GEOLOGY OF THE SIERRA DE LA CRUZ AREA

SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The Sierra de la Cruz area consists of strata that range in age from late Pennsylvanian to Quaternary. These strata include the Madera Limestone, the Bursum, Abo, and Yeso Formations, Glorieta Sandstone, San Andres Formation, Dockum Group, Cretaceous Undivided, Baca Formation, andesitic dikes, and alluvial deposits.

This sequence is disturbed by numerous faults and folds. The oldest of these structures are the low-angle detachment faults which are Paleocene in age or older. These are cut by northeast-striking faults and are folded by large, upright, northeast-trending folds. Smaller overturned folds developed along the edges of the map area as the low-angle detachment faults formed.

The low-angle detachment faults may have developed as the result of high pore pressures, gypsum dehydration or translation of a stiff rock sequence over a low viscosity gypsum sequence in the upper Yeso Formation. The latter mechanism better explains the development of stratigraphic omission and overturned folding in the study area. The first two mechanisms may also have contributed to detachment fault development.

The northeast-striking faults developed in the early Laramide in response to a N65E to N70E directed compressive stress. Movement on this fault set was right lateral and continued into the late Laramide. The large northeast-trending and small northeast-trending folds developed as a result of right-lateral motion between two widely spaced northeast-striking faults.

TABLE OF CONTENTS

FIGURES

TABLES

PLATES

INTRODUCTION

Purpose and Scope

The purpose of this investigation is to:

1) prepare a geologic map of the Sierra de la Cruz area;
2) establish a stratigraphic framework based on currently accepted terminology for this and any future studies;
3) establish a structural framework based on field observations, general mechanical models, and data derived from the literature, and
4) develop a geologic history based on all of the above data.

Location and Accessibility

The Sierra de la Cruz area lies 13 miles (20.9 kilometers) northeast of Socorro, New Mexico in central Socorro County. It covers an area of about 18.5 square miles (29.8 square kilometers) and includes all or parts of sections 21 to 29 and 32 to 36, T.1S., R.2E. and sections 1 to 12, T.2S., R.2E. Access is by county-maintained gravel roads from Pueblitos to the southern half of the field area. Unimproved ranch roads cross the remainder of the area. Access on these roads depends on weather conditions. Most of the area can be covered on foot with ease; no part is more than 2 miles from any road. Figure 1 shows the location of the study area in central New Mexico.

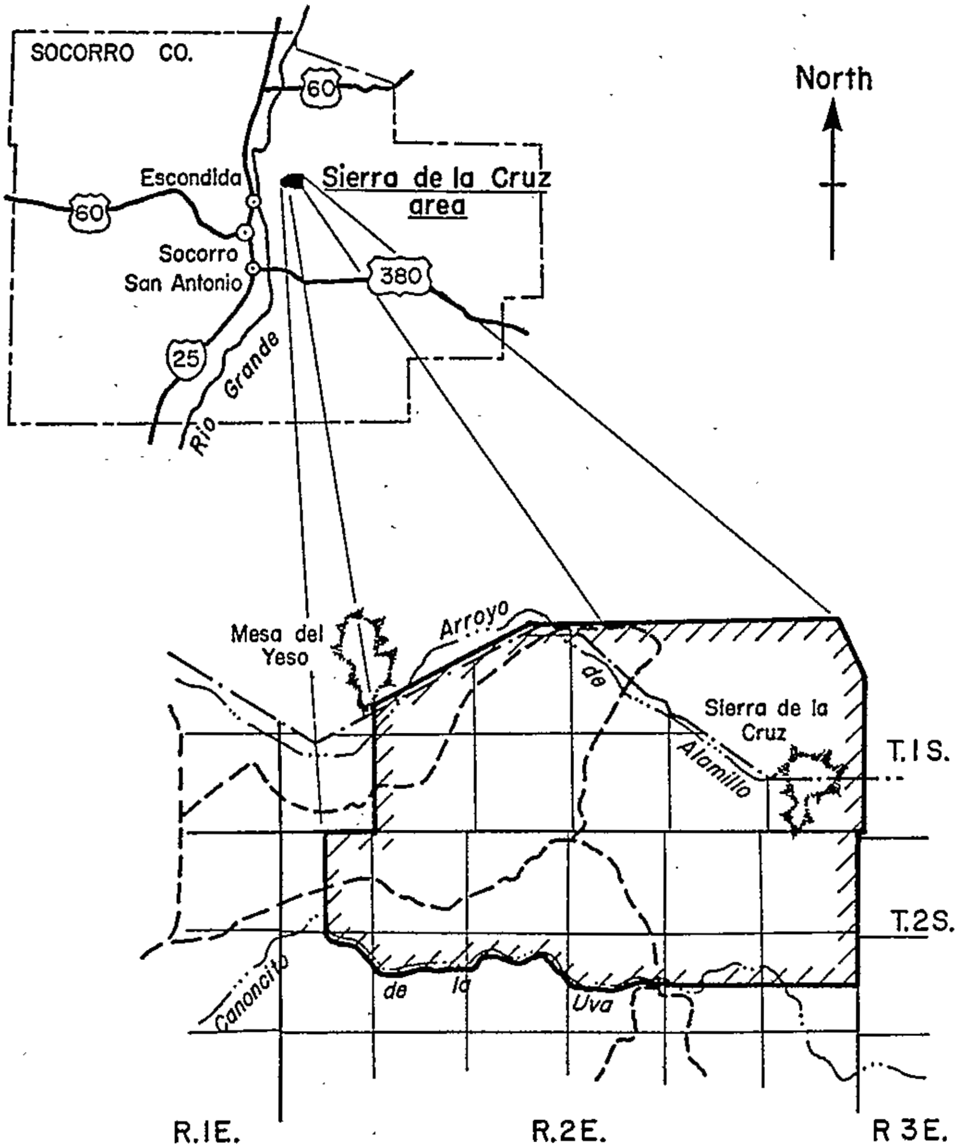

Figure 1 -- Location of the Sierra de la Cruz study area in central Socorro County, New Mexico.

Previous Work

Several workers have examined the Sierra de la Cruz area in some detail; many workers include the area in broad, generalized reconnaissance investigations.

The first worker to actually visit the study area was Lee (Lee and Girty, 1909). He prepared a reconnaissance stratigraphic section of the Abo and Yeso Formations in Sec. 33, T.1S., R.2E. and Sec. 4, 5 and 8, T.2S., R.2E. on the west edge of the map area. He designated part of this sequence the Yeso type section, named after Mesa del Yeso 3 miles north. Darton (1922, 1928) prepared a geologic map and cross sections that include the Sierra de la Cruz area. He also discussed structural relationships along the east flank of the Los Pinos anticline (Darton, 1922 and 1928) which includes Sierra de la Cruz (then known as Cibola Cone) and measured a stratigraphic section on the north face of Sierra de la Cruz. Needham and Bates (1943) remeasured Lee's section and designated strata in Sec. 33, T.1S., R.2E. and Sec. 4 and 5, T.2S., R.2E. as the type section of the Yeso Formation. Wilpolt and Wanek (1951) prepared a reconnaissance geologic map, cross sections, and stratigraphic sections of part of central Socorro County that includes the map area. Bieberman and Kottlowski (1963) prepared a road log for a field trip to the Yeso type section measured by Needham and Bates (1943). Kottlowski and Stewart (1970) describe a general stratigraphic section of the Bursum Formation adjacent to Canoncito de la Uva along the south edge of the map area. Rosen (1983) mapped an area immediately north of the map area while Osburn (1983) prepared a brief report on an exploratory hole drilled for the purpose of gathering stratigraphic and structural data along the northern edge of the map area. Broadhead and others (1983) prepared a road log for a field trip to examine parts of the Abo and Yeso Formations in the southeastern quarter of the map area. Smith and others (1983) prepared a road log for a field trip to examine unusual structural complexity on the south edge of Rosen's (1983) field area. McLemore (1983) lists uranium occurrences and production figures for 2 mines situated in the northeast corner of the map area. Hunt (1983) discusses plant impressions and biostratigraphy in the upper Abo Formation along the southern edge of the map area.

Other works that discuss areal relationships important to this study or that are immediately outside the study area include: Herrick (1900) who commented on the Permian section and its relationship to older rocks east of Socorro; Lee (1907) who noted two sequences of red beds east of the Rio Grande and proposed a Permian or Triassic age for them; Gordon (1907) who discussed Pennsylvanian rocks along the Rio Grande Valley and proposed several new names for formations or groups for these rocks; Wilpolt and others (1946) who prepared a reconnaissance geologic map immediately north of the study area that covers the Joyita Hills, Los Pinos Mountains and northern Chupadera Mesa;

Siemers (1978, 1983) who described the Pennsylvanian system in western Socorro County; Baker (1981) who mapped and described Cretaceous and Triassic rocks northwest of the study area; Hunter and Ingersoll (1981) who summarized depositional environments for the Yeso Formation in general and the Canas Gypsum Member in particular across central Socorro County; Baker and Wolberg (1981) who presented an interim report on Cretaceous marine vertebrates in the Sevilleta Land Grant; Smith (1983) who summarized the many structural problems east of the Rio Grande; Hook (1984) who summarized upper Cretaceous stratigraphic nomenclature for Socorro County; and Wolberg (1985) who described Cretaceous marine vertebrates in Baker's (1981) study area.

Methods of Investigation

Geologic mapping, stratigraphic, and structural studies were carried out during fall and winter of 1984 and spring and summer of 1985 as classes, teaching responsibilities, weather and road conditions permitted. Geology was recorded on a topographic base constructed from the Mesa del Yeso (1959) and Sierra de la Cruz (1972) 7.5 minute quadrangles at a scale of 1:12,000. A supplementary detail map at a scale of 1:6,000 was prepared from the Sierra de la Cruz (1972) 7.5 minute quadrangle for detailed structural mapping in Sec. 28 and 33, T.1S., R.2E. All mapping was done using a Brunton compass and an optical tape measure as well as brunton-and-pace traverses. These methods are outlined in various field geology texts. A Jacob's staff and Brunton compass were used to measure all stratigraphic sections. Methods for this procedure are outlined in Kottlowski (1965). An American Stratigraphic grain size card and ten power handlens was used to determine grain size, sorting and roundness in the field. All colors were determined using a G.S.A. Rock Color Chart (Goddard and others, 1979) and are for fresh surfaces only. Seventeen thin sections were prepared for microscopic examination of sedimentary and igneous rocks. Appendix I contains descriptions of all measured sections and a brief summary of criteria used for those descriptions. Appendix II contains thin section data for the samples collected. Classification of stratigraphic units is mainly based on Wilpolt and Wanek (1951) and Siemers (1978, 1983).

Acknowledgments

Many people have contributed directly or indirectly to this study. Without their help this work could not have been done.

My thanks go to Dr. Antonius Budding who first introduced me to this area and its many structural problems. He encouraged and helped me through problems with suggestions and good advice. I also appreciate his loan of aerial photographs, his discussions of structural problems and their analysis, his overall guidance on this study, and for being my advisor.

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I am deeply indebted to my mother and my wife for their financial and moral support. I am also grateful to New Mexico Bureau of Mines and Mineral Resources (Virginia McLemore) and the Department of Petroleum Engineering (Dr. William Lyons) for providing jobs and teaching assistantships. Without this support my continued schooling and thesis work would not have been possible.

Additional thanks go to Curtis McKallip and Tim Altares for their help on some of the stratigraphic problems and to Donald Wolberg and Dan Bobrow who helped identify some of the fossils that I collected. Bob Osburn and Virginia McLemore helped by discussing various ideas about how some of the many structural problems might be interpreted. They also asked some probing questions and fielded a few of their own ideas about some of my interpretations. I am grateful for their input.

I am grateful to Mr. Joe Santillanes, Mr. Wayne Galliheair and Mr. Robert Creel for their hospitality and for allowing me access to their private and state-lease lands.

Last of all, I want to thank my wife Dorothie, for her love, patience and encouragement during those long hours when studying, field mapping and teaching responsibilities

kept me occupied away from home and for accompanying me into the field on several occasions.

I dedicate this thesis to the memory of my father, Robert M. Colpitts, Sr., who passed away while I was attending school.

Geographic Setting

The Sierra de la Cruz area lies east of the Rio Grande valley in central Socorro County. It consists of gently rolling hills and mesas with several prominent peaks located on the west and east sides of the map area. The area is sparsely covered by various grasses, creosote and mesquite bushes, and scattered pinyon and juniper trees.

Relief is moderate to low; elevations range from a maximum of 6380+ feet (1945+ meters) on Sierra de la Cruz to a minimum of 5150 feet (1570 meters) where Arroyo de Alamillo leaves the west edge of the map area in Sec. 29, T.1S., R.2E.; maximum relief is 1230 feet (375 meters).

The area is bounded by Canoncito de la Uva on the south, by an arm of Valle del Ojo de la Parida on the west, by the Sevilleta Land Grant boundary (approximately) and an unnamed tributary of Arroyo Alamillo that runs past Stapleton Well on the north, and by the township line common to T.2E. and T.3E. on the east side. Drainage is mainly controlled by outcrop patterns of resistant rocks and or faults. Drainage from the broad open valley in the central part of the area shows no apparent structural or stratigraphic control except along the margins. Present day topographic expression is a product of differential weathering of exposed stratigraphic units; resistant beds form ridges and peaks that protect softer underlying units and soft beds form valleys and lowlands.

GEOLOGY

Geologic Setting

Pennsylvanian to Quaternary rocks crop out in the Sierra de la Cruz area. These rocks include Pennsylvanian Madera Limestone of the Magdalena Group (Gordon, 1907); Permian Bursum, Abo, Yeso, Glorieta Sandstone, and San Andres Formation; Triassic Dockum Group; Cretaceous undivided; Tertiary Baca Formation and andesitic dikes; Quaternary - Tertiary Santa Fe Group(?); and various Quaternary alluvial deposits. Regional folding causes the Pennsylvanian and Permian strata to young northeastward; faults break and segment their distribution throughout the map area.

Pennsylvanian Rocks

Madera Limestone

The Madera Limestone was first named by Keyes (1903) for limestone beds on the east slope of the Sandia Mountains near the town of La Madera. Gordon (1907) later included the Madera Limestone with the underlying Sandia Formation in his Magdalena Group. Thompson (1942) subdivided the Madera Limestone into a series of formations and groups based on fusilinid faunal zones. He sought to clarify Keyes'poorly defined use of the term Madera. Wilpolt and others (1946) divided the Madera Limestone into a lower, gray limestone member and an upper arkosic limestone member. In spite of extensive use of Thompson's subdivisions, Kottlowski and others (1956) and Siemers (1978, 1983) retain Wilpolt and others (1946) designation of lithostratigraphic units.

The Madera Limestone occurs in small, irregular patches in Sec. 10 and 12, T.2S., R.2E. An incomplete section consisting of 73.3 feet (22.3 meters) of interbedded wackestones and carbonate mudstones was measured in Sec. 10, T.2S., R.2E. in Canoncito de la Uva. This sequence correlates with Thompson's (1942) Moya Formation (Altares, 1984, oral communication); the upper parts of the Pennsylvanian sequence are apparently missing.

The limestones consist of a lower sequence of bioclastic wackestones and packstones, and an upper sequence of carbonate mudstones. The wackestones and packstones are light brownish gray to brownish gray in color and are composed of fossil debris including brachiopod shell fragments, gastropods, pelecypods(?), bryozoans, phylloid algae, fusilinids (Triticites sp.) and crinoid ossicles with some peloids. They are medium to thick bedded and laterally continuous. The carbonate mudstones are light gray to light brownish gray in color, thin to thick bedded, locally nodular with scattered brachiopod, gastropod, fusilinid and phylloid algae fragments. Locally abundant crinoid ossicles also occur in some beds. These mudstones grade to wackestones along strike. Beds are laterally continuous with upper beds showing signs of erosion and channeling. The upper-most beds grade eastward into medium gray, nodular, bioclastic packstones and grainstones.

The contact between the Madera Limestone and the overlying Bursum Formation is drawn on a clean, medium bedded to nodular marine limestone immediately below a dusky red, micaceous, sandstone and shale sequence. This contact is adequate for this area but may not be appropriate elsewhere.

Permian Rocks

Bursum Formation

The Bursum Formation was first described by Wilpolt and others (1946) from a designated type section in Sec. 1, T.6S., R.4E. Thompson (1942) includes some of what is now mapped as Bursum Formation in his Bruton Formation (Wilpolt and Wanek, 1951). Based on faunal studies, Thompson (1942) considers this unit as Wolfcamp in age. Bates and others (1947) and Lloyd (1949) give measured sections other than the indicated type section (Jicha and Lochman-Balk, 1958, pg. 24). Kottlowski and Stewart (1970) described a Bursum section in Sec. 8, T.2S., R.2E., just south of the edge of the map.

Outcrops of the Bursum Formation occur along the south edge of the map area adjacent to Canoncito de la Uva. It is also exposed in anticlines in Sec. 1, 3 and 4, and 8 to 12, T.2S., R.2E. A complete section consisting of 207.4 feet (63.2 meters) of interbedded conglomerate, sandstone, shale and limestone was measured in the NW 1/4, Sec. 12, T.2S., R.2E., east of Canoncito de la Uva. Total thickness varies over the map area; it ranges from 190 feet (57.9 meters) to 207.4 feet (63.2 meters) over a distance of about one -

half of a mile. Kottlowski and Stewart (1970) observed that the Bursum Formation generally thins toward the Joyita Hills, northwest of the map area.

The conglomerates are light brownish gray in color mottled medium gray and consist of pebble- to cobble-sized clasts of limestone in a matrix of medium lower to very coarse upper (see Appendix 1 for an explanaton of this terminology), angular, poorly sorted, medium to thick bedded, micaceous arkose. They are hard, calcareous and contain numerous fragments of brachiopods and crinoid ossicles. They are quite lenticular and are absent in the lower part of the section in outcrops 2 miles west of the measured section. Altares (1984, oral communication) observed thin lenticular conglomerates at the base of the Bursum Formation south of the map area. The conglomerates grade upward into medium to very coarse grained feldspathic sandstones. Conglomerates also occur in the upper part of the section in Sec. 9, T.2S., R.2E. They contain carbonate mudstone pebbles in a coarse grained, feldspathic sandstone matrix. One conglomerate bed along the top of the Bursum in the NW 1/4, NW 1/4, Sec. 9, T.2S., R.2E. has tooth and bone fragments scattered on the outcrop surface. Don Wolberg identified one tooth as that of a land-dwelling reptile and another tooth as belonging to Janessa sp., a shark-like vertebrate that ranged from marine waters to brackish-water estuaries (Wolberg, 1985, oral communication). This conglomerate was mapped with the

The contact with the overlying Abo Formation is drawn on top of a moderate brown weathering, cliff-forming, cross bedded, lenticular sandstone bed that contains numerous log impressions and scattered glauconite grains. This suggests that this sandstone unit was deposited in shallow marine conditions, making it more closely associated with the underlying marine and continental deposits of the Bursum Formation. Moreover, it is a prominent unit, easily mapped, and is overlain by a soft, dark reddish brown clay shale; the combination of all these features makes this a good mapping horizon. This unit is probably transitional with the overlying Abo, but fills channels cut into the upper marine limestones and shales. The contact appears to be, in part, an erosional unconformity.

Abo Formation

The Abo Formation was named by Lee (Lee and Girty, 1909) and later redescribed by Needham and Bates (1943) from outcrops in Abo Canyon in the Manzano Mountains, northeast of the study area. Thompson (1942) correlated the Abo Formation southward into the Wolfcampian Hueco Limestone, Baars (1962) correlated the Abo with the lower Cutler Formation in the Four Corners area and the Supai Formation in Arizona; all are Wolfcampian (Early Permian) in age. Numerous workers have attempted to define the age range of the Abo on the basis of plant biostratigraphy (Hunt, 1983, pg. 160-162). Hunt (1983) considers this approach unsatisfactory since the floral assemblages are not fixed

Bursum Formation; later work may prove this assignment incorrect.

The sandstones are light brownish gray to grayish orange pink and dusky red in color, and are fine lower to very coarse upper, angular to subangular, poorly to well sorted, quartz and feldspar grains. They are hard, calcareous, massive bedded to thickly laminated, and are lenticular. They contain impressions of log fragments especially in the upper-most sandstone bed.

The shales are medium dark gray, brownish gray and dark yellowish gray in color, calcareous, silty, very thinly to thinly laminated, and poorly exposed except in freshly cut arroyo banks. They contain scattered limestone concretions, thin nodular limestones, and very thin coaly layers; scattered algae-encrusted, carbonized tree trunks (Altares, 1984, oral communication) also occur in the western part of the map area along Canoncito de la Uva.

The limestones range from carbonate mudstones to bioclastic, feldspathic packstones and grainstones and are dark gray, brownish black, and medium gray, medium to thick bedded, locally nodular with numerous brachiopods (including Composita sp.), gastropods, scaphopods, pelecypods, digitate and fenestrate bryozoans, fusilinids (including Triticites sp.), crinoid ossicles, ostracods, abundant scattered peloids. Some fossil fragments are jasperized. The limestones form prominent ledges in the upper part of the section.

well enough in time or environmental range to be used as index fossils; adequate correlations can only be made when marine strata occur within the Abo. Hunt (1983, pg. 162) observed that "the Abo probably does not represent an isochronous unit".

The Abo Formation is broadly distributed across the southern half of the map area; it constitutes about one-third of the rocks mapped in the Sierra de la Cruz area. It forms gentle rolling hills and dip slopes where resistant sandstones protect underlying soft mudstones. A complete section composed of 682 feet (207.9 meters) of conglomerates, sandstones, siltstones, mudstones and a few scattered reddish, nodular carbonate mudstones was measured in the NE 1/4, Sec. 12, T.2S., R.2E., east of Canoncito de la Uva. This thickness agrees well with those that I observed on wireline logs from wells south and east of the map area. Cappa (1975) and Cappa and MacMillan (1983) report a thickness of about 575 feet (175.2 meters) for the Abo near Minas del Chupadero, south of the field area. Cappa (1975) reports that this thickness is incomplete because of normal faults that cut out part of the lower mudstone. Faults are very difficult to recognize in Abo mudstones; extreme variations in thickness may be due to local faulting. What appears to be an erosional unconformity was observed on the underlying Bursum Formation. This irregularity may also contribute to thickness variations observed by other workers in this region.

The Abo Formation can be broken into two general sequences in the Sierra de la Cruz area: an upper, rhythmically bedded sand and mudstone unit and a lower mudstone unit. Both units are well exposed along the eastern edge of the map area and can be easily traced westward and southward for several miles. A similar sequence was observed by Kottlowski and others (1956) in Rhodes Canyon in the northern San Andres Mountains.

The conglomerates are pale red to grayish orange pink in color with coarse granule to very fine pebble-sized clasts of limestone and chert in a matrix of poorly sorted, angular, well indurated arkosic and locally micaceous, calcareous sandstone. They are thin to medium bedded and are quite lenticular, often occurring as stacked channel-fill deposits in the upper half of the formation. One conglomerate and sandstone-filled channel in the lower half of the formation crops out along Canoncito de la Uva and is over 30 feet (9.1 meters) thick. Large channels like this trend S20W in the map area.

The sandstones are grayish red to dark grayish red in color, and consist of very fine lower grading to coarse silt-sized, angular, well sorted to very well sorted quartz and feldspar grains. They are hard, locally calcareous, and very thickly laminated to massive bedded. Very coarse upper to medium upper arkosic to feldspathic sandstones occur in the lower part of the section. The sandstones display a wide variety of sedimentary structures; climbing ripple cross laminations, ripple marks, trough cross bedding, mudcracks, raindrop impressions and flaser beds are all very common. Also preserved are a wide variety of plant impressions identified as Walchia sp., Brachyphyllum sp., Supia sp., Glenopteris sp. and Callipteris(?) sp. by Hunt (1983, pg. 160). The sandstones are ledge-forming units that cap hills and form dip slopes.

The siltstones are grayish red to dark grayish red in color, calcareous to siliceous and increase in number upsection. They commonly have plant impressions, some bioturbation and numerous very pale orange reduction spots. They are very resistant and form slope breaks in the thick mudstone sections.

The mudstones are dark reddish brown in color, slightly calcareous and contain a few scattered septarian nodules. They are slope formers and are poorly exposed except in a few arroyo bottoms cut in the sides of steep cliffs. The mudstones form approximately three-quarters of the entire Abo section in the Sierra de la Cruz area.

A few sedimentary structures can be seen in the mudstones in steep arroyo banks where exposures are freshest. These include lens-shaped, channel-like structures that cut through underlying mudstones (no conglomerates were observed with these features) and vertical, tubular siltstone bodies that project 5 feet (1.52 meters) down into underlying mudstones. This last structure may represent either vertical burrows or root casts projecting from an old soil horizon. Cappa (1975) observed similar features near Minas del Chupadero and suggested that they might be root casts.

The limestones are grayish red in color, and consist of nodular, carbonate mudstones enclosed in dark reddish brown mudstone. They are restricted to the lower part of the section, are laterally discontinuous and devoid of fossil debris. They form gravelly-looking slopes and are not well exposed.

The contact between the Abo Formation and the overlying Yeso Formation is selected on the basis of: 1) a distinct change from dark reddish browns and grayish reds to light browns, light brownish grays, and pinkish grays; 2) the appearance of salt hoppers and salt casts; and 3) a change in the overall tabularity of the beds, and the disappearance of fluvial structures (channelling, trough crossbeds and climbing ripple laminations). All of these criteria usually occur at once although the color change is, many times, more gradational. This sharp contrast is easily mapped on the ground and on aerial photographs. The contact is conformable and transitional in the Sierra de la Cruz area; the upper-most Abo sandstone beds bear a striking resemblance to overlying Yeso sandstones, which suggests intertonguing of the two formations.

Yeso Formation

The Yeso Formation was named by Lee (Lee and Girty, 1909) for orange and gray strata exposed in Mesa del Yeso. He measured a reconnaissance stratigraphic section in Sec. 4 and 5, T.2S., R.2E. and Sec. 33, T.1S., R.2E. and designated it as the Yeso type section. Darton (1922) measured a more detailed section on the north face of Cibola Cone (Sierra de la Cruz) but did not correlate it to Lee's section. Needham and Bates (1943) measured their section a short distance east of Lee's to avoid some faulting and designated it the type for the Yeso Formation. They subdivided the Yeso Formation into a lower clastic zone, a sequence of interbedded limestone, gypsum, siltstone, and sandy shale known as the "middle evaporite unit", a thick bed of gypsum which they named the "Canas Member" and upper unit of soft, crossbedded sandstones which they named the "Joyita Member". Wilpolt and others (1946) measured the Yeso Formation in Agua Torres Canyon and combined Needham and Bates' lower clastic unit and middle evaporites into the "Torres Member". Read (in Bates and others, 1946) separated the upper part of the Abo Formation at Needham and Bates' Abo type section and correlated it with the Meseta Blanca Sandstone of Wood and Northrup (1946). This lowers the Abo-Yeso contact about 300 feet (91.4 meters) at the Yeso type section. Needham (in Bates, 1942) correlated the Yeso Formation southeastward with the Bone Springs Formation and believed it equivalent with the lower two-thirds of the

Leonard series (Jicha and Lochman-Balk, 1958). Baars (1962) later correlated the Yeso Formation with the Yeso and De Chelly Formations in Arizona. He also recommended that "Meseta Blanca Member" be dropped in favor of De Chelly Formation on the basis of regional correlations (Baars, 1962, pg. 180); he shows both De Chelly and Yeso Formations as Leonardian in age. Kottlowski and others (1956, pg. 59 and 60) collected faunal remains from limestones in the middle and upper parts of the Yeso Formation. Flower (in Kottlowski and others, 1956) reports that the specimens are Leonardian in age. Based on this evidence, they concluded that the entire Yeso Formation is Leonardian in age.

The Yeso Formation is divided into four members in the Sierra de la Cruz area. These include:

1) The basal Meseta Blanca Member;
2) the Torres Member;
3) the Canas Gypsum Member; and
4) the Joyita Sandstone Member.

This scheme follows Wilpolt and Wanek's (1951) usage of subdivisions for the Yeso Formation.

The Yeso Formation is distributed in a broad arcuate series of outcrops covering a large part of the map area. I measured three incomplete sections consisting of interbedded sandstone, siltstone, limestone and gypsum at two different locations in the Sierra de la Cruz area. The first section comprising the Meseta Blanca and the lower half of the Torres Member was measured in Sec. 4 and 5, T.2S., R.2E.

and along the south edge of Sec. 33, T.1S., R.2E. at Needham and Bates' (1943) original Yeso type section. The second section was measured in the NW 1/4, Sec. 36, T.1S., R.2E., on the north flank of Sierra de la Cruz near Darton's (1922) measured section. All sections were tied together by walking individual limestone beds and contacts from one area to the next. This was done to avoid complex faulting that breaks up the entire section in many places in the map area. A short reconnaissance section was measured in Sec. 33, T.2S., R.2E. to check units observed further to the east and confirm thicknesses for the Canas Gypsum and Joyita Sandstone Members.

Meseta Blanca Member- The Meseta Blanca Member is composed of 294 feet (89.6 meters) of interbedded sandstones and siltstones with minor shales.

The sandstones are very pale orange, pinkish gray in color, and consist of moderate reddish brown, very fine lower to coarse lower, rounded to subangular,very well to poorly sorted quartz with minor feldspar grains. They are friable, calcareous and are thickly laminated to thickly bedded. Sedimentary structures include asymmetric and symmetric ripple marks, soft-sediment deformation (slumps and convoluted bedding), ripple cross laminations, and salt hoppers and casts. Higher in the section, wedge and concave-upward cross beds occur in the coarser grained sandstones. These coarser sandstones are broadly lenticular although a general coarse sandstone sequence can be traced east for several miles. The fine-grained sandstones grade laterally into coarse siltstones; their color changes from light pinks and whites to moderate reddish browns.

The siltstones are dark reddish brown, moderate reddish brown and dark gray in color and consist of angular, coarse quartz silt. They are thick to thinly laminated, locally very thin bedded and are even layered. They grade laterally into dark reddish brown mudstones that resemble those in the Abo Formation; isolated outcrops can cause some confusion though associated sandstones with salt casts and a lack of fluvial structures help make the distinction. No fossilized animal or plant remains were found in the sandstones or siltstones of the Meseta Blanca Member.

The contact with the overlying Torres Member is drawn at the base of the first limestone bed; this contact makes a distinctive mapping horizon. This marker bed was found by Wilpolt and others (1946) several miles north of the map area and can be traced southward towards Loma de las Canas. It also forms a prominent marker on resistivity curves on wire-line logs from wells east of the study area. The contact is transitional and forms a conformable boundary in the study area.

Torres Member- The Torres Member is composed of 512 feet (156 meters) of interbedded sandstone, limestone, gypsum and, locally, breccia due to collapse of surrounding strata caused by gypsum dissolution.

The sandstones are moderate to pale reddish brown, grayish pink, grayish red and moderate brown in color with occasional very pale orange, and consist of fine upper to medium upper, angular to subrounded, moderate to well sorted feldspar and quartz grains. They are friable to soft, locally clayey and calcareous and are thickly laminated to thinly bedded. Occasional thin flakes of dark reddish brown claystone occur along bedding planes and partings. Sedimentary structures include soft sediment deformation, asymmetric ripple marks, local simple cross bed sets, salt casts, and occasional ripple cross laminations.

The limestones are pale yellowish brown, brownish gray, brownish black and olive black in color. They range from carbonate mudstones with scattered angular, silt-sized quartz grains near the base to argillaceous, peloidal wackestones and grainstones near the top. They are locally fetid and are medium bedded. The lowest limestone contains small asphalt-filled vugs and has polygonal dessication cracks on the upper-most bedding surfaces. It too is locally fetid. Peloids, oncoids, pisoids, ooids and shell fragments are common in the thick mesa-forming unit (Needham and Bates' Unit 34) near the top of the sequence at the type section of the Yeso Formation. Sedimentary structures in the grainstones include low angle, small scale cross stratification and scour structures; the carbonate mudstones are usually featureless.

The upper-most limestone beds are locally folded. Folds in these units are usually overturned or recumbent and orange and grayish red in color and contain angular to rounded fragments of sandstone and limestone in a calcite matrix. Locally, the calcite forms a layered encrustation on some clasts that resembles travertine. The breccias are laterally discontinuous and rarely extend more than 500 feet (152 meters) along strike. No folds were found to be associated with these breccias.

The contact with the overlying Canas Gypsum Member is mapped at the top of a fetid, locally fossiliferous, peloid packstone which is underlain by very-fine grained sandstone; above this, gypsum predominates. The contact is somewhat arbitrary but can be traced reliably from the type section of the Yeso Formation east to Sierra de la Cruz. Where the Canas is exposed, the contact appears conformable.

Canas Gypsum Member- The Canas Gypsum Member is composed of 79 feet (24.1 meters) of poorly exposed, laminated and recrystallized gypsum with some thin layers of sandstone and limestone in the middle of the member.

The gypsum is white in color, very fine to fine crystalline with olive black laminations (usually 6 per inch) and occasional layers with scattered porphyroblasts of olive gray selenite. It is poorly exposed on slopes and weathers to a jumbled, blocky appearance; pink silt covers most of the outcrops. The laminations disappear in the lower half of the sequence and are replaced by abundant selenite porphyroblasts in a fine crystalline, acicular gypsum matrix.

The sandstone is pale yellowish brown in color, and consists of very fine lower, angular to subrounded quartz grains. It is clayey to calcareous, friable and very poorly exposed. It is underlain by a thin, light olive gray, rotten limestone. Both units are traceable from Sierra de la Cruz to the type section of the Yeso Formation. Where the limestone is thicker (at the type section of the Yeso Formation) it is a dark gray peloid grainstone. At Sierra de la Cruz it is badly weathered and no proper identification can be made.

The contact with the overlying Joyita Sandstone Member is picked at a slope break where a friable, pinkish gray, fine-grained sandstone rests on gypsum. The contact appears conformable and may be transitional.

Joyita Sandstone Member- The Joyita Sandstone Member consists of 96 feet (29.3 meters) of sandstones and a few interbedded thin shales which occur low in the section.

The sandstones are pale reddish orange, moderate orange pink, and pinkish gray in color and consist of very fine upper to fine upper, subangular, well sorted quartz and feldspar grains. They are friable, calcareous, locally silty, and thickly laminated to thick bedded. Low angle, sweeping concave upward, cross beds occur in the upper parts of the section.

The shales are grayish red in color, silty, very thickly laminated, well indurated and generally non-calcareous. In the Sierra de la Cruz area they occur in the lower to middle parts of the section though in other areas they may occur in other parts of the sequence (Fagrelius, 1982, Plate 6).

The contact with the overlying Glorieta Sandstone is placed above a silty sandstone where the grain size becomes medium lower and the bedding massive. At a distance the color change is very sharp, going from brick red to pale cream. This contact is sometimes tectonic, with the Joyita sandstone, Canas Gypsum, and part of the upper Torres Members missing; the Glorieta Sandstone rests directly on sharply folded limestones and sandstones of the Torres Member. Where this occurs, the contact is marked by a breccia that consists of pebble- to cobble-sized, angular to rounded fragments of red sandstone, white quartzitic sandstone, and dark gray, fetid limestone and dolomite in a matrix of poorly sorted, angular to rounded, very fine lower to medium upper quartz grains. In other places, a wedge of Joyita Sandstone Member may occur between the fault plane and the overlying Glorieta Sandstone; Canas Gypsum Member and part of the upper Torres Member are missing. Where the contact is not tectonic, the Joyita is gradational with the overlying Glorieta Sandstone.

Glorieta Sandstone

The Glorieta Sandstone was first named by Keyes (1915a and 1915b) for sandstones at Glorieta Mesa that he believed to be Cretaceous in age. Hager and Robitaille (1919, in Jicha and Lochman-Balk, 1958), Rich (1921) and Wilmarth

(1938) assigned Glorieta sandstones to the top of the Yeso Formation. Needham and Bates (1943) designated a new type section on Glorieta Mesa and considered the Glorieta a formation on the basis of its wide distribution, persistent lithology, bold topographic expression and its stratigraphic importance (Jicha and Lochman-Balk, 1958, pg. 53). Read and Andrews (1944) were the first to separate the Glorieta from the Yeso; they designated it a member of the overlying San Andres Formation. King (1945) felt that the Glorieta could not be distinguished from the underlying upper Yeso sands in southeastern New Mexico. Kottlowski and others (1956) also were unable to distinguish the Glorieta in the San Andres Mountains. Baars (1962) correlated the Glorieta Sandstone with the Coconino Sandstone in Arizona. The U. S. Geological Survey usually maps the Glorieta as a member of the overlying San Andres Formation (C. T. Smith, 1986, oral communication). In New Mexico the Glorieta is mapped as a separate formation (from either the underlying Yeso or overlying San Andres Formations [Jicha and Lochman-Balk, 1958, pg. 53]) by the New Mexico Bureau of Mines and Mineral Resources. In keeping with this convention, and because it is a very distinctive unit, I have mapped the Glorieta Sandstone as a separate formation in the Sierra de la Cruz area.

A complete section comprising 206 feet (68.2 meters) of cross and tabular bedded sandstone was measured in SE 1/4, NW 1/4, Sec. 33, T.1S., R.2E. The sandstones are white and very pale orange mottled pale yellowish orange in color and consist of fine lower to medium lower, subrounded to well rounded, very well sorted quartz grains. They are friable to well indurated siliceous to calcareous and thin to massive bedded. The lower two-thirds of the formation has broad, sweeping, low angle, simple cross bed sets and weathers to rounded cliffs. The upper one-third is tabular bedded with occasional low angle, wedge-shaped, cross bed sets and weathers into bold steep-faced cliffs immediately below the San Andres contact.

Locally, the base of the Glorieta Sandstone is brecciated where it is in fault contact with either the Torres Member of the Yeso Formation or the Dockum Group. Here the breccias consist of 1/2 to 1 inch (1.27 to 2.54 centimeter) rounded to well rounded fragments of Glorieta in a matrix of poorly sorted, angular quartz grains. Quartz grains in the matrix have a distinctive, shattered or crushed appearance in thin section; the Glorieta fragments are well preserved.

The contact with the overlying San Andres Formation is marked by a medium to thick bedded, pale brown dolomitic limestone bed above a white, medium upper, hard, quartzose sandstone. The contact appears sharp but the presence of two thin, well sorted, quartzose sandstone beds in the lower part of the overlying San Andres Formation indicate that the contact is transitional and intertongues with the overlying beds.

San Andres Formation

The San Andres Formation was first designated by Lee (Lee and Girty, 1909) as the "San Andreas limestone" (sic) for a sequence of massive limestones exposed in the northern San Andres Mountains. Darton (1922, 1928) continued Lee's usage of "San Andreas limestone" in his study of the Socorro region. Current spelling of "San Andres" first appears in Lang (1937). Needham and Bates (1943) designated the type section as exposures located in Rhodes Canyon in the San Andres Mountains and assigned the formation to the upper Leonard series. Kottlowski and others (1956) remeasured Needham and Bates' type section at Rhodes Canyon. They collected and identified Leonard-age brachiopods, scaphopods, nautiloids, and ammonoids from this section. Baars (1962) correlates the San Andres Formation with the Kaibab Formation in Arizona and the Four Corners region.

An incomplete section consisting of 191 feet (58.3 meters) of interbedded limestone, dolomite, dolomitic limestone, sandstone, and breccia was measured in the NE 1/4, Sec. 28, T.1S., R.2E. Although a complete section is not preserved in the Sierra de la Cruz area, about 400 feet (121.92 meters) of this formation is exposed southwest of the of the map area (based on reconnaissance just outside of the map area). Local faulting may have reduced the thickness; the actual thickness may be more on the order of 500 feet (152.4 meters) based on sections measured by Kottlowski and others (1956) and Fagrelius (1982). Erosion and complex faulting make a complete thickness difficult to estimate anywhere in this area.

The limestones range from carbonate mudstones to grainstones, are brownish black to pale yellowish brown in color, medium bedded, slightly fetid, and contain peloids, ooids(?), brachiopods (generally Dictyoclostus sp.), gastropods, cephalopods(?), pelecypods, phylloid algae, and occasional encrusting bryozoans. A large bryozoan(?) was found in a limestone bed in the lowest San Andres Formation at the type section of the Yeso Formation. This specimen has not yet been identified. The limestones are dolomitic in part and grade to calcitic dolomite along strike and upsection.

The dolomites are medium brownish gray to brownish black in color, slightly fetid to fetid, very fine crystalline and thin to thick bedded. They contain scattered molds of shell fragments and occasional aggregates of very coarse, blocky, mosaic calcite spar.

The sandstones are pale yellowish orange mottled white in color, and consist of medium lower to medium upper, rounded, very well sorted quartz grains. They are friable, calcareous, thick bedded and have some limonite staining. They are persistent across area and occur low in the section. Based on strong lithologic similarities with the underlying Glorieta Sandstone; these sand bodies are probably tongues of that unit.

One breccia bed was found in the lower part of the section and is pale yellowish orange in color. It consists of angular fragments of sandstone and limestone in a medium lower sandstone matrix. There is no evidence of crushing or shearing in the outcrop. This may be a thin collapse zone resulting from gypsum dissolution. Gypsum beds are reported in the lower part of the San Andres Formation outside of the field area by Wilpolt and Wanek (1951) and Kottlowski and others (1956).

Similar breccia beds were observed by Fagrelius (1982, pg. 22) who noted that they passed vertically and laterally into adjacent beds. The breccias are locally persistent and can occur at several levels in the lower 150 feet (45.7 meters) of the section.

The contact with the overlying Triassic Dockum Group is exposed in the SE 1/4, SE 1/4, SW 1/4, Sec. 28, T.1S., R.2E. It is an erosional unconformity; the upper gypsum member of the San Andres Formation observed by Fagrelius (1982) near Carthage is missing. The contact is picked at the top of a grayish orange, arenaceous limestone which is overlain by grayish red, very fine upper, quartz sandstones and interbedded, coarse siltstones. No section was measured at this location because the contact is very poorly exposed and could not be related to any of the other measured sections.

Triassic Rocks

Dockum Group

The Dockum Group was first named and described by Cummins (1890) for exposures near Dockum, Texas. The earliest mention of Triassic rocks is by Lee (Lee and Girty, 1909) where he observed red beds between the top of the San Andres Formation and the base of the yellow, Cretaceous sandstones (Dakota Sandstone) near the old lime kilns at Carthage. Case (1916) discovered bone fragments near the same location that confirmed a Triassic age for those rocks. Darton (1928, pg. 83, fig. 8) first introduced the term "Dockum" into the Sierra de la Cruz area. He interpreted outcrops of red shale in the valley in Sec. 29, T.1S., R.2E. as being part of the Dockum Group. Wilpolt and Wanek (1951) mapped Triassic rocks in the Jornada del Muerto, Carthage area, and north of the map area as belonging to the "Dockum Formation". Kottlowski and others (1956) and Kottlowski (1963) made a tentative correlation of a lower sandy unit with the Santa Rosa Sandstone. Wilpolt and Wanek (1951) show 410 feet (124.0 meters) of Dockum in an incomplete section measured 2 1/2 miles (4 kilometers) north of the Sierra de la Cruz area on the Sevilleta Land Grant. Fagrelius (1982) measured 777 feet (236.8 meters) of Dockum Group near Carthage, and subdivided it into the lower Santa Rosa Sandstone and upper Chinle Formation. Lucas and others (1985, pg. 181) recommended that the term "Dockum Group" not be applied to Triassic rocks in east-central New

Mexico. This would, of course, extend into this area where Triassic rocks are widely distributed. Unfortunately, exposures of Triassic-age rocks are poor and do not allow construction of a complete section. Therefore, the Triassic rocks have not been subdivided into members in this report.

The Dockum Group occurs as scattered, isolated outcrops in sections 27, 28, 29, 32, 33, and 34, T.1S., R.2E. Several handspecimens were used to obtain a general description.

The Dockum Group consists of interbedded conglomerates, sandstones, mudstones, and some minor limestones. The conglomerates are grayish brown to dark grayish red in color and consist of weathered, subrounded, fine to coarse pebbles of limestone and chert in a matrix of light brownish gray, fine lower, subangular, poorly sorted, silty sandstone. They are friable to well indurated, calcareous, locally crossbedded, and lenticular. One exposure of conglomerate in NE 1/4, SW 1/4, NW 1/4, Sec. 34, T.1S., R.2E. has scattered, weathered vertebrate bone fragments on the outcrop surface. The conglomerates occur as low rounded hills surrounded by valley alluvium.

The sandstones are grayish purple, light bluish gray in color, light to medium gray and light brownish gray, and consist of fine lower to medium upper, angular, poorly to well sorted grains of quartz, chert, magnetite, feldspar(?), and lithic fragments. They are well indurated to friable, calcareous, and thin bedded to very thickly laminated;

outcrops have a flaggy appearance.

The mudstones are brownish gray to pale red in color, soft, silty, calcareous, and very poorly exposed in arroyo walls and beneath hard sandstone ledges in arroyo bottoms.

The limestones are light gray to light brownish gray in color, and consist of carbonate mudstones with scattered ostracod shell fragments, quartz grains and chert nodules. Only one outcrop occurs in the NE 1/4, NW 1/4, SW 1/4, Sec. 28, T.1S., R.2E. Wilpolt and Wanek (1951) noted several thin, light gray limestone beds 180 to 260 feet (54.9 to 79.3 meters) above the base of the Dockum 2 1/2 miles (4 kilometers) north of this location. Fagrelius (1982) did not report any limestones in his measured sections of Dockum in the Carthage area.

The contact with the overlying Dakota Sandstone is not exposed in the Sierra de la Cruz area. Fagrelius (1982) reports that it is an erosional unconformity.

Cretaceous Rocks

Cretaceous undivided

Cretaceous rocks occur as an isolated outcrop in the N 1/2, Sec. 32, T.1S., R.2E. It consists of 240 feet (73.2 meters) of dark gray shale, a thin coquina of inoceramid shell fragments and a 15 foot (4.6 meter) sandstone bed. No section of these beds was described in detail because exact correlations are not certain.

Hook (1983, pg. 167) correlated Cretaceous age rocks from east of the Joyita Hills to Bustos Well, southeast of the study area; no collections or sections were made in the map area. He also summarized known molluscan faunal zones for Socorro County and other areas of New Mexico.

The shales are dark gray to grayish black in color, very thinly laminated to thinly laminated, and calcareous, with scattered, broken septarian nodules. They weather to dark greenish gray to light olive gray slopes and are well preserved though poorly exposed beneath resistant sandstone and/or conglomerate ledges. The inoceramid coquina is dark brown, poorly exposed, laterally discontinuous, and consists of a well indurated hash of broken shell fragments. This bed occurs low in the exposed section and is mainly found along the east side of the outcrops near a road. The sandstones are pale yellowish brown in color, and consist of very fine upper, subrounded, well sorted quartz and feldspar. They are calcareous, well indurated to moderately indurated, medium to thick bedded, locally burrowed, and contain scattered plant(?) impressions and oyster shells. Several oyster shells were collected in the NE 1/4, NW 1/4, NW 1/4, Sec. 32, T.1S., R.2E. and tentatively identified as Pycnodonte cf. P. kellumi and Inoceramus cf. I. macconnelli. Cobban (1977) and Wolberg (1983) show that Pycnodonte cf. P. kellumi occurs in the lower tongue of the Mancos Shale and in the Two Wells Tongue of the Dakota Sandstone. Correlation of this sequence with other Cretaceous sections remains uncertain due to lack of diagnostic ammonites and poor exposures.

The contact with the overlying Baca Formation is an angular unconformity in this area (Wilpolt and Wanek 1951, and Fagrelius, 1982).

Tertiary rocks

Baca Formation

The Baca Formation was first named by Wilpolt and others (1946) from exposures originally measured by Winchester (1920) in the northern Bear Mountains, in Socorro County. Earlier, Gardner (1910) described strata now called Baca and reported finding bone fragments and a tooth, identified by J.W. Gidley as being from Paleosyops indicating a middle Eocene age for the strata. Cather (1980, 1982, 1983a, and 1983b) and Cather and Johnson (1984) discuss the tectonic setting and depositional environments for the Baca Formation. Snyder (1970, 1971), Lucas and others (1982) and Lucas (1983) describe vertebrate remains in the Baca as being Eocene in age, and Lucas (1983, pg. 191) prepared preliminary correlations of mammal-bearing, Eocene strata in central and southern New Mexico.

The Baca Formation occurs as scattered, poorly exposed outcrops along the western edge of the map area. The outcrops form rounded hills and long rounded ridges in Sec. 5 and 6, T.2S., R.2E. and Sec. 32, T.1S., R.2E. Since it is poorly exposed, no sections were measured. Descriptions of the various kinds of rocks that make up the Baca Formation were made at several exposures. Cather (1983b) and Cather and Johnson (1984) show that these outcrops belong to the mid-fan subdivision of a braided alluvial plain system.

The Baca Formation consists of interbedded conglomerates and sandstones. No mudstones, siltstones or shales were found during mapping.

The conglomerates are pale red to pinkish gray in color and have pebble- to boulder-size, well rounded clasts of arkosic sandstone (from the Abo Formation), fossiliferous limestone (from the Madera Limestone), and quartzite, quartz-mica schist and granite (from Precambrian rocks) in a matrix of very coarse upper to medium lower, angular to rounded, poorly sorted, quartz, chert, and feldspar. They are friable to well indurated, calcareous, thick to massive bedded and cross bedded. The conglomerates cap many of the long ridges and form small, scattered, low rounded hills in Sec. 32, T.1S., R.2E.

The sandstones are moderate reddish brown, pinkish gray and very pale orange in color and consist of very fine upper to coarse upper, angular, moderately to poorly sorted quartz, feldspar, mica and gneiss(?) grains. They are friable, clayey to calcareous, and are thin to thick bedded. They have horizontal and small scale cross stratification, and occasional small clay flakes occur on some bedding surfaces.

No contact relationships with overlying units were observed in the field area; contact with underlying units is an angular unconformity.

Tertiary Andesitic Dikes

An andesitic dike crops out in Sec. 23, 26, and 27, T.1S., R.2E. in the northern part of the map area. It is greenish black to olive black in color and consists of euhedral to subhedral phenocrysts of green hornblende and scattered white, fibrous, plagioclase laths in a matrix of of microcrystalline plagioclase, hornblende, and scattered magnetite. The hornblende phenocrysts are usually leached to hematite or limonite on most outcrop surfaces; fresh hornblende appears an inch or so below the weathered rock surface.

Surrounding sandstones of the Yeso Formation are usually baked and silicified up to 2 feet (0.61 meters) away from the dike. The dike is irregularly exposed and occurs as thin, patchy outcrops within the core of a small anticline; both the fold axis and the dike trend are parallel and strike northeast. Erosion has exposed the top of the dike, which does not penetrate above the lower half of the Torres Member of the Yeso Formation.

Fagrelius (1982) observed dikes with a similar composition in his field area. Fagrelius (1982, pg. 48) reports that the dikes in his area resembled Spears-age dikes in the Joyita Hills, and are possibly of Oligocene age.

Quaternary(?) and Tertiary(?) Rocks

Santa Fe Group(?)

The Santa Fe Group(?) was first named by Hayden (1869) for exposures in the Rio Grande Valley near Santa Fe, New Mexico. It has been assigned either group or formation status by many subsequent workers (Fagrelius, 1982). It will be considered a group following the usage of Osburn and Lochman-Balk (1983).

Two small outcrops of well-cemented pebble and cobble conglomerates occur along the south edge of the map area in the S 1/2, NW 1/4, Sec. 11, T.2S., R.2E. I have assigned these deposits to the Santa Fe Group for two reasons:

1. They lie above surrounding alluvial surfaces by 20 to 30 feet (6.1 to 9.1 meters) and have themselves been eroded; and
2. They are very well cemented which is not typical for any recently deposited alluvium in this area.

The conglomerates are grayish red in color and consist of fine, pebble- to boulder-sized clasts of red brown siltstone and sandstone, gray limestone, white quartzose sandstone, and some grayish siltstone; no volcanic clasts were observed in these outcrops. They are well indurated and calcareous. They are separated from underlying strata of the upper Abo Formation by a 1.5 to 2 feet (0.46 to 0.61 meter) thick layer of white, calichified conglomerate. They are overlain by soft, sandy soils and modern alluvium. They display a crude, planar cross-stratification with pebbles imbricated toward the west. The outcrop geometry suggests that the deposits are broadly lenticular. They are elongate in an east-west direction.

It is possible that these conglomerates are well-cemented terrace gravels from an earlier, higher arroyo bed of Canoncito de la Uva which has long since been eroded away. Assignment of these beds to the Santa Fe(?) Group should only be considered tentative.

Quaternary Rocks

Alluvial deposits

Pleistocene(?) and Recent alluvial deposits occur as valley alluvium, colluvium, and stream alluvium in the Sierra de la Cruz area.

Valley alluvium consists of gray to tan, fine to very coarse sand with interbedded pebble and cobble gravel lenses. They are thin to massive bedded and locally cross bedded. They occupy many of the broad, flat areas in the map area and represent older stream and eolian deposits. They are covered with a thin, sandy soil supporting various grasses, bushes, and trees.

Colluvium occurs on steep slopes on a few hill sides and consists of boulders and cobbles derived from those hills; it is unconsolidated.

Stream alluvium occurs in arroyo bottoms and consists of interbedded, unconsolidated, poorly sorted medium upper to very coarse upper sand and pebble to cobble gravel. The gravel consists of fragments of red brown sandstones and siltstones, gray limestones, white quartzose sandstone and occasional white, laminated gypsum. These materials are derived from cliffs and hills of Pennsylvanian and Permian-age rocks which border the arroyos in this area.

The general lack of alluvial deposits in the Sierra de la Cruz area make it an excellent area for geologic studies; stratigraphic and structural relationships are well exposed over much of the area.

STRUCTURAL GEOLOGY

The Sierra de la Cruz area lies east of the Rio Grande Rift, northwest of the Jornada del Muerto basin and west of the Prairie Springs anticline. Numerous folds and faults occur throughout the map area, warping and breaking most of the exposed rock sequence. Figure 2 shows the various structural elements of the Sierra de la Cruz area. Table 1 lists the stratigraphic sequence in the study area and styles of deformation that characterize each unit.

Folds

The Sierra de la Cruz area has undergone widespread folding since Cretaceous time. These folds can be broadly divided into three groups:

1) asymmetric folds with variable wavelengths;
2) large upright folds with wavelengths from .5 to to 3.0 miles (0.8 to 4.8 kilometers); and

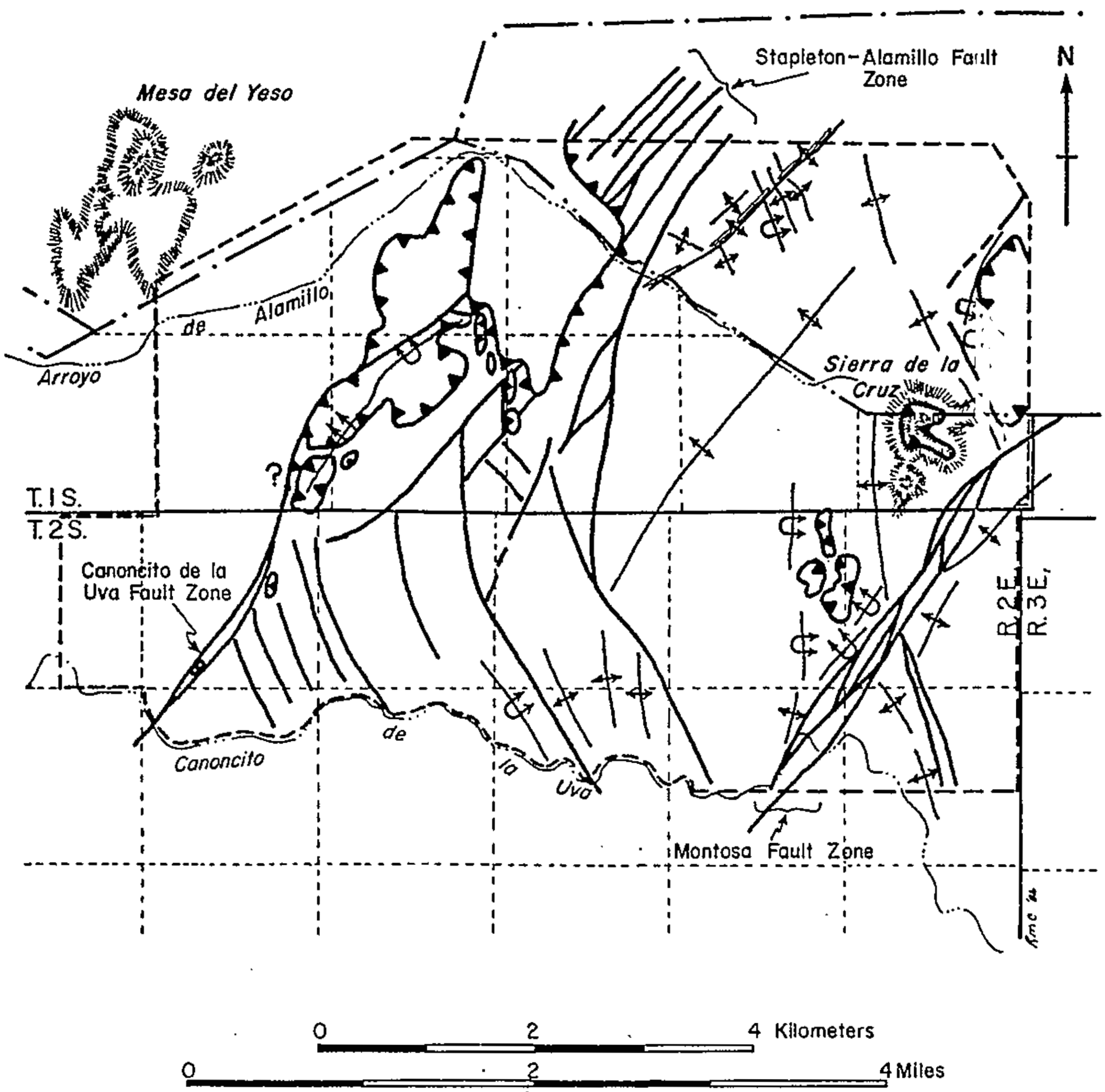


Figure 2 -- Structural features of the Sierra de la Cruz study area.

STRATIGRAPHIC UNIT		STYLE OF DEFORMATION
Mancos Shale		Normal Faulting, Block Rotation.
Dockum Group		Normal Faulting, Low-Angle Detachment Faulting; Broad Folding With Local, Small Folds
San Andres Formation		Normal Faulting, Low-Angle Detachment Faulting; Broad Folding With Local Small Folds, Block Rotation.
Glorieta Sandstone		Normal Faulting, Low-Angle Detachment Faulting; Broad Folding, Block Rotation.
Yeso Formation	Joyita Sandstone member	Normal Faulting, Low-Angle Detachment Faulting, Block Rotation, Structural Omission, Block Rotation
Yeso Formation	Cañas Gypsum member	Low-Angle Detachment Faults; Structural Omission
Yeso Formation	Torres member	Normal Faulting, Low-Angle Detachment Faulting; Overturned Folding, Broad Open Folding
Yeso Formation	Meseta Blanca member	Normal Faulting; Broad Open Folding
Abo Formation		Normal Faulting; Broad Open Folding
Bursum Formation		Normal Faulting; Broad Open Open Folding, Local Overturned Folding
Madera Limestone		Normal Faulting; Broad Open Folding, Local Overturned Folding

Table 1 -- Stratigraphic units with their characteristic styles of deformation, Sierra de la Cruz study area.

3) small upright folds with wavelengths less than .5 miles (0.8 kilometers).

These groups are somewhat arbitrary but do represent the kinds of folds that occur in the study area.

Figure 3 is a diagram after Rickard (1971) that contains all measured folds in the study area. Ragar (1985) states that all possible fold orientations can be described with this diagram. It was used to name all of the folds in the Sierra de la Cruz area.

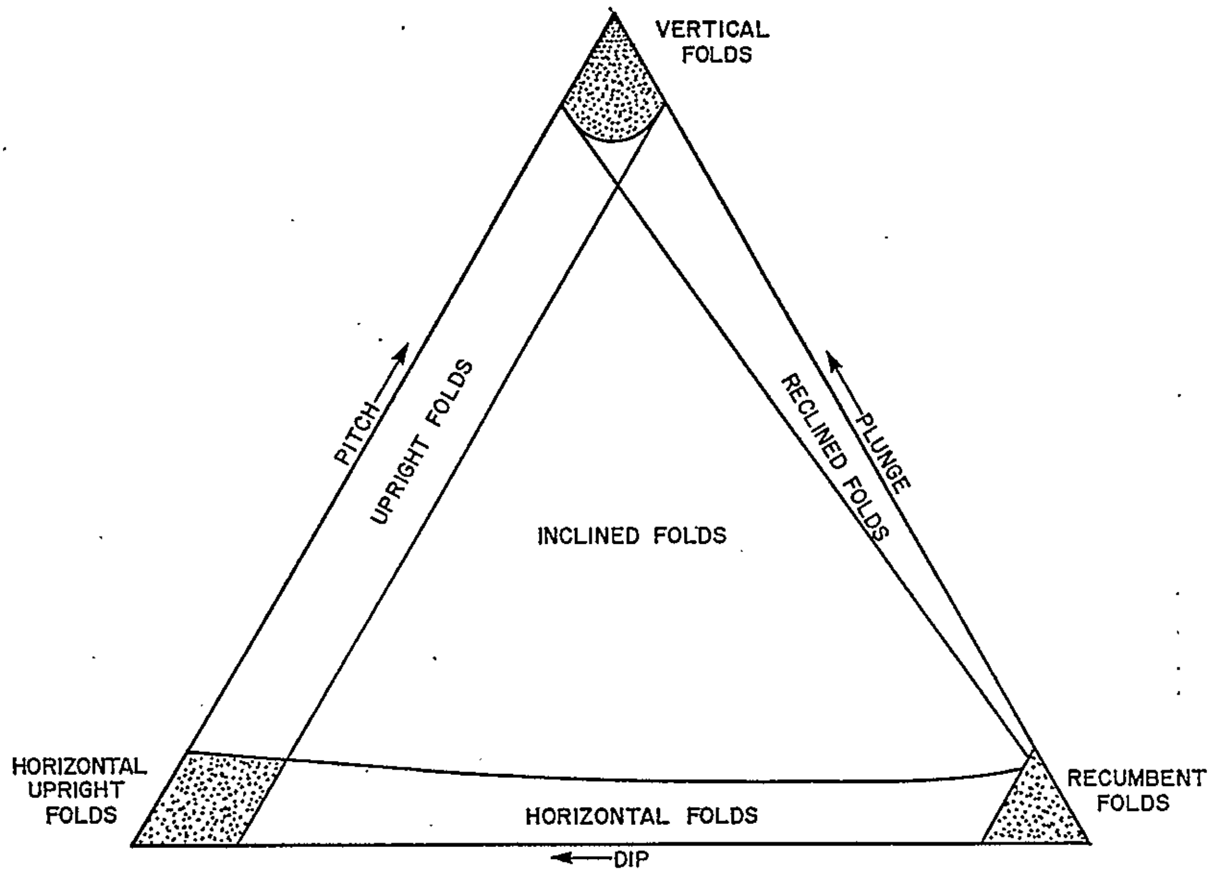
Fold Group 1

Fold group 1 consists of overturned or recumbent, horizontal to gently plunging anticlines and synclines. They are the most numerous of all the folds in the study area and are confined to the middle and upper Torres member of the Yeso Formation. Stereonet analysis of these folds indicates that the dips of the axial surfaces range from 25 to 72 degrees; fold axes plunge from 1 to 23 degrees northeast or southwest. From figure 3, two sets or clusters of points for the overturned folds are apparent:

1) axial plane dips that range from 25 to 42 degrees and
2) axial plane dips that range from 52 to 72 degrees.

A total of 33 folds are plotted on this figure.

The significance of this grouping is not clear. The more steeply dipping folds are usually associated with the more shallow dipping folds; they show no preferred grouping


VERTICAL FOLDS
PITCH
UPRIGHT FOLDS
RECLINED FOLDS
PLUNGE
INCLINED FOLDS
HORIZONTAL UPRIGHT FOLDS
HORIZONTAL FOLDS
RECUMBENT FOLDS
DIP

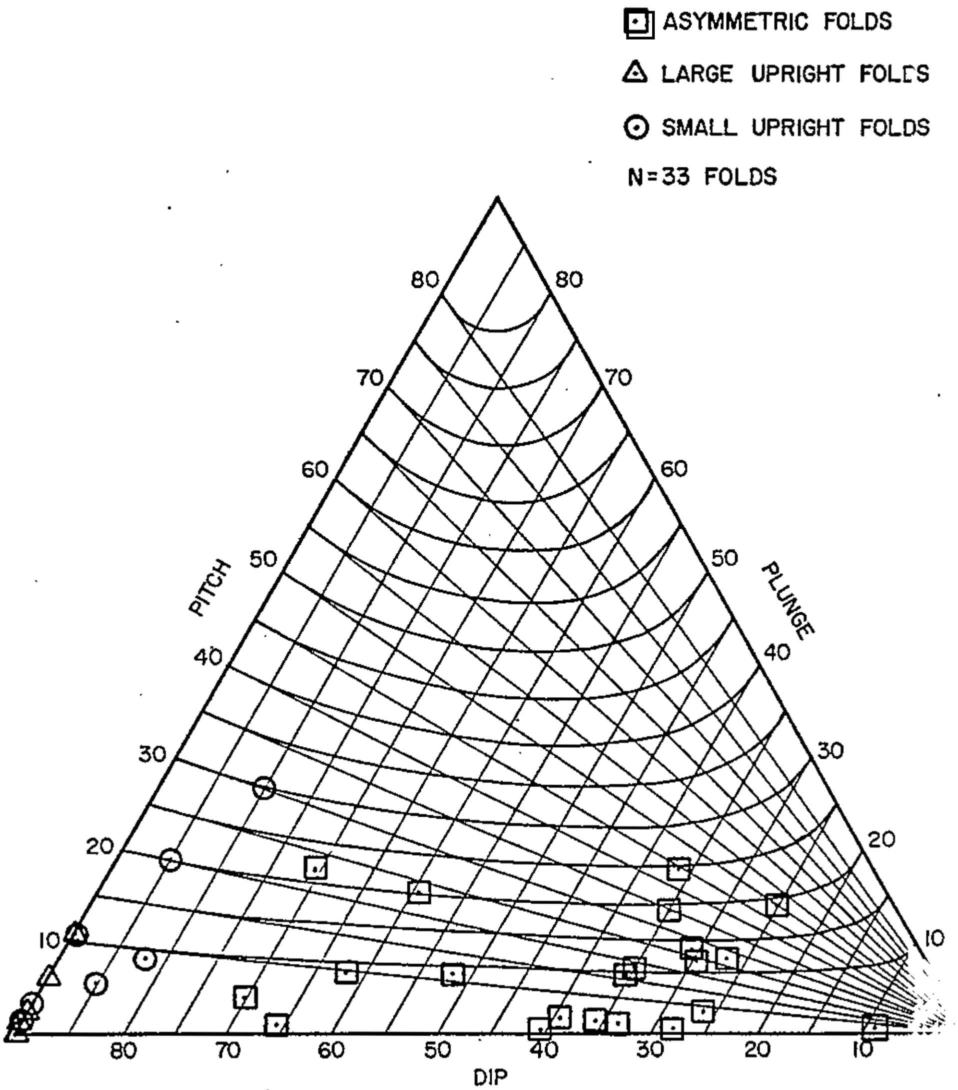


Figure 3 -- Fold orientation diagram (after Rickard, 1971) showing folds measured in the Sierra de la Cruz study area.

anywhere in the study area. Three of the steeply dipping folds are south of Sierra de la Cruz, one lies northeast of there and the last two occur west of the Yeso type section near the west edge of the map area. These folds are relatively minor compared to other Group 1 folds.

Group 1 folds are predominantly cylindrical, although several folds in the NW 1/4, NW 1/4, NW 1/4, NE 1/4, Sec. 33 and the SE 1/4, SW 1/4, SE 1/4, Sec. 28, T.1S., R.2E. appear to be non-cylindrical with non-planar axial surfaces. The folds are so poorly preserved that no clear sense of cylindricity can be obtained. One fold seems to be a continuation of the recumbent fold in the NE 1/4, NE 1/4, NW 1/4, Sec. 33.

These folds may represent superimposed fold episodes with one set deforming another. Some evidence for this occurs in the SE 1/4, SW 1/4, SE 1/4, Sec. 28, where the axial trace of one fold curves from a westerly trend to a northeasterly trend. This fold may have originally trended west-northwest. This and other folds like it were not analyzed because of poor exposures and insufficient data.

Group 1 folds are the oldest folds in the study area. They have been cut by some of the normal faults and have been deformed by the large upright folds of Group 2. They are associated with low-angle detachment faults and are well developed where Canas Gypsum Member is absent between the sole fault and the underlying Torres Member. Figure 4 shows this general relationship. Unfortunately, subsequent

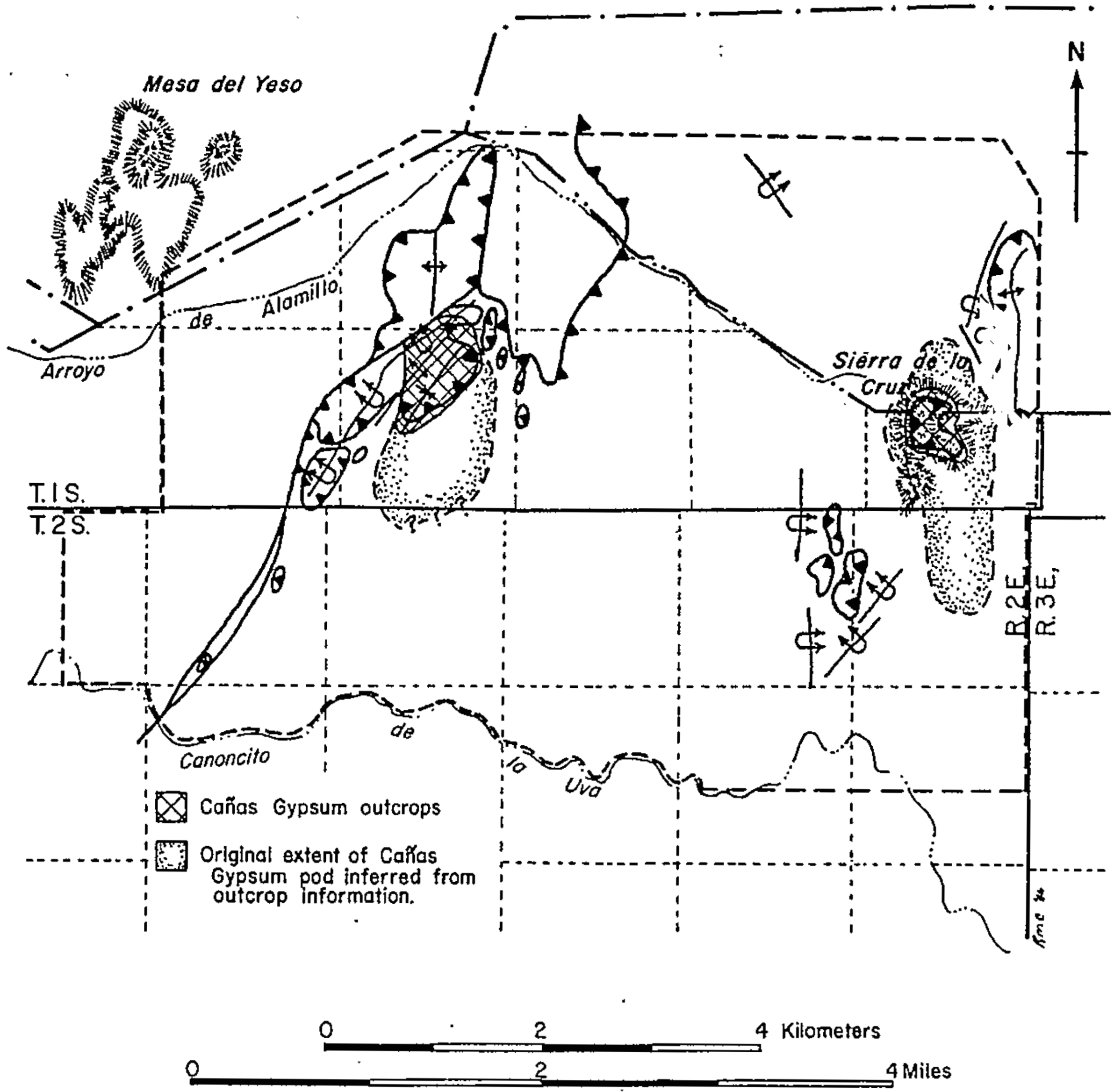


Figure 4 -- Relationship of overturned folds to allochthons, Canas Gypsum outcrops and possible original extent of Canas Gypsum pods, Sierra de la Cruz area.

folding, faulting and erosion have destroyed any folds that might once have existed in the upper Torres Member in the central part of the field area.

Fold Group 2

Group 2 folds consist of upright, horizontal to slightly plunging, large wavelength anticlines and synclines. They are characterized by gently dipping flanks and can be recognized by outcrop patterns on Plate 1. Group 2 folds are shown on figure 3 as horizontal upright or upright folds.

The largest of these folds is an anticline that strikes northeast across the center of the field area. Stereonet analysis of this fold shows that it plunges 5 degrees, N38E and has a vertical axial surface. The northeasterly plunge of this anticline exposes rocks ranging in age from Pennsylvanian to Permian. It is truncated by a large, northwest-trending anticline that lies northeast of the map area; only the southwest flank extends into this area.

The large northeast-trending anticline is faulted and folded in Sec. 3, 4, 9, and 10, T.2S., R.2E., north of Canoncito de la Uva where Bursum Formation and Madera Limestone are exposed. The geologic map of Wilpolt and Wanek (1951) shows that this fold continues southwest where progressively older rocks are exposed in its core.

Associated with the large, northeast-trending anticline are incomplete, faulted synclines. One syncline in Sec. 26 (projected), T.1S., R.2E. has numerous small wavelength folds that lie parallel to its fold axis. These smaller folds are probably parasitic, having been formed at the same time as the syncline.

Other large wavelength folds occur near Sierra de la Cruz and are associated with the Montosa Fault Zone. These folds plunge 2 to 4 degrees to the north or northwest and have vertical axial surfaces. Detailed structural information is not available because the Torres Member of the Yeso Formation is poorly exposed in this area. These north and northwest-striking folds do not seem to be related to the northeast-striking anticline. They may be related to the large northwest-trending anticline mentioned above.

Fold Group 3

Group 3 folds consist of small wavelength anticlines and synclines. They form scattered fold aggregates in the map area. Based on their relative ages, they can be separated into two sets:

1) northwest-trending folds and

2) northeast-trending folds.

The northwest-trending fold set is the oldest of the group. They are deformed by the northeast-trending, large wavelength synclines as well as refolded by the younger northeast-trending, small wavelength fold set. Restcration of several of these folds with a stereonet shows that they originally plunged about 6 degrees S30E; axial surfaces for these folds are vertical.

One overturned fold is associated with this set and occurs in Sec. 26 (projected), T.1S., R.2E. Its fold axis plunges about 6 degrees S30E; the axial surface dips 78 degrees to the northeast.

The exact age of these folds is unclear. The presence of an overturned fold in this set suggests that these structures might be related to Fold Group 1 (the asymmetric folds). This is difficult to confirm, however, since overlying strata that might have been folded are eroded away.

The northeast-trending fold set is the youngest of the group. These folds plunge 2 to 3 degrees N38E; axial surfaces are vertical. Fold axes of this set are parallel to the axial trace of the large northeast-trending anticline of Fold Group 2. They are situated in the core of a northeast-trending syncline in Sec. 26 (projected), T.1S., R.2E. One anticline is intruded by a Tertiary-age Andesitic dike; the trend of the dike coincides with the folds axial trace.

Other small wavelength folds occur in Sec. 3, 4, 9, and 10, T.2S., R.2E., north of Canoncito de la Uva. Their fold axes plunge 4 degrees N22W; the axial surfaces are vertical. They are associated with complex faulting and affect the Bursum Formation and Madera Limestone. In the W 1/2, W 1/2, Sec. 3, T.2S., R.2E., the lower contact of the Abo is also folded, although the fold does not seem to propagate into the overlying mudstones. However, structural data is difficult to get in the Abo; complex faulting in these sections also makes fold recognition hard.

One fold in Sec. 10, T.2S., R.2E. is overturned to the southwest and involves both Bursum and Madera. At Canoncito de la Uva, the axial surface dips about 40 degrees northeast. The axial surface gradually becomes vertical in the NW 1/4, Sec. 10 and is then cut off by a north-northwest-trending normal fault. Reconnaissance shows that this fold persists in the Madera Limestone southeast of the map area; its extent in that region is not known. This particular fold does not seem to be related to any of the Group 1 folds. It may be related to overturned folds observed by Rejas (1965) in the Minas del Chupadero area.

Faults

Faults in the Sierra de la Cruz area include high angle normal faults, low angle detachment faults (called decollements by Bauch [1982]) and high angle reverse faults. High-angle faults are grouped according to their azimuths into northeast- and northwest-striking faults. A third category includes the low-angle detachment faults.

Northeast-Striking Faults

Northeast-striking faults are the dominant faults in the Sierra de la Cruz area. They form 3 distinct zones that include:

1) The Montosa Fault Zone which crosses the southeast corner of the map area;

2) the Stapleton-Alamillo Fault Zone, which crosses Sec. 22 (projected), 27, 33 and 34, T.1S., R.2E. and Sec. 4, T.2S., R.2E.; and
3) the Canoncito de la Uva Fault Zone which crosses Sec. 28, 32 and 33, T.1S., R.2E. and Sec. 5 and 8, T.2S., R.2E.

Each zone is labled on figure 2.

Montosa Fault Zone- The Montosa Fault Zone strikes N35E and separates upthrown Madera Limestone, Bursum and Abo Formations and the Meseta Blanca Member of the Yeso Formation on the east from downdropped Meseta Blanca and Torres Members on the west. It is not well exposed; the trace was determined by mapping the distribution of formations within and around the fault zone itself. It extends northeastward out of the map area to Abo Pass (Wilpolt and Wanek, 1951; Wilpolt and others, 1946; and Stark and Dapples, 1946). Southwest of the map area, it apparently dies out along the south edge of Sec. 23, T.2S., R.2E.

Dip of the fault planes in the zone is variable. In the NW 1/4, NW 1/4, NE 1/4, Sec. 1, T.2S., R.2E., it dips 60 degrees southeast while in the SW 1/4, Sec. 1 it dips 85 degrees southeast. 60 degrees southeast was taken to represent the dip of the fault zone in this area. North of the study area in Abo Pass and along the east side of the Los Pinos Mountains, the Montosa Fault Zone dips about 45 degrees to the west (Stark and Dapples, 1946).

The zone is 600 to 1500 feet (182.9 to 457.2 meters) wide. Individual faults form an anastomosing pattern (Plate 1). In cross section (Plate 2), the various faults are interpreted as being upward diverging strands of a master fault. This master fault becomes vertical with depth. Harding (1985) interprets such a pattern as belonging to a positive flower structure in a convergent wrench-fault system. The braided pattern dies out to the north in Sec. 36, T.1S., R.2E., and becomes a single fault.

Various formations crop out within the zone itself; Yeso, Abo, and Bursum Formations and Madera Limestone occur as blocks within the zone. The blocks are typically folded or tilted to some degree. Similar types of folding and slicing were observed by Stark and Dapples (1946) along the trace of the Montosa adjacent to the Los Pinos Mountains. They attributed these structures to imbricate thrusting along the fault trace. Stratigraphic juxtapositions range from upper Madera rocks against the Torres Member of the Yeso Formation in the SE 1/4, NW 1/4, Sec. 1, T.2S., R.2E. to Bursum Formation against lower Torres and Meseta Blanca Members in the E 1/2, NE 1/4, Sec. 11 where the fault passes out of the map area. Apparent overall stratigraphic throw varies between about 900 feet (274.3 meters) on the south to 1330 feet (405.4 meters) in the SE 1/4, NW 1/4, Sec. 1.

Stapleton-Alamillo Fault Zone- The Stapleton-Alamillo Fault Zone strikes N30E to N40E and separates upthrown Meseta

Blanca and Abo strata within the zone from down dropped lower Torres Member on the east. A low-angle detachment fault forms its western boundary and is concealed by valley alluvium; Triassic rocks are exposed further west.

The zone varies from 1500 to 3800 feet (457.2 to 1158.2 meters) in width. Dips on a few fault planes range from 60 to 68 degrees southeast, similar to the Montosa Fault Zone. Stratigraphic throws within and east of the fault zone range from 50 to over 300 feet (15.2 to over 91.4 meters). The zone has an overall appearance like that of the Montosa Fault Zone; slices of older units are faulted in with younger units within the zone itself. The principal differences are, 1) the Stapleton-Alamillo Fault zone does not display the anastomosing pattern of the Montosa Fault Zone and 2) stratigraphic throws are not as great as those found along the Montosa Fault Zone. The Stapleton-Alamillo Fault Zone dies out in the NW 1/4, Sec. 4, T.2S., R.2E.; decreasing stratigraphic displacements make the zone hard to trace. No connection could be established between the Canoncito de la Uva Fault Zone and the Stapleton-Alamillo Fault zone.

Canoncito de la Uva Fault Zone- The Canoncito de la Uva Fault Zone strikes N35E and gradually loses its identity northeast of the NE 1/4, Sec. 5, T.2S., R.2E. (figure 2 and Plate 1). To the south it separates upthrown Abo to San Andres rocks on the east from down dropped Dockum, Cretaceous and Tertiary rocks on the west.

The zone varies in width from 300 to 1200 feet (91.4 to 365.8 meters). It has a step-like geometry along the southern exposures where rocks of the Meseta Blanca and Torres Members lie in a block between Abo Formation on the east and Baca Formation on the west. This intermediate block is itself severely faulted and tilted, imparting a folded aspect to the strata; no actual folding was observed in this zone.

The faults are poorly exposed throughout the entire length of the zone in the study area. Reconnaissance to the southwest shows that although the fault planes are poorly exposed, the stratigraphic juxtaposition is well developed and can be easily traced into the Coyote Hills. Observed dips of the fault surface range from 60 to 62 degrees west. Slickensides show that latest movement was dip slip with subordinate left slip of the down-thrown block. Stratigraphic throw across the zone varies from 900 to 1500 feet (274.3 to 457.2 meters).

Northwest-Striking Faults

Northwest-striking faults are mainly distributed in the west half of the map area. A few northwest-striking faults occur in the east half of the map area but generally these are not as well developed as those in the west. Fault strikes vary from N15W to N60W; they are somewhat curvilinear. Locally, a few of these become north-south or northeast-striking, and merge with the northeast-striking faults.

Most of the faults are normal though several in Sec. 5 and 10, T.2S., R.2E. have reverse displacement. Fault plane dips range from vertical to nearly 35 degrees; dip direction can be either northeast or southwest. Stratigraphic throw is relatively small and ranges from less than 10 feet (3.0 meters) to about 150 feet (45.7 meters).

Many northwest-striking faults cross into exposures of the Abo Formation where they cannot be readily traced. Since the Abo consists mainly of soft mudstones and discontinuous, thin sandstones, there are no adequate markers for tracing faults through this unit. Many faults appear to die out in the thick mudstones. Some northwest-striking faults were mapped through the Abo on the basis of an apparent lack of section. Others were located on aerial photos as light-colored lineations that connect with faults mapped in the overlying Meseta Blanca Member. Only those faults which could be traced with certainty are shown as solid lines on Plate 1.

Northwest-striking faults are usually truncated by northeast-striking faults. In several cases, however, the opposite is true. Where this occurs, the northeast-striking faults developed after or at the same time as the northwest-striking faults and are probably not related to any of the main northeast-striking faults.

Low-angle Detachment Faults

Low-angle detachment faults occur in two general locations in the Sierra de la Cruz area:

a) around the type section of the Yeso Formation in Sec. 28, 32, 33, and 34, T.1S. R.2E. and Sec. 5, T.2S, R.2E. and

b) in a northeast-trending series of hills which include Sierra de la Cruz in Sec. 25 (projected), 35 and 36, T.1S., R.2E. and Sec. 2, T.2S., R.2E.

These faults are wide spread throughout much of the region east of Socorro (Smith, 1983). They occur from north and west of the field area (Rosen, 1983 and Smith and others, 1983) to as far south as the Carthage area (Maulsby, 1981; Bauch, 1982 and Fagrelius, 1982). Bauch (1982) calls them "decollements" in the Loma de las Canas area.

In the study area, low-angle detachment faults have dips that range from 0 to 10 degrees. They are locally irregular or undulose and usually occur at several stratigraphic levels. These include the upper Torres, Canas Gypsum and Joyita Sandstone Members of the Yeso Formation, lower Glorieta Sandstone, lower to middle San Andres Formation and, probably, the lower to middle part of the Dockum Group as well. The fault planes are typically coincident with bedding planes; at least four vertically separated movement planes can be identified in the type section of the Yeso Formation.

These faults can be divided into two general classes based on the ages of the autochthonous (foot wall) rocks. The first type of low angle faults consists of those that separate younger rocks above from older rocks below. The allochthonous (hanging wall) rocks include (in ascending order) the upper Torres, Canas Gypsum, and Joyita Sandstone Members of the Yeso Formation, Glorieta Sandstone, and San Andres Formation. The autochthonous (foot wall) rocks include the Meseta Blanca and Torres Members of the Yeso Formation. No allochthonous rocks were found resting on either the Abo or Bursum Formations or on the Madera Limestone in this area.

The Canas Gypsum Member occasionally occurs above and below the low-angle detachment faults as large elongate pods of laminated and locally, recrystallized gypsum. These occur in two localities: at the type section of the Yeso Formation in Sec. 33, T.1S., R.2E. and at Sierra de la Cruz in Sec. 36, T.1S., R.2E. These pods are no more than a mile (1.6 kilometers) in width; their lengths are not known because they are poorly preserved. General field relationships suggest that their long dimensions are oriented approximately north-south. Although field evidence is lacking, these elongate pods resemble the turtle back structures of Death Valley. Wright and Troxel (1973) and Davis (1984) both consider those features as fault-mullion structures formed by early to middle Tertiary, low-angle detachment faulting. It may be that the pods observed in the study area originated in a similar fashion.

Where the Canas Gypsum Member is well preserved, it is overlain by a complete, or nearly complete section of the Joyita Sandstone Member. Near the edges of the pods, the

Joyita Sandstone and Canas Gypsum Members wedge out and Glorieta Sandstone rests on the Torres Member. This wedging is well displayed in the NE 1/4, SE 1/4, Sec. 2, T.2S., R.2E. and in the NE 1/4, NW 1/4, Sec. 33, T.1S., R.2E. Where the Canas Gypsum Member is absent, the Glorieta Sandstone and San Andres Formation dip into the fault surface and overlie asymmetric folds in the upper or middle Torres Member. The asymmetric folds, in turn overlie another low-angle detachment fault; the folds having formed due to a shear couple between the two fault surfaces. Folded Torres generally does not occur directly beneath any exposures of the Canas Gypsum Member within the study area. However, some folding has taken place under the edge of one pod at the type section of the Yeso Formation in Sec. 28 and 33, T.1S., R.2E. At this location the Canas Gypsum Member is thinning rapidly and complex folds appear at or beneath the edge of the gypsum pod itself.

The second type of low-angle detachment faults are those that separate older rocks above from younger rocks below. The allochthonous rocks consist of the Meseta Blanca, Torres, Canas Gypsum and Joyita Sandstone Members of the Yeso Formation, Glorieta Sandstone, San Andres Formation and lower to middle (?) Dockum Group; autochthonous rocks belong to the Triassic Dockum Group. This older-over-younger relationship is not well exposed in the study area except for an isolated outcrop in the W 1/2, NE 1/4, Sec. 28, T.1S., R.2E. Here, Dockum Group underlies allochthonous

Glorieta Sandstone and San Andres Formation. Colluvium and valley alluvium conceal the remaining faults; their positions were inferred from apparent juxtapositions of older-on-younger rocks and from the sinuous nature of outcrop patterns in the west half of the map area where Yeso-age rocks are closely associated with Dockum-age rocks.

This relationship is better exposed outside of the field area. Older-over-younger faults occur in outcrops north of the study area where Rosen (1983) mapped allochthonous Yeso, Glorieta, and San Andres strata overlying autochthonous Cretaceous and Triassic rocks. Other hills west of this outcrop also have older-over-younger low-angle detachment faults.

In Sec. 22 (projected) of the map area, lower Yeso Formation appears to have been thrust over the Dockum. The faulted contact between Yeso rocks on the east and Dockum rocks on the west is sinuous. A test hole drilled by New Mexico Bureau of Mines and Mineral Resources to locate the sole of the thrust failed to reach its objective; the hole was abandoned because of drilling problems (Osburn, 1983). Still, outcrop relationships suggest a thrust fault concealed beneath alluvium west and south of the Yeso outcrops in Sec. 27. Rosen (1983 and in Smith and others, 1983) interprets these same exposures as a low-angle fault contact. This interpretation is also shown in Plates 1, 2 and 3.

In the NW 1/4, Sec. 34, Dockum-age rocks are also in fault contact with Yeso strata (mainly the Meseta Blanca Member). The stratigraphic throw at this outcrop is approximately 1800 feet (548.6 meters). East of this location, similar outcrop relations can also be inferred. The valley draws to an apex in this area and is floored by Dockum rocks surrounded on the east, west, and south by hills of lower Permian rocks. Moreover, the hills immediately to the west are capped with klippen of San Andres which rest on normal faulted Torres and Meseta Blanca Members. The apparent "crowding" of rocks with large age differences and the sinuous nature of the contact suggests a thrust-faulted contact with Triassic strata exposed in a half fenster through Permian strata.

This half fenster is elongated north-south and is floored by the Dockum Group, mainly covered by valley alluvium. The low-angle detachment fault outcrop shown on Plates 1 and 3 and figure 2 was approximated by mapping the first occurrences of Dockum float in valley alluvium exposed in arroyo walls along the west side of the valley. The position of the fault along the east side of the valley could only be approximated using outcrops of the Dockum Group and San Andres Formation in the NW 1/4, Sec. 27, T.1S., R.2E. The fault contact becomes more obscure southward. It may dip beneath Torres and Meseta Blanca Members, and the Abo Formation exposed in the S 1/2, Sec. 34. West dip of the fault surface is suggested by presence of Triassic rocks in the valley west of the type section of the Yeso Formation. Further evidence can be found in outcrops in the W 1/2, W 1/2, NE 1/4, Sec. 28 mentioned above and in the SE 1/4, NE 1/4, Sec. 32 where Permian rocks (Torres Member and Glorieta Sandstone) are in very close association with the Dockum Group. Many allochthonous blocks are cut by northeast-striking faults and, locally, lie across them. They are also deformed by the large upright folds in the central part of the map area. These relations show that the low-angle detachment faults are older than the large upright folds and both older and younger than the northeast-striking faults.

In many places, the allochthons are broken by normal faults. These faults extend only to the sole fault and not beyond. They are well exposed at the type section of the Yeso Formation and around Sierra de la Cruz. Here, faults that break the klippe cannot be traced below the sole fault into the underlying Canas Gypsum or Torres strata. These faults cause rotation of some allochthons and may account for some of the wedging. Unfortunately, very few remain in the study area so a determination of how they affected the allochthons cannot be made. These faults probably formed at the same time as the low-angle detachment faults.

Other structures associated with the low-angle detachment faults include small, isolated, lozenge-shaped blocks of Permian rocks enclosed by fault surfaces. These duplexes (also called tectonic horses) are usually made up of Yeso-age rocks, but other units such as the Dockum Group or Mancos Shale may also be involved.

One duplex in the SW 1/4, SW 1/4, NE 1/4, Sec. 28, T.1S., R.2E. consists of a triangular block of Torres Member surrounded on the sides by Glorieta Sandstone, on top by San Andres Formation and beneath by Dockum Group. Another possible duplex is located in the NW 1/4, SW 1/4, Sec. 28 where a block of Dockum has been faulted in next to San Andres and Glorieta. Exact structural relationships at this outcrop are not very clear.

Other small duplexes occur outside the study area. Rosen (1983) and Smith and others (1983) show several in the east slope of Mesa del Yeso, immediately west of the study area. Boyer and Elliott (1982) state that tectonic horses (small duplexes) are common in the more internal, older and deeper parts of thrust belts. Knipe (1985) suggests that small duplexes form when the sole fault takes a "short cut" through a large irregularity in the footwall of a low angle thrust. He also believes that these features are associated with moderate to rapid displacement rates in the overlying allochthon.

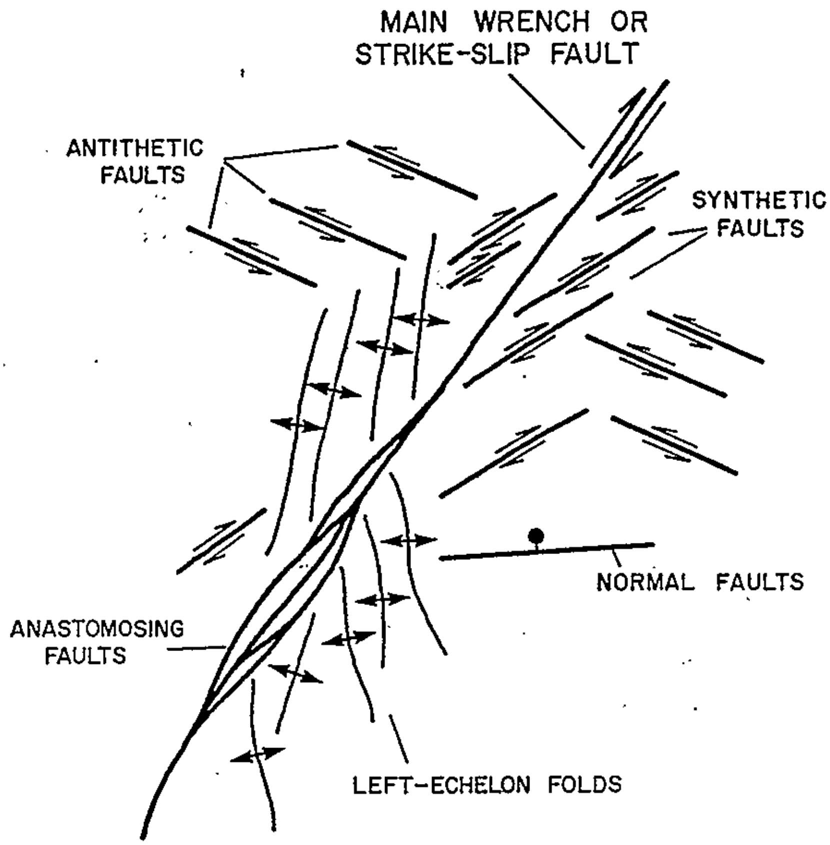
Although the general geometry of the low-angle detachment faults and their associated allochthons is not well preserved, it may resemble a ramp-decollement geometry, as proposed for non-rotational extension faults by Wernicke and Burchfiel (1982).

Structural Development

At first glance, the multitude of structures in the Sierra de la Cruz area appears confusing. However, two dominant structural features are apparent: 1) low-angle detachment faults and 2) northeast-striking faults with considerable stratigraphic displacement. The low-angle detachment faults appear to be the oldest recognizable structures in the study area. Plate 2 shows that the allochthonous blocks occupy a lower structural position than similar rocks east of the Montosa Fault Zone. Reconnaissance work several miles east of the study area confirms the presence of low-angle detachment faults confined to the upper Yeso Formation (Torres, Canas Gypsum, Joyita Sandstone Members)-Glorieta Sandstone interval. When this low-angle fault is projected westward, there is considerable offset at the Montosa Fault Zone. This suggests that the detachments developed before the Montosa Fault Zone.

The age of the detachment faults can be estimated by not only establishing their structural relationship to the Montosa Fault Zone but also by estimating a relative age for the development of the Montosa Fault Zone itself. Chapin and Cather (1981) proposed a two-stage Laramide Orogeny based on regional structural relationships, sedimentologic studies in various late Cretaceous to Eocene-age basins in the Rocky Mountains and Plate Tectonic evidence. They divide the Laramide into an early phase where the greatest compressive principal stress direction was oriented N70E from late Cretaceous to middle Paleocene time and a late phase where the greatest principal stress direction changed to approximately N45E during latest Paleocene to middle Eocene time. During this late phase, a broad zone of decoupling formed along the axis of the modern Rio Grande rift made up of a series of en-echelon fault strands. Two of these strands pass through the Sierra de la Cruz area and are named the Montosa Fault Zone and the Canoncito de la Uva Fault Zone.

As stresses increased early in the Laramide a series of north-trending, left-echelon folds developed along the present trace of the Montosa Fault Zone. Subsequently, a through-going master right slip fault striking N30E to N35E developed across the folds. The folds developed because of east-northeastward translation of the Colorado Plateau into the North American craton (Chapin and Cather, 1981). Right slip may have started at this time and become better developed as the stress orientations changed from N70E to N45E. The sequential development of structures listed above is based on experimental models developed by Wilcox and others (1973) and Reading (1980) for a transpressive, right-lateral strike slip fault. Figure 5 shows the relationship of the Montosa Fault Zone and the left-echelon folds associated with it. It also shows structures that might be expected with a right lateral strike slip fault system (on the overlay). This figure suggests that the Montosa


MAIN WRENCH OR
STRIKE-SLIP FAULT
ANTITHETIC
FAULTS
SYNTHETIC
FAULTS
NORMAL FAULTS
ANASTOMOSING
FAULTS
LEFT-ECHELON FOLDS

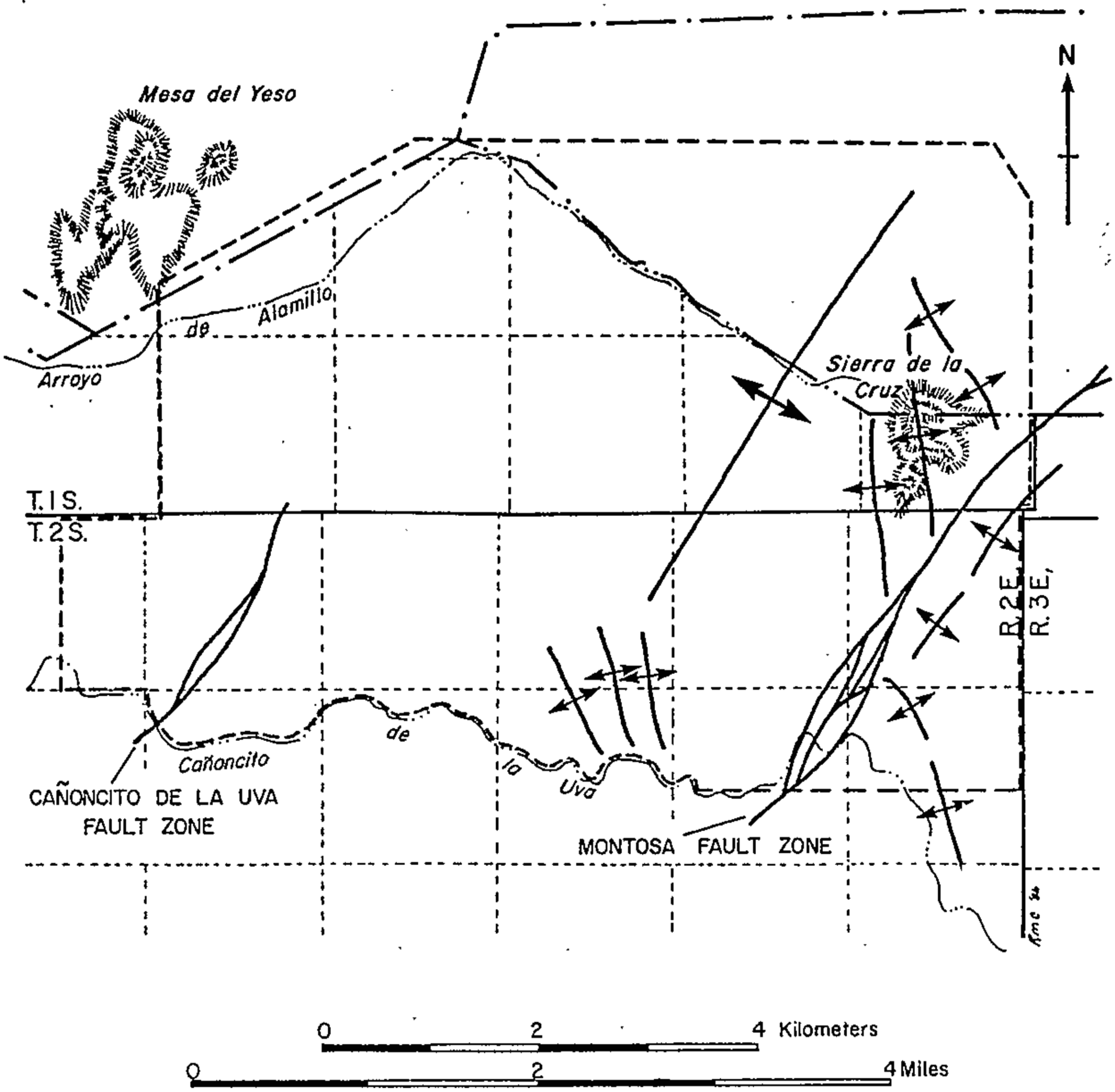


Figure 5 -- Relationship of Montosa Fault Zone, Canoncito de la Uva Fault Zone, left-echelon folds and the large, northeast-trending fold, Sierra de la Cruz area. Overlay shows structures associated with a right-lateral strike-slip fault system.

with shallow dipping flanks is all that is needed to produce low-angle detachments.

Kelley and Duncan (1984) observed that the Sandia Uplift was very active from late Cretaceous to early Eocene time with strongest uplift occurring on the northern end of the range. Uplift decreased southward toward the modern Los Pinos Mountains. This activity may have produced a south-dipping ramp from which Permian, Triassic and Cretaceous (?) strata might have moved. Any ramps or earlier structures were probably down faulted into the Rio Grande rift during middle or late Tertiary time.

Some evidence for possible movement of detached sheets along a northeast-southwest trend is in the nature of the folding in the Torres and Canas Gypsum Members. Figure 4 shows the relationship between overturned folds, Canas Gypsum outcrops and allochthonous blocks and their structures. Fold axial surfaces display a symmetry in the direction of overturning with those in the west verging east and the easterly ones verging west. The symmetric arrangement of these folds is remarkably similar to the pattern proposed by Suppe (1985) for sub-thrust drag folds. Figure 6 based on Suppe (1985) illustrates this concept. Differences in shear stress can develop beneath an allochthon in underlying duplexes as the allochthon continues to move. These differences cause local changes in drag along the base of the allochthon and force folds to distend in the transport direction of the allochthon. The

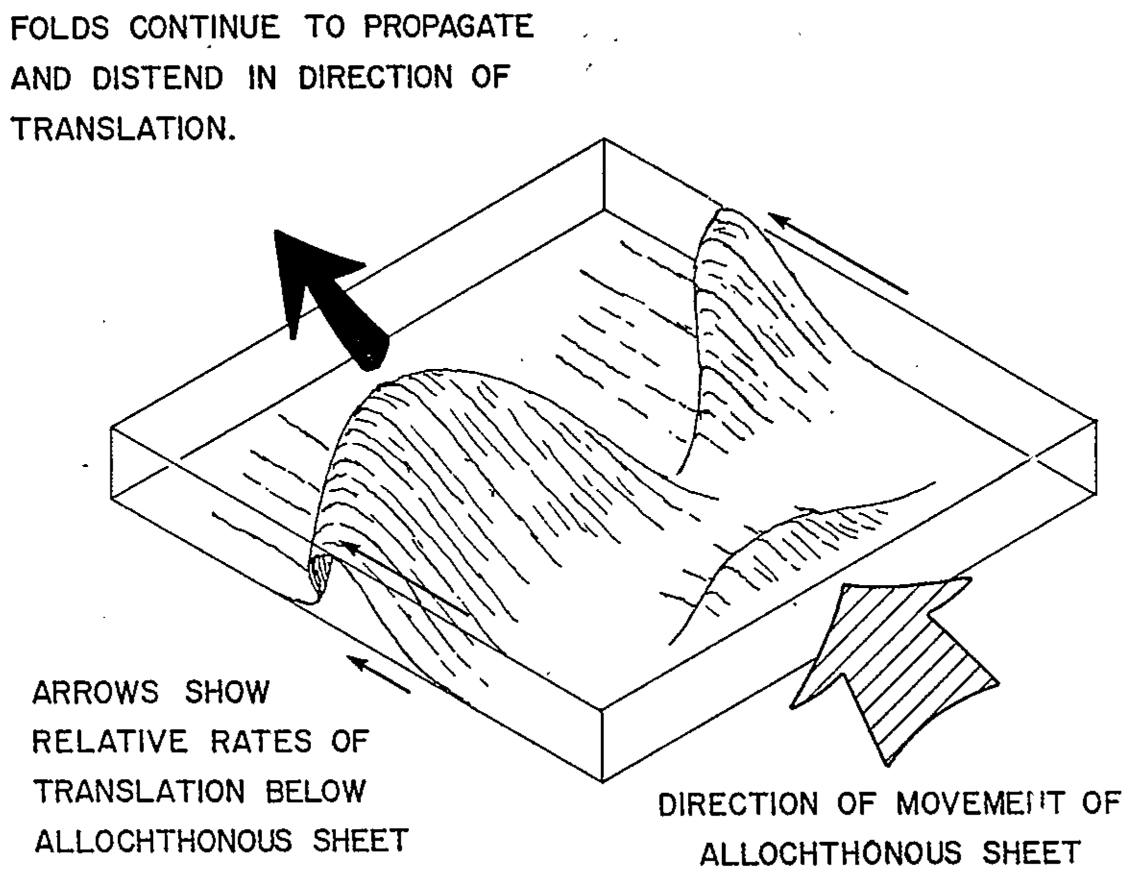


Figure 6 -- Development of overturned folds as a result of drag below a moving allochthonous sheet (after Suppe, 1985).

result is an apparent rotation of fold axes into the general propagation direction of the allochthonous sheets. Kehle (1970) reports that this type of folding is common in duplexes where there is pronounced differential slip between two low-angle fault surfaces or across a zone of detachment.

Other evidence lies in the distribution of outcrops of the Canas Gypsum Member and structures in the allochthons shown in figure 4. Field evidence suggests that the gypsum outcrops were once much larger and were elongated in a north-northeasterly direction. The differences in shear stresses described above were probably responsible for their orientations and elongation.

Another structural high lies south of the map area and is the southwest extension of the large upright anticline in the central part of the field area. This structure is one possible source but several questions about it need to be answered before it can be considered. The first of these is timing. If this fold developed at the same time as the strike-slip faults, then it cannot be the source for the older low-angle faults. However, it might be a source for the allochthons in the upper duplexes. More field work will need to be done to establish how this structural high contributed to the overall distribution of allochthonous blocks. The second question concerns the duration of movement of the upper allochthons on the detachment surfaces. Since there has been movement on the shovel-shaped faults in the volcanic pile west of the field area during Tertiary time (Smith and others, 1983), there may also have been continued movement on detachment faults in the study area as well. Moreover, is that movement related to Miocene extension in the Rio Grande rift? The relationship of the low-angle detachments to the shovel-shaped faults cannot be established without additional field work. Since the study area is not large enough to answer the above questions conclusively, the presence of a southern source area for the allochthons will remain problematic until more field work is done.

The possibility of an uplift west-southwest of the field area must also be considered. Cather (1983a) and Cather and Johnson (1984) showed that an uplift at the present location of Socorro existed during Eocene time and served as the source area for the Baca Formation. Much of the Baca rests on an erosional surface that truncates tilted Cretaceous to Pennsylvanian strata (Smith, 1983). If this uplift were the source of the allochthonous blocks, then movement must have started during the initial stages of uplift prior to the beginning of Baca deposition. No allochthons resting on Baca strata can be demonstrated on the east side of the Rio Grande. Evidence for movement from the west is inconclusive.

Mechanical models for development of detachment faults.

Many models have been proposed for the emplacement of thrust sheets and nappes. Each has its advantages and disadvantages. Most models were developed to explain how large areas of allochthonous rocks could overcome frictional resistance to movement and still move great distances from their original source areas. They were proposed to explain the mechanical enigma associated with the movement of thrust sheets, taking into account their dimensions and physical properties (Hubbert and Rubey, 1959).

These models have been applied to the study of orogenic translation in low-angle detachment faulted terrains where no push from the rear is evident. The models most often used include:

1) high fluid pressures that are close to the lithostatic gradient; the fluid is mostly water and is either connate or is derived from dehydration of minerals, e.g. gypsum, and
2) translation on some layer that is much less viscous than rocks in the hanging wall block (such as halite, gypsum, anhydrite or shale).

In the Sierra de la Cruz area, about 3600 feet (~1100 meters) overburden was available to confine the detachment planes at or below the Joyita Sandstone Member of the Yeso Formation. This includes a complete section of Cretaceous and Triassic rocks with a partial section of Permian rocks and assumes no Baca Formation present at the time of initial movement. Average density values for these units were derived from wireline logs for wells in nearby areas and used to estimate the lithostatic pressure (vertical stress) at the levels where faults occur. A value for lithostatic pressure of 240 bars (24 MPa) was calculated using that data.

Confining pressure used in experimental studies ranges from 0 to 5000 bars (0 to 500 MPa) (Handin and others, 1963 and Heard and Rubey, 1966) and equals burial depths of 0 to 9.1 miles (0 to 14.7 kilometers). Temperatures used in these models range from about average surface temperature of 40 to 60 degrees F (4.5 to 15.6 degrees C) to more than 500 degrees F (260 degrees C) (Heard and Rubey, 1966). Temperatures along the low-angle faults at the time of sliding are not known but must have been about 100 to 110 degrees F (38 to 43 degrees C), assuming a normal geothermal gradient.

High pore pressures were proposed by Hubbert and Rubey (1959) and Rubey and Hubbert (1959) as a possible way of offsetting lithostatic pressures and reducing the shear stress. With pore pressure and an appropriate slope, very little force would be required to produce a differential stress adequate to cause the allochthon to move. High pore pressures require water and some way to seal it into the rock so that the pore pressure can exceed the hydrostatic pressure. Any permeable pathway will allow pressures to vent. Since the Paleozoic section (especially the Permian section) was well lithified at the time of movement, compaction can be ruled out as a source for increased pressure. However, the Permian section in this area consists of sandstone with minor interbedded carbonate, evaporite, and mudstone (largely confined to the Abo Formation). Wireline logs from nearby areas where the Permian section is still deeply buried show porosity values from 0% to 15%. The lowest porosity values occur in the carbonates and evaporites in the upper Torres and Canas Gypsum Members of the Yeso Formation. It is possible that these lithologies acted as seals, preventing the release of high pore pressures. What effect the lateral continuity of these beds had on the venting of high pressures is not certain. If the build up of high pore pressures was rapid (in terms of geologic time), then they may have played an important role in the development of low-angle detachment faults in this area. What role compressive stresses during the early Laramide played in the development of high pore pressures cannot be clearly established.

Gypsum dehydration is another important process that may have contributed to the development of the detachment faults. Gypsum is particularly abundant in the upper part of the Torres Member and is the dominant lithology in the Canas Gypsum Member. Many detachment faults occur within this stratigraphic interval throughout this region. The main assumption that is made here is that the gypsum was not originally anhydrite or recrystallized to anhydrite following deposition. The presence of laminations in gypsum in the field area suggests that it has not been recrystallized by diagenetic processes.

Heard and Rubey (1966) performed experiments on gypsum samples to try and discover how dehydration affected the physical properties of the rock, such as strength and yield point. They found that when gypsum is heated and then subjected to high confining pressures (5000 bars [500 MPa]) it passed first to hemi-hydrate plus water then to anhydrite plus water. During the transition to hemi-hydrate, rock strength approached zero; a result of chemical bonds being broken during the release of water (Heard and Rubey, 1966, pg. 744).

Heard and Rubey (1966) observed that at the threshold where gypsum changed to hemi-hydrate plus water, as little as 2% strain was required to produce a differential stress equal too or exceeding the strength of the rock. Failure would then occur with the entire mass of gypsum probably flowing as a viscous body. Addition of water to the connate water already present could have caused locally high pore pressures, further reducing the force required to move an allochthonous sheet.

The change from gypsum to anhydrite-plus-water can occur with temperatures as low as 40 degrees C (104 degrees F) at 1100 meters (the depth to the top of the Canas Gypsum Member) (Heard and Rubey, 1966, fig. 5). This suggests that assuming a normal geothermal gradient, the dehydration process may have been under way for a long period of time.

Failure may have resulted as the gypsum passed the anhydrite-plus-water threshold. Any gypsum involved in the dehydration and subsequent movement should show effects of recrystallization.

Some gypsum in the study area has been recrystallized but most of it retains its original laminated texture. Low-angle detachment faults pass through this laminated gypsum without a trace in most cases. The recrystallized gypsum is usually associated with folding in the Torres Member; folds form as a result of differential shear between two detachment faults. Because of the presence of laminated gypsum in the stratigraphic interval which includes the upper Torres-Canas Gypsum Members, gypsum dehydration cannot have occurred except locally.

The model proposed by Kehle (1970) states that displacement of large allochthonous sheets can easily be accomplished by deforming low viscosity strata by sinple shear. His contention is that this generates much lower shear stress than if a single, through-going detachment fault is used as the plane of dislocation.

Kehle (1970) also states that the difference in viscosity between the detachment zone and the moving, allochthonous plate need only be about one order of magnitude. Table 2 is a summary of rock viscosities derived by Handin (1966) and summarized by Kehle (1970). Kehle's viscosities are given in m.y.-bars; corresponding viscosities in poises are also listed. Figure 7 shows the

LITHOLOGY	VISCOSITY M.Y.-BARS	VISCOSITY POISES
Crystalline Rocks:	$10^{3} - 10^{5}$	3.14×10^{22}- 3.14×10^{24}
Silica-Cemented Sandstones:		
-Some Sandstones	10^{-1}	3.14×10^{18}
-Quartzites	10^{5}	3.14×10^{25}
Clay-Cemented Sandstones:	10^{-2}	3.14×10^{17}
Calcite- or Dolomite-Cemented Sandstones:	10^{2}	3.14×10^{21}
Shales:		
-Gulf-Coast Gumbo	10^{-5}	3.14×10^{14}
-Siliceous Paleozoic Shales	10^{1}	3.14×10^{20}
-Average Shales	10^{-1}	3.14×10^{18}
Carbonates f(temperature):		
@ 68° F (20° C)	10^{2}	3.14×10^{21}
@ 725° F (400° C)	10^{-5}	3.14×10^{14}
Average	10^{1}	3.14×10^{20}
Bedded Salts f(temperature):		
@ 68° F (20° C)	10^{-1}	3.14×10^{18}
@ 392° F (200°C)	10^{-5}	3.14×10^{14}
Interbedded Limestone and Shale:	10^{0}	3.14×10^{19}
Gypsum (my estimate):	$10^{-2.5}$	1×10^{17}
Interbedded Gypsum, Limestone and Sandstone (my estimate):	10^{-2}	3.14×10^{17}
Brecciated Glorieta Ss. (my estimate):	10^{-1}- 10^{-2}	3.14×10^{17}- 3.14×10^{18}

Table 2 -- Summary of various rocks with their assigned values of viscosity (from Handin, 1966 and Kehle, 1970).

UNIT	THK. (M)	VISCOSITY M.Y.-BARS	VISCOSITY POISES	DENSITY (gm/cc)
Ku	610	10^{-1}	3.15×10^{18}	2.35
TRd	235	$10^{0}-10^{1}$	3.15×10^{19} – 3.15×10^{20}	2.3
Psa	185	10^{1}	3.15×10^{20}	2.6
Pg	61	10^{3}	3.15×10^{22}	2.25
Pyj	36	10^{1}	3.15×10^{20}	2.25
Pyc	39	$10^{-2.5}$	1.0×10^{17}	2.95
upper Pyt	77	10^{-2}	3.15×10^{17}	2.75
lower Pyt	79	10^{1}	3.15×10^{20}	2.6
Pym	91.4	10^{1}	3.15×10^{20}	2.5
Pa	208	10^{-1}	3.15×10^{18}	2.4

Figure 7 -- Lithostratigraphic packages and their estimated values of viscosity and density, Sierra de la Cruz area.

stratigraphic column for the Sierra de la Cruz area broken down into lithologic packages. Each package has been assigned an estimated viscosity both in m.y.-bars and in poises and an average density value derived from wireline logs of wells in adjacent areas.

Kehles model is an attractive one for this area for several reasons. The first is shallow burial. It does not require high pressures to bring about failure; movement may occur between 1 and 2 kilometers (3280 to 6560 feet) depth. The second is that it only requires a moderate viscosity contrast for the allochthon to start moving. The third is that it does not require a push from the rear (tectonic compression), high pore pressures (which Kehle believes are relatively rare in nature, especially when evaporites [gypsum, etc.] are present [Kehle, 1970, pg. 1652]) or even the presence of evaporites (as in the Heart Mountain Thrust described by Pierce, 1957). High pore pressures associated with evaporites (or from gypsum dehydration) would only reduce the viscosity in a detachment zone rather than "buoy up" the overburden (Kehle, 1970, pg. 1652). Movement only requires a gradient of about 1% (.5 degree slope) and instability in one of the layers for the sheet to slide.

Kehle (1970) also derived a set of formulas for calculating velocity of the moving plate, stress at the toe of the plate and for constructing velocity profiles through detachment zones to show relative dislocation rates. Figures 8 and 9 are graphs relating slope gradient to detachment

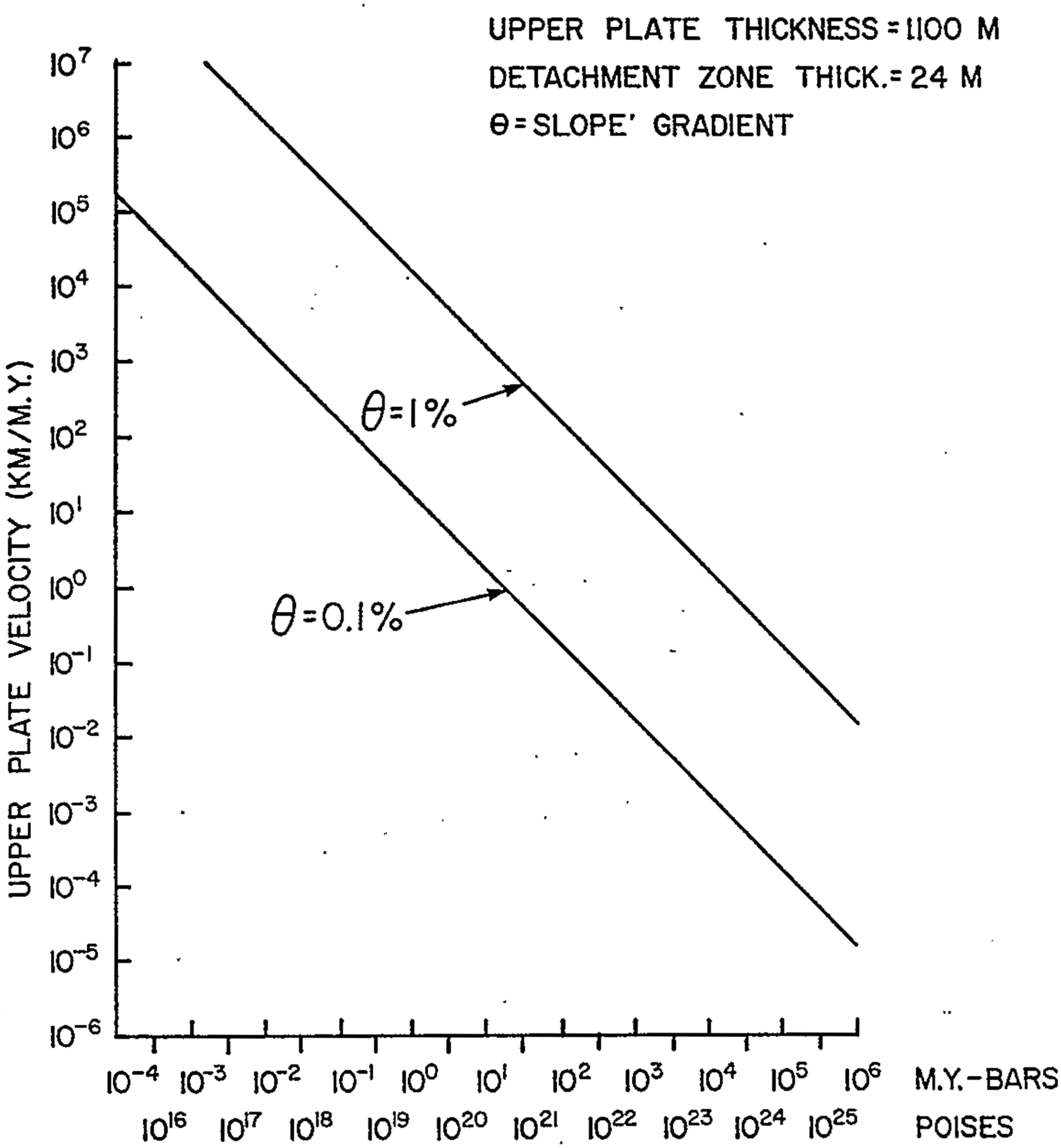


Figure 8 -- Graph of upper plate velocity (KM/M.Y.) versus detachment zone viscosity as a function of regional slope gradient, upper plate thickness and a detachment zone thickness of 24 meters.

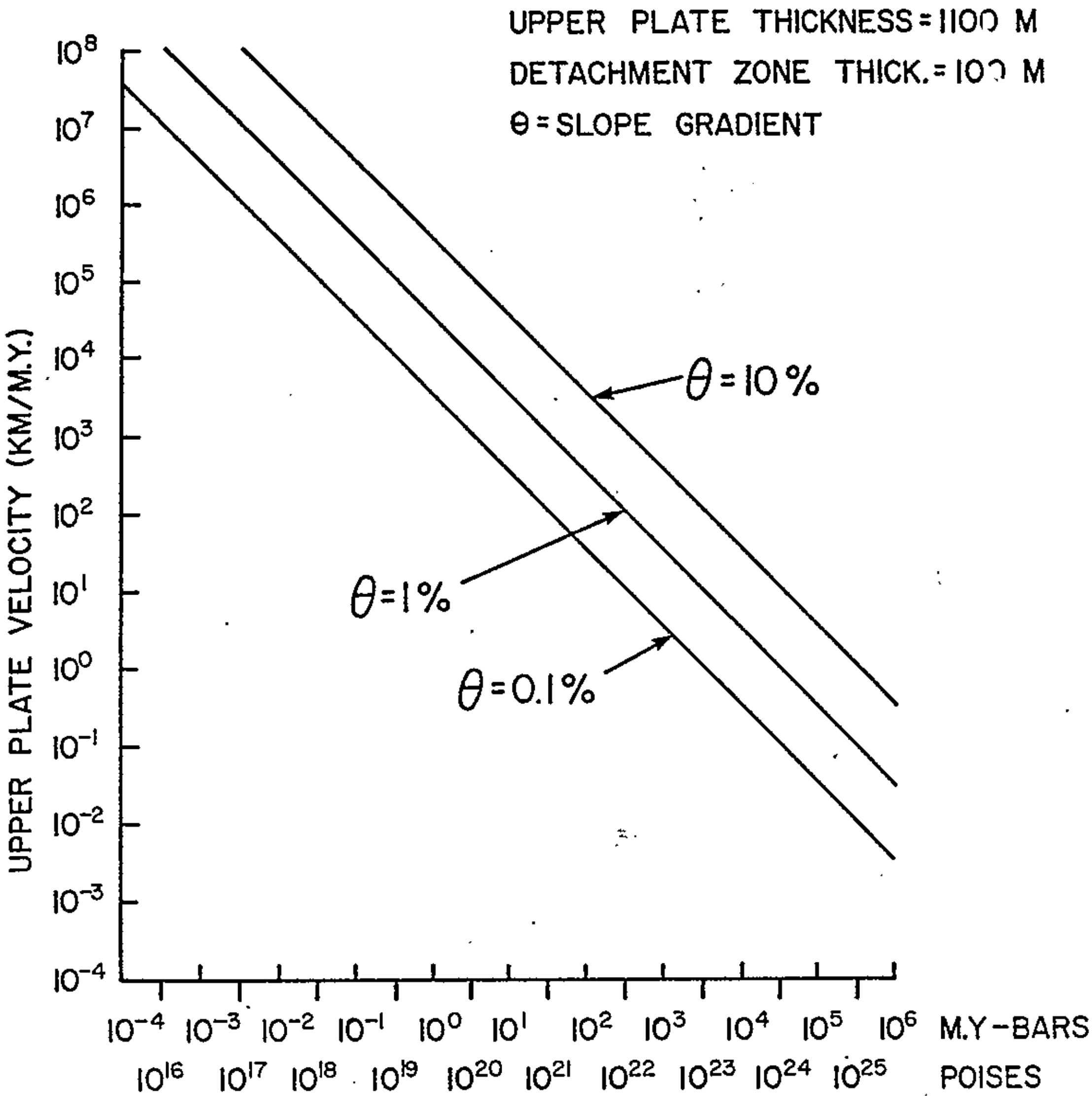


Figure 9 -- Graph of upper plate velocity (KM/M.Y.) versus detachment zone viscosity as a function of regional slope gradient, upper plate thickness and a detachment zone thickness of 100 meters.

zone viscosity and velocity of an allochthonous plate when the upper plate is 1100 meters (~3610 feet) thick and detachment zone thickness is 24 and 100 meters (79 to 328 feet). High velocity values for any given low viscosity value only indicate that instability occurs within a detachment zone at very low slope angles. It neglects irregularities in the slope that the plate moves over as well as any down-dip restraints it might encounter during translation.

Figures 10 and 11 show the generalized stratigraphic column for the Sierra de la Cruz area and velocity profiles through the detachment zones calculated for two different slope angles using Kehle's (1970) methods (pg. 1659-1662). Velocities were calculated assuming Newtonian (linear) behavior of the material during translation of the overlying allochthon. Kehle (1970) shows velocities calculated assuming both Newtonian and Power Law (non-linear) behavior for rocks in a detachment zone. Velocities assuming Power Law behavior were not calculated for figures 10 and 11 but should be lower than those illustrated (Kehle, 1970).

These figures show that by increasing slope angle slightly, there are large increases in velocity in the allochthonous block. They also give a general idea about maximum velocities for each slope angle. Once an original average slope angle is established for this region, velocity figures can be re-calculated and used to estimate stresses

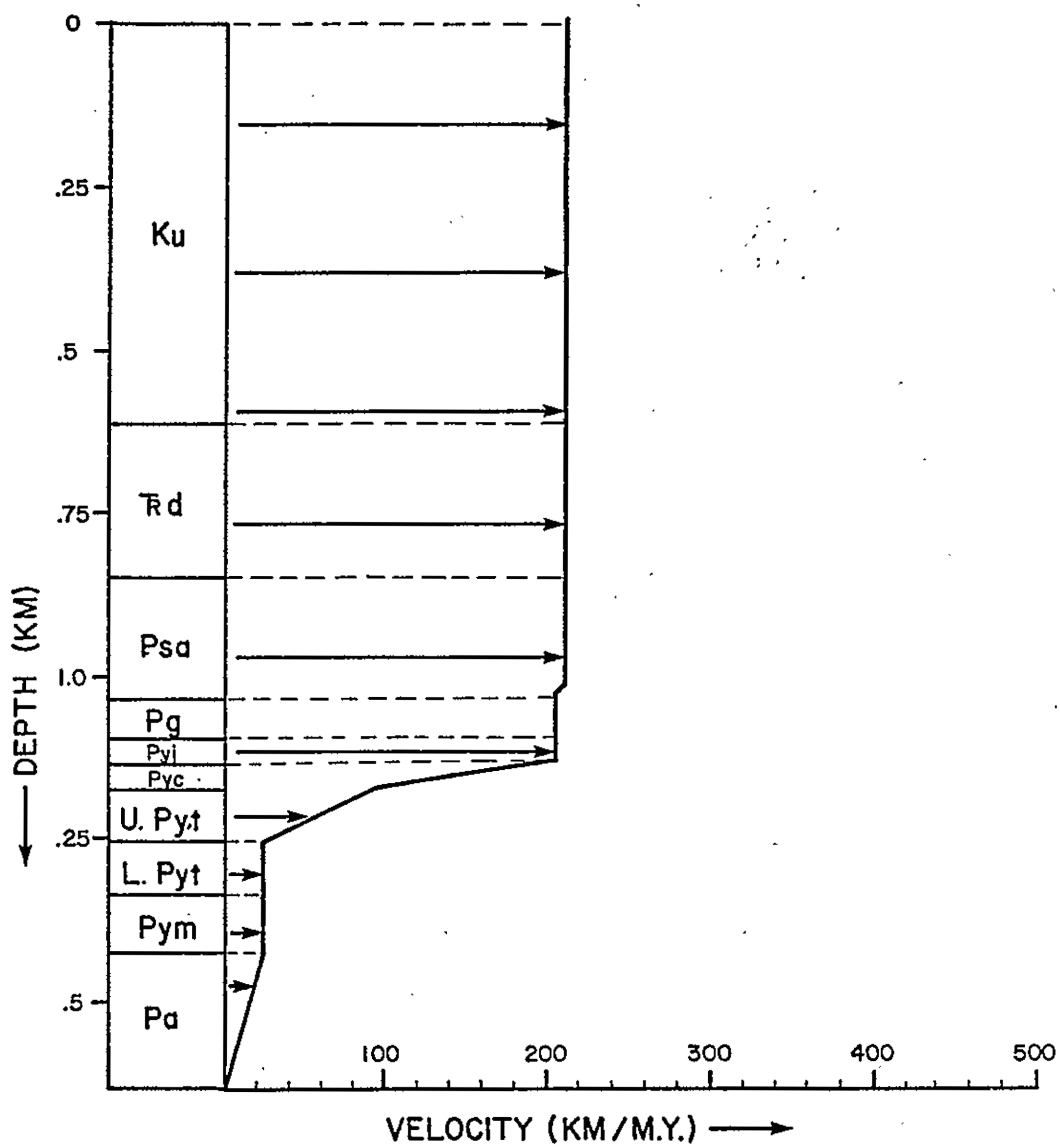


Figure 10 -- Calculated velocity profile using viscosity and density values listed in figure 7, assuming a slope gradient of 1.75% (slope angle = 1°).

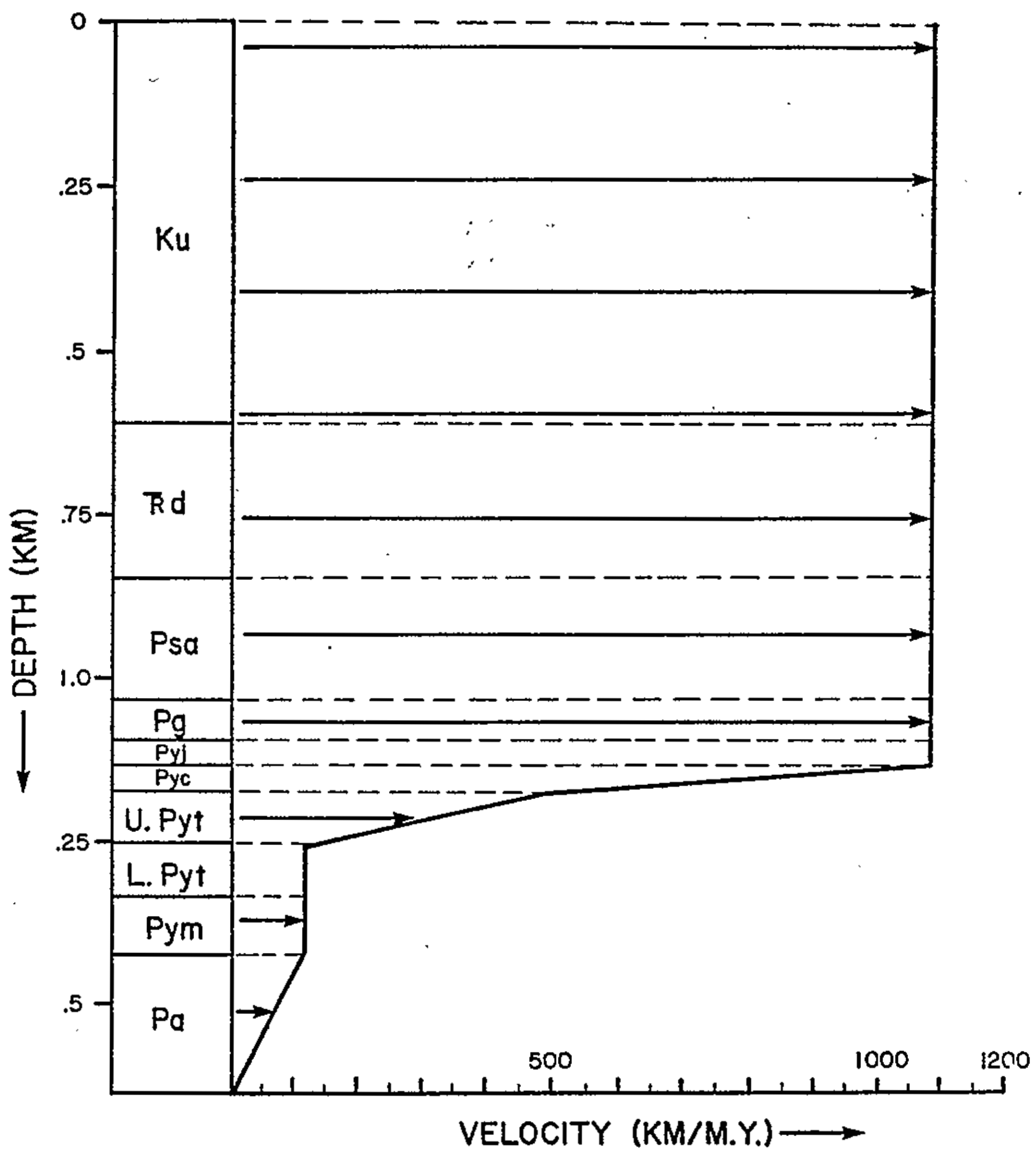


Figure 11 -- Calculated velocity profile assuming a slope gradient of 8.75% (slope angle = 5°).

along the front of the slide. Kehle (1970, pg. 1649 and 1650) discusses this technique. These stress estimates can then be used to confirm whether the estimated velocity of the allochthonous sheet is realistic or not.

The main disadvantage to Kehle's model is that it is relatively simplistic. He uses estimated viscosities for his calculations. Another small problem is that rocks cannot be assigned viscosities in the same way as a fluid. Handin (1966) refers to this property in rocks as "pseudoviscosity". This needs to be taken into account when calculating the velocity of an allochthonous sheet. Even so, this should not create much of a disadvantage.

Kehle's (1970) model is important for the region east of the Rio Grande for three reasons. First, the stratigraphic sequence is not overly complex, although some averaging of viscosities had to be done in the upper Torres-Canas Gypsum lithologic packages. Second, multiple detachments occur in the study area and are similar in some respects to the multiple decollement model shown by Kehle (pg. 1658). Third, it provides a simple explanation for the formation of the overturned folds in the study area. The calculations applied to the stratigraphic section in the map area show that differential movement is particularly strong in the interval occupied by the upper Torres and Canas Gypsum Members (figures 10 and 11). The simple shear exerted on this interval is responsible for the folding and tectonic thinning that developed in these rocks.

Kehle (1970) points out that stiff units in his model are mechanically isolated from rigid units above and below the detachment zone. He predicts that the stiff layer will fold regardless of any continuing deformation of the low viscosity rocks in the sequence. Folding will occur as long as there is a viscosity contrast of two orders of magnitude or more between the stiff layer and the surrounding rock.

This is very applicable to the upper Torres Member sequence which consists of interbedded sandstone, limestone and gypsum. This package contains most of the overturned folds in the study area; other folds occur lower in the section but are also associated with low viscosity strata (usually gypsum). According to Kehle, these folds form as creep develops below an incipient allochthon. Translation occurs during folding rather than vice-versa.

The main difference between Kehle's model and actual field observations in the study area is that low-angle detachment faults did form in the upper Torres, Canas Gypsum and Joyita Sandstone Members. Kehle states (pg. 1652, 1653 and 1658) that faults should not form during translation of allochthons over this type of sequence and that they either mark the boundaries of a detachment zone or occur in the toe of the allochthon. This difference may be a function of distance of transport, which cannot yet be established for this region or the proposed model (figures 10 and 11) does not exactly fit the actual conditions that existed during movement.

Late Cretaceous and Tertiary Structural History

The first evidence of extensive deformation in the Sierra de la Cruz area is related to the Laramide orogeny. Most of the early geologic history of this region has been summarized by other workers (see Baars, 1962; Siemers, 1978 & 1983; Maulsby, 1981; Bauch, 1982; Fagrelius, 1982; and Smith, 1983).

In late Cretaceous time the Laramide orogeny commenced in New Mexico with an episode of east-northeast directed compression. It culminated in late Eocene time with deposition of the Baca Formation and the onset of Oligocene volcanism (Chapin and Cather, 1981).

This compressional episode is directly related to the increased convergence rate between the Farallon Plate in the Pacific Ocean and the North American Plate. This allowed the Farallon Plate to be subducted at an increasingly shallow angle causing viscous coupling between the subducted plate and the continental crust of the Colorado Plateau (Chapin and Cather, 1981). As a result, the Colorado Plateau was pressed into the craton along a line of Precambrian and late Paleozoic crustal weakness. Although no actual thrusts or overturned folds related to this compression are evident in the study area, they do occur in areas to the south (Kelley and McCleary, 1960; Smith, 1983; and Smith and others, 1983). During this episode, the principal stress direction was oriented N70E and created uplifts and basins along or close to the axis of the modern

Rio Grande rift northward into the Wyoming province (Chapin and Cather, 1981, pg. 191).

During this period of compression and uplift, low-angle detachment faults developed across much of central New Mexico. Detachment occurred within a weak sequence of interbedded gypsum, sandstone and limestone in the upper Torres and Canas Gypsum Members of the Yeso Formation. As the allochthons started to move, shear stresses developed in low viscosity zones of slip resulting in formation of passive, overturned or recumbent folds. As folding and movement of the allochthons continued, low-angle detachment faults formed within and around the low viscosity zones. The direction that the allochthons moved is still not clear at this time. During or after the development of the low-angle detachments, north-trending folds began to form along the present trace of the Montosa Fault Zone. Subsequently, a through-going master fault developed with minor right-slip motion.

In late Paleocene to early Eocene time, the greatest principal stress direction rotated in response to counter-clockwise rotation of the North American Plate during the opening of the Norwegian Sea (Chapin and Cather, 1981 and Gries, 1983). With this rotation, the greatest principal stress direction changed to N45E (Chapin and Cather, 1981). This change caused increased right lateral strike slip motion between the Colorado Plateau and the North American Craton along a series of en-echelon faults. Two such faults occur in the Sierra de la Cruz area: the Canoncito de la Uva Fault Zone and the Montosa Fault Zone. The Stapleton-Alamillo Fault Zone cannot be clearly related to the other two at this time.

As the Montosa Fault Zone continued to develop, a series of anastomosing strands formed to help take up the shear stresses and possible transtension that developed on the fault. These are distributed in Sec. 1 and 12, T.2S.,R.2E.

Right slip cannot be easily demonstrated on the Canoncito de la Uva Fault zone, but other evidence suggests that it too is part of this right slip system. The Montosa Fault Zone terminates in Sec. 23, T.2S., R.2E., so strike slip motion has to step off in some direction. The most likely direction is west onto the Canoncito de la Uva Fault. With slippage occurring on two faults, the area in between was subjected to compression and some counter-clockwise rotation. As a result, a large northeast-trending upright anticline formed through the center of the map area. Based on the sequential development of structures listed above, this large fold is probably late Laramide in age. As this large fold formed, small wavelength, northeast-trending anticlines and synclines developed as parasitic folds with their axes parallel to that of the main fold.

As strike slip faulting continued, a series of asymmetrical uplifts developed along the axis of the modern

Rio Grande rift and shed sediments west, north and east forming the Baca Formation (Chapin and Cather, 1981; Cather, 1983a & b; and Cather and Johnson, 1984). These uplifts are also documented to the south by Brown and Clemons (1983) and Seager (1983).

At the start of Oligocene time, volcanism had commenced in the Socorro region, and is recorded by the presence of the Spears Formation volcaniclastics and the Hells Mesa Tuff west of the field area. Late Laramide stresses still had not entirely relaxed by this time. Evidence of this lies in the orientation of the andesitic dike in the northern part of the study area. Dikes are usually intruded parallel to the greatest principal stress direction (Ramsay, 1967), so the dike is probably Oligocene in age. To the west, extension started in the Rio Grande rift about 29 m.y.a. (Chapin and Seager, 1975). This extension may have contributed to continued movement on some of the low angle detachment faults.

As extension continued, some of the western-most faults were affected. These show dip slip with some left slip motion. Kelley (1978, 1979 and 1982) argued that there is good evidence for left-lateral motion on pre-existing strike-slip faults during rifting. This evidence includes oblique, left-slip faults, right-echelon folds, and displacement of basins and formation contacts across the rift. He estimates as much as 55 kilometers (34.2 miles) offset resulted from this motion. Wilpolt and Wanek (1951) show at least 2 to 3.5 miles (3.2 to 5.6 kilometers) of apparent left slip on the contact between the Meseta Blanca and Torres Members across the Canoncito de la Uva Fault Zone. Part of this displacement may also be due to normal faulting and earlier folding. Lipman (1981) noted that the least principal stress direction changed from east-northeast to about east-southeast at about 10 m.y.a. Prior to this rotation, the intermediate principal stress would have been oriented south-southeast. This stress orientation could have caused some left slip on pre-existing fault surfaces (such as the Canoncito de la Uva fault), but 55 kilometers (34.2 miles) is unlikely. Except for some Tertiary-age normal displacement on the Canoncito de la Uva fault, middle to late Tertiary extensional tectonics are not well-preserved in the study area.

At present, deformation is continuing across the study area. This is mainly rapid uplift due to intrusion of a magma body into the lower crust in the Socorro-Bernardo region (Larsen and Reilenger, 1983; Sanford, 1983; and Sanford and others, 1983). Sanford and others (1983) show surface uplift of about 105 millimeters (4.1 inches) during the last 40 years in the Sierra de la Cruz area. This uplift could explain the presence of the erosional remnants of well-cemented Tertiary (?) gravels along Canoncito de la Uva discussed earlier.

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APPENDIX I

MEASURED STRATIGRAPHIC SECTIONS

TERMS USED IN THE DESCRIPTIONS:

ROCK NAME: (note: classification system shown for detrital rocks is arbitrary but easily used in field; silt and sand content in mudrocks was estimated by grinding a chip between the teeth.)

Detrital:

- Sandstone: >75% sand-size grains
- Siltstone: >75% silt-size grains
- Mudstone: Clay with <50% silt and sand and no fissile parting (laminations <.1 inches thick)
- Claystone: Clay with <25% silt; non-fissile.
- Shale: Clay with <50% silt and sand; fissile parting

Carbonate Rocks:

- Limestone: <10% dolomite (classification follows Dunham, 1972)
  - Carbonate Mudstone: <10% grains; mud supported
  - Wackestone: >10% grains; mud supported
  - Packstone: <40% mud; grain supported
  - Grainstone: <10% mud; grain supported
- Dolomitic Limestone: >10% but <50% dolomite
- Calcitic Dolomite: >50% but <90% dolomite
- Dolomite: >90% dolomite

(Dolomite content estimated by reaction to 10% HCl and Alizarin Red S staining in the field.)

COLOR: G.S.A. Rock Color Chart (Goddard and others, 1979), all colors are for fresh surfaces only.

GRAIN SIZE: Adapted from Wentworth (1922) and the American Stratigraphic Grain Size Card.

Cobbles:	64 - 256 mm	
Pebbles:	8 - 64 mm	GRAVEL
Granules:	2 - 8 mm	
Very Coarse upper:	1.41 - 2.00 mm	
Very Coarse lower:	1.00 - 1.41 mm	
Coarse upper:	.710 - 1.00 mm	
Coarse lower:	.500 - .710 mm	
Medium upper:	.350 - .500 mm	
Medium lower:	.250 - .350 mm	SAND
Fine upper:	.177 - .250 mm	
Fine lower:	.125 - .177 mm	

Very Fine upper:	.088 - .125 mm	
Very Fine lower:	.062 - .088 mm	SAND (Con't)
Silt:	.004 - .062 mm	
Clay:	.00024 - .004 mm	

BED THICKNESS: Adapted from Tucker (1982)

>3 feet:	Massive Bedded
1 - 3 feet:	Thick Bedded
4 - 12 inches:	Medium Bedded
1 - 4 inches:	Thin Bedded
.5 - 1 inch:	Very Thin Bedded
.1 - .5 inches:	Thickly Laminated
<.1 inch:	Thinly Laminated

SORTING (of central 67% of grains):

Very Well Sorted:	One Grade
Well Sorted:	Two Grades
Moderately Sorted:	Three Grades
Poorly Sorted:	Four Grades
Very Poorly Sorted:	Five or more Grades

INDURATION:

Well Indurated:	Specimen breaks through grains
Moderately Indurated:	Specimen breaks around grains; <4 grains liberated when specimen rubbed with thumb
Poorly Indurated:	4 to 10 grains liberated by rubbing with thumb
Friable:	>10 grains liberated by rubbing with thumb

MADERA LIMESTONE: Measured in the NE 1/4, SW 1/4, SE 1/4, NW 1/4, Sec. 10, T.2S., R.2E., NMPM, Socorro County, New Mexico, (measured in Canoncito de la Uva).

-Unconformable with overlying Bursum Formation-

UNIT	THICKNESS FEET	METERS	DESCRIPTION
9	8.0	2.44	WACKESTONE- Light brownish gray, brachiopods, crinoid ossicles with a trace of gastropods and occasional scattered algae, abundant crinoid ossicles on the upper surface of this unit, medium to thick bedded.
8	7.2	2.19	CARBONATE MUDSTONE- Light gray to brownish gray, trace of gastropods, brachiopods, foraminifera, and scattered phylloid algae, thin to medium bedded, nodular.
7	5.2	1.58	CARBONATE MUDSTONE- Grayish orange, scattered algal remains, occasional shell fragments (brachiopods and fusilinids), thick bedded.
6	13.1	4.00	COVERED WITH TALUS.
5	2.4	0.73	MUDSTONE- Brownish gray, arenaceous, arkosic(?), devoid of fossil debris, laterally discontinuous, medium to thick bedded.
4	17.1	5.21	PACKSTONE- Light brownish gray, brachiopods, bryozoans, gastropods, crinoid ossicles and shell fragments, medium bedded, poorly exposed.
3	5.9	1.80	WACKESTONE- Light brownish gray, abundant brachiopods, bryozoans, gastropods, crinoid ossicles and shell fragments, occasional *Triticites* sp., medium to thick bedded.
2	8.4	2.56	PACKSTONE- Medium dark gray to brownish gray, abundant bryozoans, brachiopods, gastropods, fusilinids, algae(?), and crinoid ossicles, thin to medium bedded, nodular.

1	6.0	1.83	PACKSTONE- Grayish orange, abundant shell fragments, peloids, bryozoans, pelecypods(?), brachiopods, and algae(?), massively bedded.

TOTAL MEASURED THICKNESS: 73.3 FEET (22.34 METERS)

BURSUM FORMATION: Measured from C, SE 1/4, NW 1/4, Sec. 12, T.2S., R.2E. to C, E 1/2, Sec. 12, T.2S., R.2E, Canoncito de la Uva, Socorro County, New Mexico.

-Unconformable(?) with overlying Abo Formation-

UNIT	THICKNESS FEET	METERS	DESCRIPTION
18	20.8	6:34	SANDSTONE- Grayish orange pink mottled moderate reddish orange and moderate yellowish brown, fine lower to medium upper, subangular, well sorted, quartz; well indurated, calcite cement, massive to thick bedded, trough cross beds with local herring-bone cross beds, bioturbated, impressions of log fragments, trace glauconite.
17	3.8	1.16	CONGLOMERATE- Grayish orange, coarse granule to fine pebble, rounded to angular, poorly sorted, clasts of limestone, quartz and pink feldspar (orthoclase); well indurated, medium to thick bedded.
16	7.0	2.13	COVERED
15	1.6	0.49	GRAINSTONE- medium gray, peloids, ostracods, irregularly bedded, nodular at base.
14	14.0	4.27	COVERED
13	12.8	3.90	PACKSTONE- Medium gray, peloids, digitate and fenestrate bryozoans, crinoid ossicles, fusilinids, productid brachiopods, medium to thick bedded, hard, trace of orthoclase grains, scattered shale partings.

12	2.0	0.61	SILTSTONE- Brownish gray, arenaceous, well indurated, arkosic.
11	2.2	0.67	PACKSTONE- Medium gray, mainly fossil hash with some crinoid ossicles and fusilinids, nodular, scattered orthoclase grains.
10	17.6	5.36	MUDSTONE- Brownish gray, very calcareous, poorly exposed, thickly laminated.
9	2.5	0.76	WACKESTONE- Brownish gray, very argillaceous, thick bedded, numerous gastropods and scaphopods, rodular at the base.
8	6.2	1.89	SHALE- Dark yellowish brown, locally clayey, silty, thinly to thickly laminated, very calcareous, brittle, occasional gastropods.
7	14.7	4.48	CARBONATE MUDSTONE- Dark gray to brownish black, grades to irtraclast packstone along strike, thirly laminated, locally nodular, yields dark brown oily scum with acid application. Crinoid ossicle and shell hash wackestone at the base.
6	1.1	0.34	SHALE- Medium dark gray, very calcareous, silty, very thir bedded, bioturbated.
5	59.1	18.01	SHALE- Medium dark gray, silty, very calcareous, occasional thin beds of argillaceous limestone, scattered septarian nodules, very poorly exposed, forms slopes.
4	24.8	7.56	LIMESTONE PEBBLE CONGLOMERATE- Medium gray to light brownish gray, pebbles to cobbles, angular to well rounded, very poorly sorted, limestone, quartz, chert, and shell fragments; well indurated, calcite cement, medium to thick bedded, trough crossbeds. Has numerous channel sandstones (medium lower, feldspathic, moderately sorted, upward fining).

3	1.7	0.52	SANDSTONE- Light brownish gray, very coarse lower, angular, poorly sorted quartz and feldspar; well indurated, calcite cement, limonite staining, feldspathic.
2	3.7	1.13	LIMESTONE PEBBLE CONGLOMERATE- Light brownish gray, cobbles, angular to well rounded, very poorly sorted limestone, quartz and feldspar; well indurated, calcite cement, trough crossbeds, medium to thick bedded.
1	12.4	3.79	SANDSTONE- Light brownish gray, fine upper, angular to subround, well sorted, quartz and feldspar; friable, calcite cement, thin to medium bedded, scattered muscovite, discontinuous laterally.

TOTAL THICKNESS: 208.0 FEET (63.40 METERS)

-Unconformable with underlying Madera Limestone-

ABO FORMATION: Measured in the NE 1/4, SW 1/4, NE 1/4 to the E 1/2, SW 1/4, SE 1/4, NE 1/4, Sec. 12, T.2S., R.2E, NMPM, Canoncito de la Uva, Socorro County, New Mexico.

Conformable and transitional with overlying Meseta Blanca member of the Yeso Formation.

	THICKNESS		
UNIT	FEET	METERS	DESCRIPTION
56	0.8	0.24	SANDSTONE- Grayish red, very fine upper, subangular, well sorted quartz and feldspar; well indurated, trace of calcite cement, thin bedded, feldspathic. Salt casts in bed above.
55	3.8	1.16	MUDSTONE- Dark reddish brown, hard, brittle, calcareous, forms slopes.
54	1.3	0.40	SILTSTONE- Dark reddish brown, hard, nodular to blocky weathering, forms ledges, scattered light gray and greenish gray reduction spots.
53	10.3	3.14	MUDSTONE- Dark reddish brown, hard, brittle, calcareous, forms slopes.

52	1.0	0.30	SILTSTONE- Dark reddish brown, hard, nodular to blocky weathering ledges, scattered greenish gray reduction spots.
51	4.6	1.40	MUDSTONE- Dark reddish brown, hard, brittle, calcareous, forms slopes.
50	1.0	0.30	SILTSTONE- Dark reddish brown, hard, weathers to blocky and nodular ledges, scattered greenish gray reduction spots.
49	3.0	0.91	MUDSTONE- Dark reddish brown, hard, brittle, calcareous, forms slopes.
48	3.0	0.91	SANDSTONE- Medium dark gray, very fine lower, angular, well sorted quartz; well indurated, non-calcareous, thickly laminated to thin bedded, trough cross beds, trace of dark minerals, local climbing ripple laminations, grayish red partings at the top, silty.
47	1.0	0.30	SILTSTONE- Moderate brown, hard thickly laminated, planar bedded.
46	2.4	0.73	MUDSTONE- Grayish red, brittle, forms slopes.
45	2.3	0.70	SILTSTONE- Moderate brown, thickly laminated, planar bedded with local slump strictures, mudcracks.
44	5.5	1.68	MUDSTONE- Grayish red, silty, hard, brittle, forms slopes, siltstone partings, a sandstone (very fine lower) channel near the top.
43	3.4	1.04	SANDSTONE- Pinkish gray to light brownish gray, very fine upper, subangular, well sorted, quartz; well indurated, non-calcareous, medium to thin bedded, trough crossbeds, cliff former; develops into an 8 foot thick channel laterally, well developed throughout this area, mudcracks, local bioturbation.
42	17.4	5.30	MUDSTONE- Dusky red with greenish red reduction spots, brittle, thinly

			laminated, weathers to slopes, non-calcareous.
41	1.4	0.43	SILTSTONE- Grayish red, clayey, very hard, very thin bedded to thinly laminated, forms a persistant ledge, mudcracks, non-calcareous.
40	7.0	2.13	CLAYSTONE- Grayish red, trace silt, brittle, slope former.
39	4.0	1.22	SANDSTONE- Grayish red, very fine lower, angular, moderately sorted quartz and feldspar; well indurated, thick bedded, non-calcareous, silty, leached, feldspathic.
38	8.7	2.65	CLAYSTONE- Grayish red, slightly silty, brittle, slope former, scattered greenish gray reduction spots.
37	3.0	0.91	SILTSTONE- Grayish red, clayey, hard, nodular, slightly calcareous.
36	2.7	0.82	CLAYSTONE- Grayish red, hard, brittle, crumbly, forms slopes.
35	2.0	0.61	SANDSTONE- Grayish red, very fine lower, angular, well sorted, quartz and feldspar; well indurated, clay cement, medium bedded, hematite staining, forms ledges.
34	28.4	8.66	MUDSTONE- Grayish red, hard, brittle, forms slopes.
33	2.4	0.73	SANDSTONE- Grayish red, very fine lower to coarse silt, angular, moderately sorted, quartz; well indurated, slightly calcareous, medium to thin bedded, grades to sandy siltstone along strike, scattered grayish orange pink reduction spots.
32	44.3	13.50	CLAYSTONE- Grayish red, brittle, weathers to blocky outcrops, trace of silt, trace calcite to non-calcareous.
31	17.5	5.33	SANDSTONE- Grayish red, very fine lower, angular, moderately sorted

			quartz and feldspar; well indurated, slightly calcareous, thin to very thin bedded, slightly silty, ripple cross laminations, mudcracks, feldspathic.
30	18.6	5.67	CLAYSTONE- Dusky red, hard, brittle, slightly silty, slightly to non-calcareous, forms slopes.
29	2.0	0.61	SILTSTONE- Grayish red, hard, thickly laminated, non-calcareous.
28	10.3	3.14	SANDSTONE- Grayish red, very fine lower, angular, well sorted, quartz; well indurated, slightly calcareous, medium bedded, silty, trace muscovite, mudcracks, raindrop impressions, tool marks (?), current ripples, plant impressions.
27	6.5	1.98	SILTSTONE- Grayish red, thickly laminated, grayish orange pink reduction spots, mudcracks, ripple-marks, plant impressions.
26	6.2	1.89	SANDSTONE- Grayish red, very fine lower to coarse silt, angular, well sorted, quartz; well indurated, traces of clay and hematite, non-calcareous, thick to massive bedded.
25	1.4	0.43	CONGLOMERATE- Pale red, fine pebble to granule, trace of calcite cement, clasts of red brown mudstone; white, very fine grained sandstone; white siltstone; quartzite and limestone; well indurated, lenticular.
24	12.6	3.84	SANDSTONE- Grayish red, very fine lower, angular, well sorted, quartz; well indurated, trace of clay and hematite, non- calcareous, thick to massive bedded, ripple marks, ripple cross laminations.
23	2.2	0.67	MUDSTONE- Grayish red, non-calcareous, forms slopes.
22	1.3	0.40	SILTSTONE- Grayish red, clayey, well indurated, non-calcareous, grayish orange pink reduction spots.

21	25.6	7.80	CLAYSTONE- Dark reddish brown, slightly calcareous, brittle, weathers to small blocks, forms slopes; siltstone tubular volumes extend 5 feet into this unit from unit 22 above.
20	4.0	1.22	SILTSTONE- Dark reddish brown, very clayey grading to shale, weathers blocky, forms small slope breaks, non-calcareous, well indurated.
19	14.5	4.42	CLAYSTONE- Dark reddish brown, trace of calcite, forms slopes.
18	1.0	0.30	SILTSTONE- Dark reddish brown, well indurated, trace calcareous, medium bedded, forms isolated ledges, laterally discontinuous.
17	2.5	0.76	MUDSTONE- Grayish red, trace to slightly calcareous, forms slopes.
16	3.5	1.07	SILTSTONE- Dark reddish brown, well indurated, trace calcareous, mudcracks, medium to thick bedded.
15	16.0	4.88	CLAYSTONE- Dark reddish brown, slightly calcareous, moderately indurated, brittle, forms slopes.
14	3.1	0.94	SILTSTONE- Grayish red, some very fine lower quartz sand, well indurated, slightly calcareous, thin to thick bedded, lenticular.
13	31.2	9.51	CLAYSTONE- Dark reddish brown, moderately indurated, slightly calcareous, occasional very calcareous nodular zones, forms slopes.
12	3.0	0.91	SILTSTONE- Dark reddish brown, calcareous, nodular, scattered grayish orange pink reduction spots; grades laterally into conglomerate beds, poorly exposed, forms faint ledges.
11	200.4	61.08	CLAYSTONE- Grayish red to dark reddish brown, slightly calcareous, waxy luster, scattered muscovite and thin grayish red septarian

			nodule zones, prominent slopes throughout area, slightly silty near base, scattered cobbles of conglomerate on the outcrop surface.
10	4.4	1.37	SANDSTONE- Grayish red, medium upper to coarse upper, angular to well rounded, moderately sorted, quartz and orthoclase; well indurated, locally friable, calcite cement, thin bedded, occasional scattered dark reddish brown, calcareous mudstone clasts.
9	14.4	4.42	CLAYSTONE AND NODULAR CARBONATE MUDSTONE- Dark reddish brown (claystone) and grayish red (carbonate mudstone nodules), weathers to nodular slopes, claystone is very calcareous.
8	12.8	3.90	SANDSTONE- Grayish orange pink to grayish pink, coarse lower, angular, poorly sorted, quartz, orthoclase and dark reddish brown mudstone; well indurated, very calcareous, thin to medium bedded, occasional pebbles of dark reddish brown, calcareous mudstone, trough crossbeds, locally stacked channels, grades to fine pebble conglomerate down section, laterally discontinuous.
7	37.2	11.34	MUDSTONE- Dark reddish brown, calcareous, poorly exposed, forms slopes.
6	6.7	2.04	SANDSTONE- Grayish red, medium upper to very coarse upper, angular, poorly sorted, quartz and orthoclase; well indurated, locally friable, calcareous, clay matrix, medium bedded, trough crossbeds, arkosic, laterally discontinuous.
5	30.6	9.33	MUDSTONE- Dark reddish brown, calcareous, very poorly exposed.
4	4.6	1.40	SANDSTONE- Moderate brown, very fine upper to fine upper, subangular, moderately to poorly sorted, quartz, orthoclase, muscovite and biotite;

			well indurated, calcite cement, lenticular, arkosic, ripple laminations.
3	11.2	3.41	CLAYSTONE- Dark reddish brown, slightly calcareous, very poorly exposed.
2	6.6	2.01	SANDSTONE- Pale red, dusky red at base, very fine upper, angular, well sorted, at top, poorly sorted at base, quartz, orthoclase, and biotite; friable, calcite cement, very thin to medium bedded, arkosic, laterally discontinuous.
1	5.2	1.58	SANDSTONE- Light brownish gray, fine upper, subangular, well sorted quartz, orthoclase and scattered biotite; friable, calcite cement, poorly exposed, scattered petrified wood (?) fragments, laterally discontinuous.

TOTAL THICKNESS: 682 FEET (207.87 METERS)

-Unconformable (?) with underlying Bursum Formation-

MESETA BLANCA MEMBER; YESO FORMATION: Measured from W 1/2, NW 1/4, SW 1/4, Sec. 5, to W 1/2, W 1/2, Sec. 4, T.2S., R.2E., NMPM, Socorro County, New Mexico (at Yeso type section).

-Conformable with overlying Torres member-

UNIT	THICKNESS FEET	METERS	DESCRIPTION
59	8.9	2.71	SANDSTONE- Grayish orange to very pale orange, fine lower to very fine upper, subangular, well sorted, quartz; friable to poorly indurated, calcite cement with atrace of limonite, thin bedded to thickly laminated.
58	7.5	2.29	SANDSTONE- Grayish orange, fine lower, subrounded to rounded, well sorted, quartz; friable to very

			soft, calcite cement, trace limonite stain, thick bedded.
57	3.0	0.91	SANDSTONE- Moderate reddish brown, very fine upper, subangular, moderately sorted, quartz and feldspar; friable, calcite cement, thick bedded, feldspathic.
56	2.0	0.61	SILTSTONE- Moderate reddish brown, arenaceous, very calcareous.
55	4.5	1.37	SANDSTONE- Moderate reddish brown, very fine upper, subangular, well sorted, quartz; friable to moderately indurated, calcite cement, medium bedded, silty, ripple laminations, symmetric ripple marks, scattered salt casts, trace feldspar (?) grains.
54	1.0	0.30	SILTSTONE- Moderate reddish brown, arenaceous, very calcareous.
53	2.5	0.76	SANDSTONE- Moderate reddish brown, very fine upper, subangular, moderately sorted, quartz; friable, calcite cement, thin to medium bedded, symmetric ripple marks, salt casts, trace feldspar (?) grains.
52	3.5	1.07	SILTSTONE- Moderate reddish brown, arenaceous, thick bedded, calcareous, poorly exposed.
51	6.7	2.04	SANDSTONE- Moderate reddish brown, very fine lower, subangular, poorly sorted, quartz and feldspar; friable, calcite cement, thick bedded, salt casts, feldspathic, poor exposures.
50	3.0	0.91	SILTSTONE- Moderate reddish brown, arenaceous, thick bedded, calcareous, poorly exposed.
49	9.7	2.96	SANDSTONE- Pale reddish brown, fine lower, subangular, moderately sorted, quartz and feldspar; friable, calcite cement, thick to massive bedded, broadly lenticular

			with exposures discontinuous over ~1/2 mile, feldspathic, cliff former.
48	13.3	4.05	SANDSTONE- Pale red, fine upper to medium lower, subangular, moderately sorted, quartz and feldspar; friable, calcite cement (cementation variable along strike), thick to massive bedded, outcrops have a curdled appearence, feldspathic.
47	42.5	12.95	SANDSTONE- Pale red, very fine upper to fine lower, moderately sorted, quartz and feldspar; friable, calcite, clay and some hematite cement, thick bedded to thickly laminated, feldspathic, slightly micaceous, local channeling, asymmetric ripple marks, soft-sediment deformation, load casts, local wavy bedding.
46	5.0	1.52	SANDSTONE- Pale red, very fine lower, angular to subangular, moderately sorted, quartz and feldspar; moderately to poorly indurated, hematite and calcite cement, thickly laminated to thin bedded, very silty, feldspathic, poorly exposed.
45	3.6	1.10	SANDSTONE- Pale red, medium lower, subangular, well sorted, quartz and feldspar; friacle to poorly indurated, calcite and a trace of clay cement, thick bedded, feldspathic.
44	6.0	1.83	SANDSTONE- Grayish red, very fine lower, angular, moderately to well sorted, quartz and feldspar; poorly indurated, calcite and clay cement with minor hematite, thickly laminated, feldspathic, froms slopes.
43	3.5	1.07	SANDSTONE- Pale red, coarse lower, rounded, moderately sorted, quartz and feldspar; friable, calcite and some clay cement, medium to thick bedded, feldspathic, cross bedded.

42	2.8	0.85	SILTSTONE- Moderate reddish brown, arenaceous grading to very fine lower, moderately sorted, quartz sandstone laterally, scattered muscovite and tiny salt casts on bedding surfaces, thinly laminated to thin bedded, channeled along top, soft sediment deformation and slump structures, forms slopes.
41	7.1	2.16	SANDSTONE- Pale red, medium upper, subround, poorly sorted, quartz and feldspar; friable to poorly indurated, clay and calcite cement, medium to thin bedded, feldspathic to arkosic, clay and mudstone laminations associated with wavy and contorted bedding, outcrops show curdled appearance, bioturbation.
40	2.4	0.73	SANDSTONE- Moderate orange pink, very fine lower, subangular, poorly sorted, quartz; friable, calcite and clay cement, medium to thin bedded.
39	6.6	2.01	SANDSTONE- Grayish orange pink, moderate orange pink and moderate reddish brown, coarse lower, subangular, moderately sorted, quartz and feldspar; friable, clay and calcite cement, medium to thick bedded, feldspathic, low angle simple cross beds, unit is broadly lenticular, locally bioturbated.
38	6.4	1.95	SANDSTONE- Moderate reddish brown, very fine upper to fine lower, subangular, moderately sorted, quartz and feldspar; poorly indurated, calcite cement with abundant hematite staining, thin bedded, feldspathic, asymmetric ripple marks, soft sediment deformation, top is channeled.
37	5.0	1.52	SILTSTONE- Moderate to dark reddish brown, arenaceous, very thin bedded.

36	1.7	0.52	SANDSTONE- Very pale orange, coarse lower, rounded, moderately sorted, quatrz and feldspar; moderately indurated, calcite and clay cement, small scale simple cross bed sets with tangential bottoms, medium bedded, feldspathic.
35	2.2	0.67	SILTSTONE- Moderate reddish brown, calcareous, considerable clay laminations, wavy bedded, thickly laminated.
34	5.0	1.52	SANDSTONE- Grayish orange pink, pale red and moderate reddish brown, medium lower to coarse lower, upward fining, rounded to sub-angular, moderately sorted, quartz and feldspar; friable, clay and calcite cement, very thin to medium bedded, feldspathic, asymmetric ripple marks, hematite stair reduced along bedding planes, laterally discontinuous.
33	3.8	1.16	SANDSTONE- Moderate reddish brown, very fine lower becoming coarse silt, angular, poorly sorted, quartz; friable to poorly indurated, calcite and hematite cement, very thin bedded, local clay partings.
32	1.2	0.37	SILTSTONE- Very light gray, arenaceous, thickly laminated, trace muscovite, calcareous, well indurated, scattered salt casts.
31	5.1	1.55	SANDSTONE- Very pale orange to moderate reddish brown, fine lower, subangular, well sorted, quartz and feldspar; friable, calcite cement with minor hematite and limonite, medium to thick bedded, feldspathic, bioturbated, outcrops have curdled appearance.
30	7.9	2.41	SILTSTONE- Dark reddish brown to moderate reddish brown, arenaceous, occasional asymmetric ripple marks, poorly indurated, poorly exposed.

29	1.8	0.55	SANDSTONE- Dark reddish brown to very pale orange, very fine upper, subangular, well sorted, quartz and feldspar; moderately indurated, calcite cement, thin bedded, feldspathic.
28	5.3	1.62	SILTSTONE- Dark reddish brown, arenaceous, calcareous, trace muscovite, moderately indurated, occasional mudstone partings.
27	5.0	1.52	SANDSTONE- Very pale orange to dark reddish brown, very fine lower to fine lower, subangular, well sorted, quartz and feldspar; friable, calcite cement with minor hematite, thin to thick bedded, scattered very pale orange reduction spots.
26	6.0	1.83	SILTSTONE- Very pale orange, arenaceous, slightly calcareous, thinly laminated, salt casts.
25	2.7	0.82	SANDSTONE- Very pale orange, fine lower, angular, well sorted, quartz and feldspar; friable, calcite cement, thin to medium bedded, carbonaceous debris, feldspathic.
24	14.0	4.27	SANDSTONE- Pale red, pinkish gray and light brown, very fine lower, subrounded, well sorted, quartz; poorly to moderately indurated, thick to thin bedded, calcite cement with minor hematite and limonite, asymmetric ripple marks, scattered salt casts.
23	4.0	1.22	SILTSTONE- Pale red, arenaceous, friable, slightly micaceous, thin bedded, asymmetric ripple marks.
22	1.4	0.43	SANDSTONE- Very light gray, medium lower, subrounded, well sorted, quartz; moderately indurated, clay cement with a trace of calcite, thin bedded, salt casts, symmetric ripple marks.

21	0.2	0.06	CARBONATE MUDSTONE- Olive gray, peloids, slightly arenaceous, dolomitic, very thinly laminated, stromatolitic (?).
20	2.7	0.82	SILTSTONE- Pinkish gray, arenaceous, moderately indurated, very thin bedded, salt casts.
19	2.6	0.79	SANDSTONE- Very pale orange to pale yellowish orange, fine lower, subrounded, well sorted, quartz; friable, minor clay cement, thin to very thin bedded.
18	3.4	1.04	SILTSTONE- Yellowish gray, friable, thin to medium bedded, symmetric ripple marks.
17	4.0	1.22	SANDSTONE- Pale yellowish brown, very fine lower, subrounded, well sorted, quartz; friable to poorly indurated, clay cement, massive bedded, trace feldspar.
16	5.8	1.77	SILTSTONE- Yellowish gray to very light gray, thick bedded, salt casts.
15	8.4	2.56	SILTSTONE- Very light gray to yellowish gray, arenaceous, well indurated, very thin bedded, salt casts, asymmetric ripple marks.
14	15.0	4.57	SANDSTONE- Pale red, very fine lower to fine lower, angular to subangular, poorly sorted, quartz and feldspar; friable, clay cement with a trace of calcite, thin to massive bedded, feldspathic to arkosic, siltstone and mudstone partings; traced across a fault.
13	2.8	0.85	SANDSTONE- Yellowish gray, fine upper, subangular, moderately sorted, quartz; friable to poorly indurated, calcite and clay cement with minor hematite, thin to medium bedded, asymmetric ripple marks, salt casts.
12	1.2	0.37	SILTSTONE- Light greenish gray with dark gray laminations, arenaceous,

			carbonaceous debris on partings, salt casts.
11	8.0	2.44	SANDSTONE- Yellowish gray with pale red laminations, medium lower, subrounded, moderately sorted, quartz; friable to poorly indurated, calcite and clay cement, thin to medium bedded, asymmetric ripple marks, salt casts, trace of feldspar.
10	1.1	0.34	SILTSTONE- Light greenish gray with dark gray laminations, arenaceous, carbonaceous debris on partings, malachite coatings associated with some of the carbonaceous debris, salt casts.
9	2.8	0.85	SANDSTONE- Pale red, fine lower, subangular, moderately sorted, quartz; friable to poorly indurated, calcite and clay cement with minor hematite, thin to medium bedded, trace of feldspar.
8	1.2	0.37	SILTSTONE- Light greenish gray with local dark gray, arenaceous, scattered carbonaceous debris, malachite coatings and patches occasionally associated with the carbonaceous debris, salt casts, thin bedded.
7	2.4	0.73	SANDSTONE- Yellowish gray, medium lower, subrounded, moderately sorted, quartz; friable to poorly indurated, calcite and clay cement, thin bedded, silty.
6	5.0	1.52	SANDSTONE- Pale red, grayish orange and very pale orange, very fine upper to fine upper (coarsens upward), angular, moderately sorted quartz; friable to moderately indurated, calcite to clay cement, very thin to thick bedded, trace of feldspar, asymmetric ripple marks.
5	1.1	0.34	SANDSTONE- very light gray to pinkish gray, fine lower, subangualr, well sorted, quartz;

			friable to moderately indurated, calcite cement, thick bedded, abundant salt casts.
4	3.9	1.19	SANDSTONE- Yellowish gray to light olive gray, very fine upper, subrounded, well sorted, quartz; friable, trace clay cement, thin bedded to thickly laminated, thin coatings of dark gray organic matter along partings.
3	3.0	0.91	SANDSTONE- Pale reddish brown, fine lower, angular, moderately sorted, quartz and feldspar; friable, clay cement, thin to thick bedded, arkosic to feldspathic, local pale brown reduction spots.
2	1.0	0.30	SANDSTONE- Pale reddish brown grading to greenish gray along strike, very fine upper, angular, poorly sorted, quartz; friable, clay cement, thin to medium bedded, trace of muscovite, scattered salt casts.
1	1.0	0.30	MUDSTONE- Dark reddish brown grading upward to greenish gray, thinly laminated, brittle, silty, salt casts along upper-most partings.

TOTAL THICKNESS: 300.2 FEET (91.50 METERS)

-Conformable and gradational with underlying Abo Formation-

TORRES MEMBER; YESO FORMATION (Section no. 1): Measured from the SW 1/4, Sec. 33, T.1S., R.2E., to the NW 1/4, Sec. 4, T.2S., R.2E.,NMPM, Socorro County, New Mexico (measured at the Yeso type section)

	THICKNESS		
UNIT	FEET	METERS	DESCRIPTION
18	4.8	1.46	WACKESTONE- Pale yellowish to dark yellowish brown, oolitic, occasional gastropod molds, locally arenaceous. Correlates with Unit 4 in Torres Section no. 2

17	13.7	4.18	SANDSTONE- Pinkish gray to grayish yellow, very fine lower to fine lower, well rounded to subangular, well sorted, quartz; friable, trace clay cement, very thin bedded, poorly exposed.
16	43.0	13.11	SANDSTONE- Pale reddish brown with grayish red, very fine lower, angular, moderately sorted, quartz; friable, clay cement, thickly laminated to thin bedded, poorly exposed, forms slopes.
15	18.2	5.55	PACKSTONE- Grayish orange, oolitic, peloids (?), very arenaceous (very fine upper, angular to subangular, well sorted, quartz grains), very thin to medium bedded, cross laminated.
14	13.0	3.96	SANDSTONE- Very light gray, fine lower, subround to round, well sorted, quartz and feldspar; friable, calcite cement, very poorly exposed, forms slopes.
13	24.0	7.32	SANDSTONE- Pale reddish brown, very fine upper, subangular, well sorted, quartz; friable to poorly indurated, calcite cement, thin to medium bedded, occasional grayish red claystone partings.
12	2.2	0.67	CARBONATE MUDSTONE- Medium light gray, very silty, thin bedded, vuggy, laterally continuous.
11	1.4	0.43	SANDSTONE- Grayish orange pink, very fine lower, angular, well sorted, quartz; friable, calcite cement.
10	4.4	1.34	SANDSTONE- Pale reddish brown, very fine lower with fine upper partings and laminations, subangular, well sorted, quartz; friable, calcite cement, thin bedded, occasional thin grayish red claystone partings.
9	2.0	0.61	BRECCIA- Pale reddish brown leached to very pale orange, chaotic jumble of boulder-, cobble-, and

			pebble-sized fragments of sandstone, laterally discontinuous.
8	10.8	3.29	SANDSTONE- Pale reddish brown, very fine lower with very fine upper partings and laminations, subangular, well-sorted, quartz; friable, calcite cement, thin bedded, occasional thin grayish red claystone partings.
7	2.3	0.70	SANDSTONE- Grayish orange pink, very fine lower, angular to subangular, well sorted, quartz; friable, calcite cement, laterally discontinuous.
6	0.5	0.15	CARBONATE MUDSTONE- Medium light gray, very silty, thin bedded, vuggy, laterally discontinuous.
5	55.0	16.76	SANDSTONE- Pale reddish brown mottled moderate reddish brown near the base, very fine lower to very fine upper with partings and laminations of medium lower, angular, well sorted, quartz; friable, calcite and some clay cement, thin to medium bedded, scattered salt casts, local ripple laminations, occasional clay flakes (grayish red) along bedding planes.
4	13.5	4.11	WACKESTONE- light brownish gray, slightly dolomitic, very argillaceous, scattered fine quartz grains, thin to very thin bedded.
3	8.8	2.68	SANDSTONE- Very pale orange with patchy grayish orange, fine lower, subangular, very well sorted, quartz; friable, calcite cement, thickly laminated to medium bedded, trace feldspar (?).
2	33.0	10.06	SANDSTONE- Moderate reddish brown, very fine upper to fine upper, subangular, well sorted, quartz and feldspar; friable, minor calcite cement, medium to very thin bedded, occasional grayish

			red claystone flakes along partings in rock, scattered salt casts.
1	9.1	2.77	CARBONATE MUDSTONE- Pale yellowish brown, silty, slightly fetid at top with soft asphalt (?) in isolated vugs, thin to medium bedded.

TOTAL THICKNESS: 259.7 FEET (79.16 METERS)

-Conformable with underlying Meseta Blanca member-

TORRES MEMBER; YESO FORMATION (Section no. 2): Measured from the SW 1/4, NW 1/4, SE 1/4, NW 1/4 to the NE 1/4, NW 1/4, SW 1/4, NW 1/4, Sec. 36, T.1S., R.2E., NMPM, Socorro County, New Mexico, (north face of Sierra de la Cruz).

-Conformable with overlying Canas Gypsum member-

	THICKNESS		
UNIT	FEET	METERS	DESCRIPTION
24	7.1	2.16	GRAINSTONE- Light brownish gray, ooids, peloids, medium upper, local low angle ripple laminations and cross laminations, medium to thick bedded.
23	7.8	2.38	SANDSTONE- Grayish pink to grayish orange, very fine upper, subround, moderately sorted, quartz; friable, clay cement, very poorly exposed, forms slopes.
22	17.8	5.43	SANDSTONE- Light brown, very fine upper to fine lower, subangular, moderately sorted, quartz; friable, clay cement, poorly exposed, locally mottled grayish pink.
21	27.5	8.38	GYPSUM- Very light gray with olive gray laminations, very fine to fine crystalline.
20	1.6	0.49	SANDSTONE- Light brown, mottled grayish pink, fine lower to medium lower, subrounded, well

			sorted, quartz; friable, calcite cement, trace of hematite staining.
19	10.3	3.14	SANDSTONE- Grayish pink to moderate pink, very fine lower to very fine upper, subangular, moderately sorted, quartz; friable, calcite with clay cement, very poorly exposed.
18	13.6	4.15	CARBONATE MUDSTONE- Brownish black to olive black, grades to wackestone along strike and yellowish gray carbonate mudstone near the base of the unit, fetid with scattered bi-valve shell fragments, vuggy due to dissolution of gypsum crystals, medium to thick bedded. Grades to peloid, oncolite, pisolite grainstone 3 miles west.
17	13.8	4.21	SANDSTONE- Very pale orange to grayish orange, fine lower to medium lower, subangular, moderately sorted, quartz with some feldspar; friable to moderately indurated, calcite and clay cement, local low angle cross laminations and scour structures, thick to massive bedded, forms cliffs.
16	13.0	3.96	SANDSTONE- Moderate brown mottled grayish pink, very fine lower to very fine upper, subrounded to well rounded, well sorted, quartz; friable, calcite cement, hematite staining on grains, moderate reddish brown claystone partings near base.
15	8.2	2.50	GYPSUM- Very light gray with olive gray laminations, very fine to finely crystalline.
14	13.2	4.02	WACKESTONE- Light olive gray to olive gray, medium to coarse, peloids and ooids(?), current laminations and scour marks, argillaceous, dolomitic at the top, medium to thin bedded.

13	12.2	3.72	GYPSUM- Light gray with pale yellowish brown laminations (poorly developed), finely crystalline, chalky and soft, laminations grade to chicken-wire texture.
12	9.5	2.90	SANDSTONE- Moderate orange pink mottled grayish pink and moderate reddish orange, very fine lower to fine lower, subround, moderately sorted, quartz; friable, calcite cement, trace green chert, trace black minerals.
11	5.0	1.52	GYPSUM- Very light gray with olive gray laminations, dark reddish brown clay partings, laminations poorly developed due to re-crystallization, thick bedded.
10	12.2	3.72	SANDSTONE- Moderate brown, fine upper, subangular, moderately sorted, quartz and feldspar; friable, clay cement, hematite staining, numerous fractures filled with gypsum.
9	7.6	2.32	GYPSUM- Very light gray with olive gray laminations, very finely crystalline, sandy near the base.
8	3.3	1.01	SANDSTONE- Medium dark gray to dark gray, very fine lower, angular, moderately sorted, quartz with some feldspar; well indurated, calcite cement.
7	27.0	8.23	GYPSUM- Very light gray with olive gray laminations, very finely crystalline; base has olive black selenite porphyroblasts.
6	34.0	10.36	SANDSTONE- Moderate brown, very fine lower to medium lower, angular, moderately sorted, quartz and feldspar; friable, clay cement with hematite staining, thickly laminated to very thin bedded, poorly exposed, hopper casts and symmetric ripple marks at the base.

5	8.0	2.44	GYPSUM- Medium to very light gray, very finely crystalline, scattered olive black selenite porphyroblasts, no apparent laminations.
4	12.1	3.69	WACKESTONE- Pale to dark yellowish brown, medium lower with silt- to fine upper-sized quartz sand, scattered gastropods, ooids, peloids; interbedded with pinkish gray to grayish yellow, medium upper, rounded, moderately sorted, friable, quartz sandstone.
3	8.7	2.65	SANDSTONE- Pinkish gray to grayish yellow, coarse silt to very fine lower, angular, moderately to poorly sorted, quartz; friable, calcite cement, ripple laminations, very thin to medium bedded, scattered lenses of argillaceous carbonate mudstone to wackestone, very thinly laminated grayish orange pink siltstone at the base.
2	12.8	3.90	SANDSTONE- Pinkish gray and very light gray, very fine lower to medium lower, subangular, moderately to poorly sorted, quartz; friable, clay cement, traces of feldspar and chert, scattered gypsum veinlets, scattered claystone flakes on parting surfaces, very thin bedded to thickly laminated, poorly exposed.
1	23.2	7.07	SANDSTONE- Pale reddish brown with grayish red claystone flakes, very fine lower,angular, moderately sorted, quartz and feldspar; friable, clay and calcite cement, salt casts and hopper casts abundant in upper half of unit, thickly laminated to very thin bedded.

TOTAL MEASURED: 309.5 FEET (94.35 METERS)

-Unit 4 above correlates with Unit 18 in Torres section no.1-

CANAS GYPSUM MEMBER; YESO FORMATION: Measured in the SW 1/4, NW 1/4, SE 1/4, NW 1/4, Sec. 36, T.1S., R.2E., NMPM, Socorro County, New Mexico. (Measured on the north face of Sierra de la Cruz).

-Conformable(?) with the overlying Joyita Sandstone member-

UNIT	THICKNESS FEET	THICKNESS METER	DESCRIPTION
4	30.0	9.14	GYPSUM- White, very finely crystalline with 2.5 mm by 5.0 mm porphyroblasts of selenite scattered throughout. Selerite is olive gray. Unit recrystallized.
3	6.0	1.83	SANDSTONE- Pale reddish brown, very fine lower to coarse silt, angular, moderately sorted, quartz; friable, calcite cement, very silty grading locally to siltstone, poorly exposed.
2	0.5	0.15	CARBONATE MUDSTONE- Dark yellowish brown to dusky brown, fetid, rotten on both fresh and weathered surfaces, very poorly exposed.
1	42.9	13.08	GYPSUM- White, very finely crystalline with porphyroblasts of olive gray selenite. Some faint laminations present; weathers to a jumbled blocky appearence; a thin grayish orange pink, very fine lower, poorly sorted, quartz sandstone occurs at the base.

TOTAL THICKNESS: 79.4 FEET (24.20 METERS)

-Conformable with underlying Torres member-

JOYITA SANDSTONE MEMBER; YESO FORMATION: Measured in the NW 1/4, SW 1/4, SE 1/4, NW 1/4, Sec. 36, T.1S., R.2E., NMPM, Socorro County, New Mexico. (Measured on the north face of Sierra de la Cruz).

-Conformable with overlying Glorieta Sandstone-

	THICKNESS		
UNIT	FEET	METERS	DESCRIPTION
13	4.5	1.37	SILTSTONE- Moderate reddish brown, moderately indurated, shaly along base, very thin bedded to thickly laminated, poorly exposed.
12	1.6	0.49	SANDSTONE- Light brown, fine lower to fine upper, rounded, well sorted, quartz; poorly indurated to friable, calcite and limonite cement.
11	6.7	2.04	SANDSTONE- Pale reddish brown, very fine upper to fine lower, subround, well sorted, quartz and feldspar; moderately to well indurated, calcite cement with hematite staining on many grains, thick to massive bedded.
10	1.5	0.46	SANDSTONE- Grayish orange pink to pale yellowish orange, very fine upper to fine lower, subrounded, well sorted, quartz and feldspar; moderately indurated, calcite cement.
9	2.7	0.82	SANDSTONE- Moderate reddish brown, very fine upper, subangular, well sorted, quartz and feldspar; friable, calcite cement, scattered well rounded fine upper quartz grains.
8	4.9	1.49	SANDSTONE- Very pale orange, fine upper to fine lower, subrourd, well sorted, quartz and feldspar(?); friable, trace calcite cemert, trace green chert, thick bedded.
7	12.6	3.84	SANDSTONE- Moderate reddish orange, very fine upper to fine lower, subround, well sorted, quartz and feldspar; friable, calcite cement with hematite stain, thick bedded.

6	7.4	2.26	SANDSTONE- Very pale orange, fine lower to fine upper, subround, well sorted, quartz and feldspar; friable, calcite cement, unit grades into overlying red unit, laterally continuous around mountain, thick laminated to thin bedded.
5	12.6	3.84	SANDSTONE- Moderate reddish orange, fine lower to fine upper, subangular, well sorted, quartz and feldspar(?); friable, calcite cement in small aggregates, medium thick bedded.
4	10.4	3.17	SANDSTONE- Moderate orange pink to pale red, very fine upper to fine lower, subangular, well sorted, quartz; friable, calcite cement with laminations of hematite staining, thin to medium bedded.
3	8.0	2.44	SANDSTONE- Very light gray interbedded with pale reddish brown, very fine upper, subangular, well sorted, quartz and feldspar; friable, calcite cement, thick to medium bedded.
2	16.7	5.09	SANDSTONE- Pale reddish brown, very fine upper to fine lower, subangular, well sorted, quartz; friable, some calcite cement, trace green chert, wedge-shaped cross beds; shale partings near middle are grayish red, silty, hard, non-calcareous and are poorly exposed in the lower part.
1	6.8	2.07	SANDSTONE- Pinkish gray, fine lower to fine upper, angular, well sorted, quartz and feldspar; friable, calcite cement, tabular, thick bedded, silty along base, grades to gypsum below.

TOTAL THICKNESS: 96.4 FEET (29.38 METERS)

-Conformable(?) with underlying Canas Gypsum member-

TOTAL YESO FORMATION: 1045.2 FEET (318.58 METERS)

GLORIETA SANDSTONE: Measured in NW 1/4, SW 1/4, NE 1/4, Sec. 33, T.1S., R.2E., NMPM, Socorro County, New Mexico.

-Conformable with overlying San Andres Formation-

UNIT	THICKNESS FEET	METERS	DESCRIPTION
2	76.7	23.38	SANDSTONE- White, fine upper to medium lower, subrounded, very well sorted, quartz and chert(?); well indurated, silica and calcite cement, medium to massive bedded; interbedded siliceous, cross bedded sandstone and calcitic and siliceous tabularly bedded sandstone. Forms dark, bold cliffs below San Andres outcrops.
1	129.7	39.53	SANDSTONE- Very pale orange mottled pale yellowish orange, fine lower to fine upper, subangular, very well sorted, quartz and chert(?); moderately indurated, calcite cement, thin to thick bedded with simple and planar cross bed sets. Forms rounded-weathering slopes above Joyita Sandstone member of Yeso formation.

TOTAL THICKNESS: 206.4 FEET (62.91 METERS)

-Conformable(?) with underlying Joyita Sandstone member of the Yeso Formation-

SAN ANDRES FORMATION: Measured from the SW 1/4, SW 1/4, NE 1/4, to the SE 1/4, SW 1/4, NE 1/4, Sec. 28, T.1S., R.2E., NMPM, Socorro County, New Mexico.

-Top eroded. Section incomplete-

UNIT	THICKNESS FEET	METERS	DESCRIPTION
22	10.0	3.05	CARBONATE MUDSTONE- Light to dark yellowish gray, slightly fetid, hard, trace ostracod shell fragments, traces of gypsum, mediun to thick bedded.
21	7.8	2.38	CARBONATE MUDSTONE- Moderate to dark yellowish brow, scattered

			pelecypod and ostracod shells, medium to thin bedded.
20	7.6	2.32	CARBONATE MUDSTONE- Pale to moderate yellowish brown, slightly fetid, scattered peloids at the top, medium to thin bedded.
19	21.7	6.61	DOLOMITE- Pale yellowish brown, very finely crystalline, calcitic, locally gypsiferous, grades from carbonate mudstone in Unit 18, medium to thin bedded.
18	8.8	2.68	GRAINSTONE- Moderate yellowish brown, fine upper to medium lower, slightly dolomitic, peloids and ooids, medium to thick bedded.
17	5.7	1.74	DOLOMITE- Brownish black, calcitic, very finely crystalline, slightly fetid, very hard, occasional fossil fragments, banded chert nodules scattered along bedding planes.
16	9.4	2.86	WACKESTONE- Brownish black, slightly fetid, fossiliferous (with pelecypods, gastropods, brachiopods, phylloid algae, occasional encrusting bryozoans and peloids), dolomitic near the top, medium to thick bedded.
15	26.5	8.08	WACKESTONE- Brownish black, slightly fetid, numerous fossils (pelcypods, gastropods, brachiopods, phylloid algae, and occasional encrusting bryozoans and peloids), poorly exposed.
14	2.5	0.76	CARBONATE MUDSTONE- Brownish gray, fetid, scattered fossil debris (gastropods, pelecypod fragments), scattered limonite pseudomorphs after pyrite on the outcrop, medium bedded.
13	15.4	4.69	GRAINSTONE- Pale yellowish brown, fine upper to medium lower, peloids grading to oolites up section, slightly fetid, thick to medium bedded, cherty near the top.

12	6.3	1.92	DOLOMITIC GRAINSTONE- Brownish gray, fine upper to fine lower, non-fetid, peloids, moldic porosity.
11	5.1	1.55	DOLOMITE- Brownish black, fine crystalline, slightly fetid, hard, thick bedded.
10	8.1	2.47	DOLOMITE- Medium brownish gray to brownish black, very finely crystalline, slightly fetid, scattered gastropod and bi-valve shell fragments, medium to thick bedded.
9	3.0	0.91	SANDSTONE- Pale yellowish orange mottled white, medium lower to medium upper, rounded, very well sorted, quartz; friable, calcite cement, limonite and hematite staining, thick bedded.
8	1.5	0.46	CARBONATE MUDSTONE- Brownish gray, ~7% scattered, fine upper, angular, well sorted, quartz grains.
7	8.6	2.62	DOLOMITE- Medium brownish gray to moderate brown, very finely crystalline, very hard, slightly fetid, scattered very coarse crystalline calcite aggregates, increasingly calcitic near the top, medium to massive bedded.
6	2.0	0.61	BRECCIA- Pale yellowish orange, angular fragments of sandstone and limestone in a sandstone matrix.
5	14.2	4.33	SANDSTONE- Pale yellowish orange mottled white, medium lower to medium upper, rounded, very well sorted, quartz; friable to well indurated, calcite with some silica cement near the top, ~1% scattered hematite aggregates, thick to massive bedded.
4	4.6	1.40	PACKSTONE- Pale yellowish brown, fine upper to medium lower, peloids with occasional scattered pelecypod shells, hard, very

			slightly fetid, no apparent sedimentary structures.
3	10.0	3.05	GRAINSTONE- Light brown, fine upper to medium lower, peloids with some ooids and scattered shell fragments, occasional coarse crystalline calcite aggregates, current and ripple cross beds and laminations, thick to massive bedded; unit grades to packstone along strike.
2	7.8	2.38	DOLOMITIC LIMESTONE- Olive black, very fine crystalline, very hard, fetid, scattered coarse crystalline calcite aggregates, becomes calcitic dolomite in upper 3 feet of unit, medium to thick bedded.
1	4.4	1.34	DOLOMITE- Brownish gray to olive black, very fine crystalline, very hard, slightly fetid, medium to thin bedded.

TOTAL MEASURED THICKNESS: 191 FEET (58.22 METERS)

-Conformable with underlying Glorieta Sandstone-

APPENDIX II

THIN SECTION DESCRIPTIONS

The thin section descriptions are presented on forms developed by MacMillan (1981) for his Advanced Sedimentary Petrology course. The parameters listed on the description forms are described by Folk (1974) and MacMillan (1981). Grain size and roundness were determined with an American Stratigraphic grain size card. Feldspar composition was determined using charts presented in Moorhouse (1959, p. 57 and 59).

The samples of the intrusive rocks were named using the classification system outlined by Moorhouse (1959, p. 154-155).

Abbreviations:

N.O. = Not Observed

SRF = Sedimentary Rock Fragments

MRF = Metamorphic Rock Fragments

GRF = Granitic Rock Fragments

Slide: SR-Tm-dc (Dike Core)

Components:

N.O. % Quartz

43 % Plagioclase:
AN# 38 - 43
Name: Andesine
Description: Laths and microlites showing Albite twins. Most have undulose extinction making determination of the AN composition difficult

10 % Hornblende: Poorly preserved phenocrysts, locally altered to hematite staining.

10 % Calcite: Scattered patches of mosaic spar and filling vugs.

5 % Magnetite: Euhedral crystals < .062 mm scattered throughout slide.

2 % Apatite: Euhedral crystals with alteration rims (composition indeterminate).

30 % Glass: Isotropic mineral in groundmass with scattered microlites of Andesine Plagioclase.

Name: Hornblende Andesite Porphyry.

Slide: Pg Breccia

Clasts:
- Grain size of clasts: 5 mm
- Roundness: Very Well Rounded
- Elongation Index: .9 (very equant)
- Internal Fabric: See description of Glorieta Sandstone (Slide: YSTM-1-Pgu)

Matrix:
- Grain size: .062 - .5 mm (medium upper to very fine lower)
- Roundness: angular to well rounded
- Sorting: Poorly Sorted
- Description: Grains cemented with calcite; some grains have relect quartz syntaxial rim cement, grains are unstrained and have a chipped or pitted appearence.

Thin Section YSTM-1-Rd

Grain Size and Texture:

Average Apparent Diameter: .2 mm, +2.3 ∅

Wentworth grade: Fine (upper)

Sorting: Poorly Sorted

Overall Roundness: Angular

60 % Detrital Grains

10 % Cement: Calcite as grain coatings and poikilotopic spar cement.

15 % Matrix:

Ortho- N.O.

Epi- Hematite coatings on grains; some feldspars altered to clay.

Pseudo- Lithic fragments of brown shales.

15 % Present Pore Space: Intergranular

Textural Maturity: Submature

Inversions: N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Line
2. Sutured
3. Floating
4.

Rock Name: Lithic Arkose

Grain Types:

51 % Quartz: Size .2 mm, +2.3 Ø
Roundness: Angular
Elongation Index: .65 (subelongate)

Monocrystalline:
Inclusions: N.O.

Extinction: Straight with some undulose

Polycrystalline:
Crystals/grain: 12 ; Range: 3-16
Contacts: Sutured
Size: .2 mm; Shape: Anhedral

15 % K-Spar: Size N.O. mm, N.O. Ø
Roundness:
Elongation Index: Altered to clay
Orthoclase: %; Sanadine: %; Microcline: %;
Perthite: %.

10 % Plagioclase: AN# (Michel-Levy):
Name:
Size:
Roundness: Altered to clay
Elongation Index:
A-Twins/C-Twins:
Inclusions:

5 % Chert:

15 % Lithic Fragments:
Varieties: SRF; Pebble and granule-size Mudstone clasts; most poorly preserved during thin section preparation.

Tr. % Micas:
Light: Muscovite

Dark: N.O.

Light/Dark:

N.O. % Clays: (Detrital)

1 % Non-Opaque Heavy Minerals: Hematite dust on quartz grains

3 % Opaque Heavy Minerals: Euhedral to anhedral hematite between grains in pores.

N.O. % Others:

Thin Section YSTM-1-Psa

Carbonate constituents (% of rock):

N.O. % Intraclasts: varieties:
diagenetic changes:

N.O. % Ooids: varieties:
diagenetic changes:

N.O. % Peloids: varieties:
diagenetic changes:

80 % Skeletal material: varieties and their diagenetic changes: Shell fragments, Gastropods, Brachiopods, Trilobite fragments, Stromatolite (algal mat); micritized or filled with blocky mosaic spar

N.O. % Micrite (not including alterations of above):

5 % Neomorphic Spar: size, shape, occurrence: Microspar between grains; may have been micrite.

10 % Precipitated Spar: size, shape, occurrence: Spar filling molds of skeletal material

Other Constituents

N.O. % Terrigeneous debris: varieties, occurrence:

N.O. % Organic Material: occurrence:

5 % Present Pore Space: varieties and occurrence: Intragranular, intergranular, moldic.

Rock Name: after Folk (1962): Biosparrudite
after Dunham (1962): Bioclastic grainstone

Thin Section YSTM-1-Pgu

Grain Size and Texture:

Average Apparent Diameter: .3 mm, +1.75Ø

Wentworth grade: Medium (lower)

Sorting: Very Well Sorted

Overall Roundness: Well Rounded

89 % Detrital Grains

3 % Cement: Quartz syntaxial rim cement.

N.O.% Matrix:

Ortho-

Epi-

Pseudo-

8 % Present Pore Space: Intergranular

Textural Maturity: Mature

Inversions: None

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Floating
2. Point
3.
4.

Rock Name: Quartzarenite

Grain Types:

99 % Quartz: Size .3 mm, +1.75 Ø
Roundness: Well Rounded
Elongation Index: .65 (subelongate)
Monocrystalline:
Inclusions: Small, thin, vacuoles

Extinction: Straight to slightly undulose.

Polycrystalline: N.O.
Crystals/grain: N.O. ; Range:
Contacts:
Size: mm; Shape:

N.O. % K-Spar: Size mm, Ø
Roundness:
Elongation Index:
Orthoclase: %; Sanadine: %; Microcline: %;
Perthite: %.

N.O. % Plagioclase: AN# (Michel-Levy):
Name:
Size:
Roundness:
Elongation Index:
A-Twins/C-Twins:
Inclusions:

1 % Chert: .35 mm, angular, elongate

N.O. % Lithic Fragments:
Varieties:

N.O. % Micas:
Light:

Dark:

Light/Dark:

N.O. % Clays:

N.O. % Non-Opaque Heavy Minerals:

Tr. % Opaque Heavy Minerals: Unknown black mineral in pores.

N.O. % Others:

Thin Section SDLC-Pyj-1

Grain Size and Texture:

Average Apparent Diameter: .20 mm, +2.3 Ø

Wentworth grade: Fine (lower)

Sorting: Very Well Sorted

Overall Roundness: Subround

92 % Detrital Grains

2 % Cement: Finely crystalline aggregates of calcite on grains and in pores.

N.O.% Matrix:

Ortho-

Epi-

Pseudo-

5 % Present Pore Space:

Textural Maturity: Mature

Inversions: N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Point
2. Sutured
3. Concavo-convex
4. Line

Rock Name: Quartzarenite

Grain Types:

97 % Quartz: Size .2 mm, +2.3 Ø

Roundness: Subround

Elongation Index: .8 (very equant)

Monocrystalline:

Inclusions: Occasional scattered vacuoles

Extinction: Slightly undulose.

Polycrystalline:

Crystals/grain: 4 ; Range: N.O.

Contacts: Straight to sutured

Size: .3 mm; Shape: Anhedral

1 % K-Spar: Size .2 mm, +2.3 Ø

Roundness: Round

Elongation Index: .8 (very equant)

Orthoclase: -- %; Sanadine: -- %; Microcline: 50 %;

Perthite: 50 %.

1 % Plagioclase: AN# (Michel-Levy): 51-62

Name: Labradorite

Size: .2 mm

Roundness: Subangular

Elongation Index: .7 (subequant)

A-Twins/C-Twins: 100/0

Inclusions: N.O.

N.O. % Chert:

1 % Lithic Fragments:

Varieties: MRF; schist(?), gneiss(?), .21 mm, equant, subrounded, clay alteration rims

N.O. % Micas:

Light:

Dark:

Light/Dark:

N.O. % Clays:

N.O. % Non-Opaque Heavy Minerals:

N.O. % Opaque Heavy Minerals:

N.O. % Others:

Thin Section 8th Pyt Limestone

Carbonate constituents (% of rock):

10 % Intraclasts: varieties: Oncolite fragments
diagenetic changes: Coated with precipitated spar

10 % Ooids: varieties: .5 mm diam. to pisolites
diagenetic changes:

37 % Peloids: varieties: micrite, .5 - 1mm diam.
diagenetic changes: coated woith some ppt'd spar.

3 % Skeletal material: varieties and their diagenetic changes: Small ostracod shell fragments filled with precipitated spar.

N.O. % Micrite (not including alterations of above):

N.O. % Neomorphic Spar: size, shape, occurrence:

20 % Precipitated Spar: size, shape, occurrence:

Other Constituents

N.O. % Terrigeneous debris: varieties, occurrence:

N.O. % Organic Material: occurrence:

20 % Present Pore Space: varieties and occurrence:
Moldic, intercrystalline and intergranular.

Rock Name: after Folk (1962): Intraclast, oolite, oncholite pelsparite
after Dunham (1962): Peloid, oolite, orcholite grainstone

Thin Section SDLC-Pyt-5

Grain Size and Texture:

Average Apparent Diameter: .07 mm, +3.85 Ø

Wentworth grade: Very Fine (lower)

Sorting: Well Sorted

Overall Roundness: Angular

77 % Detrital Grains

5 % Cement: Calcite; scattered rhombs along grain surfaces

3 % Matrix:

Ortho- Clay minerals surrounding grains

Epi- Hematite staining and aggregates derived from oxidation of hematite.

Pseudo-Claystone chips (poorly preserved).

15 % Present Pore Space: intergranular; may be high due to grain plucking during thin section preparation.

Textural Maturity: Submature

Inversions: N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Floating
2. Line
3. Point
4.

Rock Name: Sublitharenite

Grain Types:

88 % Quartz: Size .07 mm, +3.85Ø
Roundness: Angular
Elongation Index: Subequant
Monocrystalline:
Inclusions: Small vacuoles

Extinction: Straight with some slightly undulose.

Polycrystalline: N.O.
Crystals/grain: N.O. ; Range:
Contacts:
Size: mm; Shape:

N.O. % K-Spar: Size ____ mm, ____ Ø
Roundness:
Elongation Index:
Orthoclase: %; Sanadine: %; Microcline: %;
Perthite: %.

Tr. % Plagioclase: AN# (Michel-Levy): 51-56
Name: Labradorite
Size: .062 mm
Roundness: Angular
Elongation Index: .50 (very elongate)
A-Twins/C-Twins: 100/0
Inclusions: N.O.

10 % Chert:

2 % Lithic Fragments:
Varieties:
SRF: Red claystone chips

N.O. % Micas:
Light:

Dark:

Light/Dark:

1 % Clays: Small aggregates of clay surrounding quartz grains

5 % Non-Opaque Heavy Minerals: Hematite as stain and cement.

3 % Opaque Heavy Minerals: Magnetite: .05 mm subhedral, altered to hematite.

1 % Others: Unknown, pale green, rounded mineral, very slightly pleochroic, no apparent extinction, .075 mm.

Thin Section 1st Pyt L.S.

Carbonate constituents (% of rock):

N.O.% Intraclasts: varieties:
diagenetic changes:

N.O.% Ooids: varieties:
diagenetic changes:

50 % Peloids: varieties: Relect micrite ghosts
diagenetic changes: recrystallized to micrcspar

N.O.% Skeletal material: varieties and their diagenetic changes:

N.O.% Micrite (not including alterations of above):

37.5 % Neomorphic Spar: size, shape, occurrence: .01 mm, euhedral, occurs in area between peloid ghosts. Pseudospar, .05 - .4 mm in area between peloid ghosts.

7.5 % Precipitated Spar: size, shape, occurrence: Monocrystalline calcite filling pores

Other Constituents

1 % Terrigeneous debris: varieties, occurrence: Angular quartz (silt-sized), very elongate, scattered throughout the slide.

3 % Organic Material: occurrence: Scattered dark brown sappropelic oily material

1 % Present Pore Space: varieties and occurrence: Intercrystalline

Rock Name: after Folk (1962): Pelmicrite
after Dunham (1962): Peloidal Wackestone

Thin Section YSTM-Pym-1

Grain Size and Texture:

Average Apparent Diameter: .062 mm, +4.0 Ø

Wentworth grade: Very Fine (lower)

Sorting: Well Sorted

Overall Roundness: Subangular

95 % Detrital Grains

2 % Cement: Silica (?)

1 % Matrix:

Ortho- N.O.

Epi- N.O.

Pseudo- Muscovite grains bent around quartz grains

2 % Present Pore Space: Intergranular

Textural Maturity: Mature

Inversions: N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Line
2. Concavo-convex
3.
4.

Rock Name: Sublitharenite

Grain Types:

__90__ % Quartz: Size __.07__ mm, __+3.85 Ø

Roundness: Angular

Elongation Index: .5 (very elongate)

Monocrystalline:

Inclusions: Trace of vacuoles

Extinction: Straight to slightly undulose

Polycrystalline:

Crystals/grain: __4__; Range: 2-6

Contacts: Sutured

Size: .062 mm; Shape: anhedral

__Tr__ % K-Spar: Size __.065__ mm, __+3.95__ Ø

Roundness: Angular

Elongation Index: .8 (very equant)

Orthoclase: -- %; Sanadine: -- %; Microcline: -- %;

Perthite: 100 %.

__3__ % Plagioclase: AN# (Michel-Levy): 58

Name: Labradorite

Size: .05 mm

Roundness: Angular

Elongation Index: .7 (subequant)

A-Twins/C-Twins: 100/0

Inclusions: N.O.

__5__ % Chert: .61 mm, subelongate, angular

__N.O.__ % Lithic Fragments:

Varieties:

__2__ % Micas:

Light: Muscovite

Dark: N.O.

Light/Dark:

__N.O.__ % Clays:

__N.O.__ % Non-Opaque Heavy Minerals:

__N.O.__ % Opaque Heavy Minerals:

__N.O.__ % Others:

Thin Section CDLU-2-Pa

Grain Size and Texture:

Average Apparent Diameter: .55 mm, +.85 Ø

Wentworth grade: Coarse (lower)

Sorting: Poorly Sorted

Overall Roundness: Angular

50 % Detrital Grains

20 % Cement: Calcite as scattered granules and poikilitic spar.

25 % Matrix:

Ortho- Clay minerals deposited with grains

Epi-Hematite staining clay in pores.

Pseudo- N.O.

5 % Present Pore Space: Intergranular

Textural Maturity: Immature

Inversions:N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Floating
2. Sutured
3. Concavo-convex
4.

Rock Name: Subarkose

Grain Types:

51 % Quartz: Size .55 mm, +.85 Ø
Roundness: Angular
Elongation Index: .45 (very elongate)
Monocrystalline: anhedral
Inclusions: Small vacuoles

Extinction: straight to slightly undulose.

Polycrystalline: anhedral
Crystals/grain: 6 ; Range:
Contacts: sutured
Size: .7 mm; Shape: anhedral

10 % K-Spar: Size .65 mm, +.65 Ø
Roundness: Angular
Elongation Index: .45 (very elongate)
Orthoclase: 100 %; Sanadine: -- %; Microcline: -- %;
Perthite: -- %.

5 % Plagioclase: AN# (Michel-Levy): 52
Name: Labradorite
Size: .5 mm
Roundness: Angular
Elongation Index: .7 (subequant)
A-Twins/C-Twins: 2.3
Inclusions: N.O.

1 % Chert:

N.O. % Lithic Fragments:
Varieties:

Tr. % Micas:
Light:

Dark: Biotite

Light/Dark: 0/100

25 % Clays: Clay hash with floating silt-size quartz grains stained with hematite.

5 % Non-Opaque Heavy Minerals:
Hematite as stain on grains and in matrix

3 % Opaque Heavy Minerals:
Hematite (anhedral) scattered throughout intergranular area.

N.O. % Others:

Thin Section CDLU-1-Pa

Grain Size and Texture:

Average Apparent Diameter: .1 mm, +3.3 Ø

Wentworth grade: Very Fine (upper)

Sorting: Poorly Sorted

Overall Roundness: Angular

70 % Detrital Grains

5 % Cement: Calcite filling pores

20 % Matrix:

Ortho- Detrital clay deposited with grains

Epi- Hematite staining clay; Feldspars altered to clay.

Pseudo- Scattered mica flakes pressed between quartz grains.

5 % Present Pore Space: intergranular

Textural Maturity: Immature

Inversions: N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Line
2. Concavo-convex
3.
4.

Rock Name: Subarkose

Grain Types:

65 % Quartz: Size .1 mm, +3.3 Ø
Roundness: Angular
Elongation Index: .55 (elongate)
Monocrystalline: 100%
Inclusions: Small vacuoles

Extinction: Straight with some slightly undulose.

Polycrystalline: N.O.
Crystals/grain: ______; Range:
Contacts:
Size: mm; Shape:

5 % K-Spar: Size .08 mm, +3.65 Ø
Roundness: Angular
Elongation Index: .65 (subelongate)
Orthoclase: 100 %; Sanadine: -- %; Microcline: -- %;
Perthite: -- %.

8 % Plagioclase: AN# (Michel-Levy): 51-66
Name: Labradorite
Size: .1 mm
Roundness: angular
Elongation Index: .6 (elongate)
A-Twins/C-Twins: 3.0
Inclusions: N.O.

1 % Chert: .1 mm, angular

N.O. % Lithic Fragments:
Varieties:

1 % Micas:
Light: Muscovite

Dark: N.O.

Light/Dark: 0/100

7 % Clays: Whispy clay minerals deposited with grains (orthomatrix)

3 % Non-Opaque Heavy Minerals: Red hematite; stains matrix and grain surfaces

10 % Opaque Heavy Minerals: Hematite grains altered to red hematite.

______ % Others:

Thin Section CDLU-Pb-4

Grain Size and Texture:

Average Apparent Diameter: .125 mm, 3 Ø

Wentworth grade: Fine (lower)

Sorting: Moderately sorted

Overall Roundness: Angular

70 % Detrital Grains

15 % Cement: Scattered calcite grain coatings and poikilitic spar.

10 % Matrix:

Ortho-N.O.

Epi-Altered hematite along parting in section

Pseudo-Mica grains squeezed between quartz grains.

5 % Present Pore Space:

Textural Maturity: Immature

Inversions: N.O.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Line
2. Sutured
3. Floating
4.

Rock Name: Subarkose

Grain Types:

66 % Quartz: Size .125 mm, +3 Ø
Roundness: Angular
Elongation Index: .8 (very equant)
Monocrystalline:
Inclusions: Scattered vacuoles

Extinction: Straight to strongly undulose

Polycrystalline:
Crystals/grain: 6 ; Range: 2-13
Contacts: Sutured
Size: .125 mm; Shape: Anhedral

3 % K-Spar: Size .125 mm, +3 Ø
Roundness: Subangular
Elongation Index: .5 (very elongate)
Orthoclase: 35 %; Sanadine: -- %; Microcline: -- %;
Perthite: 65 %.

10 % Plagioclase: AN# (Michel-Levy): 65-100
Name: Labradorite (5%), Bytownite (45%)
Size: .125 mm Anorthite (50%)
Roundness: Angular
Elongation Index: .5 (very elongate)
A-Twins/C-Twins: 99/1
Inclusions: N.O.

3 % Chert: .125 mm, anhedral, calcite inclusions

5 % Lithic Fragments:
Varieties: SRF; Limestone grains, subangular, .185 mm

5 % Micas:
Light: muscovite

Dark: Biotite

Light/Dark: 100/tr.

N.O. % Clays:

5 % Non-Opaque Heavy Minerals: Hematite grains less than .062 mm, euhedral to anhedral

Tr. % Opaque Heavy Minerals: Magnetite grains less than .062 mm, euhedral, altered to hematite.

3 % Others:
Fossil fragments (trilobite and brachiopod shell fragments)

Thin Section CDLU-Pb-3

Carbonate constituents (% of rock):

N.O.% Intraclasts: varieties:
diagenetic changes:

N.O.% Ooids: varieties:
diagenetic changes:

N.O.% Peloids: varieties:
diagenetic changes:

60 % Skeletal material: varieties and their diagenetic changes: Phylloid algae, encrusting bryozoans Gastropods, Braciopod shell fragments, Ostracods; most recrystallized; voids filled with precipitated spar.

N.O.% Micrite (not including alterations of above):

20 % Neomorphic Spar: size, shape, occurrence: Euhedral dolomite, .15 mm, hematite stained, locally recrystallized to calcite.
Pseudospar replacing microspar

10 % Precipitated Spar: size, shape, occurrence: Euhedral calcite filling voids in in shells and open pore space.

Other Constituents

10 % Terrigeneous debris: varieties, occurrence: Angular quartz, plagioclase (oligoclase), GRF, and rounded chert; .04 - 1.0 mm

0 % Organic Material: occurrence:

N.O.% Present Pore Space: varieties and occurrence:

Rock Name: after Folk (1962): Terrigeneous biosparrudite
after Dunham (1962): Terrigeneous packstone

Thin Section CDLU-Pb-1

Grain Size and Texture:

Average Apparent Diameter: .6 mm, +0.75 Ø

Wentworth grade: Coarse (lower)

Sorting: Moderately Sorted

Overall Roundness: Subangular

96.5 % Detrital Grains

2.5 % Cement: Calcite as sparry cement on grains

1 % Matrix:

Ortho- N.O.

Epi- N.O.

Pseudo- Mica grains bent around quartz and limestone grains.

2 % Present Pore Space: Intergranular

Textural Maturity: Submature

Inversions: Well-rounded limestone grains in an overall submature sedimentary rock.

Most Common types of grain-to-grain contacts (listed in relative order of abundance).

1. Line
2. Sutured
3. Concavo-convex
4.

Rock Name: Litharenite

Grain Types:

37 % Quartz: Size .6 mm, +0.75 Ø
Roundness: Subangular
Elongation Index: .8 (very equant)
Monocrystalline:
Inclusions: N.O.

Extinction: Straight to slightly undulose

Polycrystalline:
Crystals/grain: 6 ; Range: 4-18
Contacts: Sutured to Line
Size: .65 mm; Shape: Anhedral

5 % K-Spar: Size .55 mm, +0.85 Ø
Roundness: Angular
Elongation Index: .8 (very equant)
Orthoclase: --%; Sanadine: -- %; Microcline: 2 %;
Perthite: 98 %.

N.O. % Plagioclase: AN# (Michel-Levy):
Name:
Size:
Roundness:
Elongation Index:
A-Twins/C-Twins:
Inclusions:

2 % Chert: .3 mm, angular, elongate

55 % Lithic Fragments:
Varieties: SRF; Limestone, .5 mm, rounded, equant, micrite rims; considerable fossil debris (echinoid spines, shell fragments)

1 % Micas:
Light: Muscovite

Dark: N.O.

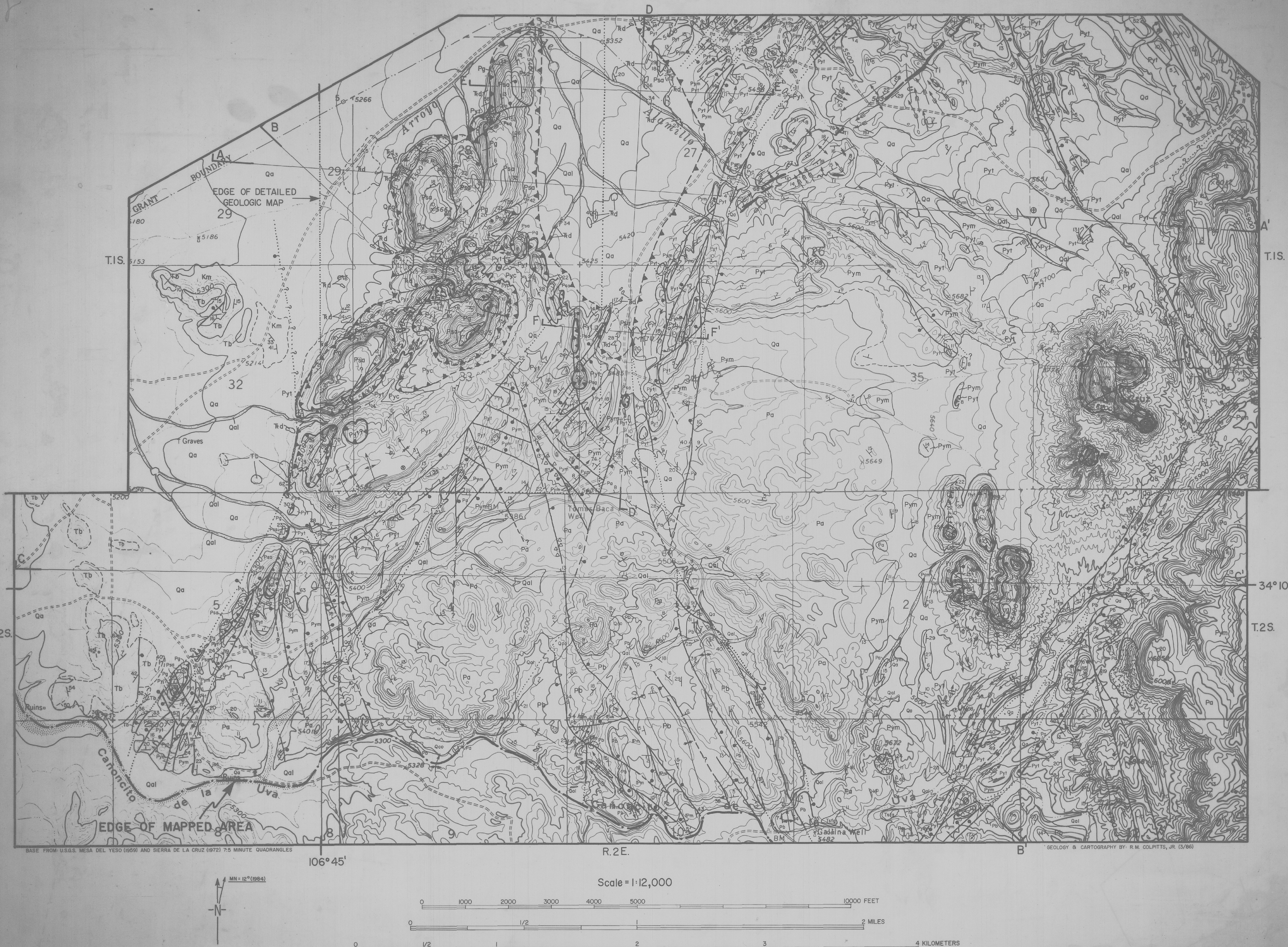
Light/Dark:

N.O. % Clays:

N.O. % Non-Opaque Heavy Minerals:

N.O. % Opaque Heavy Minerals:

N.O. % Others:



GEOLOGIC MAP OF THE SIERRA DE LA CRUZ AREA, SOCORRO COUNTY, NEW MEXICO

BY: ROBERT M. COLPITTS, JR.

1986

EXPLANATION

Age	Symbol	Unit	Description
Quaternary	Qal	Stream Alluvium	Sands and gravels in arroyo bottoms.
Quaternary	Qco	Colluvium	Boulders and gravel on steep hillsides.
Quaternary	Qa	Valley Alluvium	Interbedded sand and gravel filling open valleys.
Tertiary	Tsfg?	Santa Fe Group (?)	Isolated, well cemented gravel near Canoncito de la Uva.
Tertiary	Ti	Andesitic Intrusives	Greenish black, hornblende andesite porphyry.
Tertiary	Tb	Baca Formation	Interbedded reddish brown to pink, sandstone and conglomerate.
		—ANGULAR UNCONFORMITY—	
Creta.	Km	Mancos Shale (Undivided)	Dark gray shale with minor coquina and yellowish brown sandstone.
		—EROSIONAL UNCONFORMITY—	
Triassic	₸d	Dockum Group	Interbedded brownish gray to pale red and purplish gray mudstone, sandstone, conglomerate and minor limestone.
		—EROSIONAL UNCONFORMITY—	
Permian	Psa	San Andres Formation	Interbedded gray limestone, dolomite and minor sandstone with local breccia.
Permian	Pg	Glorieta Sandstone	White, crossbedded sandstone.
Permian	Pyj	Joyita sandstone member	Orange to pink sandstone and minor shale.
Permian	Pyc	Canas gypsum member	Light gray to white, laminated gypsum with minor limestone.
Permian	Pyt	Torres member	Interbedded light gray gypsum, gray limestone and light reddish brown sandstone with local breccia.
Permian	Pym	Meseta Blanca member	Orange, pink and reddish brown sandstone and siltstone.
Permian	Pa	Abo Formation	Interbedded pale red, grayish red and dark reddish brown conglomerate, sandstone, siltstone and mudstone.
		—EROSIONAL UNCONFORMITY—	
Permian	Pb	Bursum Formation	Interbedded light brownish gray, dark gray and brownish black conglomerate, sandstone, shale and limestone.
		—EROSIONAL UNCONFORMITY—	
Pennsyl.	IPm	Madera Limestone	Light brownish gray limestone.

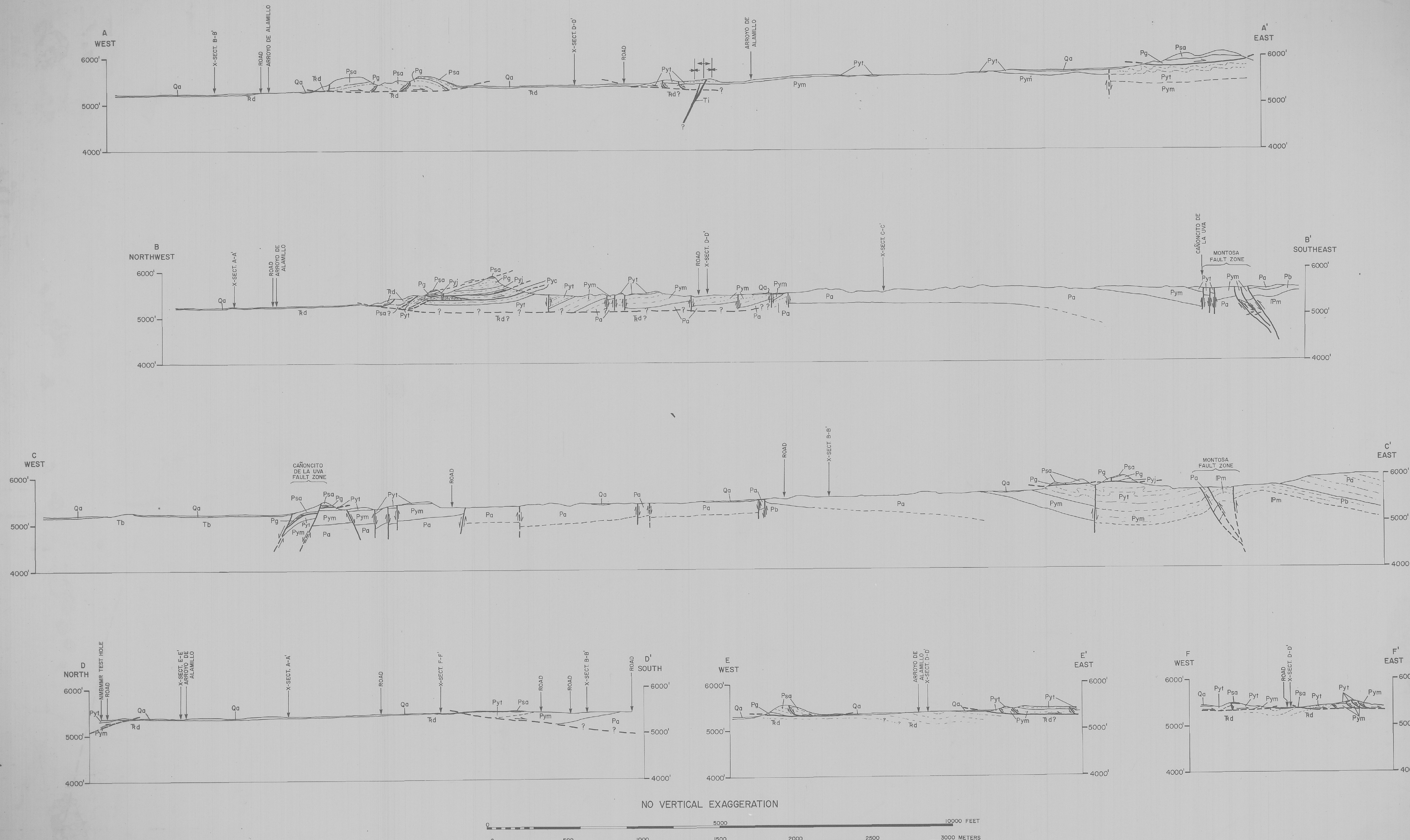
Psa and Pg: Psg — San Andres – Glorieta undivided.

Pyj, Pyc, Pyt, Pym: Yeso Formation

SYMBOLS

- 15 — Strike and dip of beds.
- 45 — Approximate strike and dip.
- 80 — Strike and dip of overturned beds.
- Horizontal beds.
- Vertical beds.
- Tie leader (connects outcrops of equivalent rocks).
- Breccia.
- Contact: dashed where approximate; dotted where concealed.
- ? 68 80 — High-angle fault: dashed where approximate; dotted where concealed; question marks show continuity uncertain; ball-and-bar on downthrown side; short arrow shows dip direction of fault surface; long arrow shows trend and plunge of slickensides.
- Low angle detachment fault; arrow does not imply movement direction on cross sections.
- Low-angle detachment fault: dashed where approximately located beneath thin alluvial cover; teeth toward upper plate.
- Slumps and landslides.
- Anticlines: arrow shows plunge direction.
- Synclines: arrow shows plunge direction.
- 45 5 — Overturned or recumbent anticline with dip of axial surface; arrow shows trend and plunge of fold axis.
- Overturned or recumbent syncline.
- Small, closely spaced folds (individual folds too small to plot separately); arrow shows plunge direction.
- A A' — Cross section lines.

244

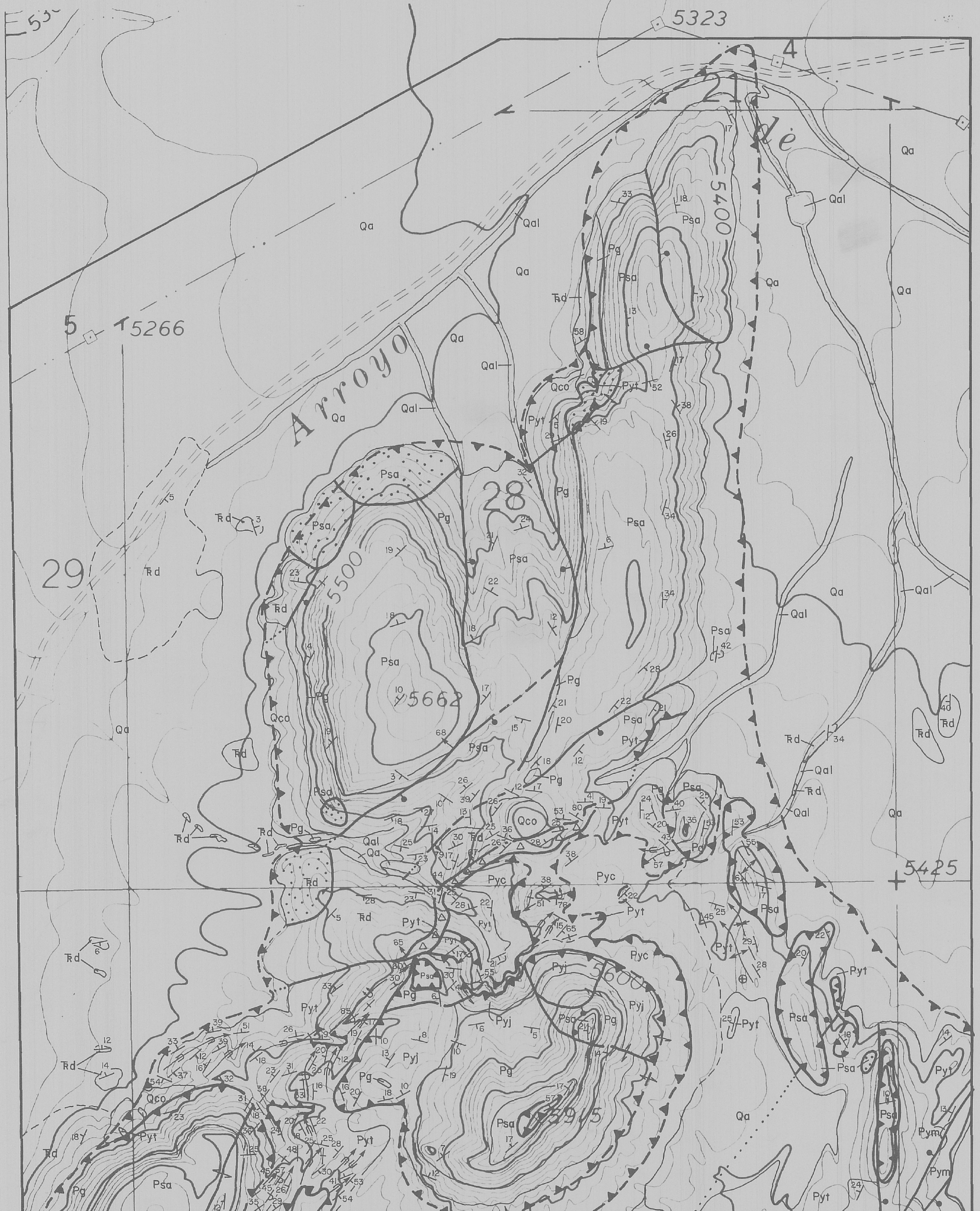


CROSS SECTIONS A-A' TO F-F'

(SEE PLATE I FOR EXPLANATION AND LOCATION OF CROSS SECTION LINES)

244 244

PLATE 3



DETAILED GEOLOGIC MAP OF SEC. 28 & 33, T.I S., R.2 E., SIERRA DE LA CRUZ AREA

(SEE PLATE I FOR EXPLANATION & LOCATION OF AREA COVERED)

244 244