New Mexico Geological Society

Downloaded from: https://nmgs.nmt.edu/publications/guidebooks/37



Geology of the Fra Cristobal Range, south-central New Mexico

Eric P. Nelson
1986, pp. 83-91. https://doi.org/10.56577/FFC-37.83

in:

Truth or Consequences Region, Clemons, R. E.; King, W. E.; Mack, G. H.; Zidek, J.; [eds.], New Mexico Geological Society 37th Annual Fall Field Conference Guidebook, 317 p. https://doi.org/10.56577/FFC-37

This is one of many related papers that were included in the 1986 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, and other selected content are available only in print for recent guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

This page is intentionally left blank to maintain order of facing pages.

GEOLOGY OF THE FRA CRISTOBAL RANGE, SOUTH-CENTRAL NEW MEXICO

ERIC P. NELSON
Geology Department, Colorado School of Mines, Golden, CO 80401

Abstract—The Fra Cristobal Range is a horst along the east edge of the Rio Grande rift near Truth or Consequences. Precambrian crystalline rocks, including the granitic Fra Cristobal pluton and its metamorphic wallrocks, are unconformably overlain by at least 1,200 m of Paleozoic strata. These strata include the Cambrian–Ordovician Bliss Formation, the Ordovician El Paso and Montoya Groups, the Pennsylvanian Magdalena Group, and the Permian Abo, Yeso, and San Andres Formations. These strata, which include clastic, carbonate, and evaporite rocks, were deposited near the southeast margin (present coordinates) of the North American craton in shallow marine, near-shore, and continental environments. Disconformities, or very low-angle angular unconformities, below the Magdalena Group, and possibly below the Montoya Group, represent epeirogenic movements in the Paleozoic. Mesozoic strata in the area include the Dakota, Mancos, Mesaverde, and McRae Formations. These strata are exposed mainly at the southern end of the range, where they dip into the Cutter sag to the south. The McRae Formation is also exposed in depositional contact with Precambrian rocks at the north end of the range, and in a klippe bounded by low-angle normal faults in the west-central portion of the range.

Structures are of Precambrian, Laramide, and Rio Grande rift age. Precambrian structures include foliation in the granite and tectonite fabrics in the metamorphic rocks. Thick-skinned Laramide structures include basement-cored folds and thrust faults carrying basement and Paleozoic strata. Thin-skinned Laramide structures include thrust faults bounding plates with generally upright, north-trending folds (commonly with box geometry). Rift-related structures include normal faults and related fractures, both of which are locally silicified and mineralized (fluorite fissure-vein deposits).

INTRODUCTION

The Fra Cristobal Range, in Sierra and Socorro Counties, is a fault-bounded, east-tilted horst marginal to the Rio Grande rift (Engle Valley; Fig. 1). The north-trending range is approximately 24 km long and up to 5 km wide (Fig. 1), and is steepest on its western flank that has the greatest structural relief. A gentle homoclinal slope forms the eastern flank. Elevations range from ~1,500 to 2,045 m, the highest and most rugged terrane being along the western flank. The range is bounded to the west by the Engle Valley where Elephant Butte reservoir is located on the Rio Grande, and to the east by the Jornada del Muerto. (Note that the establishment of Engle is in the Jornada del Muerto.) These valleys merge to the north where the range terminates. To the south the range tapers into the Cutter sag, a Mesozoic–Tertiary synclinal basin.

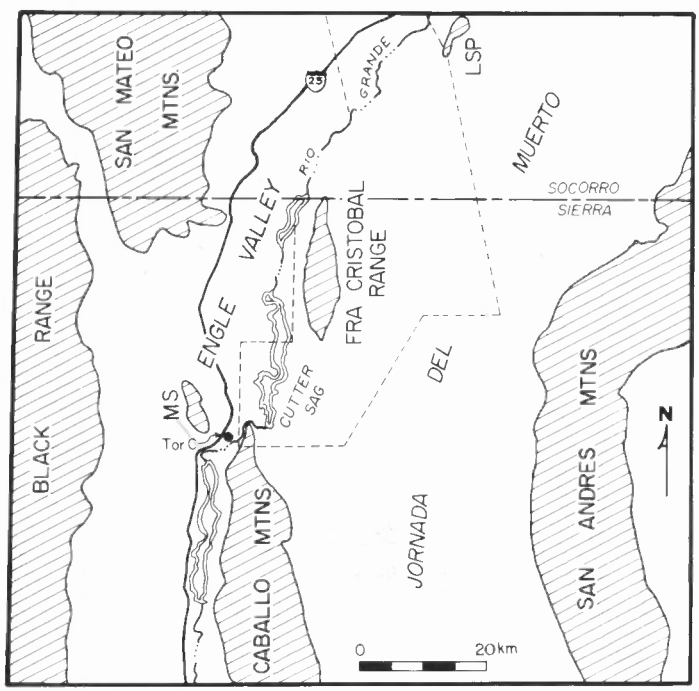


FIGURE 1—Location map of Fra Cristobal Range. LSP = Little San Pascual Mountain; MS = Mud Springs Mountains. Dashed line bounds Pedro Armendaris grants 33 and 34.

Geologic and tectonic setting

The Fra Cristobal Range is within the Mexican Highland section of the Basin and Range physiographic province. In this region, the Rio Grande rift begins to bifurcate southward and to merge with the Sonoran sector of the Basin and Range geologic province (Fig. 2). To the west, the Palomas Basin (within the Rio Grande rift) is filled with at least 1,990 m of Tertiary–Quaternary Santa Fe Group sedimentary and volcanic rocks (Melvin 1963). This contrasts with the Jornada del Muerto to the east, which is a synclinal basin with less than 100 m of Santa Fe Group and Quaternary sediments and basalt which cover Mesozoic and Tertiary strata. To the south, strata in the range dip beneath Mesozoic–Cenozoic rocks in the Cutter sag. Most of the rock units exposed in the Fra Cristobal Range are present south and west of the Cutter sag in the Caballo and Mud Springs Mountains (Fig. 1). The Fra Cristobal Range, Cutter sag, and Caballo Mountains together form an uplift marginal to the Rio Grande rift (Fig. 2).

Throughout the Paleozoic, the region was part of the cratonic platform affected only by epeirogenic movements (Kelley & Silver 1952), although some evidence of the Ancestral Rockies event may be present. During the early Mesozoic the region was a positive element, whereas during the late Mesozoic it received continental, marine, and near-shore sediments adjacent to the Cretaceous interior seaway. The region occupied a foreland position during the Late Cretaceous to early Tertiary Laramide orogeny, and elements of Laramide uplift and subsidence are preserved in the Fra Cristobal Range. During the Cenozoic, volcanism and continental sedimentation in the region were mostly related to development of Basin and Range and Rio Grande rift extensional structures.

The entire range is on the privately owned Pedro Armendaris Grant nos. 33 and 34, and public access normally is not available.

Previous work

In 1955, Thompson pointed out from his extensive search of the literature that, although little detailed mapping had been done, "a surprising amount has been written on this small but not insignificant range." The first mining claim in New Mexico, as recorded in the

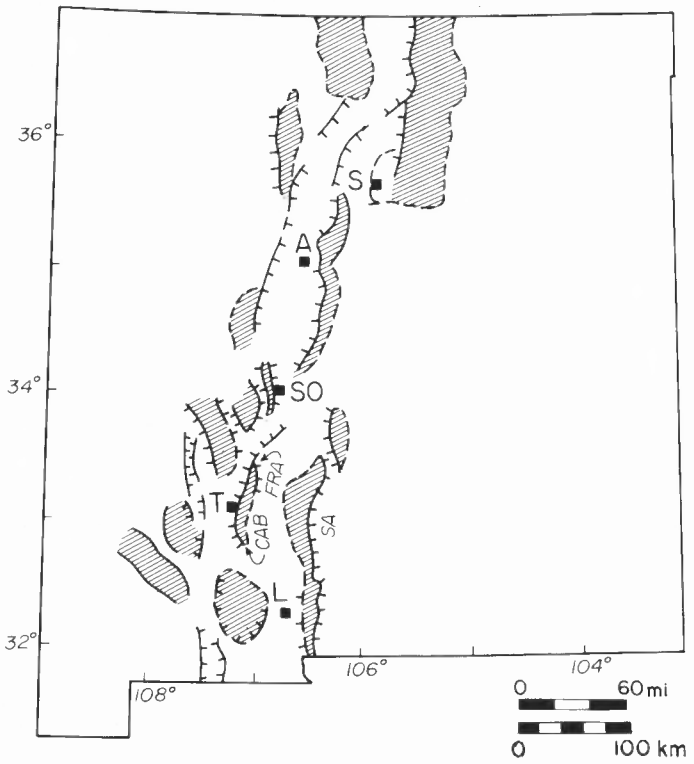


FIGURE 2—Location of uplifts (diagonally lined) and normal faults (tick mark on hanging wall) marginal to the Rio Grande rift system in New Mexico. S = Santa Fe; A = Albuquerque; SO = Socorro; T = Truth or Consequences; L = Las Cruces; FRA = Fra Cristobal Range; CAB = Caballo Mountains; SA = San Andres Mountains. Note that Fra Cristobal and Caballo ranges are shown as one uplift which includes the Cutter sag. Modified from NMGS Highway Geologic Map.

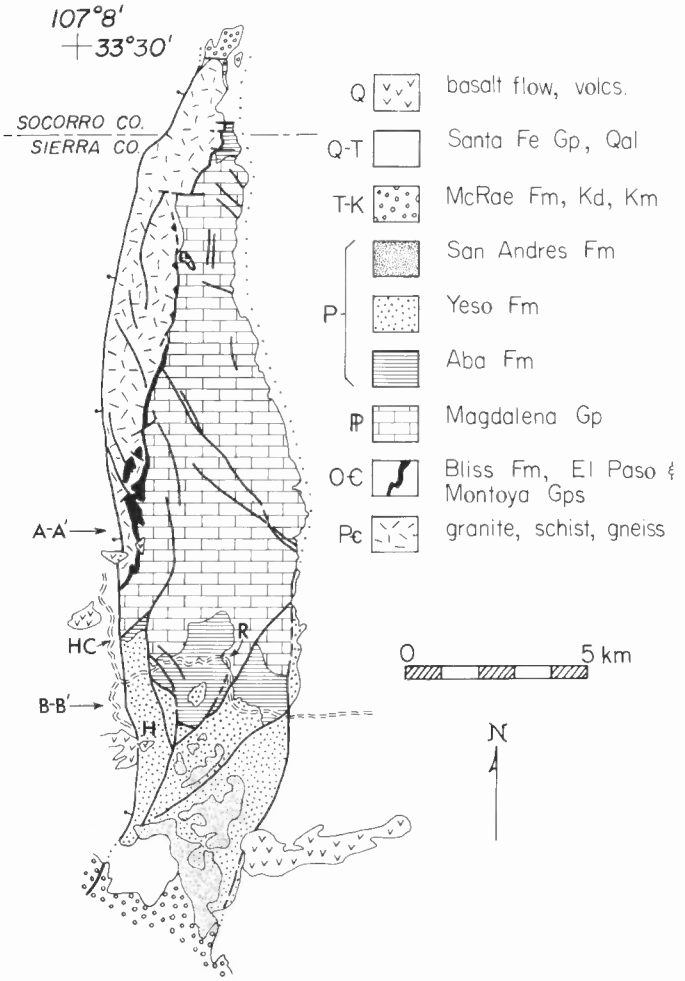


FIGURE 3—Generalized geologic map of Fra Cristobal Range. H = Hamburger Hill; HC = Hackberry Canyon; R = Red Gap. Geology taken from graduate theses listed in text and from Van Allen et al. (1983). A–A′ and B–B′ indicate approximate location of cross sections in Fig. 13.

Spanish Archives of New Mexico (Twitchell 1914), was in the northern part of the "Fray Cristobal Mountains" in 1685. Other early reports of the geology in the area were by Shumard (1859), Keyes (1903, 1905), and Darton (1922) who discussed the structure of the Jornada del Muerto, Lee & Girty (1909) and Darton (1928) who discussed stratigraphic aspects of the area, and Harley (1934) who compiled previous work on the range. In 1952, Kelley & Silver made observations in the Fra Cristobal Range while studying the Caballo Mountains to the south. During the late 1950's a number of theses were completed in and around the range (Thompson 1955, Bushnell 1953, Jacobs 1956, Cserna 1956, McCleary 1960). Although these were the first workers to map portions of the range, none had the benefit of topographic maps, and the mapping was at small scale.

Since the late 1950's, no work has focused on the fundamental geology of the range. Warren (1978) studied the Quaternary basalts and their xenoliths and mapped the west-central portion of the range. In 1978–1981 Tenneco Minerals made an extensive geologic reconnaissance and mineral exploration in and around the range (Van Allen et al. 1983, 1984). Hunter (1986) studied the McRae Formation in and south of the range, Chapin & Nelson (this guidebook) studied thick-skinned Laramide deformation in the range, and Nelson & Hunter (this guidebook) and Hargett (in preparation) studied Laramide deformation in upper Paleozoic rocks in the range.

GEOLOGIC UNITS

Discussion of the geology of the Fra Cristobal Range will be limited to exposures bounded by the Walnut Canyon–West Vein fault system on the west, the Fra Cristobal fault system on the east, and the Paleozoic–Mesozoic contact on the south (Fig. 3). Precambrian crystalline rocks, Paleozoic, Mesozoic, and Cenozoic strata, and Quaternary volcanic rocks and hypabyssal intrusive rocks are exposed within the range (Fig. 4). Paleozoic units include the Bliss Formation, El Paso Group, Montoya Group, Magdalena Group, Abo Formation, Yeso Formation and San Andres Formation. The Cretaceous–Tertiary McRae Formation is the only Mesozoic–Cenozoic bedrock unit exposed in the range. The Dakota(?) and Mesaverde Formations are exposed within the western range-boundary fault zone, suggesting that these units covered the range prior to erosion. The Dakota, Mesaverde, and McRae Formations are exposed in the Cutter sag south of the range (Fig. 1). Tertiary–Quaternary rift fill (Santa Fe Group) and younger, poorly consolidated alluvial deposits are exposed in the adjacent valleys, but are not discussed here in detail.

Precambrian crystalline rocks

Precambrian granitic and metamorphic rocks are exposed along the northwestern front of the range in a belt roughly 15 × 2 km (Fig. 3). Southern exposures are dominantly granitic, with metamorphic xenoliths and roof pendants being more abundant to the north. The Precambrian rocks form both steep, cliffy exposures in some of the highest peaks in the range, and rounded, knobby hills farther south. The Fra Cristobal pluton is composed of reddish-brown-weathering, pink to red, medium- to coarse-grained, hypidiomorphic granular, locally gneissic, S-type granite. The mineral composition is 22% quartz, 41% orthoclase, 26% microcline, 9% albite, 2% muscovite, and minor biotite, hornblende, and magnetite (Cserna 1956). Metamorphic rocks include dark-green to black chlorite schist, amphibolite, and metamorphosed intermediate plutonic rocks. Both the granite and metamorphic rocks are cut by numerous Precambrian pegmatite and aplite dikes.

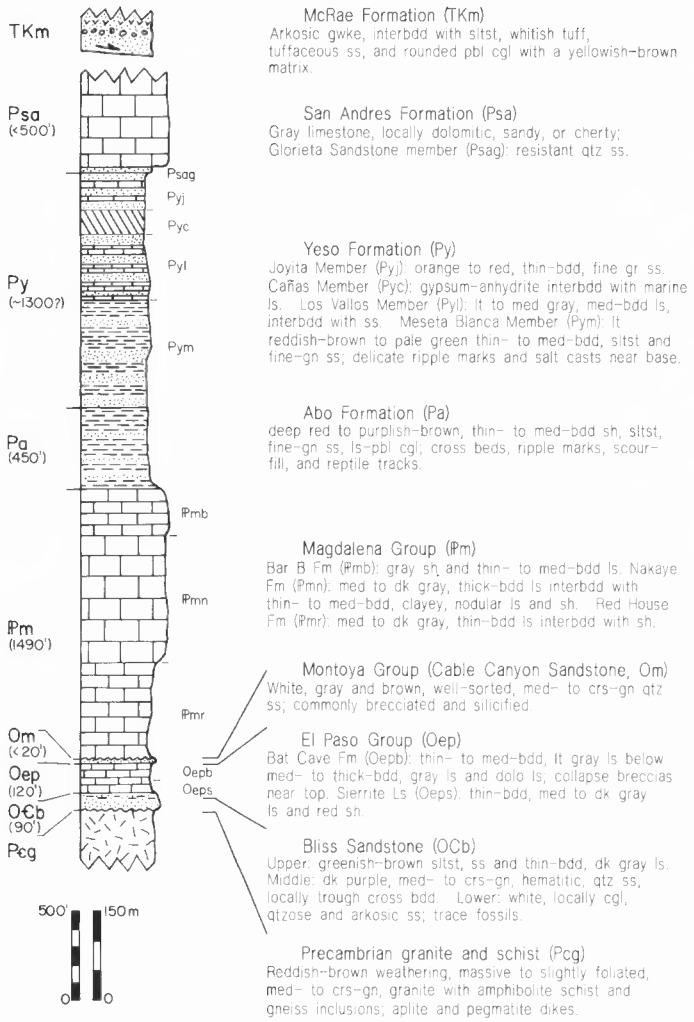


FIGURE 4—Generalized stratigraphic section of Fra Cristobal Range. TKm is both in tectonic and stratigraphic contact. Thicknesses compiled from graduate theses listed in text.

Although no isotopic age has been determined for the Fra Cristobal pluton, it is considered to be part of a belt of 1.4–1.5 billion yrs old Precambrian intrusives (Condie 1981). Lower Paleozoic rocks that unconformably overlie the Precambrian rocks thin to the north as a result of both onlap and truncation below a pre-Pennsylvanian erosion surface. In places, Precambrian rocks are in thrust contact with Paleozoic rocks (Precambrian in upper plate).

Bliss Formation

The Bliss Formation, El Paso Group, and Montoya Group, with a maximum combined thickness of 84 m, crop out in a sinuous and discontinuous belt between the eastern and southern boundaries of the Precambrian basement and the steep, cliffy exposures of the Magdalena Group (Fig. 3). The Bliss varies in thickness from about 49 m in the south to zero in the north. Three informal members are recognized in the range, primarily for the purpose of mapping (Chapin & Nelson in this guidebook). The lower member consists of a resistant, white, locally conglomeratic, quartzose sandstone overlain by yellowish-tan, poorly sorted, fine- to very coarse-grained arkosic sandstone with intercalations of micaceous, fine-grained, glauconitic sandstone. The basal contact shows erosional topography on the Precambrian basement, with granitic boulders over 1 m in diameter in channel lags (Fig. 5). Trace fossils are locally abundant in this unit (Fig. 6). The middle member consists of moderately resistant, dark-gray to dark-purple, medium- to coarse-grained, hematitic, oolitic quartzose sandstone that is locally trough



FIGURE 5—Boulder of Precambrian granite in channel lag within basal Bliss Formation. Mark Chapin is standing on unconformity between Precambrian and Bliss.

cross-stratified. The upper member consists of slope-forming, interbedded, greenish and tan to dark-brown siltstone, sandstone, and thin-bedded, dark-gray limestone. The clastic rocks are micaceous and glauconitic; trace fossils are abundant in this extensively bioturbated unit. The upper contact is gradational with El Paso rocks and is marked by a decrease in quartz, hematite, and glauconite contents and an increase in calcic sandstone.

In southern New Mexico the Bliss is considered Middle Cambrian to Lower Ordovician on the basis of two faunal zones which are recognized in south-central New Mexico (Kottlowski et al. 1956).

El Paso Group

The El Paso Group consists of the Sierrite Limestone and overlying Bat Cave Formations. These formations, with a maximum combined thickness of 49 m in the Fra Cristobal Range, were named by Kelley & Silver (1952) for exposures in the Caballo Mountains. The Sierrite consists of slope-forming, medium to dark-gray, thin-bedded limestone with chert laminations and brick-red shale partings. It is locally dolomitic and glauconitic, and has stromatolite bands up to 15 cm thick. The Bat Cave consists of a lower slope-forming unit and an upper cliff-forming, banded unit. The lower unit consists of thin- to medium-bedded limestone with common stromatolitic biostromes and bioherms. The upper unit consists of medium- to thick-bedded, alternating bands of dark-gray and medium-gray limestone, dolomitic limestone, and



FIGURE 6—Trace fossils in Bliss Formation 15 cm above Precambrian.

dolomite, plus local chert beds. Silicified collapse breccia is common near the top of the unit.

Montoya Group

The basal member of the Montoya Group, the Cable Canyon Sandstone, is up to 6 m thick; it is probably the only member of the group present in the Fra Cristobal Range. A small amount of the overlying Upham Dolomite may be present, but this has not been confirmed. The Cable Canyon Sandstone consists of white to mottled gray and brown, well-sorted, medium- to coarse-grained sandstone with calcitic dolomite or dolomite cement. Pebble conglomerate is present locally. The upper contact with the Magdalena Group is a major erosion surface and much of the unit consists of silicified collapse breccia related to this unconformity (Fig. 7).

Magdalena Group

The Magdalena Group consists of three formations named for exposures in the Caballo Mountains (Kelley & Silver 1952). From bottom to top these are: Red House, Nakaye, and Bar B Formations. The group crops out in steep cliffs along the northwest flank of the range and forms much of the eastern, homoclinal slope of the range (Fig. 3). Estimates of the combined thickness of the group vary from 350 to 450 m.

The Red House Formation is a poorly exposed slope-former that rests unconformably on all pre-Pennsylvanian units (on Montoya Group in the south and on Precambrian basement in the north). The basal unit consists of thin (<2 m) quartz- or chert-pebble conglomerate (Fig. 8) and red quartz arenite. Where it rests on the Precambrian, angular blocks of green chlorite schist are present in a basal limestone unit. The basal clastic beds, where present, grade up into interbedded black shales and thin-bedded, gray to black, fossiliferous, micritic limestone with wackestone, packstone, and mottled dolomite ledges near the base and top of the unit.



FIGURE 7—Collapse breccia of Ordovician Cable Canyon Sandstone. Pencil for scale.

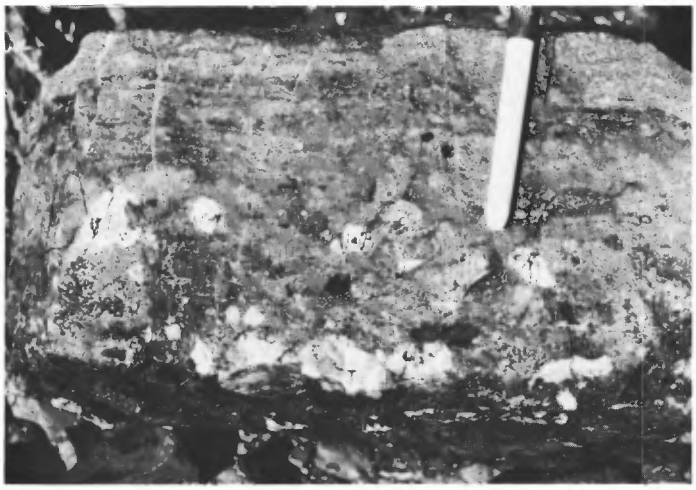


FIGURE 8—Chert-pebble conglomerate near base of Pennsylvanian Magdalena Group. Marking pen is 1 cm wide.

The Nakaye Formation is a massive cliff-former with ledges of crystalline micrite, packstone, and grainstone, 1–9 m thick, alternating with thin (<1 m) black shales. Chert bands and nodules and dolomitic nodules increase in abundance up-section. The limestone is grayish brown to medium gray, fine- to very fine-grained, fetid, and fossiliferous.

The Bar B Formation is a slope-forming unit with 1–7 m thick ledges of packstone, wackestone, and crystalline micrite interbedded with black shale. Nodular chert and dolomite are common.

Abo Formation

The Abo Formation crops out in distinct red exposures in the region of Red Gap (the main pass in the range), in a few small outliers near the top of the range, and at the northern end of the range (Fig. 3). The Abo Formation, which rests conformably on the Magdalena Group, is 137 m thick. It consists of poorly resistant, thin- to medium-bedded, locally laminated, deep-red to purplish-brown shale, siltstone, and very fine-grained sandstone interbedded with ledge-forming, reddish-brown, fine-grained sandstone. Shale is locally green. Lenses, nodules, and thin beds of grayish-brown limestone and reddish-gray limestone-pebble conglomerate beds are locally present. Common sedimentary structures include crossbeds, ripple marks, scour and fill structure, mud cracks, and animal tracks (Fig. 9).

The Abo Formation is considered Permian in age and represents a floodplain deposit (Kelley & Silver 1952).

Yeso Formation

The Yeso Formation is exposed in low hills and in slopes below the prominent limestone cliffs of San Andres Formation south of the Hackberry Canyon–Red Gap area in the southern portion of the range (Fig. 3). The true thickness is unknown and estimates vary from 120 to 395 m due to lateral facies variations and complex deformation and flowage within this lithologically variable formation. Four members are recognized in the Fra Cristobal Range. From bottom to top these are: Meseta Blanca, Los Vallos, Cañas, and Joyita. The Meseta Blanca Member rests conformably on the Abo Formation, in places with a gradational contact (base of Yeso placed at the first ledge-forming reddish-brown sandstone), and in places with a sharp contact marked by a distinct color change from red shale below to light-green siltstone and very fine-grained sandstone above. The Meseta Blanca consists of thin- to medium-bedded, pale-reddish-brown and light-green, well-sorted,



A

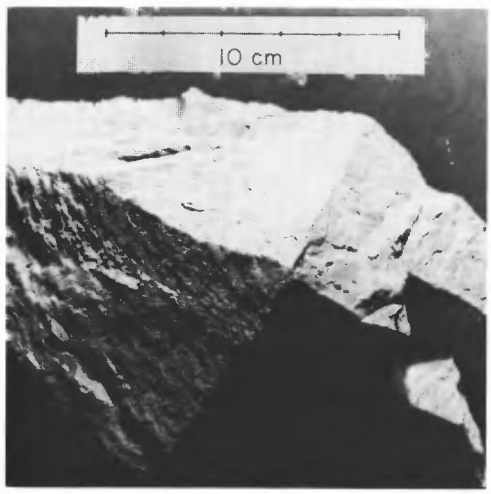


B

FIGURE 9—Primary structures in Abo Formation. **A,** Animal trails. **B,** Mud cracks.



A



B

FIGURE 10—**A,** Salt-crystal mold in Meseta Blanca Member, Yeso Formation. **B,** Pseudomorph of salt-crystal cast from same horizon.

fine- to very fine-grained sandstone and siltstone. Delicate ripple marks and salt casts up to 25 cm across (Fig. 10) characterize the lower portion of the section. This member is estimated to be between 153 and 183 m thick.

The Los Vallos Member consists of light- to medium-gray, medium-bedded, locally fossiliferous limestone with sandstone intercalations, and local gypsum, anhydrite, and salt. The base is placed at the lowest limestone bed. This member is estimated to be 92–122 m thick.

The Cañas Member consists of laterally variable gypsum–anhydrite beds separated by marine carbonate rocks and some sandstone beds (Hunter & Ingersoll 1981). Thickness can be variable and average estimates range between 43 and 49 m.

The Joyita Member consists of medium-bedded, tan to red, fine- to medium-grained sandstone with local interbeds of carbonate. It can be up to 100 m thick (Hunter & Ingersoll 1981).

The Meseta Blanca Member was deposited in a low-energy, near-shore environment characterized by restricted circulation and evaporation at times. The Los Vallos Member was probably deposited on a low, flat coastal plain which was periodically submerged by brief marine transgressions. The percentage of carbonate increases up-section, indicating an overall trend of rising sea level, gradual subsidence, and/or lessening of detrital input (Hunter & Ingersoll 1981). Laminated gypsum in the Cañas Member was probably deposited during a 10,000–50,000 year interval of relative sea-level stability in a barred marine basin. This is based on the assumption that 1–5 mm thick laminae in the Cañas represent yearly cyclic deposition (Hunter & Ingersoll 1981). The Joyita Member was deposited in a coastal and eolian(?) environment, probably as a progradational beach and dune deposit.

San Andres Formation

The San Andres Formation is exposed mainly in prominent cliffs above the slope-forming Joyita Member of the Yeso Formation in the southern portion of the range, and in a few normal fault blocks along both sides of the range. It is also exposed in a small klippe above a detachment fault in the Walnut Canyon area (Fig. 3). An incomplete section of about 152 m is present in the range; thickness estimates range from 100 to 200 m. The formation consists of medium- to thick-bedded, locally laminated, light- to dark-gray, fine-grained limestone. It is locally dolomitic, sandy, cherty, fetid, and very fossiliferous. A basal member, the Glorieta Sandstone, is regarded by some as a separate formation. It is a resistant unit approximately 2.5–4.5 m thick, consisting of massive, yellowish-brown-weathering, whitish, calcareous, fine-grained, well-sorted quartzose sandstone.

McRae Formation

The Cretaceous–Tertiary McRae Formation is exposed in a small tectonic slice above a detachment fault in the Walnut Canyon area (Fig. 3). Because of poor exposure and structural complications, its strati-

graphic thickness is unknown. Here the McRae consists of light-reddish-brown to light-olive, medium- to very coarse-grained arkosic graywacke interbedded with siltstone, whitish tuff, and tuffaceous sandstone, and rounded-pebble conglomerate with a yellowish-brown, arkosic matrix. It locally contains dark-brown to black petrified logs, some over 1 m in diameter and 3–4 m long (Fig. 11). At the northern end of the range, the McRae sits unconformably on Precambrian granitic gneiss. There it consists of mudstone, sandstone, conglomeratic sandstone, angular to subrounded cobble and boulder conglomerate, and purplish to dark-brown tuff. Kelley & McCleary (1960) cited this locality as evidence for a pre-McRae beginning of strong Laramide deformation which led to post-Mesaverde erosion. Most McRae exposures are in the Cutter sag, a Laramide synclinal trough, south of the Fra Cristobal Range (Fig. 1; Bushnell 1953, Hunter 1986). The McRae is generally interpreted as a syn- to post-orogenic molassic deposit which received detritus shed off a Laramide high to the west (Hunter 1986).

STRUCTURAL GEOLOGY

The Fra Cristobal Range is an east-tilted horst block bounded on both east and west by normal faults (Fra Cristobal and Walnut Canyon–West Vein fault systems, respectively; Figs. 3, 12). The western boundary fault separates the range from the Rio Grande rift (Palomas Basin) and has the most stratigraphic separation (on the order of 3,800 m). Although portions of the Fra Cristobal Range are homoclinal and structurally simple, other portions expose a complex set of structures of Precambrian, Paleozoic, Laramide, and younger Tertiary–Quaternary age. Because the overall structure of the range plunges gently south,



FIGURE 11—Petrified log in McRae Formation.

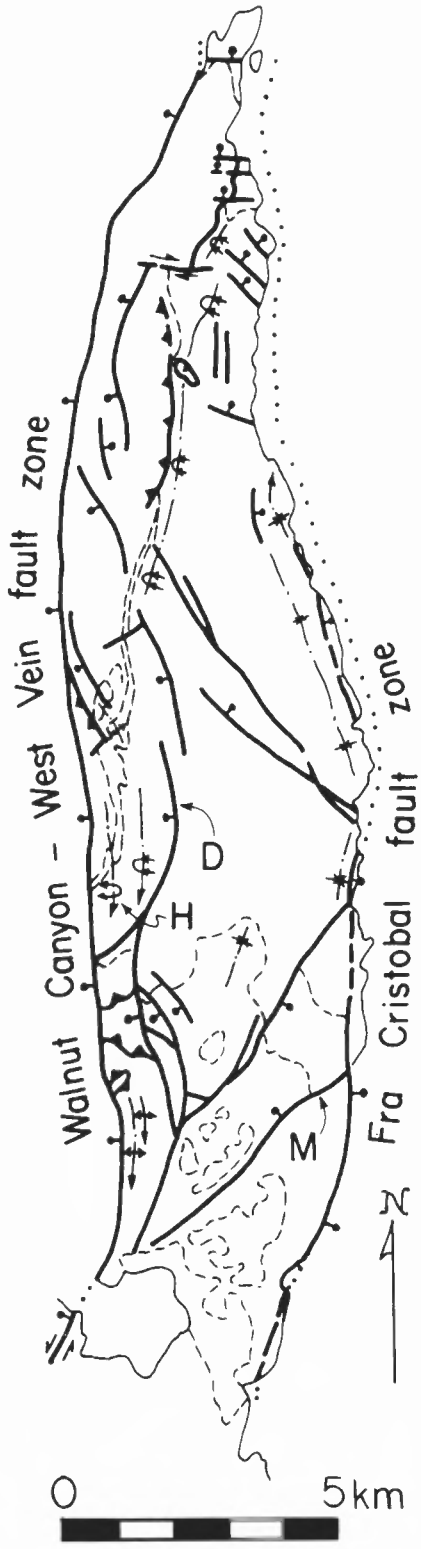


FIGURE 12—Tectonic map of Fra Cristobal Range. Major contacts (thin dashed lines) are taken from Fig. 3. Dot–dash lines are axial-surface traces of major folds; thrust faults shown with teeth on upper plate; high-angle faults shown with ball on relatively downthrown block. Faults are dashed where approximate or inferred, dotted where covered. D = Double Peak fault; H = Hellion fold structure; M = Massacre Gap fault.

Precambrian through Mesozoic rocks are exposed in different structural levels. Most of the structural complexity in the range is within a Laramide deformation front along the western flank. The eastern flank of the range is an east-tilted homocline.

Precambrian structures

Precambrian structures include foliation and lineation within chloritic and amphibolitic schist and gneiss caught as randomly oriented xenoliths and roof pendants within the Fra Cristobal pluton. The pluton itself is mildly gneissic in places and is cut by a number of pegmatite and aplite dikes.

Paleozoic structures

Evidence for Paleozoic tectonism in the region is primarily stratigraphic. The lower Paleozoic units (Bliss, El Paso, and Montoya) are progressively cut out by erosion from south to north below a pre-Pennsylvanian unconformity at the base of the Magdalena Group. In addition, pre-Pennsylvanian faulting is suggested by a number of high-angle faults that rapidly lose stratigraphic throw above the unconformity and by changes in thickness of lower Paleozoic units across the faults. The lack of strong angular unconformity suggests epeirogenic rather than orogenic activity during the Paleozoic.

Laramide structures

Laramide structures are the most spectacular in the range and display two main structural styles: thick-skinned and thin-skinned (Fig. 13). In the northwest and west-central portions of the range, Precambrian crystalline basement is involved in thrusting and folding with lower Paleozoic rocks (Chapin & Nelson in this guidebook). The style of this deformation is similar to the style of Laramide deformation seen farther north in the Rockies (Berg 1962, Sterns 1978) and consists of two types of domains separated along strike by transverse tear faults or transition zones. In one type of domain, slices of basement are thrust over upright and overturned lower Paleozoic rocks and over basement. In the north, where lower Paleozoic rocks are missing, basement is thrust over the Magdalena Group (Fig. 3). In the other type of domain, basement is folded by cataclastic flow in the cores of east-vergent, overturned folds. These domains are exposed on the overturned limb of an anticline–syncline pair (syncline to east; Figs. 12, 13) which plunges gently south for most of its length. However, the plunge of this major structure (the Hellion fold) increases rapidly near its southern termination, suggesting some basement-block control. Shortening strain related to this large structure is accommodated in the Magdalena Group by flat-ramp-geometry thrusts and overturned folds (see fig. 7 of Nelson & Hunter in this guidebook).

The second type of Laramide structural style is concentrated in the Meseta Blanca Member of the Permian Yeso Formation south of the Hellion fold, mostly south of Hackberry Canyon (Nelson & Hunter in this guidebook; Fig. 3). Here, thin-skinned deformation is expressed by low-angle thrusts separating deformed plates from relatively undeformed plates, forming complicated duplex structures (Fig. 13b). Thrusting was probably localized along mechanically weak, evaporite-bearing horizons, although evaporite minerals are now replaced by silica. Internal deformation features include imbricate thrusts, disharmonic, upright box folds, and overturned folds; folds trend north and vergence is dominantly eastward. This deformation has only been recognized west of a major down-to-the-west normal fault (Double Peak fault of Thompson 1955; Fig. 12). Similar, but less strongly developed, folds and thrusts are present in the Los Vallos Member of the Yeso and may exist in higher stratigraphic levels as well.

Other possible Laramide fold structures in the range include an anticline that plunges gently south at the southern end of the range, and an east-trending anticline near the north end of the range. In addition, broad, open, southeast-plunging folds affect Cretaceous units in the Cutter sag south of the range (Bushnell 1953).

Laramide deformation in the Fra Cristobal Range appears to represent the variable response of different lithologies to crustal shortening and uplift along a deformation front, east of which little or no deformation is evident. The Jornada del Muerto may represent a Laramide synclinal structure east of this front. The variation in structural style in different basement-involved domains and the rapid increase in plunge of the large Hellion structure suggest that pre-existing basement structures in part controlled the geometry of Laramide structures.

Tertiary–Quaternary extensional structures

Structures related to Tertiary–Quaternary Rio Grande rift/Basin and Range extension include high-angle and low-angle normal faults, some with related drag folds in adjacent rocks. The Walnut Canyon–West Vein fault zone is the most significant structure of this type. It dips 65–75° west, is up to 100 m wide, and contains rotated and deformed blocks of various Precambrian to Tertiary units (e.g. Precambrian granite, Yeso, San Andres, Mesaverde, McRae). These blocks are probably bounded by an anastomosing set of shear fractures and have been dragged down to the west along the fault during Rio Grande rifting. Late(?)-stage brecciation, silicification, and mineralization (Van Allen et al. 1984) are well exposed in resistant fault-line scarps along much of the western flank of the range (Fig. 14; these can be seen from I-25 under the right lighting conditions). Offset of basalt flows (which

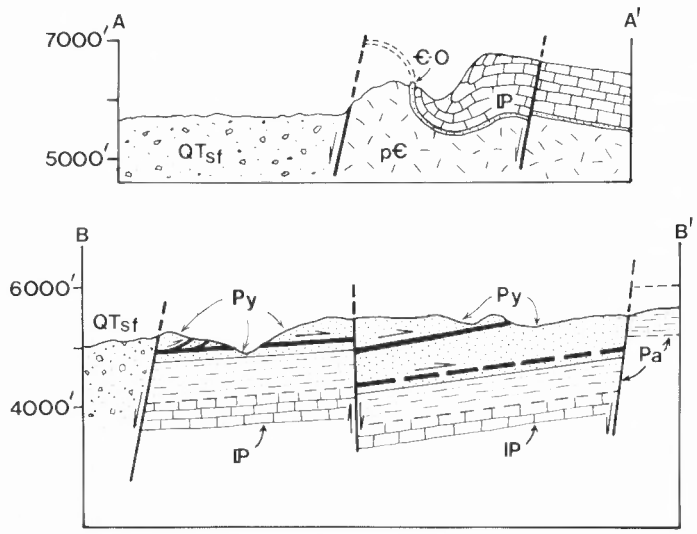


FIGURE 13—Schematic cross sections of Fra Cristobal Range (locations shown in Fig. 3). A–A′ shows thick-skinned, basement involved deformation; B–B′ shows thin-skinned, decollement-style deformation in Permian rocks. pC = Precambrian basement; C-O = Cambro-Ordovician section; P = Magdalena Group; Pa = Abo Formation; Py = Yeso Formation; QTsf = Santa Fe Group.

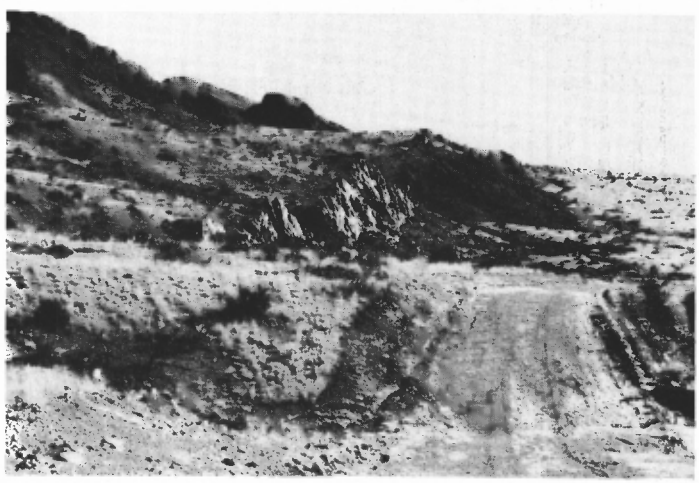


FIGURE 14—Fault-line scarp along silicified breccia within Walnut Canyon–West Vein fault zone, looking south. Precambrian rocks on left are faulted against Santa Fe Group rocks on right.

may correlate with 2 my old flows in the region; Van Allen et al. 1983) and of alluvial fans near the north end of the range suggest recent activity. The Walnut Canyon–West Vein fault zone was originally thought to be a direct extension of the Hot Springs fault zone which bounds the Caballo Mountains on the west (Thompson 1955). Warren (1978), however, showed that the two fault zones are en echelon, displacement being transferred from one fault zone to the other. Bushnell (1953) mapped both right- and left-lateral offsets on a number of faults parallel to, and east of, the Hot Springs fault zone in the Cutter sag, suggesting that these range-boundary faults are not solely dip–slip faults.

The Fra Cristobal fault zone bounds the range to the east and has blocks of San Andres and possibly other units caught in it. Stratigraphic separation is much less than on the Walnut Canyon–West Vein fault zone. Both sides of the range have a number of normal fault-blocks which step down into the adjacent basins. In addition, a number of silicified, 0.5–2 m thick fracture zones are exposed along the west side of the range subparallel to the range-boundary fault zone. These fracture zones have little or no offset where slip is evident, but offset in Precambrian crystalline rocks cannot be determined. The fractures appear to be related to rift faulting, as some are locally mineralized with fluorite and/or barite. A number of other high-angle normal faults or oblique-slip faults are present in the range (Fig. 12) and appear to fall into one of three sets: north-trending, northwest-trending, or northeast-trending. Movement on these faults probably occurred during Laramide deformation, during Tertiary extension, or both. In addition, some may be reactivated Precambrian shear zones.

In the Walnut Canyon area, two tectonic klippen, one of San Andres Formation and the other of McRae Formation, were mapped by Warren (1978) and Nelson & Hunter (this guidebook). These blocks are underlain by sub-horizontal faults which place younger strata over older with as much as 350 m of section cut out. Warren interpreted these klippen, along with a large mass of upper Yeso and San Andres north of Massacre Gap, as gravity slide blocks which developed as a result of uplift of the range. Alternatively, they could represent erosional remnants of detachment slices above low-angle normal faults which formed during early(?) rift-related extension. Similar relations have been recognized in the same stratigraphic intervals near Mesa del Yeso (Smith et al. 1983) and elsewhere along the Rio Grande rift (e.g. Chamberlin 1983).

GEOLOGIC HISTORY

Prior to intrusion of the Fra Cristobal pluton about 1.4–1.5 billion yrs ago, Precambrian sedimentary and volcanic rocks underwent deformation and metamorphism. Foliation in the pluton may be related to intrusion and may also reflect some later Precambrian deformation event.

Precambrian crystalline rocks underwent an extensive, regional, erosional event prior to deposition of the transgressive Upper Cambrian basal Bliss Formation. Between the Precambrian and the Late Cretaceous (beginning of Laramide event), deformation in the region was entirely epeirogenic (Kelley & Silver 1952). This deformation consisted of broad warping or tilting which resulted in periods of exposure of the Paleozoic shelf and very low-angle angular unconformities or disconformities. The Bliss was deposited in a near-shore environment (both subaerial and submarine). It is conformably overlain by, and transitional into, shallow-marine shelf deposits of the Ordovician El Paso Group. The Ordovician shelf was subaerially exposed prior to deposition of the shallow marine Cable Canyon Sandstone, resulting in a karsted surface below the Cable Canyon. Prior to deposition of the Magdalena Group, the area underwent extensive erosion of Upper Cambrian through Lower Pennsylvanian strata, all of which are progressively truncated to the north below the sub-Magdalena unconformity (Kottlowski 1963). In the northern Fra Cristobal Range, the Magdalena Group rests on Precambrian basement. Silurian, Devonian, and probably Mississippian strata are missing in the Fra Cristobal Range.

The Magdalena Group represents cyclic carbonate–shale deposition on the Pennsylvanian shelf. Permian deposition occurred in subaerial and shallow-marine environments. The Abo Formation red beds were deposited in a subaerial, flood-plain environment. The lithologically variable Yeso Formation represents deposition in a number of near-shore marine and marginal-marine environments, including a restricted evaporite basin where thick gypsum deposits formed during Cañas time. The presence of large salt-crystal molds and casts in the Meseta Blanca Member suggests sabkha deposition. The San Andres Formation represents marine clastic deposition (Glorieta Sandstone) followed by shallow-marine limestone deposition.

The region underwent erosion during the Triassic and Jurassic, and received dominantly clastic marine deposition during the Early Cretaceous (Dakota, Mancos, and Mesaverde Formations). During the Laramide orogeny up to 450 m of structural relief was generated, probably as a result of crustal shortening involving both thick-skinned and thin-skinned deformation. The first structural style involves Precambrian basement and Paleozoic strata in thrusting and in megascopic forced folds (Chapin & Nelson in this guidebook), whereas the second style involves dominantly Permian strata in decollement-style faulting and associated folding (Nelson & Hunter in this guidebook). This deformation and associated uplift were accompanied by syn- and/or post-orogenic (molassic) deposition of the terrigenous McRae Formation (Kelley & McCleary 1960). Overall eastward vergence of Laramide structures and paleocurrent data from the McRae Formation suggest a major Laramide positive element to the west where the Rio Grande rift is today. The deformation exposed in the Fra Cristobal Range represents the eastern deformation front of this Laramide high.

Extensional tectonism began in the Rio Grande rift in the Oligocene (Chapin & Seager 1975) and may have involved low-angle normal faulting. Younger, high-angle normal faulting produced the present structural relief on the west flank of the range. This younger Tertiary and Quaternary extensional faulting was accompanied by silicification and mineralization along the fault zones (Van Allen et al. 1984), by basaltic volcanism (Warren 1978), and by deposition of the Santa Fe Group in the rift.

ACKNOWLEDGMENTS

Oppenheimer Industries is gratefully acknowledged for allowing access to the Armendaris property. Joyce Niggley and Kyle Reid were particularly helpful. Tenneco Minerals Company assisted the program with ongoing support, and extra thanks go to Bruce Van Allen for all of his help. The New Mexico Bureau of Mines & Mineral Resources supplied a grant for some of the mapping project which was used to formulate ideas in this paper. Some field logistics were funded by the Geology Department, Colorado School of Mines. For introducing me to the wonders of the Fra Cristobal Range and for help in mapping some of its complexities, I gratefully thank Jim Hunter. Fruitful discussions on the geology of the range came from C.E. Chapin, M. Chapin, T. Hargett, P. Nelson, G.R. Osburn, W.R. Seager, and numerous students who participated in mapping exercises in the range.

REFERENCES

Berg R.R. 1962. Mountain flank thrusting in Rocky Mountain foreland, Wyoming and Colorado.—American Association of Petroleum Geologists, Bulletin, 46: 2019–2032.

Boyer S.E. & Elliott D. 1982. Thrust systems.—American Association of Petroleum Geologists, Bulletin, 66: 1196–1230.

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

Chamberlin R.M. 1983. Cenozoic domino-style crustal extension in the Lemitar Mountains, New Mexico: a summary.—New Mexico Geological Society, Guidebook 34: 111–118.

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 M. & Nelson E. 1986. Larmide basement-involved deformation in the Fra Cristobal Range, Sierra County, New Mexico.—This guidebook.

Condie K.C. 1981. Precambrian rocks of the southwestern United States and adjacent areas of Mexico.—New Mexico Bureau of Mines & Mineral Resources, Resource Map 13, scale 1:1,500,000.

Cserna E.G. 1956. 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. 1922. Geologic structure of parts of New Mexico.—U.S. Geological Survey, Bulletin 726-E: 173–275.

Darton N.H. 1928. Geologic map of New Mexico.—U.S. Geological Survey, scale 1:500,000.

Hargett T. (in preparation). Laramide deformation of the Pennsylvanian Magdalena Group, Fra Cristobal Range, New Mexico (M.S. thesis).—Colorado School of Mines, Golden.

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.

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. Cañas Gypsum Member of Yeso Formation (Permian) in New Mexico.—New Mexico Geology, 3(4): 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.

Kelley V.C. & McCleary J.T. 1960. Laramide orogeny in south-central New Mexico.—American Association of Petroleum Geologists, Bulletin, 44: 1419–1420.

Kelley V.C. & Silver C. 1952. Geology of the Caballo Mountains.—University of New Mexico Publications in Geology, no. 4: 286 pp.

Keyes C.R. 1903. Geologic structure of New Mexico bolson plains.—American Journal of Science, 15: 207–210.

Keyes C.R. 1905. Geological structure of the Jornada del Muerto and adjoining bolson plains.—Iowa Academy of Sciences, Proceedings, 12: 167–169.

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

Lee W.T. & Girty G.H. 1909. The Manzano group of the Rio Grande valley, New Mexico.—U.S. Geological Survey, Bulletin 389: 141 pp.

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

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

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

Shumard G.G. 1859. The geological structure of the Jornada del Muerto, New Mexico.—St. Louis Academy of Science, Transactions, 1: 341–355.

Smith C.T., Osburn G.R., Chapin C.E., Hawley J.W., Osburn J.C., Anderson S.D., Rosen S.D., Eggleston T.L. & Cather C.M. 1983. First-day road log.—New Mexico Geological Society, Guidebook 34: 1–27.

Sterns D.W. 1978. Faulting and forced folding in the Rocky Mountain foreland.—Geological Society of America, Memoir 151: 1–37.

Thompson S. III 1955. Geology of the southern Fra Cristobal Range, Sierra County, New Mexico (M.S. thesis).—University of New Mexico, Albuquerque, 75 pp.

Twitchell R.E. 1914. The Spanish archives of New Mexico, v. 1.—The Torch Press, Cedar Rapids, Iowa, 525 pp.

Van Allen B.R., Gill R.D. & Emmons D.L. 1983. Minerals reconnaissance of the Pedro Armendaries grants nos. 33 and 34 and adjacent areas, Sierra and Socorro Counties, New Mexico.—Internal Report, Tenneco Minerals Company, Lakewood, Colorado, 395 pp.

Van Allen 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.

Warren R.G. 1978. Characterization of the lower crust–upper mantle of the Engle basin, Rio Grande rift, from a petro-chemical and geologic study of basalts and their inclusions (M.S. thesis).—University of New Mexico, Albuquerque, 156 pp.



Construction crew at Elephant Butte dam ca 1914, pulled to work by U.S. Reclamation Service locomotive #3. Photo courtesy of Geronimo Springs Museum.