percha in the southern Florida Mountains. One prospect pit south of Gym Peak provided an exposure of 30-cm-thick *Tentaculites* limestone beds (Fig. 9) about 3 meters above the base of the Percha. Elsewhere in southern New Mexico, *Tentaculites* are found in the Oñate Formation, so the basal Percha in the Florida Mountains may actually be Oñate of Middle Devonian age.

In southeastern Arizona, Devonian rocks are referred to as the Martin, Portal and Swisshelm Formations. The Martin and Portal contain more limestone than the Percha and the Swisshelm contains more sandstone and siltstone (Ransom, 1904; Sabins, 1957; Epis et al., 1957; Kottlowski, 1963).

FIGURE 8. Silicified colonial corals in the lower part of the Fusselman Dolomite at Mahoney Park (bar = 1 mm)

Mississippian

Mississippian rocks of southwestern New Mexico are assigned to the Escabrosa Group and Paradise Formation (Armstrong 1962, 1970; Armstrong and Mamet, 1978). Armstrong also subdivided the Escabrosa into a lower Keating Formation and upper Hachita Formation. Armstrong and Mamet (1978) further subdivided the Keating Formation into a lower Bugle Member and upper Witch Member. The Keating is Kinderhookian-Osagean, the Hachita is Meramecian and the overlying Paradise is Chesterian. Total thickness of Mississippian strata increases from about 70 m in the Florida Mountains to more than 450 m in the Pedregosa basin of extreme southwestern New Mexico.

Kottlowski (1958, 1963), Armstrong (1962) and Clemons and Brown (1983) indicated that the section in the Florida Mountains was part of the Hachita Formation (a shelf equivalent of the basinal Rancheria Formation to the east). Yurewicz (1977) located the Florida Mountains section on the Hachita-Rancheria (shelf-basin) boundary, and Armstrong and Mamet (1978) placed it in the Rancheria basin facies east of the shelf-basin margin. The Rancheria Formation in the Florida Mountains is composed of thin-bedded, interstratified, spiculitic silty lime mudstones, wackestone and peloid and bioclastic grainstones. The limestones and cherts are all medium to dark gray but typically weather light gray to brown. Shale breaks are abundant low in the section, and chert content increases upsection to nearly 50% at the top. The shelf carbonates in the Klondike Hills, Big Hatchet, Animas and Peloncillo Mountains contain a basal unit (Bugle Member) of interbedded pelletoidal-crinoidal wackestone, oolitic packstone-grainstone and coral-bearing, pelletoidal to oolitic echinoderm grainstone. This unit is overlain by (Witch Member) cherty lime mudstone and micropelletoidal packstones. The overlying Hachita Formation contains massive light-gray crinoidal wackestones and packstones. Less crinoid debris and increased content of bryozoan, brachiopod, ooids and forams characterize the top of the Hachita (Armstrong, 1970).

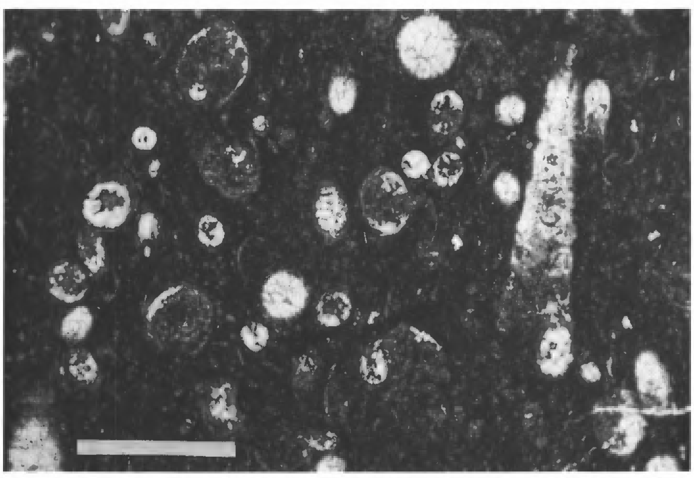

FIGURE 9. *Tentaculites* packstone from near the base of the Devonian section south of Gym Peak (bar = 1 mm).

The Paradise Formation gradationally overlies the Hachita Formation and typically consists of yellow-gray limestones with interbedded dark-gray and brown-weathering calcareous shale and siltstone. The limestones are commonly crossbedded oolitic packstones and grainstones. Thickness of the Paradise ranges from 50 to 133 m.

Pennsylvanian-Permian

The Naco Group of southeastern Arizona and southwestern New Mexico includes all strata of Pennsylvanian and Permian age (Fig. 2). Pennsylvanian rocks in southeastern Arizona are mapped as Horquilla Formation and lower part of the Earp Formation of the Naco Group. The Pennsylvanian sequence in southwestern New Mexico ranges from more than 760 m in the Big Hatchet Mountains (Zeller, 1965) to a wedge edge between the Tres Hermanas and Florida Mountains. The 170-m-thick Pennsylvanian section in the Tres Hermanas contains about 25 m of sandstone and minor shale interbedded with limestone (Kottlowski and Foster, 1962). Only two to three meters of sandstone mark the base of the Horquilla in the northern Klondike Hills (Armstrong, 1970), and no clastics occur in the Horquilla in the Big Hatchet Mountains (Zeller, 1965; Thompson and Jacka, 1981). A few thin siltstones are interbedded with the massive shelf carbonates in the northern Animas Mountains.

In southwestern New Mexico, lower Wolfcampian limestones in the upper part of the Horquilla are overlain unconformably by the upper Wolfcampian(?) Earp Formation (Zeller, 1965). The Earp here consists of nonmarine to possibly intertidal red beds and other siliciclastics. The Earp facies is an equivalent of the Abo Formation to the east. The Abo interfingers with upper Wolfcampian marine limestones of the Hueco Formation. A transitional zone between the Abo (Earp)-Hueco (Colina) facies trends east-northeast across southwestern New Mexico and consists of 64–186 m of cyclically interbedded siliciclastic and carbonate rocks, which were deposited in tidal-flat and shallow-marine environments (Mack and James, 1986; James and Mack, 1986). Permian limestone in the southeastern Florida Mountains has been mapped as Hueco (Clemons and Brown, 1983).

Conformably overlying the Earp Formation in the Big Hatchet, Animas and Peloncillo Mountains is the upper Wolfcampian(?) to Leonardian Colina Limestone, Leonardian Epitaph Dolomite and Scherrer Formation, upper Leonardian or lower Guadalupian(?) Concha Limestone (Gillerman, 1958; Kottlowski, 1963; Zeller 1965; Drewes, 1986). The black Colina limestones grade upward into the brownish-gray Epitaph dolostones. The upper part of the Epitaph includes interbedded red shale and calcareous sandstone, grading into the overlying thin, clastic-rich Scherrer. The lower part of the Concha consists of massive, light-gray fossiliferous limestone; the upper beds are very similar except some dolostone is present in the Big Hatchet Mountains (Zeller, 1965). Total thickness of the Colina-Concha section in the Big Hatchet Mountains is about 1040 m (Zeller, 1965).

Cretaceous

Cretaceous sedimentary rocks in southwestern New Mexico have a composite thickness of about 4.5 km and include marine and nonmarine siliciclastic and carbonate rocks. Lower Cretaceous rocks are thickest (3.2 km) south of Interstate 10 and are well exposed in the Peloncillo, Animas, Big Hatchet, Little Hatchet and East Potrillo Mountains (Gillerman, 1958; Armstrong et al., 1978; Drewes and Thorman, 1980a, b; Zeller, 1965, 1970; Zeller and Alper, 1965; Mack et al., 1986; Seager and Mack, in press). The standard stratigraphic terminology for Lower Cretaceous rocks was developed in the Big Hatchet Mountains by Zeller (1965), who recognized three conformable formations, which in ascending order are the Hell-to-Finish, U-Bar and Mojado (Fig. 10). Mack

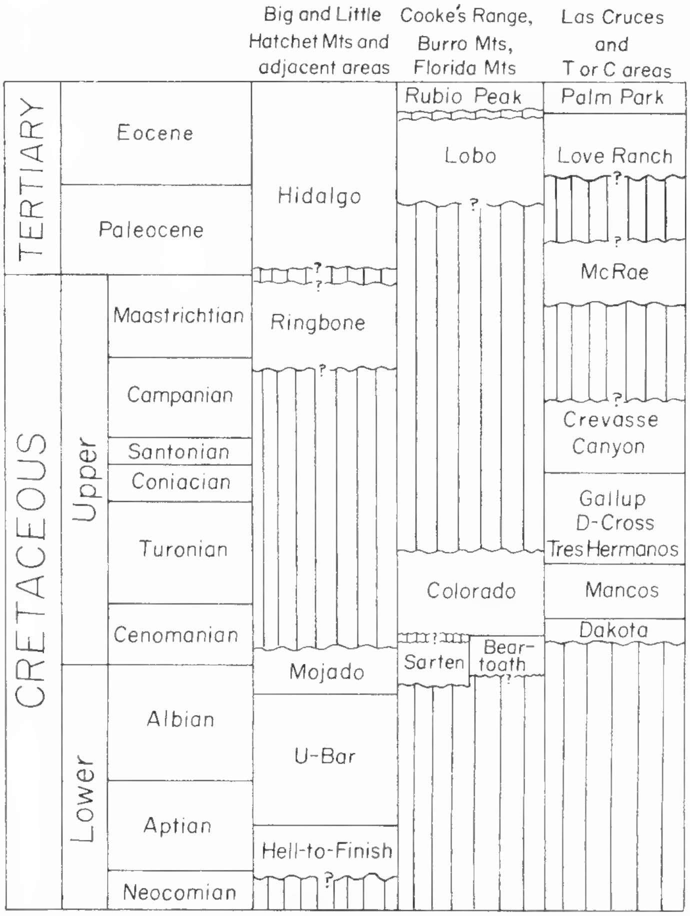

FIGURE 10. Correlation chart of Cretaceous, Paleocene and Eocene formations in southwestern New Mexico.

(1986) and Seager and Mack (in press) applied this terminology to the East Potrillo Mountains. Other stratigraphic names or a series designation have been applied to Lower Cretaceous rocks in the Peloncillo Mountains, Cerro de Cristo Rey, Victorio Mountains and Eagle's Nest, and the correlation of these rocks with the standard section is given in Mack et al. (1986).

The Hell-to-Finish Formation ranges in thickness from 120 m to at least 700 m and is composed of a basal conglomerate (Fig. 11) that is overlain by conglomerate, sandstone, shale and a minor amount of limestone. The Hell-to-Finish is almost entirely nonmarine in the Peloncillo, Animas, Big Hatchet and Little Hatchet Mountains, but, other than a nonmarine basal conglomerate, is marine in the East Potrillo Mountains (Mack, 1986, 1987b; Mack et al., 1986). The U-Bar Formation conformably overlies the Hell-to-Finish Formation and has a maximum thickness of about 1200 m in the Big Hatchet Mountains (Zeller, 1965; Weise, 1982). The U-Bar is composed of marine limestone, shale and sandstone, with the relative percentage of limestone increasing upsection. Rudistid reefs are common in the upper part of the U-Bar (Fig. 12). Index fossils in the U-Bar indicate an age from late Aptian through middle Albian (Fig. 10; Zeller, 1965; Weise, 1982). No index fossils have been found in the Hell-to-Finish, but its conformable upper contact with the U-Bar suggests that it is in part Aptian. The U-Bar grades conformably into the Mojado Formation, which consists of as much as 1500 m of sandstone, shale and a few beds of limestone. The Mojado is especially well exposed in the Big Hatchet and Little Hatchet Mountains and can be divided into lower and upper marine members and a middle fluvial member (Mack et al., 1986). Index fossils in the upper member and a conformable lower contact constrain the age of the Mojado between late Albian and early Cenomanian (Zeller, 1965).

In the Little Hatchet Mountains, Lower Cretaceous rocks are unconformably overlain by the Ringbone Formation, which consists of at least 1800 m of conglomerate, sandstone and shale. A Late Cretaceous age for the Ringbone is based on stratigraphic position (Fig. 10). The Ringbone has an unconformable upper contact with volcanic rocks of the Hidalgo Formation, whose oldest radiometric dates are latest Maastrichtian and Paleocene (Marvin et al., 1978; Loring and Loring, 1980a). The age of the base of the Ringbone is unknown, but its conglomeratic character suggests correlation with the McRae Formation (Fig. 10). Other conglomeratic formations in southwestern New Mexico that may be coeval with the Ringbone are the Little Hat Top Conglomerate in the Big Hatchet Mountains (Zeller, 1965), the Cowboy Springs and Timberlake Formations in the central Animas Mountains (Zeller and Alper, 1965) and the Bobcat Hill Conglomerate in the Peloncillo Mountains (Gillerman, 1958).

Only one formation north of Interstate 10, the Sarten Formation in the Cooke's Range, has been positively identified as Lower Cretaceous (Fig. 10). The Sarten ranges in age from late Albian to early Cenomanian (Cobban, 1987) and consists of about 120 m of interbedded marine and nonmarine sandstone and shale (Mack et al., 1986; Mack et al., this guidebook). The Beartooth Formation, exposed in the Burro Mountains and near Silver City, is lithologically similar to the Sarten but lacks index fossils. The Beartooth is generally considered to be Cenomanian in age (Molenaar, 1983), but may be as old as late Albian (Fig. 10; Mack et al., 1986; Mack et al., this guidebook). Stratigraphically overlying the Sarten and Beartooth Formations is the Colorado Formation, which is middle or late Cenomanian to middle Turonian in age and consists of about 150 m of marine and nonmarine sandstone and shale

FIGURE 11. Basal conglomerate of the Lower Cretaceous Hell-to-Finish Formation in the central Animas Mountains. Hammer is 25 cm long.

FIGURE 12. Rudistid limestone in the Lower Cretaceous U-Bar Formation in the East Potrillo Mountains. Hammer is 25 cm long.

(Hook and Cobban, 1977; Hook, 1981; Mack et al., this guidebook). Molenaar (1983) recommended abandonment of the name Colorado Formation in favor of Mancos, Atarque and Moreno Hill. The Colorado has an unconformable upper contact.

The most complete exposure of Upper Cretaceous rocks in southern New Mexico is in the Engle coal field east of Truth or Consequences (Fig. 10). The lower 315 m consists, in ascending order, of the Dakota, Mancos, Tres Hermanos, D-Cross Tongue and Gallup Formations. These sandstones and shales range in age from middle Cenomanian to Coniacian and consist of several transgressive and regressive cycles of shallow-marine, shoreline and fluvial strata (Wallin, 1983; Lozinsky, 1986). The Crevasse Canyon Formation conformably overlies the Gallup Formation and is composed of about 700 m of fluvial sandstone, shale and pebble conglomerate (Wallin, 1983). Palynological analysis has been successful on only one sample from the middle of the Crevasse Canyon Formation and indicates a Santonian to early Campanian age (A. R. Sweet, oral commun. 1988).

The Crevasse Canyon Formation in the Engle coal field is unconformably overlain by conglomerate, sandstone and shale of the McRae Formation (Fig. 10; Kelley and Silver, 1952; Bushnell, 1953, 1955; Lozinsky, 1986). The McRae is subdivided into a lower Jose Creek Member (120 m) and an upper Hall Lake Member (884 m). Dinosaur fossils in the upper Jose Creek and lower Hall Lake Members indicate a late Maastrichtian age, and the Cretaceous-Tertiary boundary is probably within the upper part of the Hall Lake Member (Fig. 10; Lozinsky et al., 1984; Wolberg et al., 1986).

Cretaceous sedimentary rocks in southwestern New Mexico were deposited in three different tectonic settings. Deposition of Lower Cretaceous rocks took place along the northern margin of a west-northwest-trending rift basin, called the Chihuahua trough in Mexico and the Bisbee basin in southeastern Arizona (Greenwood et al., 1977; Dickinson, 1981; Bilodeau, 1982; Bilodeau and Lindbergh, 1983; Mack, 1987a). Siliciclastic detritus was transported southward into the New Mexico portion of the basin from a basement-cored rift shoulder located north of Interstate 10 (Bilodeau and Lindbergh, 1983; Mack, 1987a). By Late Cretaceous time, however, southwestern New Mexico was part of the Cordilleran foreland basin and sedimentation was continuous across the state, although there is no record of post-Cenomanian and pre-Maastrichtian rocks in the extreme southwestern part of the state (Molenaar, 1983; Mack, 1987a; Mack et al., this guidebook). Siliciclastic sediment deposited in the foreland basin was derived from a mixed sedimentary and volcanic source terrane located to the west and/or southwest of southwestern New Mexico (Mack, 1987b; Mack et al., this guidebook). The transition from rift to foreland basin probably took place sometime between late Albian and late Cenomanian, and is marked by onlap of the former rift shoulder and by changes in provenance and sediment dispersal (Mack, 1987a; Mack et al., this guidebook). The foreland basin was apparently disrupted prior to deposition of the Ringbone and McRae Formations in Maastrichtian time or before. The McRae and Ringbone probably represent an early phase of the Laramide orogeny.

Paleocene and Eocene

Paleocene and Eocene rocks in southwestern New Mexico are the result of Laramide deformation and volcanism. In the Little Hatchet Mountains and adjacent areas, an early phase of Laramide deformation is represented by the Upper Cretaceous Ringbone Formation, which is unconformably overlain by andesitic volcanic rocks of the Hidalgo Volcanics (Zeller, 1970). Radiometric age dates on the Hidalgo suggest a latest Maastrichtian or Paleocene age (Deal et al., 1978; Marvin et al., 1978; Loring and Loring, 1980a). A later phase of Laramide deformation in the Little Hatchet Mountains and adjacent areas is indicated by thrust faults and folds that involve both the Ringbone and Hidalgo Formations (Zeller, 1970).

Lasky (1947) originally described the Hidalgo Volcanics as part of the Bisbee Group. Zeller (1970) indicated the Hidalgo rests unconformably on the Ringbone Formation, and includes about 1680 m of conglomerates, andesite flows, sandstone and shale in the northern part of the Little Hatchet Mountains. He indicated a probable early Tertiary age for the Hidalgo based on fossil wood. Interestingly, Hidalgo equivalents are missing in the Coyote and Brockman Hills just north of the Little Hatchets, but about 450 m of correlative rocks are mapped just north of the Brockman Hills (Thorman, 1977). Thorman and Drewes (1978) mapped possible correlative andesites in the Pyramid Mountains. Zircon from one of the lower flows yielded a fission track age of 67.3 ± 7.1 my, and the sequence of andesites was intruded by a granodiorite stock dated at 56.6 ± 1.2 my (Deal et al., 1978) and 58.5 ± 2.0 my (Marvin et al., 1978).

In the Florida Mountains and southern Cooke's Range only late Laramide deformation is recognized and was responsible for deposition of the Lobo Formation (Darton, 1916; Lemley, 1982; Mack and Clemons, this guidebook). The Lobo Formation in the Cooke's Range was previously called the Starvation Draw member of the Rubio Peak Formation (Clemons, 1982a), a name that has been abandoned (Clemons, 1984; Mack and Clemons, this guidebook). The Lobo ranges from about 150 m thick in the Florida Mountains to at least 350 m in the southern Cooke's Range, unconformably overlies rocks ranging in age from Precambrian to Cretaceous, and is unconformably overlain by the Rubio Peak Formation (Clemons, 1984; in press). Paleomagnetic data from the Lobo Formation in the Florida Mountains suggest a late Paleocene or Eocene age (Lemley, 1982).

In the vicinity of Las Cruces, the late Laramide stratigraphic unit is the Love Ranch Formation (Fig. 10; Kottlowski et al., 1956). The Love Ranch ranges in thickness from a few meters to 2.1 km in the Grimm and others well. An underlying unit contains late Paleocene and early Eocene palynomorphs (Thompson, 1982). The Love Ranch unconformably overlies rocks ranging from Precambrian to lower Eocene and is conformable with the overlying Palm Park Formation, which has been radiometrically age dated at 43 to 40 my (late middle to late Eocene) (Seager and Clemons, 1975).

The Love Ranch and Lobo Formations were deposited in basins that were complementary to west-northwest-trending, basement-cored block uplifts called the Rio Grande and Laramide Burro uplifts (Seager, 1983; Seager and Mack, 1986; Seager et al., 1986; Mack and Clemons, this guidebook). Directly adjacent to the margin of the uplifts, the Love Ranch and Lobo Formations consist of alluvial-fan conglomerates that locally were involved in the Laramide deformation. In distal parts of the basin, the sediment is finer grained, undeformed and was deposited in distal fan, lacustrine and fluvial environments (Fig. 13; Seager and Mack, 1986; Seager et al., 1986; Mack and Clemons, this guidebook). Composition of the detritus reflects unroofing of the crystalline core of the uplift and subsequent andesitic volcanism (Seager and Mack, 1986; Seager et al., 1986; Mack and Clemons, this guidebook).

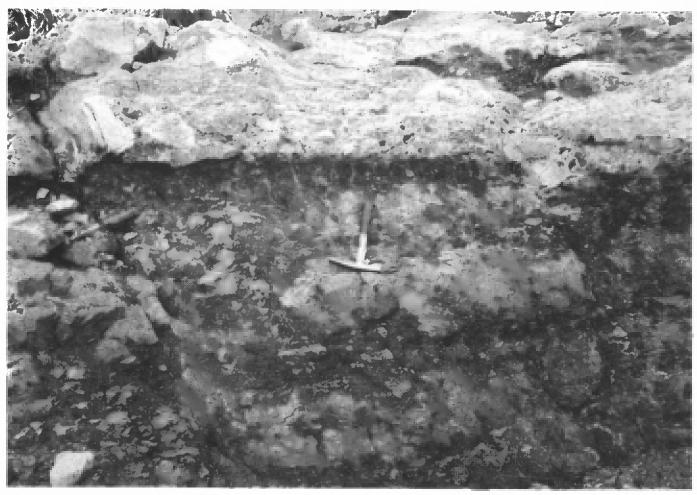

FIGURE 13. Distal alluvial-fan facies of the Paleocene-Eocene Lobo Formation in the Florida Mountains. Cobble conglomerate overlies one or more paleosols characterized by caliche nodules and tubules. Hammer is 25 cm long.

Middle to upper Eocene rocks in southern New Mexico are mostly andesite to latite flows, tuff breccias, lahars and hypabyssal intrusives with minor dacite and basalt flows (Elston, 1957; Clemons, 1976, 1977, 1979, 1982a; Seager and Clemons, 1975, Seager et al., 1976). These rocks are referred to as the Palm Park and Rubio Peak Formations. The Palm Park was largely derived from vents in the Doña Ana Mountains area (Seager et al., 1976). Rubio Peak tephra and flows came from the Goodsight Mountains vent zone (Clemons, 1979), southern Black Range and southern Cooke's Range vents (Elston et al., 1975; Clemons, 1982a), and probably other vents in southwestern New Mexico.

Ages reported for the Rubio Peak and the contemporaneous granodiorite of Cooke's Peak range from 44.7 to 32.6 my (Loring and Loring, 1980b; Clemons, 1982a; Seager et al., 1982). Correlative rocks farther to the southwest probably include the lower exposed andesites and basalts in the Tres Hermanas Mountains (Balk, 1962; Leonard, 1982), Cedar Mountain Range (Bromfield and Wrucke, 1961; Varnell, 1976), Victorio Mountains (Thorman and Drewes, 1980) and the andesite of Holtkamp Canyon in the Pyramid Mountains (Deal et al., 1978; Elston et al., 1983).

Oligocene-Quaternary

Middle to late Tertiary volcanic rocks are exposed in every mountain range in southwestern New Mexico. These volcanic rocks are by far the major component of the Cedar Mountain Range, the Alamo Hueco, Animas, Peloncillo, Pyramid, Little Florida and Grandmother Mountains, as well as the Apache, Coyote and Carrazilillo Hills (Fig. 1). Some of the first (mostly reconnaissance) mapping projects in these ranges were by Zeller (1959, 1962, 1970), Zeller and Alper (1965), Bromfield and Wrucke (1961), Flege (1959), Gillerman (1958), Wrucke and Bromfield (1961) and Strongin (1958). More recently, special projects by the University of New Mexico and the U.S. Geological Survey have added immensely to the understanding of Cenozoic volcanism in this area. Thorman (1977) and Thorman and Drewes (1979b) remapped the Coyote Hills and adjacent area, Thorman and Drewes (1978) mapped the northern Pyramid Mountains, Thorman and Drewes (1979a, 1980) mapped the Grandmother and Victorio Mountains and Drewes and Thorman (1980a, 1980b) remapped the central Peloncillo Mountains. Peterson (1976) remapped the Apache Hills and Reiter (1980) remapped the Dog and Alamo Hueco Mountains as thesis projects. The importance of cauldron volcanism in southwestern New Mexico was highlighted by Erb (1979), Elston and Erb (1977), Elston et al. (1979) and Deal et al. (1978). Relations between the Lightning Dock KGRA, Muir cauldron and Basin and Range faulting were reported by Elston et al. (1983).

Middle Tertiary volcanism began locally with eruption of andesite flows and breccias. Starting about 35–37 my, voluminous rhyolite to quartz latite ash-flow tuffs were erupted from at least nine known or suspected cauldrons. There is a general progression in rock types. Earliest ash-flow tuffs tend to be crystal-poor quartz-sanidine rhyolite tuffs (Deal et al., 1978). Latite, andesite, basaltic andesite and basalt flows are locally interlayered with the ash-flow tuffs (Fig. 14). Latite and rhyolite domes and lava flows are common, especially in the ring-fracture zones of cauldrons. Quartz monzonite stocks are also associated with several of the cauldrons, such as Muir, Apache and Juniper (Fig. 1)

Relatively little is known about the volcanic rocks in the Cedar Mountain Range. Bromfield and Wrucke's reconnaissance map (1961) and Varnell's map of the Hat Top Mountain quadrangle (1976) indicate interbedded silicic tuffs and flows with andesites. No vent areas were noted; some of these rocks may have come from the Apache cauldron (Fig. 1). Similar rocks in the Carazilillo Hills are much more altered and mineralized (Seager and Clemons, in press).

Intermittently for the past 17 my, basaltic rocks have been erupted from widely spaced vents. Included in these rocks are Black Mountain (17 my) north of Hachita, Pliocene cones in the southwestern Tres Hermanas Mountains (Seager et al., 1984), Palomas volcanic field (Frantes and Hoffer, 1982) and Quaternary Animas basalt (Deal et al., 1978).

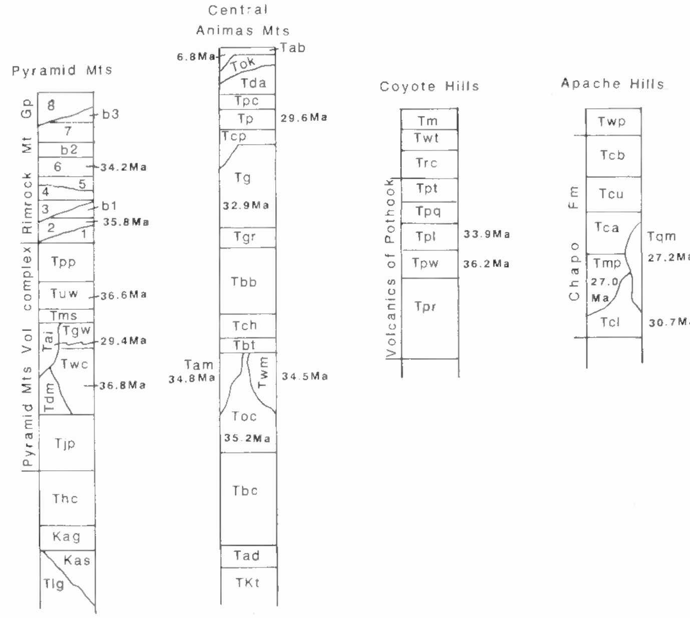

FIGURE 14. Representative columnar sections of volcanic rocks in southwestern New Mexico, modified from Deal et al. (1978) and Elston and Erb (1979). Apache Hills: Tcl lower quartz latite, Tca andesite, Tcu upper quartz latite, Tcb basalt and andesite members of Chapo Formation; Tqm quartz monzonite porphyry; Tmp monzonite porphyry; Twp rhyolite of Wamel's Pond (Petersen, 1976). Coyote Hills: Tpr rhyolitic tuff, Tpw quartz latite, Tpl lithic tuff, Tpq quartz latite lava, Tpt clastic tuffaceous members of Volcanics of Pothook; Trc rhyolite lava of Coyote Peak; Twt rhyolite tuff; Tm moonstone-bearing rhyolite ash-flow tuff (Thorman, 1977). Central Animas Mountains: TKt Timberlake fanglomerate; Tad andesite of Taylor Draw; Tbc Bluff Creek Formation; Toc Oak Creek Tuff; Tam Animas quartz monzonite; Twm Walnut Wells monzonite; Tbt Basin Creek Tuff; Tch Cedar Hill Andesite; Tbb tuff of Black Bill Canyon; Tgr tuff of Gray Ranch; Tg Gillespie Tuff; Tcp Center Peak Andesite; Tp Park Tuff; Tpc Pine Canyon Rhyolite; Tda Double Adobe Latite; Tok Ok Bar Conglomerate; Tab alkali basalt (Zeller and Alper, 1965; Erb, 1979). Pyramid Mountains: Kas andesite of Shakespeare; Kag andesite of Gore Canyon; Tlg granodiorite porphyry; The andesite of Holtkamp Canyon; Tjp rhyolite of Jose Placencia Canyon; Twc tuff of Woodhaul Canyon; Tgw tuff of Graham Well; Tms andesite of Mansfield Seep; Tuw latite of Uhl Well; Tpp rhyolite of Pyramid Peak; Tdm diorite-monzonite stock; Tai intrusive andesite; 1–8 tuff members and b1–b3 basaltic andesite members of Rimrock Mountain Group.

Little work has been done on the Miocene-Holocene sedimentary sequence in southwestern New Mexico. Overlying all the felsic volcanic rocks, and locally interfingering with the late Tertiary basalts, is an extensive blanket of mudstone, sandstone and conglomerate referred to as the Gila Group or Gila Conglomerate. This unit is probably up to 1000 m thick (or more) in some of the late Tertiary grabens but no extensive sections have been measured or described. Clemons (1986a) reported about 1280 m of basin fill in the Mimbres Basin near Deming. The Seville-Trident No. 1 City of Deming well penetrated about 480 m of red-brown clay and siltstone between depths of 244 and 724 m. Below 724 m, medium to coarse sand, silt, clay and minor gravel are interbedded to the total depth of 1280 m. Thompson et al. (1978) indicated about 706–726 m of Gila in the subsurface of the Playas Valley area. Most likely the Gila basin fill is similar to that described in southeastern Arizona by Scarborough and Pierce (1978), Gray (1967) and Johnson et al. (1975). Basal Gila deposition probably started about 21 my ago (Deal et al., 1978). It is difficult to distinguish younger Gila beds from Recent valley-fill deposits described by Schwennesen (1918), Reeder (1957) and Fleischhauer and Stone (1982). Most of the Gila exposed in this conference area is Pliocene-Pleistocene fanglomerate.

STRUCTURAL AND TECTONIC SETTING

Rocks in southwestern New Mexico have been deformed in Precambrian, Paleozoic, Laramide and middle- to late-Tertiary times. The oldest rocks known in the area are lower to middle Proterozoic granites, diabases, gneisses and amphibolites. These rocks provide evidence of regional plutonism and metamorphism 1450–1650 my ago. Hedlund (1978e) also reported 950 and 1270 my ages for granites in the southern part of the Big Burro Mountains. He showed general northwesterly and northeasterly foliations in the metamorphic rocks (Hedlund, 1978b, 1978c, 1978e). Drewes (1982) distinguished a sytem of northwest-trending, steep-faults in southeastern Arizona that had Precambrian movements. These, and similar, faults most likely extended across southwestern New Mexico and northern Chihuahua.

Shallow, alkali granites and syenites were emplaced in the Florida Mountains during the early Paleozoic (Clemons, 1986b, in press). Evans and Clemons (1987, in press) reported a 503 my age for this event. Several other granites and syenites may belong to this Cambro-Ordovician suite (see McLemore and McKee, this guidebook), but detailed petrography and radiometric dates are lacking.

Subsequent Paleozoic deformational events in Middle Ordovician, Early Silurian, Late Silurian-Early Devonian, Early Mississippian, Early Pennsylvanian and Late Permian are recorded by regional wedging out of units or locally by missing section and erosional relief. Details have been reported by Armstrong (1970), Clemons (in press), Gillerman (1958), Hayes (1975), Kottlowski (1958, 1960, 1963, 1971b), Kottlowski et al. (1973) and Zeller (1965).

Laramide structures are exposed in the Florida, Tres Hermanas, Victorio, Big and Little Hatchet, northern Animas and central Peloncillo Mountains, Sierra Rica and the Snake, Whitecap, Brockman and Klondike Hills. An overthrust model has been proposed for these structures by Corbitt (1984), Corbitt and Woodward (1973), Corbitt et al. (1977), Drewes (1978), Soule (1972), Woodward (1980) and Woodward and DuChene (1981, 1982). Most recent mappers in southwestern New Mexico have tended to favor a block-uplift model (Brown, 1982; Brown and Clemons, 1983; Clemons and Brown, 1983; Clemons, 1985, in press; Rupert, 1986; Wilson, 1986; Donnan and Wilson, 1986; Donnan, 1987). Strike-slip movements on some of the Laramide faults have also been advocated by workers favoring the block-uplift model (Seager, 1983), as well as by Drewes and Thorman (1980a, 1980b) and Thorman and Drewes (1980). Seager and Mack (1986) provided an excellent summary of Laramide paleotectonics in southwestern New Mexico. Mack and Clemons (this guidebook) review the evidence in the Florida Mountains-Cooke's Range area.

The major ranges today are the product of middle Miocene and younger extensional faulting. Extension may have begun in some areas as early as 28–29 my ago as postulated to the east by Seager et al. (1984). Evidence for this early extension is sparse in southwestern New Mexico. Deal et al. (1978) indicated Basin and Range faulting had to postdate the younger felsic volcanic rocks which are about 21 my old. The rhyolite of the Little Florida Mountains (23.6 my) predates uplift of the Florida Mountain block. A dacite intrudes rhyolite fanglomerate at the southeastern end of the Little Floridas. Dating the dacite would bracket the probable initial major uplifting of the block. Faulting has continued locally into late Pleistocene as evidence by fault scarps in Gila fanglomerates along the margins of the Mimbres, Animas, Hachita and Playas Valleys (Zeller, 1970; Clemons 1982b, 1984; Wilson, 1986).

GEOMORPHOLOGY

The present land surface of southwestern New Mexico typifies Basin and Range topography. From west to east, the north-trending Peloncillo Mountains, Animas-Pyramid Mountains and Alamo Hueco-Hatchet Mountains-Coyote-and-Brockman Hills blocks are separated by the Animas and Playas Valleys. East of the Hachita Valley (Fig. 1), the pattern is more complex as the Apache Hills-Sierra Rica, Cedar Mountains Range and Tres Hermanas Mountains reflect partly eroded and buried northwest-trending fault blocks. The Florida Mountains are another north-trending fault block; they are surrounded by Mimbres basin sediments. Utilizing the soil mapping units of Neher and Buchanan (1980), Clemons (1984, 1985) mapped parts of a probable Mimbres River distributary system south of Deming.

Little has been published on the geomorphology of this region. Schwennesen (1918) briefly discussed the topography and Quaternary lakes in the Animas and Playas Valleys. The Quaternary geology of Lake Animas (see Third-Day Road Log) was described by Fleischhauer and Stone (1982). Hawley (1981) reported on the Pleistocene and Pliocene history east of Columbus and is currently preparing a report on southwestern New Mexico (J. Hawley, oral commun. 1987). Reeves (1965) described a pluvial Lake Palomas on the New Mexico-Chihuahua border during the Pleistocene.

Several of the mountain ranges have fault scarps that mark the edges of pediments one to three kilometers from bedrock exposures. More typically the pediment grades into broad, gently-sloping bajadas which then extend for many kilometers to basn-center playas. Large, well developed alluvial fans extend from all canyons at the southern end of the Florida Mountains. At the northern end of the range, only a thin blanket of gravel covers the pediment except at Lobo Draw and Headquarters Draw where remnants of alluvial fans are preserved 5–10 m above the present-day pediment.

MINERAL RESOURCES

Mineral exploration has been enhanced by the presence of relatively thick sedimentary and volcanic sequences cut by Tertiary stocks, dikes and cauldron features. Griswold (1961) provided a good summary of the mineral deposits in Luna County and Elston (1965) summarized the activity of mining districts in Hidalgo County. Detailed studies of mining districts include: reports on the Lordsburg copper and precious metals district by Lasky (1938) and Flege (1959), Little Florida Mountains manganese deposits by Lasky (1940), Little Hatchet Mountains copper-lead-zinc-silver deposits by Lasky (1947), Apache Hills copper-lead-zinc mineralization by Strongin (1958) and Peterson (1976), Granite Gap and Central Peloncillos copper-lead-zinc-silver-tungsten mineralization by Gillerman (1958). McAnulty (1978) described fluorspar prospects, including recorded production in the Little Florida, Pyramid and Animas Mountains, and Fluorite Ridge. About 90% of the production value has come from the Lordsburg copper-lead-zinc-silver-gold mines.

Oil and gas exploration in southwestern New Mexico has been intermittent over the past several decades. The oil and gas potential has been described and analyzed by several workers over the past 25 years (Greenwood, 1970; Greenwood and Kottlowski, 1975; Greenwood et al., 1970, 1977; Kottlowski, 1965, 1971a; Kottlowski et al., 1969; Thompson, 1976, 1977, 1980, 1981, 1982; Thompson et al., 1978; Wengerd, 1969, 1970). Stratigraphic studies indicate that both source rocks and reservoir rocks are present in the Paleozoic and Cretaceous sections, and several shows of hydrocarbons have been reported. The emplacement of abundant Tertiary plutons and cauldrons plus Basin and Range faulting probably destroyed or allowed the escape of some hydrocarbons. An increase in wildcat drilling during the early 1980s brought to a total of about 20 wells drilled to Paleozoic or older rocks in southwestern New Mexico (Broadhead, 1982, 1983, 1984). Some of these later wells were drilled on a belief that an overthrust belt extended across this corner of the state (see also discussions in road logs of this guidebook).

Numerous seismic lines were run across the region but apparently no data have been released for publication. Clemons (1986c) suggested that blocks which had been down dropped both by Laramide and Basin and Range faults, farthest from known cauldrons, would have the best exploration potential.

The presence of reliable, good quality ground water in southwestern New Mexico has been long recognized. Early studies by Darton (1916, 1917) and Schwennesen (1918) identified adequate supplies for ranching and valley farming needs. More recently Reeder (1957) and McLean (1977) have reviewed the water supplies in the Animas and Mimbres basins.

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Three Little Hills, east piedmont of Florida Mountains. View is N14°E. The three hills are composed of northeast-dipping Eocene Rubio Peak Formation resting on Lobo Formation. The latter is exposed in lower slope of left hill. Pennsylvanian limestone is exposed in foreground. Ocotillo is especially common on the slopes underlain by limestone. Juniper trees are sparsely scattered on piedmont and slopes of Three Little Hills. Good Sight Mountains are visible on skyline at right. Camera station is in NW1/4 NW1/4, sec. 5, T26S, R7W. Altitude about 1460 m. W. Lambert photograph No. 87L9. 18 July 1987, 1:05 p.m., MDT.