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GEOLOGY OF THE TRUTH OR CONSEQUENCES AREA

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Abstract—Rocks exposed in the T or C area range from Precambrian to Recent, with all the systems except Triassic and Jurassic represented. Triassic and possibly Jurassic rocks crop out southeast of Socorro just north of the conference area. Maximum thickness of 5,260 m has been estimated for the Cambrian–Quaternary sedimentary section in the T or C area.

The area has been affected by Precambrian, late Paleozoic, Laramide, and middle to late Tertiary deformations. The Precambrian and Laramide deformations were compressional events involving folding and uplift. The Paleozoic event is evidenced by regional wedging out of units and by small unconformities or missing stratigraphic intervals. Mid- to late Tertiary deformation has been largely normal faulting related to extension along the Rio Grande rift.

The region is dominated physiographically and structurally by basins and ranges created by late Tertiary normal faulting. Alluvium was shed from mountain ranges into closed basins or into the more deeply subsided, en-echelon sequence of basins forming the axis of the Rio Grande rift. Aggradation dominated until about 0.5 my ago, forming the broad, coalesced fan surfaces (bajadas) which are prominent high geomorphic surfaces today. Since capture of the ancestral Rio Grande near El Paso about 0.5 my ago, base level has episodically lowered, causing entrenchment of the river and its tributaries into the deeply incised valleys they now occupy. Man has been a dominant geomorphic agent (especially in 1916 and 1938), creating the Elephant Butte and Caballo reservoirs that have at least temporarily altered the landscape and have become so important to the economy of the area.

Most of the mining districts of Sierra County were discovered and developed following the construction of railroads through New Mexico in the late 19th century. Early prospecting concentrated on silver and gold. Base metals, especially copper, lead, and zinc, were produced in significant quantities in the early 1900's. Tin was discovered in 1918 along Taylor Creek. Beryllium and tungsten were produced in the Iron Mountain district. Iron and manganese ores were also produced on a small scale. More recently, copper, silver, and gold from the St. Cloud mine, and fluorite and barite, have been produced, but mining exploration and development are dormant at this time.

INTRODUCTION

This paper is intended as a geological overview of the area covered by this conference. The area is approximately outlined by Sierra County lines, but overlaps somewhat to the north and south into Socorro and Doña Ana Counties, respectively. The paper also provides new data and references that constitute an updated version of the Society's Sixth Field Conference in 1955. Previously, the Third Field Conference had closed at T or C in 1952. The geology has not changed, but, hopefully, we have learned more about it. Certain rock units and geologic features are treated in more detail than others in this paper. The reader will be referred to papers in this guidebook for those apparently slighted topics. Recent and current geologic investigations in the Black and Fra Cristobal Ranges and Caballo Mountains, as well as the basin-fill sediments and fossils, provided the incentive to review this part of south-central New Mexico again.

STRATIGRAPHY

Precambrian

Exposures of Precambrian rocks in the region are restricted mostly to the lower slopes of uplifted sides of fault-block mountains. A summary of Precambrian rocks was included in the Society's Guidebook 6 (Anonymous 1955b). Foster & Stipp (1961) showed outcrop locations on their geologic and relief map of Precambrian rocks, and Condie & Budding (1979) included descriptions of most of these rocks which are well exposed in the San Andres Mountains. Condie & Budding calculated that the Precambrian terrane consists of 70% granitic plutons intruded into 30% metamorphic rocks. Granitic rocks range from granodiorite to syenite, with quartz monzonite most common. The metamorphic rocks contain 40% phyllite and quartz–mica schist, 30% quartzose and arkosic metasedimentary rocks, 15% mafic metaigneous rocks, 10% siliceous metaigneous rocks, and 5% gneisses. Most of these rocks are believed to be 1.2–1.65 billion years old.

Kuellmer (1954) and Hedlund (1977) mapped and described graywacke, granite, and metadiabase that form small, discontinuous exposures in the Kingston area of the Black Range. Seager et al. (1971) mapped Precambrian granite, gneiss, migmatites, and diabase on the northeastern side of San Diego Mountain. Kelley & Silver (1952) mapped and described Precambrian granite and granite gneiss with minor schist, metadiorite, and greenstone in the Caballo and Mud Springs Mountains and Fra Cristobal Range. Bauer & Lozinsky (this guidebook) describe the Precambrian geology of the Caballo Mountains. McLemore (this guidebook) is currently studying the alkalic granite–syenite rocks in the Red Hills southeast of Caballo reservoir. Syenite was reported in the bottom of the Gartland No. 1 Brister well drilled in sec. 8, T12S, R4W (Foster & Stipp 1961); several other wells are reported to have bottomed in granite.

Cambrian–Ordovician

The Bliss and El Paso Formations represent Late Cambrian to Middle Ordovician sedimentation in the region (Fig. 1). The Bliss contains 35–50 m of slightly fossiliferous, medium- to coarse-grained, dark-brown, hematitic and glauconitic sandstone with minor interbeds of siltstone, dolostone, and limestone (Flower 1955, Kottlowski et al. 1956, Kottlowski 1963, Kelley & Silver 1952, Thompson 1955, Jahns 1955). The Bliss crops out as a conspicuous dark-brown unit along the lower west flank of the Caballo Mountains (Fig. 2) and south side of Mud Springs Mountains. Thick oolitic hematite beds are conspicuous in a west-trending, 6 km wide belt from Rhodes Canyon in the San Andres Mountains, through the Caballo Mountains, to just north of Silver City (Kelley 1951, Kottlowski 1963). This oolitic-hematite facies probably parallels the Bliss shoreline. Northward thinning of the Bliss in the San Andres Mountains appears to be depositional rather than erosional (Kottlowski 1963). These two lines of evidence are possibly anomalous to the generally accepted idea of a marine transgression from the west or southwest during Late Cambrian–Early Ordovician times.

The Bliss Formation is conformably and gradationally overlain by the El Paso Formation. The El Paso has been the subject of much nomenclatural confusion. Originally called El Paso limestone or El Paso

System	Series	Southern Black Range	Winston Area	Socorro Area	T or C Area	San Mateo Mtns. /Rhodes Canyon
T	P	GILA GR.	SANTA FE GR.	SANTA FE GR. Sierra Ladrones Fm.	SANTA FE GR. Palomas Fm.	
	M		Winston beds	Popotosa Fm.	Rincon Valley, Hayner Ranch, Thurman Fms.,	
	O	rhyolite tuffs, lavas, & basaltic-andesite lavas (1), (2) Kneeling Nun Tuff Sugarlump Fm. Rubio Peak Fm.	rhyolite tuffs, lavas, & basaltic-andesite lavas (2), (3) Kneeling Nun Tuff Sugarlump Fm. Rubio Peak Fm.	rhyolite tuffs & basaltic-andesite lavas (4) DATIL GR. Baca Fm.	Uvas Basaltic andesite Bell Top Fm. (5) Palm Park Fm.	Vicks Peak tuff Rock Springs Fm. Red Rock Ranch (6)
	E					
	P	andesitic rocks at Copper Flat	?		Love Ranch Fm.	
K	U	Colorado Fm.	"upper Cretaceous"	Mesaverde Fm. Mancos Sh, Dakota Ss.	McRae Fm. Mesaverde Fm. Mancos Sh. Dakota Ss.	
	L	Sarten Ss.				
J						
₸R				DOCKUM GR.		
P	L	Abo Fm.	San Andres Fm, Yeso Fm. Abo Fm.	San Andres Fm. Yeso Fm. Abo Fm. Bursum Fm.	San Andres Fm. Yeso Fm. Abo Fm. Bursum Fm.	San Andres Fm. Yeso Fm, Abo/Hueco Fm. Bursum Fm
₱P	U	MAGDALENA GR.	Madera Fm. Sandia Fm.	Madera Fm. Sandia Fm.	Bar-B Fm. Nakaye Fm, Red House Fm.	Virgilian Missourian
	M					Desmoinesian Derryan
M	L	Lake Valley Fm. Caballero Fm.	Kelly Ls. Lake Valley Fm.	Kelly Ls.	Lake Valley Fm.	Lake Valley Fm.
D	U	Percha Fm.	Percha Fm.		Percha Fm.	Percha Fm. Contadero Fm. Sly Gap Fm.
	M		Oñate Fm.		Oñate Fm.	Oñate Fm,
	L					
S	U					
	M	Fusselman Dol.	Fusselman Dol.		Fusselman Dol.	
	L					
O	U M	Montoya Fm.	Montoya Fm.		Montoya Fm.	Montoya Fm.
	L	El Paso Fm.	El Paso Fm.		El Paso Fm.	El Paso Fm.
€		Bliss Ss.	Bliss Ss.		Bliss Ss.	Bliss Ss.

FIGURE 1—Generalized stratigraphic correlation chart for the T or C region.



FIGURE 2—Aerial view of west flank of Timber Mountain. Precambrian (g), Bliss Formation (b), El Paso Formation (e), Montoya Formation (m), Fusselman Dolomite (f), Percha Shale (p), and Magdalena Group (Cm). Photo from NMGS Guidebook 3 (1952).

formation (Richardson 1904, 1908), the unit was elevated to group status by Kelley & Silver (1952) and subdivided into a lower Sierrite Limestone and upper Bat Cave Formation with type localities in the Caballo Mountains. Subsequently, Flower (1965, 1969) and LeMone (1969) divided the El Paso into 7–11 faunal zones (they refer to them as formations) whose lithologies vary greatly from one range to the next. Lucia (1969) and Harbour (1972) subdivided the El Paso Group into other formational units in the Franklin Mountains. Hayes (1975) divided the El Paso Group into three formations, in ascending order the Hitt Canyon, McKelligon, and Padre. All those mapping at a scale of 1:24,000 or less in southern New Mexico considered the El Paso a single unit or lumped it with other units. Current detailed 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) (Fig. 3). Silt content decreases upward. The upper part contains stromatolite carbonate-mud mounds (Fig. 4). Thickness of the Hitt Canyon ranges from 60 m near Winston to 104 m in the southern Caballo Mountains. The overlying Jose Member is only 6–14 m thick, but it is a very distinctive unit. The Jose contains more of dark-gray bioturbated limestone than the rest of the El Paso. It is generally thinner-bedded, more friable, and contains prominent oolitic zones. It typically contains rounded carbonate allochems and silt to medium-grain quartz sand. The McKelligon Member is light-gray, medium- to thick-bedded limestone. Sponge–*Calathium* stromatolite mounds are common in the southern Caballo Mountains, but occur sporadically throughout the region. About 52 m of McKelligon is present in the southern Caballo Mountains, but it is eroded to the north. Only a few meters overlie the Jose near Winston and about 10 m are present at Rhodes Canyon. The Padre Member has not been observed in the T or C region due to the northward truncation of the El Paso by Middle Ordovician erosion.



FIGURE 3—Lower Hitt Canyon Member of El Paso Formation showing reticulated beds at Cable Canyon.





FIGURE 4—**A,** Stromatolite-mound complex within upper Hitt Canyon Member in northern Red Hills; cliff is about 15 m high. **B,** Close-up view of a stromatolite mound.

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. Bryozoa reported in the El Paso by Kelley & Silver (1952) most likely are *Calathium*, a problematical organism whose silificed walls closely resemble fenestrate Bryozoa. No bryozoan has been reported elsewhere in southern New Mexico. Stauffer (1962) described oolites and elongate oolites as being abundant El Paso allochems in the Caballo Mountains. Most of these are suspected to be *Nuia*, another problematical organism that has come to be widely recognized in Lower Ordovician carbonate rocks during the past 20 years (Fig. 5). Echinoderm and trilobite fragments are abundant in thin sections (Fig. 6).

The Montoya Formation unconformably overlies the El Paso throughout south-central New Mexico. The Montoya is generally considered to be of Middle through Late Ordovician age. 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.

The Cable Canyon consists of medium- to coarse-grained dolomitic sandstone that weathers dark brown. Its thickness varies regionally from zero to 18 m, generally becoming thicker southwestward from T or C where 8 m are reported in the Mud Springs Mountains. 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 in the T or C area. The Upham is a massive, medium- to coarse-crystalline, dark-brownish-gray dolostone about 15–20 m thick in the Caballo Mountains. 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 30–40 m of ribboned, fine- to medium-crystalline dolostone and dark-gray chert. Silicified brachiopods, solitary corals, and bryozoans are common in some sections. The top, Cutter Member, is composed of fine-crystalline, medium-gray dolostone with scattered medium-gray chert nodules. The Cutter is 11 m thick north of Winston and 30–40 m thick in the area. The Montoya Formation has not received much attention in recent years except for a study of the Aleman cherts in southwestern New Mexico (Geeslin & Chafetz 1982) and a regional study from southwestern New Mexico to west Texas by Measures (1985).

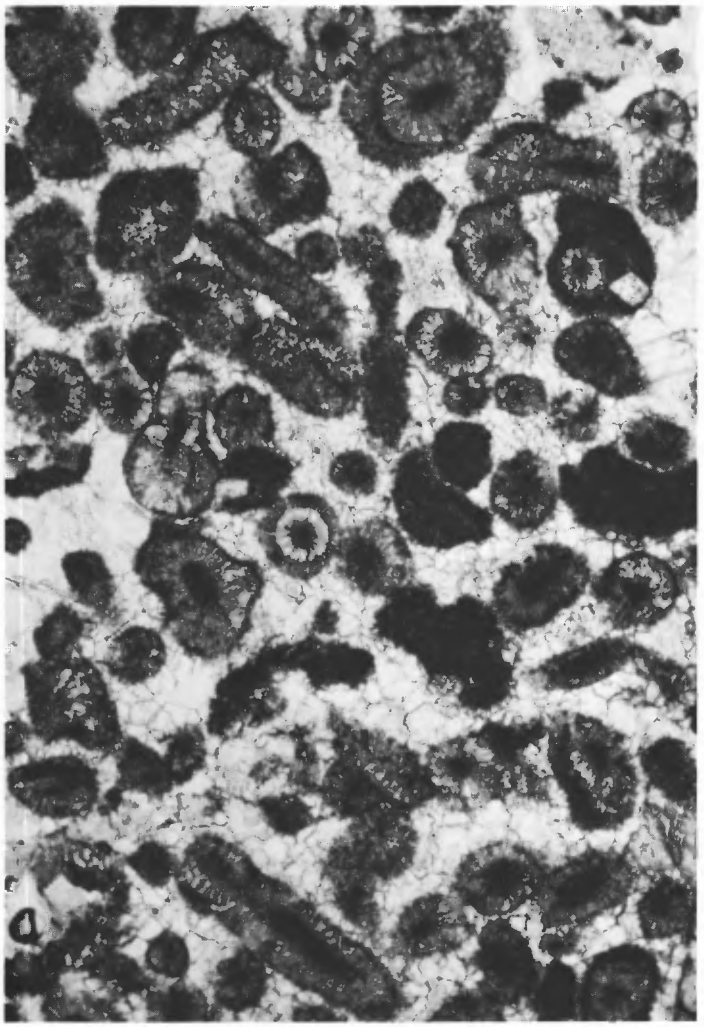


FIGURE 5—Photomicrograph of *Nuia* grainstone from McKelligon Member of El Paso Formation in the Caballo Mountains.



FIGURE 6—Photomicrograph of trilobite fragments and peloids in Jose Member of El Paso Formation in the Caballo Mountains.

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. The Fusselman in the Caballo Mountains is a dark-gray to brownish-gray cherty dolostone varying in thickness from 5 to 15 m (Kelley & Silver 1952). It is absent in the Mud Springs Mountains, northern San Andres Mountains, and northeastern part of Sierra County (Kottlowski 1963). It thickens southward to about 300 m in the Franklin Mountains (Kottlowski & Pray 1967) and to over 450 m in the Florida Mountains (Clemons & Brown 1983).

Devonian

The evolution of stratigraphic nomenclature of Devonian rocks (Flower 1958, Bowsher 1967, Cooper & Dutro 1982) in the northern San Andres Mountains is shown by Sorauf (1984). Terminology in Fig. 1 of this paper is that of Kottlowski (1955, 1963), which is being used in current mapping projects in south-central New Mexico. About 25–50 m of Middle and Upper Devonian strata in the San Andres Mountains are composed of fossiliferous calcareous, argillaceous, and sandy shelf sediments grading into dark basinal shales to the south (Sorauf 1984). In the T or C area, the partly exposed Percha Shale ranges in thickness from 5 to 30 m. It contains calcareous claystone, olive-gray shale, ferruginous siltstone, and minor fine-grained sandstone (Kelley & Silver 1952). The Percha type section, west of Hillsboro, contains 40 m of lower black fissile shale (Ready Pay Member) overlain by 14 m of fossiliferous gray calcareous shale and nodular limestone (Box Member). Lithic–faunal equivalents of the Oñate and Sly Gap appear to be present south of Winston and in the Mud Springs and Caballo Moun-

tains; they may correlate with the lower part of the Ready Pay member to the south and west (Kottlowski 1963).

Mississippian

Most Mississippian rocks of south-central New Mexico belong to the Lake Valley Formation of Osagean age. The Lake Valley is underlain by the Caballero Formation of Kinderhookian age at its type locality in the southern Black Range and in San Andres and Sacramento Mountains. Laudon & Bowsher (1949) divided the Lake Valley Formation into six members, in ascending order the Andrecito, Alamogordo, Nunn, Tierra Blanca, Arcente, and Doña Ana. The latter two members are recognized only in the Sacramento and southern San Andres Mountains.

The Caballero Formation in the Lake Valley area consists of 2 m of sandy limestone overlain by about 10 m of nodular limestone and shale. The Caballero is unconformably overlain by about 70 m of Lake Valley Formation. The basal Andrecito Member contains 20 m of thin-bedded, cherty limestone with shaly partings. The Andrecito grades upward into 10 m of massive, dark-gray, cherty limestone which weathers light gray (Alamogordo Member). The Nunn Member consists of about 23 m of nodular crinoidal limestone and marl. The Nunn grades upward into about 17 m medium-bedded, brownish-gray, coarse-crystalline, cherty, crinoidal limestone of the Tierra Blanca Member (Jicha 1954). See Kues (this guidebook) for stratigraphy and paleontology of these Mississippian strata. Kottlowski et al. (1956) reported 19 m of Lake Valley Formation at Rhodes Canyon in the northern San Andres Mountains. This section includes 2.6 m of Andrecito, 6.7 m of Alamogordo, 8.7 m of Nunn, and 1 m of Tierra Blanca. Kelley & Silver (1952) described isolated patches of Alamogordo and Nunn Members up to 12 m thick in the southern Caballo Mountains. Mississippian strata apparently were eroded from most of the area around T or C before Early Pennsylvanian time (King 1973). To the west, Jahns et al. (1978) mapped 12.5 m of Kelly Limestone overlying about 35 m of Lake Valley strata in the Sierra Cuchillo. They indicated all four members from the type locality are present in the Winston area even though the Lake Valley Formation is only half as thick.

Pennsylvanian

The Magdalena Group is divided into a lower Sandia Formation and upper Madera Formation in the Sierra Cuchillo and north of T or C. Kelley & Silver (1952) divided the Magdalena into three formations in the Caballo Mountains, in ascending order the Red House, Nakaye, and Bar B. In the northern San Andres Mountains, the Pennsylvanian is divided into the standard series: Derryan, Desmoinesian, and Missourian; the uppermost Missourian, Virgilian, and basal Wolfcampian(?) consist of the Panther Seep Formation (Kottlowski et al. 1956). Detailed studies of fusulinids (Thompson 1942) and of Middle Pennsylvanian brachiopods (Gehrig 1958) in the T or C region provided much useful data, but their proposed group and formational names were not adopted. Thickness of the Pennsylvanian strata increases from about 200 m in southwestern Sierra County to 640 m in the San Mateo Basin, north of T or C, and to over 1,000 m in the Orogrande Basin, east of Sierra County (Kottlowski 1960, 1963). McCleary (1960) described 460 m in the Fra Cristobal Range. Nelson (this guidebook) notes that the Magdalena varies in thickness from 350 to 450 m within the Fra Cristobal Range. Verville et al. (this guidebook) discuss the ages of these rocks based on their study of the fusulinids. Hill (1956) reported a thickness of 495 m in the Mud Springs Mountains and Mason (1976) mapped 244 m in the northern Caballo Mountains. Maxwell & Oakman (this guidebook) describe an unconformity within the Mud Springs Pennsylvanian section.

Stratigraphic relief on the erosional unconformity below the Magdalena Group in the southern Caballo Mountains and Red Hills is about 275 m (see third-day road log). The Red House Formation varies in thickness as it rests on rocks as old as El Paso and as young as the Nunn Member (see fig. 3-18.18 of third-day road log). At its type section, it is 110 m thick and rests on the Cutter Member of the Montoya. The Red House consists of about 80% thin-bedded, fossiliferous limestone (Fig. 7) and 20% shale with minor basal sandstones at some locales. The Nakaye contains 128 m of medium- to dark-gray, massive limestone and is overlain by 103 m of Bar B Formation. The Bar B contains about 80% shale and 20% thin-bedded, fossiliferous limestone with some sandstone and conglomerate at the top. Abundant bioclasts seen in thin sections include brachiopods, corals, bryozoans, algae, ostracods, trilobites, fusulinids, and various other forams.



FIGURE 7—Magdalena Group limestone and shale in Palomas Gap.

Permian

The Pennsylvanian–Permian boundary appears to be conformable north of T or C. Interbedded red beds and marine limestones of the Bursum Formation grade downward into Virgilian strata and upward into Abo Formation in Socorro County (Kottlowski 1963). Jahns (1978) considered 23–67 m of Bursum-like "transition beds" to be of Virgilian age in the Sierra Cuchillo. Near Rhodes Canyon, the Bursum unconformably overlies Virgilian strata and contains about 81 m of lower conglomerate and sandstone, middle shale and limestone, and upper massive limestone. The upper limestone is locally deeply channeled, but in most palces is conformably overlain by Hueco strata which intertongue upward into the Abo Formation (Kottlowski 1963).

Aggregate thickness of Permian rocks in the central Caballo Mountains is about 610 m (Silver 1955). The distinctive dark reddish-brown Abo ranges from 168 to 335 m in the Caballo Mountains; Mason (1976) measured 171 m in the northern Caballos. Nelson (this guidebook) describes 137 m of Abo in the Fra Cristobal Range. The Abo is composed of shale, siltstone, and crossbedded sandstone with minor lenses and nodules of brownish-gray limestone. The conformably overlying Yeso Formation increases in thickness from the southern Caballos to 183 m in the northern Caballos and 395 m in the Fra Cristobal Range

(Nelson in this guidebook). The Yeso is dominantly sandstone and gypsum (in upper part), with lesser amounts of siltstone, shale, and limestone. Nelson (this guidebook) and Nelson & Hunter (this guidebook) recognize four members of the Yeso in the Fra Cristobals. In ascending order, they are Meseta Blanca, Los Vallos, Canas, and Joyita. The Yeso is in turn gradationally overlain by 152– 300 m of limestone, dolomitic limestone, shale, and fine-grained sandstone belonging to the San Andres Formation (Silver 1955). Melvin (this guidebook) noted some siltstone and sandy shale overlying the San Andres in the Mescal Creek area that may belong to the Bernal Formation (upper Guadalupian). Mason (1976) assigned the uppermost Permian rocks in the Caballo Peak quadrangle to the San Andres Formation.

Cretaceous

Lower Cretaceous rocks are apparently missing in the T or C region. The Upper Cretaceous section includes, in ascending order: Dakota Sandstone, a lower Mancos Shale tongue, Tres Hermanos Formation, D-Cross tongue of the Mancos Shale, Mesaverde Group (Gallup Sandstone and Crevasse Canyon Formations), and McRae Formation (Hook et al. 1983, Wallin 1983). The McRae appears to be limited to north-central Sierra County and the upper part may be as young as early Tertiary (Kelley & Silver 1952, Bushnell 1955, Lozinsky 1984, Lozinsky et al. 1984).

The Dakota Sandstone varies in thickness from 34 to 75 m in the Caballo Mountains–Jornada del Muerto area. The poorly exposed overlying lower Mancos Shale is 107–137 m thick in the Caballo Mountains and includes a lower limestone unit of Greenhorn age (Bushnell 1955). The Mancos thickens to the north and thins abruptly to the south. The Tres Hermanos Formation consists of 86 m of nearshore marine and nonmarine deposits of Turonian age. The D-Cross tongue of Mancos Shale reaches a thickness of 73 m and represents offshore deposition. More than 1,000 m of Mesaverde strata are preserved in the lower area between the Caballo Mountains and Fra Cristobal Range. A thick section of Mesaverde sandstone, shale, siltstone, and mudstone probably once covered most of south-central New Mexico, but was eroded from Laramide uplifts (Bushnell 1955, Seager et al. in this guidebook). The Gallup Sandstone consists of a 23 m thick shoreface sandstone and three thinner marine sandstones (5–15 m thick) present within the D-Cross shale (Wallin 1983). Lignite coal described near Engle by Lee (1905) is probably correlative to the thicker, bituminous coal beds in the basal Mesaverde near Carthage to the north. Fossil leaves, petrified wood, and several marine bivalves have been reported from the Mesaverde (Melvin 1963, Mason 1976, Wallin 1983, Lozinsky 1986). Wolberg et al. (this guidebook) describe the Upper Cretaceous fossils of the Elephant Butte area.

Unconformably overlying the Mesaverde is about 1,000 m of continental clastic rocks belonging to the McRae Formation. Total thickness is uncertain because part of the section is below Elephant Butte reservoir. Bushnell (1955) subdivided the McRae into lower Jose Creek Member and upper Hall Lake Member. The Jose Creek consists of about 120 m of sandstone, shale, and conglomerate. At some locales the Jose Creek contains coarse volcaniclastic rocks that have been interpreted as vent agglomerates (Kottlowski 1963), but other workers favor a lahar-type origin for these rocks (see second-day road log). The Hall Lake Member locally has a basal conglomerate, but the bulk is about 884 m of purplish and maroon tuffaceous siltstones and shales. The Hall Lake has yielded vertebrate fossils (Lozinsky et al. 1984, Gillette et al. in this guidebook).

Tertiary

Tertiary rocks in the T or C region consist of the Cretaceous to Paleocene Love Ranch Formation (and possibly the upper beds of the McRae Formation), Cretaceous to Paleocene intrusives and volcanic rocks near Hillsboro, Eocene and Oligocene volcanic and volcaniclastic rocks of the Mogollon–Datil volcanic field, and early Miocene(?) to Pleistocene Santa Fe Group sedimentary rocks (and sparse interlayered volcanic rocks).

The Love Ranch Formation as described by Seager et al. (this guidebook) consists of varying proportions of conglomerates, sandstones, and shales. Within Sierra County, the Love Ranch crops out in the southern Caballo Mountains and in the adjoining Jornada del Muerto. These rocks are as much as 2,000 m thick in the Laramide Love Ranch and Potrillo Basins, and are in large part derived from the Rio Grande uplift which is a northwest-trending Laramide deformational front similar to the Wind River and Owl Creek Ranges (Seager et al. in this guidebook).

Uppermost Cretaceous and lowest Tertiary volcanic and plutonic rocks occur in the Black Range and Sierra Cuchillo west of T or C. Copper Flat, near Hillsboro, is an upper Cretaceous (73.4 ± 2.5 my) mineralized porphyry-copper stock surrounded by a deeply eroded andesitic volcano (Hedlund 1977). A group of intrusives extends north from Copper Flat to the Sierra Cuchillo. Two of these, a stock in the Salado Hills and the Cuchillo monzonite laccolith, have been dated at 61.4 ± 2.4 and 50.1 ± 2.0 my (recalculated to new constants), respectively (Lamarre 1974). These areas and others now buried beneath younger rocks in basins supplied the volcanic detritus which comprises most of the Jose Creek Member of the McRae Formation (Hunter 1986).

Middle Tertiary volcanic rocks are exposed in the Black Range, Sierra Cuchillo, and Salado Hills in western Sierra County; to the north in the San Mateo, Magdalena, and Chupadera Mountains and the Jornada del Muerto; and to the south in the southern Caballo, Organ, and Doña Ana Mountains and Sierra de las Uvas. The Fra Cristobal Range and northern Caballo and San Andres Mountains lack mid-Tertiary volcanic-rock exposures. However, small exposures in the southern and central Jornada del Muerto and a thick volcanic section in the southern Caballos leave open the possibility that earlier volcanic cover was more complete.

The volcanic section shows overall similarity throughout the region (Jahns et al. 1955). As noted by Jahns et al. and many other workers, the earliest volcanics are typically andesitic volcaniclastics and lavas. These are overlain by dacite to rhyolite ash-flow tuffs which are often interlayered with, and/or overlain by, andesite to basaltic-andesite lavas. This sequence of silicic tuffs and mafic lavas is considered by some workers to constitute a mildly bimodal sequence indicating extension (Elston 1984). Silicic-lava domes occur locally throughout the bimodal part of the section and at the top of the volcanic sequence in the Black Range and Sierra Cuchillos. Despite lithologic similarities, differing formal and informal nomenclature has been used between ranges and sometimes within one range. Relatively rapid pinchout of individual volcanic units and the imprecise nature of lithologic correlations have contributed to this problem. Recent advances in the precision of radiometric dating allow a greater certainty of correlations. Studies (e.g. McIntosh et al. in this guidebook) are underway which will provide a radiometric framework for the entire volcanic field based on the high-precision $^{39}Ar/^{40}Ar$ dating of widespread regional ignimbrites. Preliminary correlations are presented here in Fig. 8 and in the first-day road log.

Volcanic rocks of the Black Range, Sierra Cuchillo, and San Mateo Mountains are described in this paper. Major outflow units in the Black Range are, from oldest to youngest, Rubio Peak Formation (800 m), Kneeling Nun Tuff (>1,000 m intracaldera, 150 m outflow), basaltic andesite of Poverty Creek (30–200 m), and a rhyolitic interval containing several large dome complexes and interlayered ash-flow tuffs. Several other thin or sporadically distributed units are present locally. In addition to the outflow stratigraphy, Emory cauldron, the source of the Kneeling Nun tuff, covers most of the southern Black Range beginning southwest of the Winston area (Abitz in this guidebook). There, very thick Kneeling Nun is overlain by a thick sequence of post-cauldron intermediate to basaltic rocks and rhyolite complexes which interfinger upward with Santa Fe (or Gilda) Group sedimentary rocks (Seager et al. 1982, Abitz in this guidebook). These post-cauldron rocks correlate in part with the basaltic andesite of Poverty Creek and younger rocks of the Winston area (Abitz in this guidebook). Mid- to late Tertiary Santa Fe and Gila basin fill in most places overlies the volcanic pile. Details of the stratigraphy are provided in individual papers: Harrison describes the geology of the area south and west of Winston, largely in the Chloride mining district, whereas Abitz describes the northern part of the Emory cauldron just west and south of Harrison's study; both workers provide correlation charts comparing their units with those

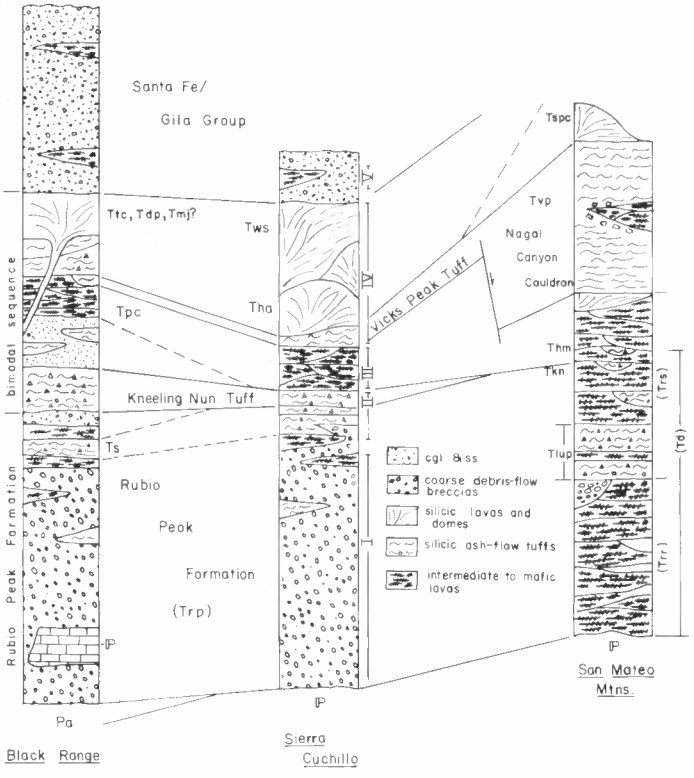


FIGURE 8—Correlation diagram for Tertiary rocks in northwestern part of T or C area. Black Range after Harrison (this guidebook), Sierra Cuchillo after fig. 1-21.0 and San Mateo Mountains after fig. 1-6.06 of first-day road log. Abbreviations: Td = Datil Group, Tdp = rhyolite of Dolan Peak, Thm = Hells Mesa Tuff (Osburn & Chapin 1983), Tho = rhyolite of HOK Ranch, Tkn = Kneeling Nun Tuff, Tlup = Luna Park Tuff, Tmj? = Moccasin John Rhyolite, Tpc = basaltic andesite of Poverty Creek, Trp = Rubio Peak Formation, Trr = Red Rocks Formation, Trs = Rock Springs Formation (Farkas 1969), Ts = Sugarlump Tuff, Tspc = Springtime Canyon quartz-latite lava, Ttc = Taylor Creek Rhyolite, Tvp = Vicks Peak Tuff, Tws = rhyolite of Willow Springs Draw. Roman numerals code the five volcanic sequences of Jahns et al. (1978): I = latite–andesite sequence, II = dacite–rhyodacite sequence, III = lower andesite sequence, IV = rhyolite–trachyte sequence, V = upper andesite sequence.

of previous studies. Eggleston & Norman and Maxwell et al. describe details of the Taylor Creek tin district. And Lawrence describes stratigraphic relationships in the Indian Peaks area of the north-central Black Range.

The volcanic section of the Sierra Cuchillo is quite similar to that in the adjoining Black Range. Jahns et al. (1978) divided the section there into five volcanic sequences. More recently, Harrison (unpubl. data) mapped the western edge of the Sierra Cuchillo. In addition, Davis (this guidebook) describes the Reilly Peak intrusive and skarn mineralization in the north-central part of the range. A.V. Heyl (U.S. Geological Survey), and R.H. Jahns and D.K. McMillan of Stanford University have independently prepared detailed geologic maps of the Chise quadrangle in the central Sierra Cuchillo; neither is yet published.

The section in the central Sierra Cuchillo consists of a lower andesitic volcaniclastic interval overlain by a sequence of interlayered rhyolitic ash-flow tuffs and mafic lavas and two thick rhyolite flow–dome complexes. The lower andesitic volcaniclastic interval consists predominantly of several hundred meters of coarse-grained debris-flow deposits with lesser conglomerate and sandstone. Clasts are most commonly porphyritic andesite containing 20–50% phenocrysts of plagioclase, biotite, and amphibole. Andesite or basaltic-andesite lavas become more abundant higher in this sequence and are interbedded with one or more ash-flow tuffs. The tuffs contain from 5 to 25% plagioclase, sanidine, and biotite phenocrysts. A phenocryst-rich, quartz-rich ash-flow tuff overlying these tuffs and mafic lavas is thought to be the Kneeling Nun Tuff; units below this tuff would then correlate with the Rubio Peak Formation in the Black Range. The phenocryst-rich Kneeling Nun Tuff is fairly thin (5–25 m) and usually forms cliffs. Overlying the Kneeling Nun is a series of mafic to intermediate lava flows (basaltic andesite of Poverty Creek equivalent) and a distinctive aphanitic, tan to gray ash-flow tuff. This tuff contains only 1–2% sanidine and a trace of quartz phenocrysts. The lack of phenocrysts and porcelaneous weathering surface suggest a correlation with the Vicks Peak Tuff in the San Mateo Mountains. Both the Vicks Peak and underlying mafic lavas thin dramatically on upthrown side of normal faults which tilt the beds eastward. This relationship suggests deposition concurrent with faulting and tilting. Two thick rhyolite flow–dome complexes overlie the Vicks Peak Tuff. These are informally called the rhyolite of HOK Ranch and rhyolite of Willow Springs Draw (Eggleston in preparation). The rhyolite of Willow Springs Draw is dated at 27.8 ± 1.0 my (Heyl et al. 1983) by the fission-track method.

The San Mateo Mountains expose a similar volcanic section. Farkas (1969) mapped the area and divided the section, in ascending order, into the Red Rock Ranch Formation, Rock Springs Formation, and the Vicks Peak Rhyolite (Tuff). The Red Rock Ranch Formation generally consists of as much as 900 m of andesitic lavas and minor sedimentary rocks. The overlying Rock Springs Formation contains another 800–900 m of interlayered ash-flow tuffs and lavas (predominantly intermediate to mafic). The Vicks Peak Tuff, a very phenocryst-poor, high-silica rhyolite ash-flow tuff, typically caps the section. The Vicks Peak is at least 1,000 m thick, suggesting to Deal & Rhodes (1976) that the tuff in the south San Mateo Mountains is within its source cauldron. The Red Rock Ranch and Rock Springs Formations are currently being remapped and subdivided into smaller genetic units by several graduate students at the New Mexico Institute of Mining & Technology (M. Herman, G. Cox, J. Dodson, C. Hesse). Two thin, quartz-rich, crystal-rich tuffs occur within the Rock Springs Formation and probably correlate to the Kneeling Nun Tuff (lower) and Hells Mesa Tuff (upper) (Osburn & Chapin 1983), respectively. Possible correlations with Rubio Peak Formation and basaltic andesite of Poverty Creek are shown in fig. 1-6.0 of first-day road log.

Santa Fe or Gila Group sedimentary deposits of various ages overlie the volcanic rocks throughout the region. Beginning from west to east, the sandstone of Innman Ranch overlies, and is perhaps interbedded with, the Taylor Creek Rhyolite in the central Black Range (Eggleston in preparation). This unit consists dominantly of sandstones with lesser conglomerates and rare pyroclastic rocks and is as much as 100 m thick. Oreodont (possibly *Promerycochoerus carrikeri*) remains date the deposit between 26 and 21 my (Tedford 1981). Younger Gila conglomerates are widespread slightly farther west near Beaverhead Ranger Station and Wall Lake. These conglomerates are as much as 100 m thick and interfinger with Bearwallow Mountain Formation and younger mafic lavas dating from 21 to 0.9 my (Elston et al. 1976).

Near Winston, Santa Fe Group sandstones, conglomerates, siltstones, and shales fill the north-trending graben between the Sierra Cuchillo and Black Range. These sediments were called the Winston beds by Jahns (1955) for convenience, and the name has been used since. Their exposures are poor except in isolated areas and little detailed study has been done. The lower Winston beds interfinger with a basaltic andesite dated at 18.3 ± 0.4 my and are capped by a vesicular basalt dated at 4.8 ± 0.1 my at Tabletop Mountain near Winston (Seager et al. 1984). Lower Pleistocene vertebrate fossils and fresh-water mollusks were reported from these rocks by Kottlowski (1955). Jahns (1955) and Chapin et al. (1978) suggested that the high geomorphic surface capping these deposits might correlate with the Palomas surface (Cuchillo surface of Lozinsky & Hawley in this guidebook). Jahns (1955) further suggested that the Winston beds can be traced continuously to the Palomas Formation in the Palomas Basin.

East of the Sierra Cuchillo, Santa Fe Group deposits occur extensively in basins of the Rio Grande rift. Most exposures are Pliocene and younger and have been described by Lozinsky (1986), and Lozinsky & Hawley (this guidebook). Older deposits, however, occur in at least two areas in the Engle Basin. Near the eastern side of the Sierra Cuchillo, apparently older Santa Fe deposits are exposed in several arroyos

north of NM-59. These rocks dip eastward 20–25° and in Roque Ramos Canyon directly overlie Oligocene volcanic rocks. The deposits consist of conglomerate and lesser amounts of sandstone. Transport was toward the east and clasts are dominantly of volcanic rocks present in the Sierra Cuchillo. Thickness is unknown due to spotty exposures. The Cuchillo surface bevels the older deposits.

Older Santa Fe Group rocks are also exposed in Cuchillo Negro Creek about 2 km east of Cuchillo. Here conglomerate and sandstone, dipping northeastward 35–45°, are exposed in the canyon wall (Maxwell et al. 1986). The base of these deposits is not exposed, and they are disconformably overlain by terrace gravels. Clast lithologies are mostly volcanic rocks similar to those exposed in the Sierra Cuchillo.

Most of the Santa Fe exposed in the T or C area is Pliocene and Pleistocene in age. These deposits have been studied by Lozinsky (1986) and are formally named the Palomas Formation by Lozinsky & Hawley (this guidebook). These authors extend the term Palomas Formation to include upper Santa Fe Group deposits in the Palomas, Engle, and San Marcial Basins of the Rio Grande rift. The Palomas Formation consists of ancestral Rio Grande sands and the voluminous piedmont deposits that interfinger with it. Lozinsky & Hawley suggest the term Cuchillo surface for the high-level Plio-Pleistocene surfaces in these basins that predate cutting of the present Rio Grande valley.

The Jornada del Muerto east of T or C is mainly a shallow syncline and typically contains only thin alluvium called the Jornada deposits (Lozinsky 1986). These deposits underlie the Cutter surface (Lozinsky 1986) and are overlain by 2.1 my old basalts in the Cutter Sag area.

Late Tertiary basaltic rocks locally overlie, and are interbedded with, Santa Fe Group deposits in the T or C region. Alkali-olivine basalts predominate, but tholeiitic basalts are locally present (Seager et al. 1984). Fairly extensive alkali basalts and related cinder cones overlie the Cutter surface in the Cutter sag (Warren 1978, J. Kelley in preparation). A cinder cone thought to represent the latest pulse of volcanism in the Cutter sag is dated 2.1 ± 0.4 my (Bachman & Mehnert 1978). Additional basaltic lavas dated at 2.2 ± 0.10 and 0.76 ± 0.1 my (Bachman & Mehnert 1978) are present in the Jornada del Muerto north of the Fra Cristobal Range. Slightly older basalt flows occur in the Winston graben (4.8 ± 1.0 my) and near Hillsboro (4.5 ± 0.1 my) (Seager et al. 1984).

STRUCTURAL AND TECTONIC SETTING

Rocks in the T or C region have been deformed in Precambrian, Paleozoic, Laramide, and mid- to late Tertiary times. The oldest rocks known in south-central New Mexico are lower(?) Proterozoic plutonic and metamorphosed supracrustal rocks exposed along the scarp edges of several ranges (Condie & Budding 1979). Although these rocks have not been dated by reliable methods, the supracrustal rocks may be equivalent to a 1,650 my old package exposed in central New Mexico (Bauer & Lozinsky in this guidebook). Bauer & Lozinsky report that Proterozoic rocks in the central Caballo Mountains are penetratively deformed and have sustained amphibolite-grade regional metamorphism. Three phases of Precambrian deformation are present and include an early, strong schistosity and gneissic layering which was tightly folded about shallow east-trending axes during the second phase of deformation. The final stage is non-penetrative cross-folding which formed small crenulations. The degree of metamorphism and style of deformation are similar to those found in central and northern New Mexico and indicate ductile deformation at mid-crustal depths.

Kelley & Silver (1952) report Paleozoic deformational events in Middle Ordovician, Late Silurian or Early Devonian, Late Mississippian, and Early Permian times. These are recorded by regional wedging out of units or locally by missing section and erosional relief. Details of stratigraphic truncations are found in the stratigraphic portion of this paper and in Kelley & Silver (1952). Maxwell & Oakman (this guidebook) report on a Pennsylvanian unconformity in the Mud Springs Mountains, and Nelson & Hunter (this guidebook) describe pre-Pennsylvanian erosion in the Fra Cristobal Range. Seager (fig. 3-18.16 of third-day road log) describes a Late Mississippian–Early Pennsylvanian domal uplift in the south-central Caballo Mountains.

Laramide structures are a dominant element of the geology in the T or C area. The backbone of the Fra Cristobal Range and the northern Caballo Mountains are north–south oriented Laramide deformational belts. Chapin & Nelson (this guidebook) describe the basement-cored folds in the central part of the Fra Cristobal Range and Nelson & Hunter (this guidebook) describe thin-skinned deformation higher in the section in the southern part of the range. The large fold which forms Turtle Mountain in the northern Caballos is described by Kelley & Silver (1952) and Mason (1976) and a revised cross section is presented by Lozinsky et al. in the second-day road log. Seager (1983) and Seager et at. (this guidebook) describe northwest-oriented, Laramide-age deformational fronts (fold and thrust complexes) in the southern Caballo Mountains. These form the northeastern structural margin of a large, structurally uplifted block (Rio Grande uplift). The Love Ranch Formation which consists largely of detritus derived from erosion of this uplifted block is described by Seager et al. (this guidebook). The somewhat older, Cretaceous and Paleocene, McRae Formation constitutes mainly volcanic detritus that filled an earlier Laramide basin slightly to the north (Hunter 1986).

Conflicting stress directions are suggested by the north–south structures in the northern Caballo Mountains and Fra Cristobal Range and the northwest-oriented structures in the southern Caballo–Tonuco uplift. This difference in structural grain and compressional direction is difficult to explain by a single event, but it fits well into the two-stage Laramide model proposed by Chapin & Cather (1981). They proposed a change in early Eocene time from east–northeast to northeast-directed compressional stress. In the T or C area, the northerly oriented deformational fronts perhaps formed during the earlier stage of the orogeny.

Chapin & Cather (1981) proposed that the major late Laramide structure in New Mexico and Colorado was a north-oriented strike–slip system separating the northward-shifting Colorado Plateau from the Great Plains province. They proposed compression direction at about N 45 E and subsequent authors (e.g. Gries 1983, Hammond 1986) suggested even more northerly orientations. The orientation of the southern Caballo–Tonuco uplift is consistent with N 45° to N 30° E compression. The postulated Eocene age for the Love Ranch Formation (fig. 3-12.1b of third-day road log and Seager et al. in this guidebook) suggests derivation from a late Laramide uplift. The Mud Springs Mountains are also oriented northwest and have been interpreted as a Laramide fold (Kelley & Silver 1952). Strike–slip faults have not been documented in detail in the T or C region. However, right slip of ca 0.5 km has been postulated for a part of the Hot Springs fault by Lozinsky (1986) and Lozinsky et al. (second-day road log), which may indicate a Laramide ancestry.

Extensional faulting has played a prominent role in the T or C region. The major ranges today are the product of late Miocene and younger faulting and were apparently near their present elevations by 4 or 5 my ago (Chapin & Seager 1975, Seager et al. 1984). Extension probably began as early as 27–32 my ago as postulated for other areas (Chapin & Seager 1975, Chapin 1979, Seager et al. 1984). However, evidence for this early extension is sparse in the T or C region as are exposures of older Santa Fe deposits which should have filled early basins. The Black Range, Winston graben, and Sierra Cuchillo expose some evidence of late Oligocene and early Miocene faulting. Eggleston (in preparation) reports sandstones and conglomerates of later Oligocene to early Miocene age (sandstone of Innman Ranch) filling a northeast-trending graben in the central Black Range. Basaltic-andesite lavas dated at 18.3 ± 0.4 my (Seager et al. 1984) are interbedded with Winston beds near Winston. In addition, the Sierra Cuchillo is broken into a number of north- to northwest-trending, east-tilted fault blocks. The Vicks Peak Tuff (28.47 my, McIntosh et al. in this guidebook) is wedge-shaped beneath overlying rhyolites on several of these blocks. The Vicks Peak, 50–100 m thick on the downside of the faults, thins to as little as 2 m on the upthrown side. The Vicks Peak (and perhaps the underlying basaltic-andesite lavas) was apparently faulted, tilted, and eroded before deposition of the overlying rhyolite. The overlying rhyolite of Willow Springs Draw is dated at 27.8 ± 1.0 my by the fission-track method (Heyl et al. 1983). Other than these scattered data, early Miocene extensional history and deposits are buried beneath younger de-

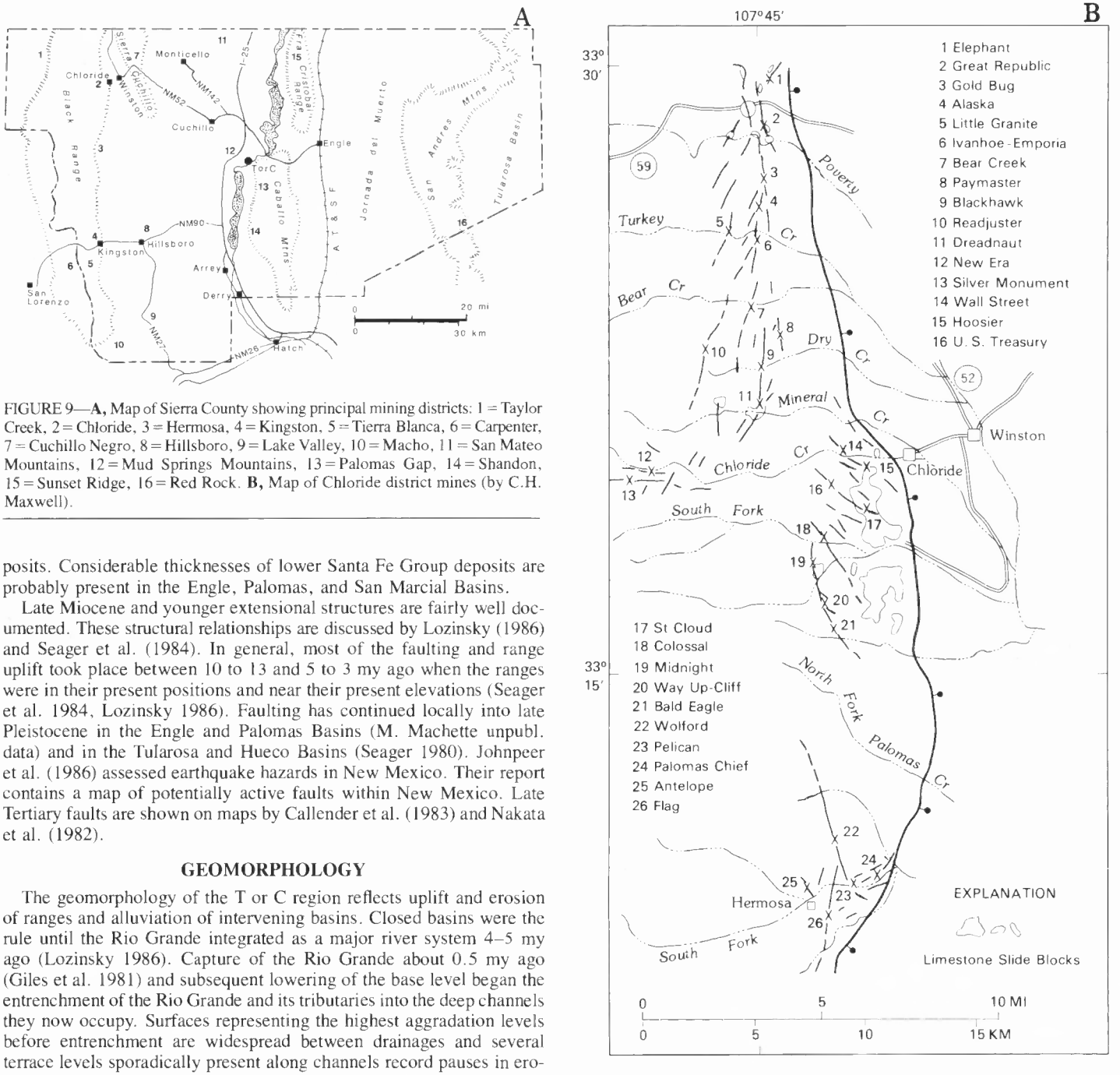


FIGURE 9—**A,** Map of Sierra County showing principal mining districts: 1 = Taylor Creek, 2 = Chloride, 3 = Hermosa, 4 = Kingston, 5 = Tierra Blanca, 6 = Carpenter, 7 = Cuchillo Negro, 8 = Hillsboro, 9 = Lake Valley, 10 = Macho, 11 = San Mateo Mountains, 12 = Mud Springs Mountains, 13 = Palomas Gap, 14 = Shandon, 15 = Sunset Ridge, 16 = Red Rock. **B,** Map of Chloride district mines (by C.H. Maxwell).

posits. Considerable thicknesses of lower Santa Fe Group deposits are probably present in the Engle, Palomas, and San Marcial Basins.

Late Miocene and younger extensional structures are fairly well documented. These structural relationships are discussed by Lozinsky (1986) and Seager et al. (1984). In general, most of the faulting and range uplift took place between 10 to 13 and 5 to 3 my ago when the ranges were in their present positions and near their present elevations (Seager et al. 1984, Lozinsky 1986). Faulting has continued locally into late Pleistocene in the Engle and Palomas Basins (M. Machette unpubl. data) and in the Tularosa and Hueco Basins (Seager 1980). Johnpeer et al. (1986) assessed earthquake hazards in New Mexico. Their report contains a map of potentially active faults within New Mexico. Late Tertiary faults are shown on maps by Callender et al. (1983) and Nakata et al. (1982).

GEOMORPHOLOGY

The geomorphology of the T or C region reflects uplift and erosion of ranges and alluviation of intervening basins. Closed basins were the rule until the Rio Grande integrated as a major river system 4–5 my ago (Lozinsky 1986). Capture of the Rio Grande about 0.5 my ago (Giles et al. 1981) and subsequent lowering of the base level began the entrenchment of the Rio Grande and its tributaries into the deep channels they now occupy. Surfaces representing the highest aggradation levels before entrenchment are widespread between drainages and several terrace levels sporadically present along channels record pauses in erosion or aggradational events (perhaps during glaciation) during an overall downcutting period.

MINERAL RESOURCES

Sierra County has had its share of excitement associated with early mineral exploration, new discoveries, and reopening of mineral districts. Harley (1934) prepared an excellent summary of the ore deposits known in Sierra County to that time. Christiansen (1974) and Eveleth (this guidebook) also included information about several of the early mining camps in the T or C region. The principal elements extracted from the early districts (Fig. 9) were gold, silver, lead, zinc, copper, vanadium, iron, and manganese. Fluorspar deposits in the Caballo and Salado Mountains, Sierra Cuchillo, and San Diego Mountains were described by Rothrock et al. (1946) and McAnulty (1978). Barite deposits were summarized by Clippinger (1949). Van Allen et al. (1984) described the Sunset Ridge fluorite deposit in the Fra Cristobal Range. Papers in this guidebook by Harrison, Sanders & Giordano, Eggleston & Norman, Maxwell et al., McLemore, and North & Tuff present updated information and interpretations on the Chloride district, Kingston district, Taylor Creek tin deposits, and barite–fluorite deposits, respectively.

Energy companies have shown intermittent interest in the Jornada del Muerto area and thick Cretaceous section near T or C. According to the New Mexico Bureau of Mines & Mineral Resources records, 32 petroleum exploration wells have been drilled in Sierra County. Three wells reported shows of oil or gas (R. Broadhead written comm. 1986).

Broadhead provided the operator's names, well names, locations, T.D., tops, and shows for nine of the more interesting wells.

1. Bruten Development Co., No. 1 Guame, 21-16S-2E, T.D. 2202, Mancos @ 649, Dakota @ 1104, San Andres @ 1135, Yeso @ 1588.

2. Clyde R. Wofford, No. 1 Graham State, 8-14S-2W, T.D. 507, show gas @ 300 ft, show oil @ 458 ft in shale.

3. Sun Oil Co., No. 1 Victoria Land & Cattle Co., 25-10S-1W, T.D. 6053, San Andres @ 1244, Abo @ 3175, El Paso @ 5712, Bliss @ 5940, Granite @ 5990.
4. Getty Oil Co., No. 1 West Elephant Butte Federal, 7-12S-4W, T.D. 7230, Penn @ 3328, Montoya @ 6286, El Paso @ 6514, Bliss @ 6925, Granite @ 7069.
5. Thomas J. Gartland, No. 1 Brister, 8-12S-4W, T.D. 8585, Penn @ 6605, Miss @ 8000?, Silurian @ 8485?, Granite @ 8567, oil show on drill-stem test from 8499 to 8527 ft (Silurian?).
6. Getty Oil Co., No. 2 West Elephant Butte Federal, 3-13S-4W, T.D. 7556, Penn @ 5156, Montoya @ 6662, El Paso @ 6906, Bliss @ 7334, Granite @ 7462.
7. Exxon Corp., No. 1 Beard Federal, 5-14S-1E, T.D. 8850, San Andres @ 2040, Abo @ 4140, Permo-Penn carbonate @ 5010, Mississippian @ 7830, Woodford @ 7890, Montoya @ 8040, Ellenburger @ 8335, Bliss @ 8680, Precambrian @ 8740, gas show in Strawn on drill-stem test from 7200 to 7430 ft.
8. Beard Oil Co., No. 1 Jornada del Muerto Unit, 17-14S-1W, T.D. 9800, Cretaceous @ 2250, San Andres @ 5838, Abo @ 7786, 1st Penn lime @ 8900, T.D. in Penn.
9. Exxon Corp. No. 1 Prisor Federal, 20-16S-1E, T.D. 11,650 in Pennsylvanian.

Woodward & Grant (this guidebook) discuss oil and gas potential in central–western New Mexico.

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REFERENCES

Abitz R.J. 1984. Volcanic geology and geochemistry of the northeastern Black Range Primitive Area and vicinity, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 121 pp.

Anonymous (C.B. Read?) 1955a. Stratigraphy of outcropping Permian rocks in part of south-central New Mexico.—New Mexico Geological Society, Guidebook 6: 77–80.

Anonymous (T.F. Stipp?) 1955b. Precambrian rocks of south-central New Mexico.—New Mexico Geological Society, Guidebook 6: 62–64.

Armstrong A.K. 1962. Stratigraphy and paleontology of the Mississippian System in southwestern New Mexico and adjacent southeastern Arizona.—New Mexico Bureau of Mines & Mineral Resources, Memoir 8: 99 pp.

Bachman G.O. & Mehnert H.H. 1978. New K–Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico.—Geological Society of America, Bulletin, 89: 283–292.

Bauer P. & Lozinsky R.P. 1986. Precambrian geology of supracrustal rocks in the Caballo Mountains.—This guidebook.

Bowsher A.L. 1968. The Devonian System in New Mexico. *In* 1967 Symposium, Silurian–Devonian rocks of Oklahoma and environs.—Tulsa Geological Society Digest, 35: 259–276.

Bushnell H.P. 1953. Geology of the McRae Canyon area, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 106 pp.

Bushnell H.P. 1955. Mesozoic stratigraphy of south-central New Mexico.—New Mexico Geological Society, Guidebook 6: 81–87.

Callender J.F., Seager W.R. & Swanberg C.A. 1983. Late Tertiary and Quaternary tectonics and volcanism. *In* Swanberg C.A. (compiler), Geothermal Resources of New Mexico.—New Mexico Energy Institute, Scientific Map Series.

Chapin W.E. 1979. Evolution of the Rio Grande rift—a summary. *In* Riecker R.E (ed.), Rio Grande rift: tectonics and magmatism.—American Geophysical Union, Washington, DC, pp. 1–5.

Chapin C.E. & Cather S.M. 1981. Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountain area. *In* Dickinson W.R. & Payne M.D. (eds.), Relations of tectonics to ore deposits in the southern Cordillera.—Arizona Geological Society Digest, 14: 173–198.

Chapin C.E. & Seager W.R. 1975. Evolution of the Rio Grande rift in the Socorro and Las Cruces areas.—New Mexico Geological Society, Guidebook 26: 297–322.

Chapin C.E., Siemers W.T. & Osburn G.R. 1975. Summary of radiometric ages of New Mexico rocks.—New Mexico Bureau of Mines & Mineral Resources, Open-file Report 60.

Chapin C.E., Jahns R.H., Chamberlin R.M. & Osburn G.R. 1978. First-day road log from Socorro to Truth or Consequences via Magdalena and Winston. *In* Chapin C.E. & Elston W.E. (eds.), Field guide to selected cauldrons and mining districts of the Datil–Mogollon volcanic field.—New Mexico Geological Society, Special Publication 7: 1–31.

Chapin M. & Nelson E. 1986. Laramide basement-involved deformation in the Fra Cristobal Range, south-central New Mexico.—This guidebook.

Clemons R.D. & Brown G.A. 1983. Geology of Gym Peak quadrangle, Luna County, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Geologic Map 58, scale 1:24,000.

Clippinger D.M. 1949. Barite of New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Circular 21: 7 pp.

Condie K.C. & Budding A.J. 1979. Geology and geochemistry of Precambrian rocks, central and south-central New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Memoir 35: 58 pp.

Cooper G.A. & Dutro J.T. 1982. Devonian brachiopods of New Mexico.—Bulletins on American Paleontology, 82–83(315): 215 pp.

Cserna E.G. 1967. Structural geology and stratigraphy of the Fra Cristobal quadrangle, Sierra County, New Mexico (Ph.D. thesis).—Columbia University, New York, 105 pp.

Darton N.H. 1928. "Red beds" and associated formations in New Mexico.—U.S. Geological Survey, Bulletin 794: 356 pp.

Deal E.G. & Rhodes R.C. 1976. Volcano-tectonic structures in the San Mateo Mountains, Socorro County, New Mexico. *In* Elston W.E. & Northrop S.A. (eds.), Cenozoic volcanism in southwestern New Mexico.—New Mexico Geological Society, Special Publication 5: 57–62.

Eggleston T.L. & Norman D.I. 1983. Taylor Creek tin district—stratigraphy, structure, and timing of mineralization.—New Mexico Geology, 5: 1–4.

Elston W.E. 1984. Subduction of young oceanic lithosphere and extensional orogeny in southwestern North America during mid-Tertiary time.—Tectonics, 3: 229–250.

Elston W.E., Rhodes R.C., Coney P.J. & Deal E.G. 1976. Progress report on the Mogollon Plateau volcanic field, southwestern New Mexico, no. 3—surface expression of a pluton. *In* Elston W.E. & Northrop S.A. (eds.), Cenozoic volcanism in southwestern New Mexico.—New Mexico Geological Society, Special Publication 5: 3–28.

Farkas S.E. 1969. Geology of the southern San Mateo Mountains, Socorro and Sierra Counties, New Mexico (Ph.D. thesis).—University of New Mexico, Albuquerque, 137 pp.

Flower R.H. 1955. Pre-Pennsylvanian stratigraphy of southern New Mexico.—New Mexico Geological Society, Guidebook 6: 65–70.

Flower R.H. 1958. Cambrian–Mississippian beds of southern New Mexico.—Roswell Geological Society, Guidebook 11: 61–78.

Flower R.H. 1965. Early Paleozoic of New Mexico.—New Mexico Geological Society, Guidebook 16: 112–131.

Flower R.H. 1969. Early Paleozoic of New Mexico and El Paso region.—El Paso Geological Society, Ordovician Symposium, pp. 31–101.

Foster R.W. & Stipp T.F. 1961. Preliminary geologic and relief map of the Precambrian rocks of New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Circular 57: 37 pp.

Geeslin J.H. & Chafetz H.S. 1982. Ordovician Aleman ribbon cherts: an example of silicification prior to carbonate lithification.—Journal of Sedimentary Petrology, 52: 1283–1293.

Gehrig J.L. 1958. Middle Pennsylvanian brachiopods from the Mud Springs Mountains and Derry Hills, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Memoir 3: 24 pp.

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

Golembeck M.P., McGill G.E. & Brown L. 1983. Tectonics and geologic evolution of the Española Basin, Rio Grande rift: structures, rate of extension, and relation to the state of stress in the western United States.—Tectonophysics, 94: 483–507.

Gries R. 1983. North–south compression of Rocky Mountain foreland structures. *In* Lowell J.D. (ed.), Rocky Mountain foreland basins and uplifts.—Rocky Mountain Association of Geologists, Denver, pp. 9–32.

Hammond C.M. 1986. Geology of the Navajo Gap area from Sierra Ladrones to Mesa Sarca, Socorro County, New Mexico: preview of a structural analysis (abstract).—New Mexico Geological Society, Proceedings of 1986 Annual Spring Meeting, p. 11.

Harbour R.L. 1972. Geology of the northern Franklin Mountains, Texas and New Mexico.—U.S. Geological Survey, Bulletin 1298: 129 pp.

Harley G.T. 1934. The geology and ore deposits of Sierra County, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 10: 220 pp.

Harrison R.H. 1986. Geology of the Cuchillo mining district and vicinity.—This guidebook.

Hedlund D.C. 1977. Geologic map of the Hillsboro and San Lorenzo quadrangles, Sierra and Grant Counties, New Mexico.—U.S. Geological Survey, Miscellaneous Field Studies Map 900-A, scale 1:48,000.

Heyl A.V., Maxwell C.H. & Davis L.L. 1983. Geology and mineral deposits of the Priest Tank quadrangle, Socorro County, New Mexico.—U.S. Geological Survey, Miscellaneous Field Studies Map 1665, scale 1:24,000.

Hill J.D. 1956. Paleozoic stratigraphy of the Mud Springs Mountains, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 72 pp.

Hook S.C., Molenaar C.M. & Cobban W.A. 1983. Stratigraphy and revision of upper Cenomanian to Turonian (Upper Cretaceous) rocks of west-central New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Circular 185: 54 pp.

Hunter J.C. 1986. Laramide synorogenic sedimentation in south-central New Mexico: petrostratigraphic evolution of the McRae basin (M.S. thesis).—Colorado School of Mines, Golden.

Hunter J.C. & Ingersoll R.V. 1981. Canas Gypsum Member of Yeso Formation (Permian) in New Mexico.—New Mexico Geology, 3: 49–53.

Jacobs R.C. 1956. Geology of the central front of the Fra Cristobal Mountains, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 47 pp.

Jahns R.H. 1944. Beryllium and tungsten deposits of the Iron Mountain district, Sierra and Socorro Counties, New Mexico.—U.S. Geological Survey, Bulletin 945-C: 45–79.

Jahns R.H. 1955. Geology of the Sierra Cuchillo.—New Mexico Geological Society, Guidebook 6: 158–174.

Jahns R.H. 1955. Second-day road log in Sierra Cuchillo and neighboring areas.—New Mexico Geological Society, Guidebook 6: 25–46.

Jahns R.H., Kottlowski F.E. & Kuellmer F.J. 1955. Volcanic rocks of south-central New Mexico.—New Mexico Geological Society, Guidebook 6: 92–95.

Jahns R.H., McMillan D.K., O'Brient J.D. & Fisher D.L. 1978. Geologic section in the Sierra Cuchillo and flanking areas, Sierra and Socorro Counties, New Mexico.—New Mexico Geological Society, Special Publication 7: 131–138.

Jicha H.L. 1954. Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 37: 93 pp.

Johnpeer G.D., Love D.W. & Hemingway M. 1986. Assessment of earthquake hazards in New Mexico.—Proceedings of 3rd U.S. National Conference of Earthquake Engineering, Earthquake Engineering Institute, El Cerrito, CA.

Kelley V.C. 1949. Geology and economics of New Mexico iron-ore deposits.—University of New Mexico Publications in Geology, no. 2: 246 pp.

Kelley V.C. 1951. Oolitic iron deposits of New Mexico.—American Association of Petroleum Geologists, Bulletin, 35: 2199–2228.

Kelley V.C. & Silver C. 1952. Geology of the Caballo Mountains.—University of New Mexico Publications in Geology, no. 5: 286 pp.

King W.E. 1973. Fusulinids *Millerella* and *Eostaffella* from the Pennsylvanian of New Mexico and Texas.—New Mexico Bureau of Mines & Mineral Resources, Memoir 26: 34 pp.

Kottlowski F.E. 1955. Cenozoic sedimentary rocks in south-central New Mexico.—New Mexico Geological Society, Guidebook 6: 88–91.

Kottlowski F.E. 1960a. Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 66: 187 pp.

Kottlowski F.E. 1960b. Depositional features of the Pennsylvanian of south-central New Mexico.—Roswell Geological Society, Guidebook to northern Franklin Mountains and southern San Andres Mountains, pp. 96–130.

Kottlowski F.E. 1963. Paleozoic and Mesozoic strata of southwestern and south-central New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 79: 100 pp.

Kottlowski F.E. & Pray L.C. 1967. Silurian outcrops of south-central and southwestern New Mexico.—Tulsa Geological Society Digest, 35: 209–230.

Kottlowski F.E., Flower R.H., Thompson M.L. & Foster R.W. 1956. Stratigraphic studies of the San Andres Mountains.—New Mexico Bureau of Mines & Mineral Resources, Memoir 1: 132 pp.

Kuellmer F.J. 1954. Geologic section of the Black Range at Kingston, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 33: 100 pp.

LaMarre A.L. 1974. Fluorite in jasperoid of the Salado Mountains, Sierra County, New Mexico: significance to metallogeny of the western United States (M.S. thesis).—University of Western Ontario, London, Canada, 134 pp.

Laudon L.R. & Bowsher A.L. 1949. Mississippian formations of southwestern New Mexico.—Geological Society of America, Bulletin, 60: 1–88.

Lawrence V.A. 1986. Developments in the Cenozoic volcanic stratigraphy of the Indian Peaks area, northern Black Range, New Mexico.—This guidebook.

Lee W.T. 1905. The Engle coal field, New Mexico.—U.S. Geological Survey, Bulletin 285: 240 pp.

Lee W.T. & Girty G.H. 1909. The Manzano Group of the Rio Grande valley, New Mexico.—U.S. Geological Survey, Bulletin 389: 356 pp.

Lozinsky R.P. 1982. Geology and late Cenozoic history of the Elephant Butte area, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 142 pp.

Lozinsky R.P. 1986. Geology and late Cenozoic history of the Elephant Butte area, Sierra County, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Circular 187: 40 pp.

Lozinsky R.P. & Hawley J.W. 1986. Upper Cenozoic Palomas Formation of south-central New Mexico.—This guidebook.

Lozinsky R.P., Hunt A.P., Wolberg D.L. & Lucas S.G. 1984. Late Cretaceous (Lancian) dinosaurs from the McRae Formation, Sierra County, New Mexico.—New Mexico Geology, 6: 72–77.

Lucia F.J. 1969. Sedimentation and paleogeography of the El Paso Group.—West Texas Geological Society, Guidebook 68-55a: 61–75.

Mason J.T. 1976. The geology of the Caballo Peak quadrangle, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 131 pp.

Maxwell C.H. & Oakman M.R. 1986. A Pennsylvanian unconformity in the Mud Springs Mountains.—This guidebook.

Maxwell C.H., Foord E.E., Oakman M.R. & Harvey D.B. 1986. Tin deposits in the Black Range tin district.—This guidebook.

McAnulty W.N. 1978. Fluorspar in New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Memoir 34: 64 pp.

McCleary J.T. 1960. Geology of the norrthern part of the Fra Cristobal Range, Sierra and Socorro Counties, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 59 pp.

McIntosh W.C., Sutter J.L., Chapin C.E, Osburn G.R. & Ratté J.C. 1986. A stratigraphic framework for the eastern Mogollon–Datil volcanic field based on paleomagnetism and high-precision $^{40}Ar/^{39}Ar$ dating of ignimbrites—a progress report.—This guidebook.

Measures E.A. 1985. Carbonate facies of the Montoya Group—description of a shoaling-upward ramp.—West Texas Geological Society, Bulletin, 25(2): 4–8, 25(3): 4–8.

Melvin J.W. 1963. Cretaceous stratigraphy in the Jornada del Muerto region, including the geology of the Mescal Creek area, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 121 pp.

Nakata J.K., Wentworth C.M. & Machette M.N. 1982. Quaternary fault map of the Basin and Range and Rio Grande rift provinces, western United States.—U.S. Geological Survey, Open-File Report 82-579.

Needham C.E. & Bates R. 1943. Permian type sections in central New Mexico.—Geological Society of America, Bulletin, 54: 1653–1667.

Nelson E. & Hunter J. 1986. Laramide thin-skinned deformation in Permian rocks, Fra Cristobal Range, south-central New Mexico.—This guidebook.

Osburn G.R. & Chapin C.E. 1983. Nomenclature for Cenozoic rocks of northeast Mogollon–Datil volcanic field, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Stratigraphic Chart 1.

Rothrock C.H., Johnson C.H. & Hahn A.D. 1946. Fluorspar resources of New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 21: 245 pp.

Seager W.R. 1980. Quaternary fault system in the Tularosa and Hueco Basins, southern New Mexico and West Texas.—New Mexico Geological Society, Guidebook 31: 131–135.

Seager W.R. 1983. Laramide wrench faults, basement-cored uplifts, and complementary basins in southern New Mexico.—New Mexico Geology 5: 69–76.

Seager W.R. 1986. Road log from Truth or Consequences to southeastern Caballo Mountains and San Diego Mountain via I-25 and the Jornada del Muerto.—This guidebook.

Seager W.R., Hawley J.W. & Clemons R.E. 1971. Geology of San Diego Mountain area, Doña Ana County, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 97: 38 pp.

Seager W.R., Mack G.H., Raimonde M. & Ryan R. 1986. Laramide basement-cored uplifts and basins in south-central New Mexico.—This guidebook.

Seager W.R., Shafiquallah M., Hawley J.W. & Marvin R.F. 1984. New K–Ar dates from basalts and the evolution of the southern Rio Grande rift.—Geological Society of America, Bulletin, 95: 87–99.

Silver C. 1955. Geology of the Caballo Mountains.—New Mexico Geological Society, Guidebook 6: 145–154.

Sorauf J.E. 1984. Devonian stratigraphy of the San Andres Mountains, Doña Ana, Sierra, and Socorro Counties, New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Circular 189: 32 pp.

Staatz M.H., Adams J.W. & Conkin N.M. 1965. Thorium-bearing microcline-rich rocks in the southern Caballo Mountains, Sierra County, New Mexico.—

U.S. Geological Survey, Professional Paper 525D: 48–51.
Stauffer K.W. 1962. Quantitative petrographic study of Paleozoic carbonate rocks, Caballo Mountains, New Mexico.—Journal of Sedimentary Petrology, 32: 357–396.
Tedford R.H. 1981. Mammalian biochronology of the late Cenozoic basins of New Mexico.—Geological Society of America, Bulletin, 92: 1008–1022.
Thompson M.L. 1942. Pennsylvanian System in New Mexico.—New Mexico Bureau of Mines & Mineral Resources, Bulletin 17: 92 pp.
Thompson M.L. & Kottlowski F.E. 1955. Pennsylvanian and lower marine Permian stratigraphy of south-central New Mexico.—New Mexico Geological Society, Guidebook 6: 71–76.
Thompson S. III 1955. Geology of the Fra Cristobal Range.—New Mexico Geological Society, Guidebook 6: 155–157.
Thompson S. III 1961. Geology of the southern part of the Fra Cristobal Range, Sierra County, New Mexico (M.S. thesis, revised).—University of New Mexico, Albuquerque, 89 pp.
VanAllen B.R., Wilson J.L. & Hunter J.C. 1984. Sunset Ridge fluorite deposit, Fra Cristobal Range, Sierra County, New Mexico.—New Mexico Geology, 6: 1–5, 12.
Verville G.J., Sanderson G. & Madsen M. 1986. Pennsylvanian fusulinids from the Fra Cristobal Range, Sierra County, New Mexico.—This guidebook.
Wallin E.T. 1983. Stratigraphy and paleoenvironments of the Engle coal field, Sierra County, New Mexico (M.S. thesis).—New Mexico Institute of Mining & Technology, Socorro, 127 pp.
Warren R.G. 1978. Characterization of the lower crust–upper mantle of the Engle Basin, Rio Grande rift, from a petrochemical and field geological study of basalts and their inclusions (M.S. thesis).—University of New Mexico, Albuquerque, 156 pp.



Abandoned schoolhouse in Winston. Photo G.R. Osburn 1981.