Circular 125

Structural Geology of Northern Part of Animas Mountains, Hidalgo County, New Mexico

by J.M. Soule

1972

New Mexico State Bureau of Mines and Mineral Resources

NEW MEXICO STATE BUREAU OF MINES AND MINERAL RESOURCES

Don H. Baker, Jr., *Director*

Full-time Staff

DIANE ALLMENDINGER, *Clerk-Typist*
WILLIAM E. ARNOLD, *Scientific Illustrator*
BLAIR R. BENNER, *Junior Metallurgist*
ROBERT A. BIEBERMAN, *Petroleum Geologist*
LYNN A. BRANDVOLD, Chemist
CHARLES E. CHAPIN, *Geologist*
RICHARD R. CHAVEZ, *Technician*
E. JACK COATS, *Bureau Info. Coordinator*
JILL COLLIS, Secretary
Lois M. DEVLIN, *Office Manager*
JO DRAKE, *Administrative Ass't. & Sec'y.*
ROUSSEAU H. FLOWER, *Senior Paleontologist*
ROY W. FOSTER, *Petroleum Geologist*
WILLIAM L. HAWKS, *Materials Engineer*
ROBERT W. KELLEY, *Editor & Geologist*
FRANK E. KOTTLOWSKI, *Ass't.* Dir. & Sr. *Geol.*
THOMAS M. PLOUF *Research Extractive Met.*
JACQUES R. RENAULT, *Geologist*
RONALD J. ROMAN, *Chief Research Metallurgist*
JOHN W. SHOMAKER, *Geologist*
JACKIE H. SMITH, *Laboratory* Assistant
KARL YONDER LINDEN, *Mng. Eng., Env. Geol.*
CHARLES W. WALKER, *Geochemist-Mineralogist*
ROBERT H. WEBER, Senior *Geologist*
SHIRLEY WHYTE, Clerk-Typist
MAX E. WILLARD, *Economic Geologist*
ROBERT WOOD, Draftsman *I*
JUARINE W. WOOLDRIDGE, *Editorial Clerk*
MICHAEL W. WOOLDRIDGE, Draftsman

Part-time Staff

CORALE BRIERLEY, *Ass't. Chemist, Biology*
ROLAND F. DICKEY, *Public Relations*
RUFIE MONTOYA, Dup. Mach. Oper.
JOHN REICHE, *Instrument Manager*

Graduate Students

ROGER ALLMENDINGER, *Geologist*
JIM BRUNING, *Geologist*
STUART FAITH, *Geologist*
MICHAEL JAWORSKI, *Geologist*
JAMES JENSEN, *Geologist*
WALTER VERNON KRAMER, *Geologist*
JESUS NAJERA, *Hydrogeologist*
CRAIG OLSON, *Metallurgist*
TERRY SEIMERS, *Geologist*
DON SIMON, *Geologist*

Plus more than z8 undergraduate assistants

New Mexico Tech Staff Advisors

GALE BILLINGS, *Geoscience*
PAIGE W. CHRISTIANSEN, *Historian-Mining*
ALLAN R. SANFORD, *Geophysics*
FRANK B. TITUS, *Hydrology*

New Mexico State Bureau of Mines and Mineral Resources

Circular 125

STRUCTURAL GEOLOGY OF NORTHERN PART OF ANIMAS MOUNTAINS, HIDALGO COUNTY, NEW MEXICO

by
James M. Soule

Socorro
1972

New Mexico State Bureau of Mines and Mineral Resources
Don H. Baker, Jr., *Director*

A Division of
New Mexico Institute of Mining and Technology
Stirling A. Colgate, *President*

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63-1-4
Printed by University of New Mexico Printing Plant, November 1972

Available from New Mexico State Bureau of Mines, Socorro, NM 87801
Deposited in public libraries

Price $2.00

CONTENTS

ROCK UNITS

STRUCTURE

TECTONIC HISTORY

FIGURES

ABSTRACT

The Animas Mountains are a north-south-trending range in south-central Hidalgo County, New Mexico. Precambrian basement rock is granite dated at 1,200±40 m.y. Approximately 3,500 ft (1,000 m) of Paleozoic marine and 10,000 to 15,000 ft (3,000 to 4,500 m) of Cretaceous clastic sedimentary rocks are exposed in the area. Cretaceous rocks are dominantly synorogenic with respect to latest Cretaceous-earliest Tertiary Laramide orogeny. Tertiary rocks are chiefly post-orogenic intrusives and volcanics. Laramide structure consists of thin thrust plates of Paleozoic and Lower Cretaceous rocks thrust to the north and northeast over Upper Cretaceous synorogenic rocks. An upfaulted block of basement and lower Paleozoic rocks at the north end of the area has resulted in local detachment and fragmentation of the lowest thrust plate and suggests a general mechanism for detachment of the lowest thrust plate outside the area studied. Post-Laramide structure involves normal faults and acidic intrusives injected along fractures, accompanied by volcanism. Normal faulting has continued to the present.

INTRODUCTION

Location

The area covered by this report consists of the northernmost part of the linear north-south-trending Animas Mountains in south-central Hidalgo County, New Mexico (fig. 1). The settlement closest to the area is the hamlet of Animas reached via U. S. Interstate Highway 10 and New Mexico State Highway 338. A passenger car could be driven on graded gravel roads to within a mile and a half of any part of the area. However, torrential rains during local summer storms can make roads impassable. Unmaintained gravel roads deteriorate rapidly.

Previous Work and Methods

Darton (1922, p. 275) mentioned the occurrence of igneous and sedimentary rocks in the Animas Mountains. The only other published work on the geology of the northern Animas Mountains is the reconnaissance geologic map by Zeller (1958). Although Zeller recognized the thrust faults and mapped many of the outcrops, most of the details of the structural geology were not known prior to the present study.

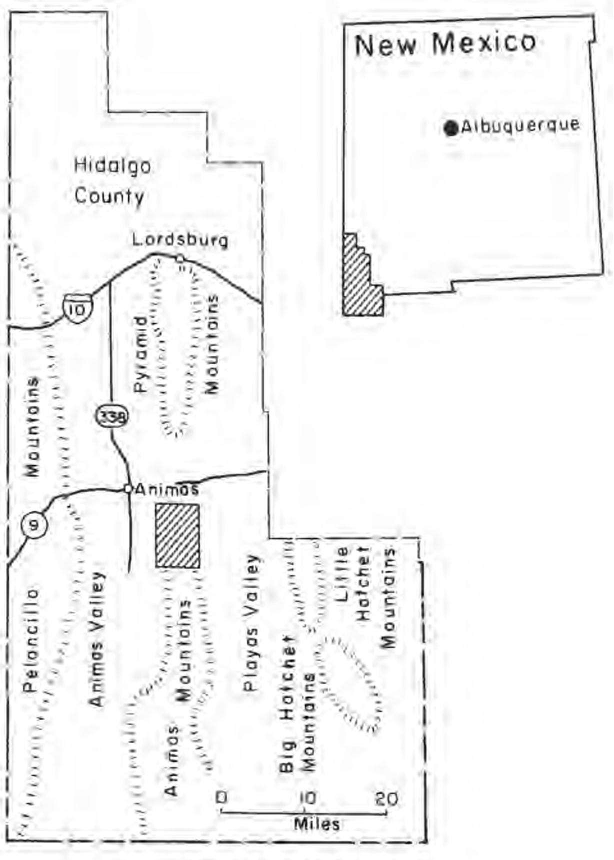


Figure 1 — Location map.

The objective of this work was to produce an accurate bedrock geologic map of the northern Animas Mountains (fig. 2, in pocket), and interpret the structure of the area. Field work was undertaken for 39 days during the spring of 1971. Field data were collected and plotted directly on 1:20,000 U. S. Soil Conservation Service aerial photographs. Accurate or large-scale or planimetric base maps of the area suitable for geologic mapping were not available. The fifteen-minute Playas topographic quadrangle covers nearly all the area, but the topography shown is highly generalized and too inaccurate for a geologic map base. The base map used was compiled as overlays on the aerial photographs. Thus, the map is distorted somewhat, especially in the north-central part. This distortion has little effect on the outcrop pattern or interpretation of the structure.

In addition to field work in the northern Animas Mountains, several days were spent reviewing the work of Zeller and Gillerman in the Big Hatchet, Animas, and Peloncillo mountains, respectively. Type and reference stratigraphic sections were studied for better control of the stratigraphy in the northern Animas Mountains.

Several geologic problems of the area remain unsolved. Although the complex structure of the area would make such work difficult, most details of the stratigraphy need additional study. Detailed analysis of fossils from Cretaceous rocks will aid greatly in understanding Laramide events. The sequence of igneous rocks presented in this paper should be considered only tentative until radiometric dates are determined. The active faulting in the area may prove important in further understanding of deformation in the region.

Physiography and Climate

The northern Animas Mountains are low, angular hills and ridges surrounded by pediments. The local relief between Animas Valley and the highest prominence at the north end of the area (6,055 ft, 1,850 m) is approximately 1,300 ft (400 m). In most places the relief is considerably less, and rarely exceeds 500 ft (150 m). Slopes probably average 25°, and depend upon composition of bedrock and location of drainage. Breaks in slope between the pediments and bedrock are abrupt and ridge and spur lines are sharp. All drainage is intermittent and radiates outward from the range.

The area lies in the Mexican Highland region of the southwestern United States and northern Mexico. The climate is dry. Precipitation is variable and unreliable; the maximum occurs during the summer months, but the annual average 8 to 10 in (20 to 25 cm) (Long, 1946) is inadequate for most agriculture. Daytime temperatures in the summer often exceed 100°F whereas below freezing temperatures, especially at night, are common during the winter. Vegetation is sparse and commonly varies locally with slope, composition of bedrock and surficial deposits, and availability of water.

Economy

At present, the only economic activity in the northern Animas Mountains is cattle grazing. Lack of water and abundant forage make this limited use marginal. In the past, one mine in the area produced some silver. The workings are presently abandoned. Exploration mining excavations, common throughout the area, were examined cursorily, and are probably valueless.

Acknowledgments

This project initiated as a thesis study for a Master of Science degree in the Graduate School at the University of New Mexico. Lee A. Woodward served as Chairman, read preliminary and final manuscripts of this report, and offered advice and suggestions throughout the course of the work. Sherman A. Wengerd and J. Paul Fitzsimmons served on the committee.

Parts of the work had the benefit of discussions with Wolfgang E. Elston, Philip T. Hayes, Frank E. Kottlowski, and Rodney C. Rhodes. The work of the late Robert A. Zeller, Jr. was consulted throughout.

This work was partially supported by the New Mexico Geological Society and the New Mexico State Bureau of Mines and Mineral Resources.

ROCK UNITS

Bedrock exposed in the northern Animas Mountains varies in age from Precambrian to Recent. Nowhere in the area are complete sections of any of the rock units exposed. Due to the complex structure of the range and intense internal deformation of individual beds, most exposures are very poor. Proximity to Tertiary igneous rocks commonly resulted in alteration of many of the sedimentary rocks inasmuch as shale is hornfelsic and limestones are locally recrystallized near their contacts with intrusives. Forceful injection of igneous bodies further complicates already complex structure making reliable section measurement nearly impossible.

The Precambrian is represented by a pink, coarse-grained, porphyritic granite. The Paleozoic to Lower Mesozoic section is composed chiefly of marine sedimentary rocks, whereas Upper Mesozoic to lower Tertiary rocks are synorogenic and clastic. Most Cenozoic rocks of the Animas Mountains are igneous. Quaternary to Recent alluvial and colluvial gravels, in many places indurated by caliche, are found as talus, stream deposits, and pediment veneer along the periphery of the mountains.

Several unconformities occur in the stratigraphic column. As reported by Kinney and others (1970, p. 21), the age of the Precambrian in the northern Animas Mountains is 1,200±40 m.y. Nonconformably overlying the Precambrian is the Bliss Formation of Late Cambrian age (Zeller, 1965, p. 11-12). This contact is undulatory; the Bliss is highly variable throughout the region. A minor disconformity occurs between the El Paso Formation (Lower Ordovician) and the overlying Montoya Dolomite (Zeller, 1965, p. 19). Due to lithologic similarities of the upper part of the El Paso and the lower part of the Montoya, this erosional break is difficult to recognize in the northern Animas Mountains. Regionally and to the east, the Silurian is represented by the Fusselman Dolomite (Kottlowski, 1963, p. 22-24). However, throughout Hidalgo County and southeastern Arizona (Gilluly, 1956, p. 29) Silurian rocks are absent. In most places in the northern Animas Mountains, an erosional surface cuts deep into the Montoya Dolomite, and in some places this latter unit is missing also. The Escabrosa Group (Mississippian) is separated from the overlying Pennsylvanian and Horquilla Limestone (Lower Permain) by an erosional surface at the top of the Paradise Formation. This erosion removed the Paradise entirely at some localities, making distinction between the two massive limestones difficult.

Rocks of Leonard or Guadalupe age are not exposed in the northern Animas Mountains. In the Big Hatchet Mountains, Zeller (1965) indicated a thickness of approximately 6,000 ft (1,850 m) for Middle to Upper Permian rocks. In structure section, Zeller and Alper (1965) estimated 5,000 ft (1,500 m) for the same interval in the southern Animas Mountains; and Gillerman (1958) indicated approximately 1,500 ft (500 m) to the west of the Animas Mountains in the Peloncillo Mountains. From the regional pattern, rocks of Leonard and Guadalupe age certainly must occur at depth in the vicinity of the northern Animas Mountains. No sedimentary rocks of Triassic or Jurassic age are known from southwestern New Mexico and southeastern Arizona (Kottlowski, 1963, p. 71; Zeller, 1965, p. 54-55; Hayes and Drewes, 1968, p. 51-54).

Cretaceous rocks of estimated 10,000 to 15,000 ft (3,000 to 4,500 m) thickness occur in the northern Animas Mountains. Similar thicknesses were measured by Zeller (1965, 1970) in the Big Hatchet and Little Hatchet Mountains, as well as by Gillerman (1958) and Gilluly (1956) for areas to the west. Zeller mentions an angular unconformity between Lower and Upper Cretaceous rocks in the Little Hatchet Mountains (1970, p. 8). A similar unconformity has been reported in southeastern Arizona by Gilluly (1956) and Hayes and Drewes (1968). This unconformtiy marks the inception of strong Laramide tectonism and is probably regional in extent, although not directly observable in the northern Animas Mountains.

Significant accumulation of sedimentary materials has not occurred in the northern Animas Mountains since early Tertiary time. Tertiary igneous rocks range in texture and composition from a porphyritic quartz monzonite to quartz latite and vitrophyre. All intrusive rock occurrences appear to be controlled by older structures in the country rock. Exposures of volcanic rock probably are remnants of an originally much more extensive volcanic pile. South of the area studied, the Animas Mountains are composed mostly of volcanic rock.

Travis' (1955) rock classification is used for sedimentary and igneous rocks. Bedding thickness modifiers are those given by Kelley (1956, p. 294); and the standard Wentworth scale (1922) is used for grain size.

Precambrian Granite

Brownish-pink, coarse-grained, porphyritic granite is exposed in the north-central part of the area immediately below the Bliss Formation, as well as in several places below the thrust plate of Mojado Formation rocks. This granite is the only Precambrian rock exposed in the northern Animas Mountains.

Microscopically, this granite is found to contain 6.0 to 12.0 mm sericitized phenocrysts of microperthite in a hypidiomorphic granular groundmass consisting of equal amounts of strained quartz and orthoclase. Chloritized and oxidized limonite-stained biotite is common. The rock also contains a small amount of microcline and opaque minerals. Cataclasis is common, as nearly all the crystals are fractured. Due to weathering, alteration, and shearing, the result of faulting, all Precambrian exposures in the area are very poor. Except where incised by drainages, the granite outcrop is seen as grus composed principally of weathered orthoclase and quartz. Where a cover of debris is absent, the exposure is stained brown from limonite derived principally from oxidized biotite. Tertiary intrusions are found near most Precambrian outcrops. Fractures in the granite result in even the best exposures being rubbly and difficult to sample.

Cambrian

Bliss Formation

The type locality of the Bliss Formation is in the Franklin Mountains, near El Paso, Texas (Richardson, 1904). In the northern Animas Mountains, the Bliss Formation is unconformable on the Precambrian, and forms a low cliff. Approximately the lowest 20 ft (6 m) of Bliss consists of arkosic conglomerate with cobbles and boulders of Precambrian granite. This passes into 0 to 30 ft (0 to 8 m) of hard, massive, glauconitic quartz sandstone. In a 360-ft (95-m) section of Bliss measured at Station 1, this sandstone contains 25 percent glauconite, and is a reliable marker horizon wherever seen in the study area. Higher in the section, the Bliss is arenaceous, brown, saccharoidal dolomite, which resembles similar, although less arenaceous, dolomite of the El Paso Formation. The highest beds of Bliss are 75 to 100 ft (20 to 30 m) of resistant white-tan orthoquartzite which forms a cliff below the El Paso dolomite. Although the Bliss is consistent lithologically throughout the area, and southwestern New Mexico in general (Zeller, 1965, p. 8-11; Gillerman, 1958, p. 18-21), extreme variation in thickness can make positive identification of the Bliss difficult. Small fensters of Bliss rocks immediately south of Station 1 are mapped as Bliss on the basis of glauconitic sandstone occurrence and proximity to Precambrian outcrops. Zeller identified the Late Cambrian brachiopod *Eorthis* sp. from the Bliss in the Big Hatchet Mountains (1965, p. 11-12); however fossils in the Bliss are generally rare, and none was found in the northern Animas Mountains.

Ordovician

El Paso Formation

The type El Paso, as defined by Richardson (1909) at Trans-Pecos, Texas (Kelley and Silver, 1952, p. 40-41), consists of approximately 1,500 ft (450 m) of limestone. In the northern Animas Mountains, the El Paso Formation (Ordovician) lies conformably above Bliss quartzite. A major thrust plate south of Station 1, and two small klippen north of Station 2 are composed of El Paso. The dominant lithology of this unit is dense, brown saccharoidal dolomite forming a rubbly outcrop. Near the base, the dolomite contains white and tan reticulated chert in bands 1 to 2 in (2 to 4 cm) across and of variable length. Kelley and Silver (1952, p. 42-52) raised the El Paso to group status, and divided it into the lower chert-bearing Sierrite Formation and the upper Bat Cave Formation. Flower (1955) divided the El Paso into three units, each characterized by a distinctive faunal zone. In the northern Animas Mountains, the lower cherty dolomite probably is equivalent to the Sierrite, considered to be late Early Ordovician in age (Flower, 1968). However, the El Paso was not subdivided in mapping. As with most units in the northern Animas Mountains, the El Paso is highly deformed. Pre-Montoya erosion undoubtedly removed some of the upper El Paso, and the original thickness can only be estimated. From sections measured by Gillerman (1958, p. 21-24, p. 108), and computation of thickness based on outcrop width in the northern Animas Mountains, the El Paso appears to be no more than 600 ft. (185 m) thick, and may be considerably less.

Montoya Dolomite

Richardson (1909) defined Montoya Dolomite as all units between the El Paso Formation and the Fusselman Dolomite (Kelley and Silver, 1952, p. 57). Remnants of the Montoya Dolomite (Ordovician) are found disconformably above the El Paso north and east of Station 1, as well as in the thrust plate and klippen of the El Paso Formation. It is resistant to deformation and erosion and is commonly fossiliferous. The exposure is usually a resistant block or blocks below nonresistant Percha Shale. The chert is distinctive brown black and occurs in irregular masses 1 to 3 in (2 to 7 cm) across. Bedding is rarely seen. Several species of brachiopods are present. Regional work (Zeller, 1965, p. 21) indicates that the Montoya thins toward the west, and is absent only a short distance into eastern Arizona. The upper contact of the Montoya is also a disconformity and the Montoya, where present in the northern Animas Mountains, is, at most, a few tens of feet thick.

Devonian

Percha Shale

Gordon and Graton (1907) first proposed the name Percha for a shale unit of southern New Mexico containing Devonian fossils. According to Kelley and Silver (1952, p. 69) a type section was not defined, but the formation is exposed along Percha Creek in Sierra County, New Mexico, and the rock exposed there is named Percha Shale.

Throughout the northern Animas Mountains, the Percha Shale is a zone of tectonic weakness at the base of the massive Escabrosa limestone. Where seen in normal stratigraphic section, the Percha lies on an irregular surface at the top of the Montoya Dolomite. The lower Percha is black, gray, and brown fissile shale. Higher in the section, the Percha contains intercalated beds of tan, argillaceous and calcareous sandstone and siltstone, which grade upward and are interbedded with massive limestone of the Escabrosa Group. Where seen at the base of the Escabrosa thrust plate, the Percha is a thin interval of highly contorted gray and black shale, mixed with underlying red Cretaceous shale. The Percha probably was not more than 200 to 300 ft (60 to 90 m) thick in the northern Animas Mountains prior to Laramide tectonism (Gillerman, 1958, p. 25-27).

Mississippian

Escabrosa Group

Named by Ransome (1904, p. 42-44) for exposures near Bisbee, Arizona, the Escabrosa limestone of Mississippian age is the most extensive carbonate rock unit of the northern Animas Mountains. The Escabrosa is found in a thrust plate covering nearly half the area. At the north end of the range, the Escabrosa forms an abrupt cliff above the Percha Shale and Cretaceous rocks. In other areas, it is seen as moderately steep and high hills in which the limestone has been highly contorted by thrusting. In a few places where complexly deformed or isolated in klippen, the Escabrosa forms low mounds and hillocks surrounded by less resistant rock; and rarely, where intensely deformed, it is non-resistant.

As in the Big Hatchet Mountains and other areas (Zeller, 1965, p. 24-27), the Escabrosa can be divided into three units. The lowest is a thick-bedded, medium-gray, encrinal, bioclastic crystalline limestone with brown chert nodules and stringers. The middle unit consists of dark-gray, finely crystalline limestone, which weathers to a characteristic dark-gray brown and contains minor, small, black chert nodules. The highest unit is light-gray-weathering crystalline limestone composed principally of crinoid columnals. The highest Escabrosa beds closely resemble the lowest unit as well as overlying Horquilla Limestone, making positive identification of isolated outcrops of any of these strata difficult.

On the basis of lithologic studies, Armstrong (1962, p. 5) raised the Escabrosa to group rank by subdividing the limestones into the lower Keating Formation and the upper Hachita Formation. Stratigraphically, this subdivision probably holds in the northern Animas Mountains, but offers little benefit for structural interpretation; therefore, the Escabrosa is mapped as one unit.

Aggregate Escabrosa thickness in the northern Animas Mountains is at least 600 ft (185 m), and may be greater. Zeller measured 1,261 ft (385 m) of Escabrosa in the Big Hatchet Mountains (1965, p. 25) and Gillerman (1958) reported 425 to 450 ft (130 to 137 m) in the Peloncillo Mountains. In the study area, reconstruction in structure section indicates a minimum of 600 ft (185 m).

Paradise Formation

The Paradise Formation of Chester age (Zeller, 1965, p. 27, 29) was named by Stoyanow (1949, p. 316-318) for exposures in the Chiricahua Mountains near Paradise, Arizona. In the study area, the Paradise is found as a thin interval of slope-forming, crinoid-biostromal, black limestone, tan and red fissile shale, and buff sandstone, between Escabrosa strata and the Horquilla Limestone. The Paradise ranges in thickness from 0 to 75 ft (0 to 23 m). Thickness changes abruptly along strike. Limestone debris covers the outcrops making identification of the Paradise difficult. The Paradise behaves incompetently as it occurs between two competent limestones, and locally may be tectonically thickened, thinned, or eliminated entirely.

Mississippian to Permian

Horquilla Limestone

The Horquilla Limestone or Early Pennsylvanian to Early Permian age (Zeller, 1965) is equivalent to a part of the Naco Limestone, as defined by Ransome (1904, p. 44-56). Gilluly and others (1954, p. 15-18) raised the Naco to group status, the lowest formation of which was then named Horquilla. The type section was at Horquilla Peak, Tombstone Hills, Cochise County, Arizona. The Horquilla is exposed above the Paradise Formation and Escabrosa Group in many pacts of the northern Animas Mountains. It holds up prominent hills and ridges, and its outcrops are among the most resistant in the range and in the region.

The dominant lithology of the Horquilla is light-gray-weathering, medium-bedded, light-gray, crystalline limestone and calcarenite. A few beds weather buff orange and are composed of darker gray, silty limestone. Rarely, thin intercalated shale beds and calcareous sandstones occur in the Horquilla.

The Horquilla Limestone is abundantly fossiliferous. The lower beds resemble the upper Escabrosa, but commonly contain *Fusulinella,* a reliable index fossil for the lower Horquilla in the area. Higher fusulinid zones contain *Fusulina* and *Triticites.* Highest beds contain robust *Psuedoschwagerina.* Several kinds of corals, notably *Chaetetes* and *Syringopora* occur in the middle and upper parts of the Horquilla. Many species of brachiopods and other fossil fragments occur throughout.

Chert occurs throughout the Horquilla Limestone. Most commonly, chert zones consist of irregular masses of brown-weathering, gray and white chert. Some of the chert occurs in distinctive bands, which, except for different matrix, resembles chert of the lower part of the El Paso Formation. Approximately 500 ft. (150 m) above the base of the Horquilla, is a zone of chert bands about 20 ft (6 m) thick with *Fusulina;* this zone is a very useful marker, especially because lower fusulinids are few in number, small, and very difficult to identify.

Thickness of the Horquilla Limestone is problematical. Fossil studies suggest that all the Horquilla Limestone is exposed in the northern Animas Mountains; however, a complete and undeformed section was not found. From the work of Zeller (1965) and Gillerman (1958), Horquilla thickness is at least 1,500 ft (460 m) and may be thicker. Regionally, the Earp Formation overlies Horquilla (Zeller, 1965, p. 45), but is not exposed in the northern Animas Mountains.

Cretaceous

U-Bar Formation

Zeller (1965) named the U-Bar Formation for exposures of Cretaceous limestones exposed on U-Bar Ridge southwest of the Big Hatchet Mountains. Rocks assigned to the U-Bar Formation are exposed at Station 3 in the west central part of the area. Assignment is based on lithologic similarity to the highest member of Zeller's type U-Bar (1965, p. 59-67), proximity to the Mojado Formation, and a fauna of Early Cretaceous age. The rock is black, fossiliferous, crystalline limestone with infillings of milk-white calcite along fractures. Proximity to Tertiary igneous rocks, and position in a thrust plate, have resulted in considerable deformation and thermal metamorphism of the limestone. The U-Bar is not seen at any other locality in the northern Animas Mountains.

Mojado Formation

The Mojado Formation, named by Zeller (1965) for a section at Mojado Pass south of the Big Hatchet Mountains, is exposed in a thrust plate in the middle of the northern Animas Mountains, as well as in rocks mapped as undivided Cretaceous. The typical exposure is sandstone or orthoquartzite rubble and disaggregated red clay shale. The quartzites are usually resistant and form massive ledges.

In the study area, the Mojado consists of thick-bedded, massive, reddish-brown quartz sandstone, and rust-red sericitic clay shale. Sandstone is composed of moderately well-rounded quartz grains cemented by silica. Limonite and ferruginous clay are common in the interstices of the grains giving the sandstone its characteristic color. In the Mojado thrust plate, the sandstones are case-hardened, becoming true orthoquartzites. Adjacent to intrusives, the shale has been thermally metamorphosed to a resistant red hornfels.

The Mojado is at least 5,000 ft (1,500 m) thick in the type section (Zeller, 1965, p. 67; 1970, p. 7-8). In the northern Animas Mountains, the true stratigraphic thickness cannot be determined, but most certainly it is at least 5,000 ft (1,500 m) thick.

Cretaceous to Tertiary

Ringbone Formation

Zeller (1970, p. 8-9) named the Ringbone Formation in the Little Hatchet Mountains for rocks consisting of limestone-cobble conglomerate, black bituminous shale and gray shale, arkose, and volcanic rocks. His fossil evidence indicates that this formation is of Late Cretaceous or early Tertiary age. It overlies the Mojado with angular unconformity, and is approximately 7,500 ft (2,250 m) thick in the Little Hatchet Mountains (Zeller, 1970, p. 9). Similar rocks occur in the northern Animas Mountains and are assigned to the Ringbone. Most of the rocks mapped as undivided Cretaceous consist of limestone pebble-cobble conglomerate, red, brown, and gray clay shale, and arkosic salt-and-pepper sandstone. Volcanic rocks are not seen. All these rocks are highly deformed.

Tertiary to Quaternary

Quartz-Monzonite Porphyry

Quartz-monzonite porphyry is found in one large body in the center of the area, as well as in several smaller bodies. These rocks appear to have been forcefully intruded. Their contacts with country rock are sharp, and intrusion has locally resulted in deformation of the country rock. The quartz-monzonite porphyry weathers dull red to brown, and is seen as spheroidal boulders and blocks forming craggy slopes and ledges.

In thin sections, the quartz-monzonite porphyry has approximately equal amounts of 2.0 to 5.0 mm subhedral phenocrysts of oligoclase and quartz. Five percent of the rock is composed of biotite or chlorite after biotite. All feldspars are sericitized and altered to clays. Secondary epidote is common as are small amounts of sphene, apatite, and opaque minerals.

Rhyolite

Dikes of bone-tan aphanitic rhyolite and rhyolite porphyry occur in the northern half of the area. These dikes have been injected along the post-Laramide normal faults or as linear zones of lit-par-lit intrusions which expand, thermally metamorphose, and deform the country rock. In several places, dikes along faults have been cut by later movement along the same faults they intrude. The rhyolite exposure typically is rubbly, fresh, and weathers light buff to tan. These rhyolite bodies are numerous, and many are of insufficient size to be shown on the geologic map.

The rhyolite consists of phenocrysts of euhedral sanidine and embayed quartz 1.0 to 2.0 mm across surrounded by spherulitic, partially devitrified glass rims in a microcrystalline groundmass of sanidine and quartz. Where phenocrysts are absent, the spherulites are more abundant. Minor amounts of biotite and opaques occur in the groundmass.

Quartz Latite

Exposures of hornblende quartz latite are confined to the south end of the area and to one small body at Station 4, in the east-central part of the area. Nearly all of the quartz latite occurs in flows, and the outcrops are resistant, forming low hills, and locally relatively high cliffs. The rock is dark gray brown, and weathers to rubbly slopes.

Twenty percent of the rock is composed of 5.0 to 10.0 mm zoned subhedral plagioclase phenocrysts with cores of andesine and rims of oligoclase. Plagioclase phenocrysts are set in a microcrystalline porphyritic groundmass consisting of 1.0 to 2.0 mm laths of euhedral hornblende, plagioclase and quartz. Calcite is common where the rock is brecciated forming masses between individual breccia fragments. Biotite and opaque minerals are minor and compose less than 5 percent of the rock.

In all respects, the quartz latite of the northern Animas Mountains closely resembles the Center Peak Latite described by Zeller and Alper (1965, p. 52-54) in the southern Animas Mountains. In the more extensive exposures to the south, the quartz latite occurs in flows which emanated from an eruptive center at Center Peak. Although eruptive centers for quartz latite were not definitely located in the northern Animas Mountains, the isolated exposure at Station 4 may be a volcanic vent; the rock exposed here does not occur in flows as seen in other areas, and the outcrop is roughly circular in plan.

Vitrophyre

Several small exposures of black vitrophyre are found in the northern Animas Mountains. These rocks are found in small dike-like bodies which are in sharp contact with the country rock, and are non-resistant. Most of these exposures are too small to be shown on the geologic map.

In thin section, the rock is composed of phenocrysts of 5.0 to 10.0 mm euhedral sanidine, quartz, and amphibole. Quartz and amphibole are surrounded by 1.0 to 2.0 mm rims of partially devitrified glass intergrown with the minerals. Microlites of quartz and feldspar are common in the groundmass. Very small amounts of biotite, sphene, and zircon are found in the glass.

STRUCTURE

The geologic structure of the northern Animas Mountains is the sum of several episodes of tectonism resulting in geometry of unusual complexity. The tectonic episodes are as follows: emplacement of Precambrian granite, Paleozoic and early Mesozoic epeirogeny, late Mesozoic to early Cenozoic orogeny (Laramide), and early Cenozoic to Recent volcano-tectonic events. The documentation of pre-Laramide structure is confined to the composition of Precambrian rock and the character of the Paleozoic sedimentary prism. Pre-Laramide structure is discussed later. Since late Mesozoic, the northern Animas Mountains and surrounding region have undergone almost continuous deformation. The Laramide consisted of thrusting and synorogenic sedimentation, probably accompanied by local volcanism. In the area studied, the Paleozoic rocks were thrust in chaotic fashion (Dennis, 1967, p. 16-17) to the north and northeast over the 3-mile (5-km) thick Cretaceous and earliest Tertiary section. The later Tertiary to Recent igneous activity and normal faulting have been superimposed on Laramide structures, producing the geometry of the northern Animas Mountains now observed.

Laramide Structure-Thrust Faults

The dominant Laramide structures of the northern Animas Mountains are three thin, sheet-like, commonly fragmented thrust plates intensely deformed internally (fig. 3). In addition, as shown in structure sections AA', BB' (fig. 2), Precambrian and Paleozoic rocks below the Percha Shale in the northern part of the area have been interpreted as an upthrown fault block (upfaulted block) from which the lowest plate has locally detached and slid out to the north over the Cretaceous rocks. Lowest to highest, the thrust plates are constituted as follows (fig. 2):

I) Escabrosa Group, Paradise Formation, and Horquilla Limestone which are basally detached from the Percha Shale, and usually found overlying Cretaceous rocks.

II) El Paso Formation, Montoya Dolomite, and rare fragments of Bliss, Percha, and Escabrosa which are probably detached from the Bliss. The Bliss is also part of Plate II in the central part of the area and occurs on Plate I or on any of the units stratigraphically below the El Paso, including the El Paso itself.

III) Mojado Formation and U-Bar Formation, probably detached from within the U-Bar. This plate is found in the central part of the area on Plate I, Plate II, or on the Precambrian rocks. The upfaulted block has been interpreted as juxtaposing Precambrian to Devonian rocks with the Cretaceous.

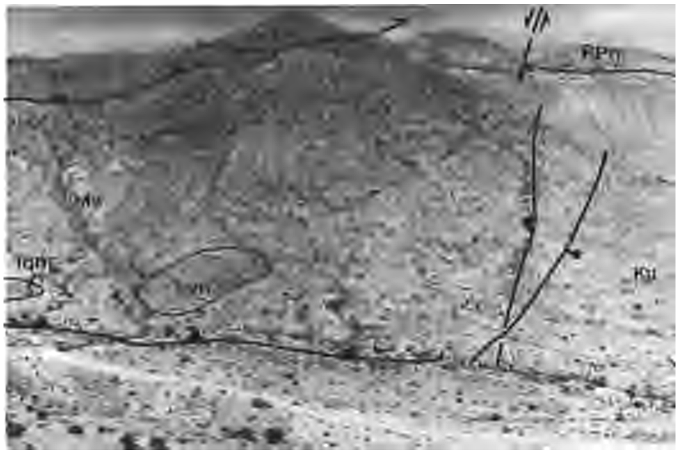


Figure 3 - Thrust plates viewed to the north-northwest from Station 5. Symbols are the same as on fig. 2.

Plate I

The lowest thrust plate, the most extensive of the three, is composed principally of intensely deformed massive middle and upper Paleozoic limestone thrust over soft Cretaceous rocks. The massive limestone is suprisingly incompetent. The surface of the basal thrust can be seen in nearly any part of the Escabrosa section (fig. 4), as well as in one place at Station 7, where the thrust lies below Escabrosa in El Paso. In a few places the thrust surface can be seen in the Horquilla Limestone. The thin zone of intensely deformed Percha Shale commonly seen at the base of Plate I is tectonically mixed with the red Cretaceous shale below the thrust surface.

Figure **4 — The middle dark gray member of the Escabrosa Group overlying a thin highly contorted zone of Percha Shale. White material is caliche. Photograph at Station 6.**

Sedimentary rocks exposed in the southern half of the area are nearly all part of Plate I, or Cretaceous rocks immediately below this plate. As shown diagrammatically in structure sections EE', FF', the plate is highly contorted by tight folds that commonly break out into subsidiary thrusts and tear faults, most of which are too complex and individually small to be shown on the geologic map or structure sections. The small klippen of Plate I immediately north of the quartz latite outcrops are erosional remnants, indicating a flat-lying thrust fault.

A major tear fault extends to the southwest from Station 7 becoming covered by surficial deposits. The fault is a distinct zone of crushed Plate I rocks, and exhibits no preference for particular stratigraphic horizons or structures within the plate. The preferred interpretation of this fault is that it is the result of differential movement within the plate and that it has no special significance for the structure of Plate I as a whole.

South of Station 7, a large mass of Horquilla Limestone has been interpreted as a separate minor thrust plate within Plate I. It overlies the Cretaceous and the Escabrosa and is considered to be the result of local differential movement within the main body of Plate I.

In the north and north-central part of the area, the structure of Plate I is more complex. Here the plate is cut by later normal faults and intrusions and the fault surface is undulatory. The plate has been locally broken into chaos blocks, the result of sliding from the upfaulted block onto the Cretaceous rocks; this pattern is a gravitational modification of the thrusting. The internal structure of Plate I is similar to other areas—intensely deformed limestone above a thin zone of Percha Shale. Locally this zone of Percha may be absent.

Plate II

Plate II is found only in the central part of the area, as well as in several chaos blocks in the vicinity of Station 2. Most of the plate is composed of El Paso dolomite, which in contrast to Plate I, is not folded, but has been shattered by extreme deformation. Consequently, outcrops are usually rubble, and little can be said of the internal structure of the plate. Near Station 8, Montoya, Percha, and Escabrosa rocks form part of Plate II. At this locality, the structure is very complex and only a general pattern is shown on the geologic map. The structure shown is a small slice in which the Percha Shale has been tectonically eliminated between the Montoya Dolomite and Escabrosa Limestone. An alternative interpretation is that Percha and Escabrosa are a small fragment of Plate I. Both possibilities were considered during the course of field work, and the former appears to be correct. If so, Plate II, at least locally, involved rock units as high as the Escabrosa.

Northwest of Station 8, El Paso rocks of Plate II are thrust over El Paso of Plate I. The evidence is a thin zone of thrust breccia at Station 9, and apparent repetition of El Paso parallel to the strike of the thrust fault trace.

North and northwest of Station 2, chaos blocks of El Paso and Montoya are interpreted as fragments of Plate II (fig. 5). They are isolated from the main body of the plate, and the exact mechanism by which they reached their present location is not known. Although bedding can be seen in the large block northwest of Station 2, the intraformational structure of the blocks is obscure, and direct inferences regarding the origin of the blocks cannot be drawn.

Throughout Plate II, evidence of the direction of tectonic transport is missing. Consequently, the direction in which Plate II moved to its present location can only be inferred. To the west, Plate II overlies the Precambrian, whereas to the east, Plate II overlies Plate I. A suggested interpretation of Plate II is that penecontemporaneous with, and probably after the detachment and thrusting to the northeast of Plate I in this area, the El Paso and possibly some Bliss broke away from the Bliss and the Precambrian. Plate II was thrust in the same general direction as Plate I. Near Station 10 are small exposures of Bliss in fensters below Plate III, possibly autochthonous above the Precambrian. If true, these Bliss exposures would be near the horizon from which Plate II was detached.

Figure 5 — Chaos blocks north of Station 2. El Paso Formation and Montoya Dolomite are fragments of Plate II. Escabrosa is a fragment of Plate I. Symbols are the same as on fig. 2.

Plate III

Plate III is found in the central part of the area, and with the exception of U-Bar limestone at Station 3, is composed entirely of quartzite and shale of the Mojado Formation. As is the case with Plate II, little can be said of the internal geometry of Plate III for most of its exposures are rubble. The base of the plate has no particular distinctive features, the fault contact being mapped at the highest occurrence of float of

Plate II or Precambrian rocks. From the outcrop pattern, rocks of Plate III probably originally covered nearly the same area as Plate II. Two small klippen of the plate are found in the vicinity of Stations 8 and 9. Near Station 10, Plate III rests on Precambrian, but in isolated exposures to the south and west, Plate III rocks overlie the El Paso of Plate II. Apparently Plate II was broken into fragments in this area, which were then overridden by Plate III. Where these fragments were absent at the time of thrusting, Plate III overlies Precambrian. The general pattern and style of thrusting are similar to that of Plate II.

Upfaulted Block and Detachment Thrust Faults

The Precambrian, Bliss, El Paso, and Montoya rocks at the north end of the area are interpreted as an upfaulted block. The fault is nowhere exposed, and its exact configuration at depth is not known. The only direct evidence for the existence of the fault is the nearly equal elevation of Precambrian and Cretaceous rocks (fig. 2, structure sections AA', BB').

In addition to the upfaulted block, a detachment thrust fault (Pierce, 1957) appears to be in the Percha Shale. Penecontemporaneous with the faulting of the block, weak Percha Shale broke under the massive upper Paleozoic limestones of Plate I, which in turn slid to the north, the chief force probably having been gravity. Along the strike of, and below this detachment thrust, consistent bedding attitudes with north dips are seen. The dip of the detachment thrust is interpreted as 10° to 15° to the north, with beds below dipping 25° to 35° in the same direction. Both fault and bedding dips appear to decrease eastward along the fault trace to where the fault is covered by Plate II.

Most exposures of Percha Shale along the detachment thrust fault are very poor. However, in a few places along the outcrop, red Cretaceous shale is tectonically mixed with Percha. As other parts of the outcrop, Percha appears only as highly deformed shale. The internal geometry or movement within the shale is puzzling.

The amount of displacement along this detachment thrust is not known. Lack of stratigraphic control and chaotic structure of the limestone blocks render exact determination impossible. The amount of relative movement of the Escabrosa, the result of this upfaulted block, is probably not too great and decreases eastward along the detachment fault trace. The common presence of a thin zone of Percha Shale at the base of Plate I suggests that a similar mechanism may have resulted in the initial detachment of the plate, away from the northern Animas Mountains. The observed detachment thrust structure in the northern Animas Mountains may be the general case for the surrounding area. If such is true, Plate I may have moved a considerable distance penecontemporaneous with, or prior to, its fragmentation by the upfaulted block.

Early Tertiary to Recent Volcano-Tectonic Structures

The three types of post Laramide structures are: 1) normal faults—both active or inactive; 2) intrusions—both discordant and concordant; and 3) associated features—including drainage and other geomorphic alignments, and aligned intrusive bodies.

Normal Faults

Normal faults are found throughout the northern Animas Mountains, but are most common near the north end. Characteristically, they cut older structures sharply. These faults can be followed in the field with ease, and in the case of active faults, are easily delineated on aerial photographs. In all cases, the displacements are small.

Immediately west of Stations 2 and 11, and extending north-south for approximately 3 1/2 mi (6 km), a major active normal fault juxtaposes Plate I rocks with the upfaulted rocks in the vicinity of Station 11. Farther north, the fault cuts the large chaos block of Plate II (about 1,000 ft northeast of Station 2), and then extends out into the autochthonous rocks at the north end of the area (fig. 6, 7). The south end of this fault cuts the pediment and diverts the drainage immediately south of outcrops of El Paso and Mojado.

To the east are several similar faults with general north and northeast trends. These faults have considerably less displacement. Their principal effect is the further breaking up of chaos blocks of Plate I. In several places these faults have been intruded by rhyolite. The fault trending east-northeast from Station 9 is typical (fig. 8). This fault cuts El Paso, Percha, Escabrosa, and talus, and is intruded by a rhyolite dike which itself has been faulted.

In the general vicinity of Station 2, faults trending approximately east are common. Usually associated with intrusions, these faults are seen as zones of thermally altered and deformed rock. Most of these east-trending faults have small displacements, are nearly all confined to Plate I rocks, and are more difficult to discern in the field than the more extensive north-and northeast-trending faults.

West of the major north-south fault first discussed, are faults mapped on juxtaposition of Escabrosa and Horquilla limestone. Two of these faults lie under drainages and are covered by surficial deposits. The northernmost fault in the area, in the isolated hill of Escabrosa and Horquilla, has been interpreted from abrupt termination of fusulinid-bearing rocks at the south end of this hill, and highly deformed limestone near the trace of the fault.

Several isolated normal faults are found in the central and southern parts of the area. All are easily recognized in the field, have small displacements, and are probably not significant. Possibly some of these faults, especially within Plate I rocks, may be Laramide features, the result of differential vertical movements within Plate I.

Intrusions

Nearly all of the intrusions of the northern Animas Mountains are of two types: discordant—forcefully intruded quartz-monzonite porphyry; and concordant—rhyolite dikes, usually associated with normal faults.

Discordant intrusions of quartz-monzonite porphyry are found in one large and several small bodies near the center of the area, and in two small bodies near the north end. Internally, the quartz-monzonite appears to be structureless. Flow banding or brecciation is not seen. Joints are relatively common in the large body. Where exposed, the contact with country rock is sharp and sub-vertical. No stoping or xenoliths of country rock are seen in the quartz-monzonite, although the common alteration of Mojado shales to hornfels indicates thermal metamorphism took place at the time of its emplacement. At depth, the form of quartz-monzonite bodies is inferred; the configuration shown in structure sections is diagrammatic. Due to the common occurrence of acidic igneous rocks of similar composition in the central and northern part of the area, magma probably came from a common chamber. The distance from the surface to such a magma chamber is not known.

Nearly all of the rhyolite dikes are found in the northwestern part of the area along normal faults. Near Station 2,

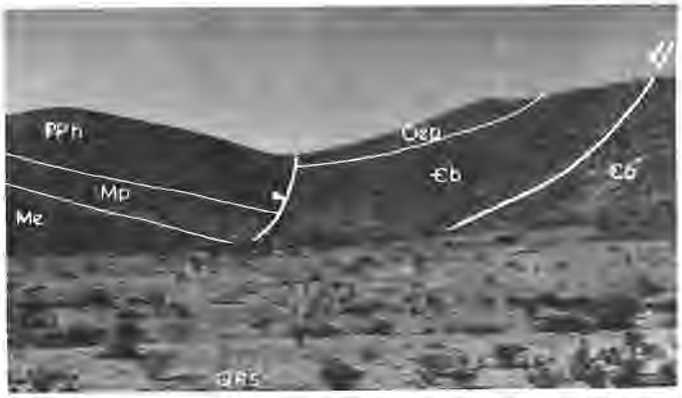


Figure 6 — View north of active normal fault near Station 11. The fault juxtaposes Mississippian and Pennsylvanian rocks of Plate I with Bliss and El Paso rocks of the upfaulted block. Small fault at right due to collapse within the upthrown block of active normal fault. Symbols are the same as on fig. 2.

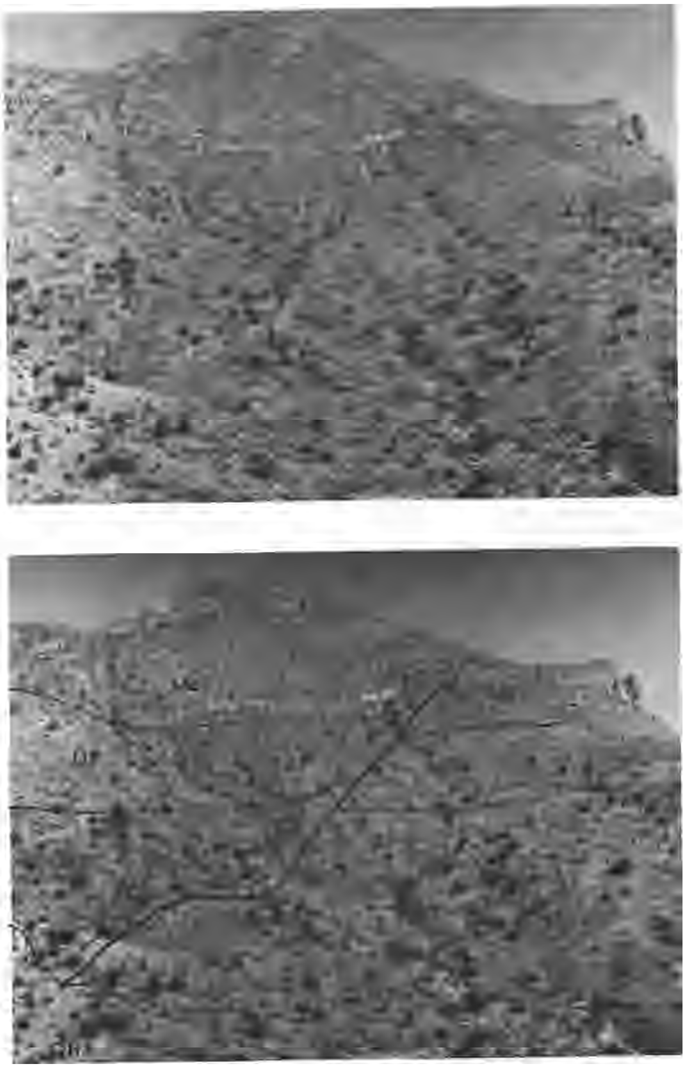


Figure 8 — Active normal fault near Station 9. The fault has been intruded by a rhyolite dike (Tr) cut by the fault. The fault cuts talus of Escabrosa on Percha Shale. Unmarked identical photograph included for comparison. Symbols are the same as on fig. 2.

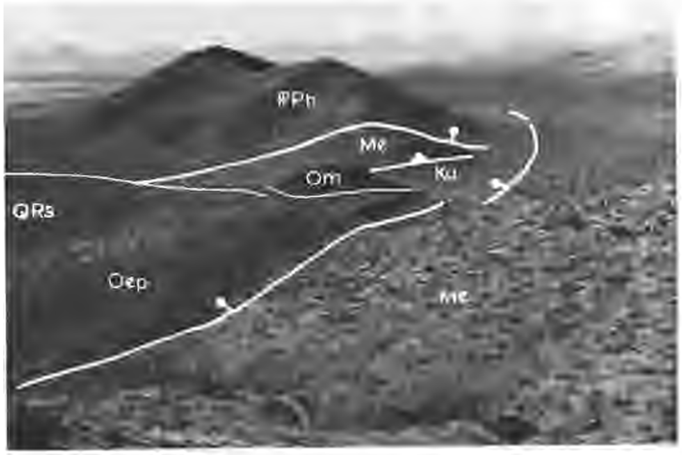


Figure 7 — Active normal fault near Station 2. The fault cuts the large chaos block of Plate II which is juxtaposed with Escabrosa limestone of Plate I. The fault extends to the north where it cuts Cretaceous rocks and recent surficial deposits. Symbols are the same as on fig. 2.

intrusion of rhyolite has resulted in considerable local deformation of the limestone of Plate I, seen as abrupt change in attitude of beds across individual dikes and very small local thrust faults which die out a short distance from the particular dike. The form of these dikes is not known precisely, although they most likely follow faults to depth. As shown diagrammatically in structure sections AA', BB', Fr, the dikes postdate the quartz-monzonite. Fine-grained rhyolite is found at the same structural level as the quartz-monzonite, suggesting later near-surface emplacement of the dikes. Most of the dikes are almost vertical.

Associated Features

Several distinctive geomorphic features, associated with normal faults and intrusions, deserve particular attention. These features aid greatly in recognition of faults, and suggest tectonic significance of the faults and discordant intrusive bodies.

Fault scarps with little relief are commonly seen where active normal faults cut pediment or talus. The faults are seen readily on aerial photographs. Their scarps can be recognized in the field as subtle linear breaks in slope of the otherwise relatively smooth pediment surfaces. Where the caliche layer is deformed, moisture seeks these fault zones; where faults cut talus, vegetation alignments are seen, although unstable talus at repose almost obliterates the scarp.

Active normal faults commonly divert drainages. Diversion is usually seen as abrupt change in direction of a drainage course, even for a short distance.

West of Stations 3 and 10, subparallel drainages appear on aerial photographs and may be controlled by faults in the pediment. As stratigraphic control is not possible for such faults, they are not shown on the geologic map.

At Station 12, the only spring in the area lies along a normal fault. Although seeps or other evidence for ground-water movement was not found along similar faults in other parts of the area, groundwater may be controlled by faulting. The only producing water well in the area at Station 13 is aligned with possible faults to the west.

Alignment of discordant intrusions is noted. The large body of quartz-monzonite porphyry in the center of the area is elongate east-west, and aligned with a smaller body to the east. Farther to the east in Playas Valley (not shown on the geologic map) are several bodies of igneous rock. These are crudely aligned and suggest linear control of these intrusions at depth. The four small bodies of quartz-monzonite porphyry north of the main body trend east-west.

TECTONIC HISTORY

Intrusion of Precambrian granitic rocks into older sedimentary and metasedimentary rocks has been demonstrated by Zeller (1965) in the Big Hatchet Mountains, by Gillerman (1958) in the Peloncillo Mountains, and by Gilluly (1956) in central Cochise County, Arizona. Ages of granitic and similar rocks in Arizona most commonly are 1,200 to 1,500 m.y. (Anderson, 1963). In most cases, these rocks closely resemble in composition and occurrence the Precambrian rock in the northern Animas Mountains. Although lack of Precambrian exposures, and an unconformity representing 600 m.y. between granite and basal Cambrian rocks make any analysis of Precambrian tectonics speculative, the widespread intrusives suggest tectonism of some magnitude took place during the Precambrian.

Paleozoic to Early Mesozoic

From Cambrian to Middle Permian time, all movements in the area of the northern Animas Mountains were epeirogenic. The extent and significance of the numerous unconformities has been reviewed by Kottlowski (1963). Zeller (1965) indicates the lack of notable angularity between disconformable units; coarse detrital material is not present above any of the unconformities. The extent of these stratigraphic breaks in the record are great, however, and locally thicknesses of some of the units may vary greatly. Thus, the Paleozoic was dominated by broad vertical movements of a quiet marine shelf.

From Leonard time to Early Cretaceous, the sedimentary prism was mildly deformed and then exposed to subaerial erosion. Although rocks of latest Paleozoic age are not exposed in the northern Animas Mountains, Zeller and Alper (1965, p. 68-71) indicated that the Winkler anticline of the central Animas Mountains became active in Leonard time. However, in the Big Hatchet Mountains, Zeller (1965, p. 45-54) suggests that during Leonard deposition was continuous and that the section was not deformed, although the Earp Formation probably was subaerially exposed. Gilluly (1956), Hayes and Raup (1968) and Hayes (1970b) indicate that this pre-Laramide tectonism is regional in extent, although in most places intense Laramide deformation has obscured pre-Laramide structure. Igneous rocks of Triassic and Jurassic age are known from Arizona (Hayes, 1970a), deposited as extrusives on a land surface of high relief. In most other places in the region, Triassic or Jurassic rocks are not known. Tectonism may have been continuous from middle Permian to Early Cretaceous regionally, but in the area of the northern Animas Mountains, the deformation known is only gentle Leonardian folding.

Late Mesozoic to Early Cenozoic

In the northern Animas Mountains, as well as in the general region of southwestern New Mexico and southeastern Arizona, great thicknesses of sedimentary rocks were deposited during Cretaceous and early Tertiary time. The sediments are of two types: those deposited prior to strong Laramide tectonism, and those accompanying the Laramide orogeny. As most of the units are nearly barren of diagnostic fossils, exact correlation of rock units with tectonic events is usually not possible. However, Lower Cretaceous rocks are overlain with angular unconformity by Upper Cretaceous and Tertiary rocks. This unconformity is considered to be correlative with strong Laramide tectonism.

Zeller (1965) recognized three Lower Cretaceous formations in the Big Hatchet Mountains: the basal Hell-to-Finish red beds and conglomerate which rest on Permian rocks, marine U-Bar limestone, and deltaic marine Mojado sandstone, shale, and minor limestone. Hayes (1970b) considers these units to be correlative with the Glance Conglomerate and Bisbee Group of southeastern Arizona. The clastics were derived from the eroded Triassic-Jurassic landmass, which was positive well into the Cretaceous. Elston (1958) states that lowest Upper Cretaceous rocks rest on the Precambrian of the Burro Uplift in southern Grant County, New Mexico, indicating Lower Cretaceous elastics were derived from multiple sources. In the northern Animas Mountains area, Lower Cretaceous rocks probably were deposited in a rapidly subsiding trough as suggested by Kottlowski (1963, p. 85). The youngest fossils known from the Mojado Formation are of Washita age (Zeller, 1965, p. 70-71), indicating a basin was active until the earliest Late Cretaceous.

The Ringbone Formation of the northern Animas Mountains is synorogenic with respect to the main phase of the Laramide orogeny. The lowest thrust plate rests on Ringbone rocks, and the coarse clastic constituents of the Ringb one suggest it was deposited during a period of strong tectonism. Precise dating of the inception of the Laramide is not possible, as the rock record from early to late Late Cretaceous is not known. The age of the Ringbone of the Little Hatchet Mountains is latest Cretaceous to earliest Tertiary (Zeller, 1970); but Zeller indicated that post-Ringbone Hidalgo Volcanics are truncated by thrust faults. If Ringbone deposition took place during a short interval of latest Mesozoic and earliest Cenozoic time, as Zeller suggests, then the complex Laramide structure of the northern Animas Mountains probably developed penecontemporaneously with Ringbone. An upper contact of Ringbone with volcanics is not seen in the area. Deformation may have resulted in the erosion of the highest Ringbone or followed deposition of these clastics.

Post-orogenic sedimentary and volcanic rocks of known age and structural relation to synorogenic rocks are not found in the northern Animas Mountains. Zeller stated (1970, p. 10-11) that the Hidalgo Volcanics of early Tertiary age are overlain with angular unconformity by volcanics of presumed middle to late Tertiary age. To the east, in the Florida Mountains, the Lobo Formation with post-orogenic molasse character is known (Corbitt and Woodward, 1970), but is yet to be precisely dated. The similar Baca Formation of west-central New Mexico is considered Eocene in age (Snyder, 1970), and may prove to be correlative with the Lobo.

Early Cenozoic to Recent

Extensive volcanism and plutonism have taken place in the northern Animas Mountains and surrounding region since the Laramide. However, too few data are available to attempt correlation between the northern Animas Mountains and surrounding ranges. Zeller and Alper (1965) considered nearly all igneous rocks of the central Animas Mountains to be Tertiary. Thus, igneous rocks at the north end of the range are probably of the same age. Normal faulting and intrusions were initially penecontemporaneous events. Fractures were the avenues along which magma moved. Deeply emplaced intrusions are now seen as aligned discordant bodies of quartz-monzonite porphyry. Later rhyolite, which may have been locally erupted at the surface, was injected along faults. Continued activity along some of the faults deformed all older rocks and is continuous to the present time.

# # #

REFERENCES

Anderson, C. A., 1963, *Simplicity in structural geology:* in Fabric of Geology, Geol. Soc. America, p. 175-183.

Armstrong, A. K., 1962, *Stratigraphy and paleontology of the Mississippian System in southwestern New Mexico and adjacent southeastern Arizona:* New Mexico State Bur. Mines Mineral Resources Mem. 8, 99 p.

Corbitt, L. L. and Woodward, L. A., 1970, *Thrust faults of Florida Mountains, New Mexico and their regional tectonic significance:* New Mexico Geol. Soc. Guidebook XXI, Tyrone-Big Hatchet Mountains-Florida Mountains Region, p. 69-74.

Darton, N. H., 1922, *Geologic structure of parts of New Mexico:* U. S. Geol. Survey Bull. 726-E, 275 p.

Dennis, J. G., 1967, *International tectonic dictionary:* American Assoc. Petroleum Geologists Mem. 7, 196 p.

Elston, W. E., 1958, *Burro uplift, northeastern limit of sedimentary basin of southwestern New Mexico and southeastern Arizona:* American Assoc. Petroleum Geologists Bull., v. 42, p. 2513-2517.

Flower, R. H., 1955, *Pre-Pennsylvanian stratigraphy of southern New Mexico:* New Mexico Geol. Soc. Guidebook IV, Southwestern New Mexico, p. 65-70.

, 1968, Part *I, Some El Paso guide fossils:* New Mexico State Bur. Mines Mineral Resources Mem. 22, p. 3-19.

Gillerman, E., 1958, *Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico, and Cochise County, Arizona:* New Mexico State Bur. Mines Mineral Resources Bull. 57, 152 p.

Gilluly, James, 1956, *General geology of central Cochise County, Arizona:* U. S. Geol. Survey Prof. Paper 281, 169 p.

----, Cooper, J. R., Williams, J. S., 1954, *Late Paleozoic stratigraphy of central Cochise County, Arizona:* U. S. Geol. Survey Prof. Paper 266, 49 p.

Gordon, C. H. and Graton, L. C., 1907, *Lower Paleozoic formations in New Mexico:* Jour. Geol., v. 15, p. 91-92.

Hayes, P. T., 1970a, *Mesozoic stratigraphy of the Mule and Huachuca Mountains, Arizona:* U. S. Geol. Survey Prof. Paper 658-A, 28 p.

- 1970b, *Cretaceous paleogeography of southeastern Arizona and adjacent areas:* U. S. Geol. Survey Prof. Paper 658-B, 42 p.

- ---, and Drewes, H., 1968, *Mesozoic sedimentary and volcanic rocks of southeastern Arizona:* Arizona Geol. Soc. Southern Arizona Guidebook III, p. 49-58.

----, and Raup, R. B., 1968, *Geologic map of the Mule and Mustang Mountains, southeastern Arizona:* U. S. Geol. Survey Geol. Map 1-509.

Kelley, V. C., 1956, *Thickness of strata:* Jour. Sed. Pet., v. 26, p. 289-300.

- ---, and Silver, C., 1952, *Geology of the Caballo Mountains:* Univ. New Mexico Pubs. in Geology No. 4, 286 p.

Kinney, E. E., and others, 1970, *Road log from Deming to Hachita, Playas Valley, and Winkler Anticline (Animas Mountains):* New Mexico Geol. Soc. Guidebook XXI, Tyrone-Big Hatchet Mountains-Florida Mountains Region, p. 17-22.

Kottlowski, F. E., 1963, *Paleozoic and Mesozoic strata of southwestern and south-central New Mexico:* New Mexico State Bur. Mines Mineral Resources Bull. 79, 93 p.

Long, A. R., 1946, *Climatological summary of Hidalgo County, New Mexico:* U. S. Weather Bureau, U. S. Dept. of Commerce Rept., 48 p.

Pierce, W. G., 1957, *Heart Mountain and South Fork detachment thrusts of Wyoming:* American Assoc. Petroleum Geologists Bull., v. 41, p. 591-626.

Ransome, F. L., 1904, *Geology and ore deposits of the Bisbee Quadrangle, Arizona:* U. S. Geol. Survey Prof. Paper 21, 168 p.

Richardson, G. B., 1904, *Report of a reconnaissance in Trans-Pecos, Texas, north of the Texas and Pacific Railway:* Univ. Texas Min. Survey Bull. 9, 119 p.

- ---, 1909, *Description of the El Paso district:* U. S. Geol. Survey Geol. Atlas, El Paso Folio, Texas, No. 166, 11 p.

Snyder, D. 0., 1970, *Fossil evidence of Eocene age of Baca Formation, New Mexico:* New Mexico Geol. Soc. Guidebook XXI, Tyrone-Big Hatchet Mountains-Florida Mountains Region, p. 65-68.

Stoyanow, A., 1949, *Lower Cretaceous stratigraphy in southeastern Arizona:* Geol. Soc. America Mem. 38, 169 p.

Travis, R. B., 1955, *Classification of rocks:* Colorado School Mines Quart., v. 50, no. 1, 98 p.

Wentworth, C. K., 1922, *A scale of grade and class terms for sediments:* Jour. Geol., v. 30, p. 377-392.

Zeller, R. A. Jr., 1958, *Reconnaissance geologic map of the Playas fifteen-minute quadrangle:* New Mexico State Bur. Mines Mineral Resources Geol. Map 7.

- ---, 1965, *Stratigraphy of the Big Hatchet Mountains area, New Mexico:* New Mexico State Bur. Mines Mineral Resources Mem. 16, 128 p.

- ---, 1970, *Geology of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico:* New Mexico State Bur. Mines Mineral Resources Bull. 96, 22 p.

- ---, and Alper, A., 1965, *Geology of the Walnut Wells quadrangle, Hidalgo County, New Mexico:* New Mexico State Bur. Mines Mineral Resources Bull. 84, 105 p.

NEW MEXICO STATE BUREAU OF MINES AND MINERAL RESOURCES

CIRCULAR 125 FIGURE 2

QUATERNARY

Qs
Surficial deposits
Alluvium, colluvium

TERTIARY

Tql
Quartz latite
May be Quaternary

Tv
Vitrophyre

Tr
Rhyolite

Tqm
Quartz monzonite porphyry

CRETACEOUS

Kr
Ringbone Formation
Red, brown, and gray shale; pebble-cobble conglomerate limestone; sandstone; arkose; includes some undivided Cretaceous rocks

Km
Mojado Formation
Red-brown sandstone; quartzite, red shale

Kub
U-Bar Formation
Black limestone

PENNSYLVANIAN PERMIAN

IPPh
Horquilla Limestone
Light-gray, medium-bedded limestone; fusulinids and other fossils abundant

MISSISSIPPIAN

Mp
Paradise Formation
Black biostromal limestone; buff sandstone; tan-red shale

Me
Escabrosa Group
Gray fossiliferous limestone, massive at top thin-bedded at bottom, with dark-gray member in middle

DEVONIAN

Dp
Percha Shale
Brown, black, and gray shale

ORDOVICIAN

Om
Montoya Dolomite
Black, microcrystalline dolomite

Oep
El Paso Formation
Brown saccharoidal dolomite with reticulated chert at base

CAMBRIAN

€b
Bliss Formation
Arkosic conglomerate; glauconitic sandstone; brown dolomite; white-tan quartzite

PRECAMBRIAN

p€
Basement
Porphyritic, coarse-grained, brownish-pink granite

Contact

Thrust fault
Points on upper plate

Detachment thrust fault
Points on upper plate

Normal fault
Ball on downthrown side

Active normal fault
Ball on downthrown side

Tear fault
Arrows show relative movement

Strike and dip of beds

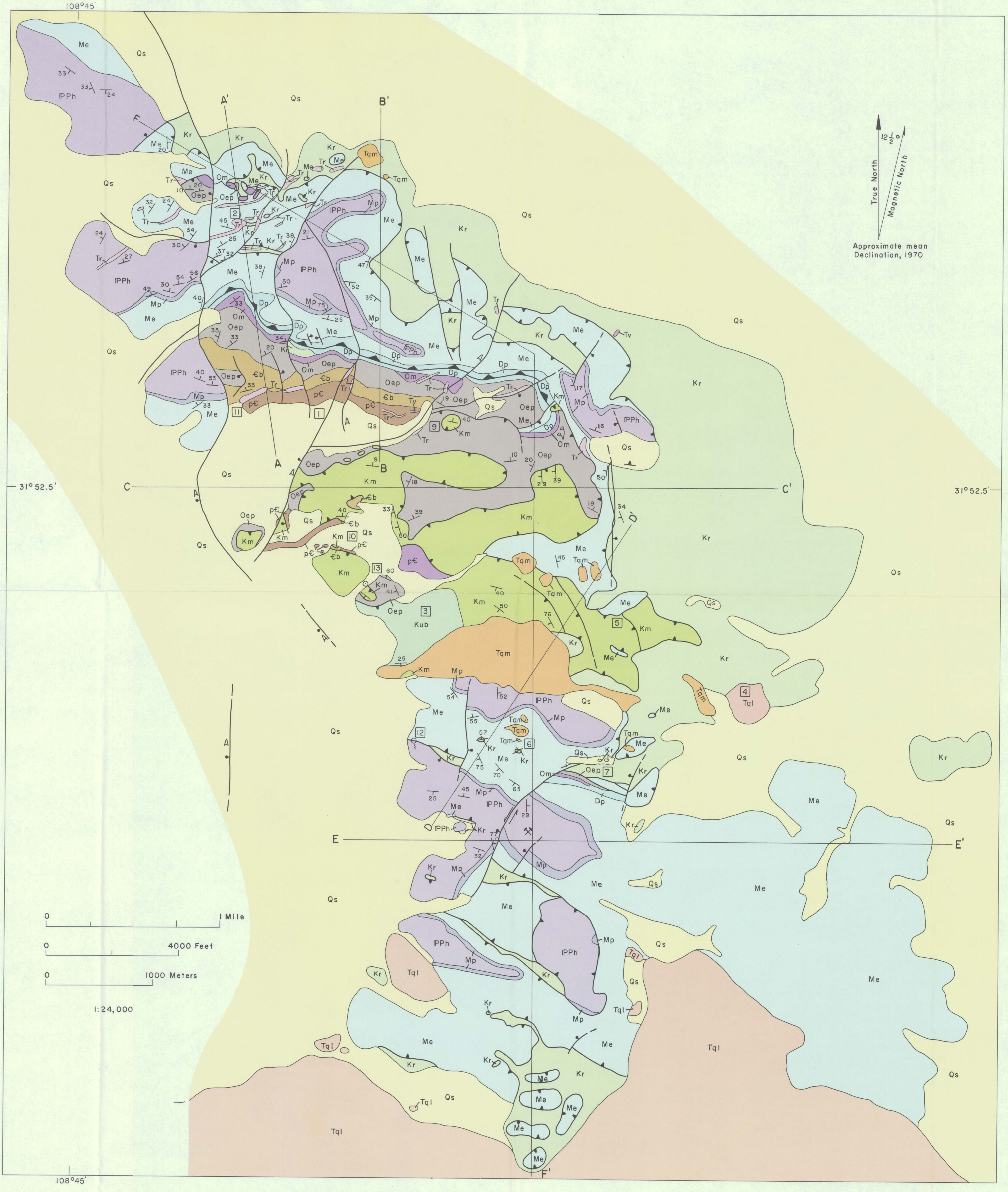
Strike of vertical beds

Water well

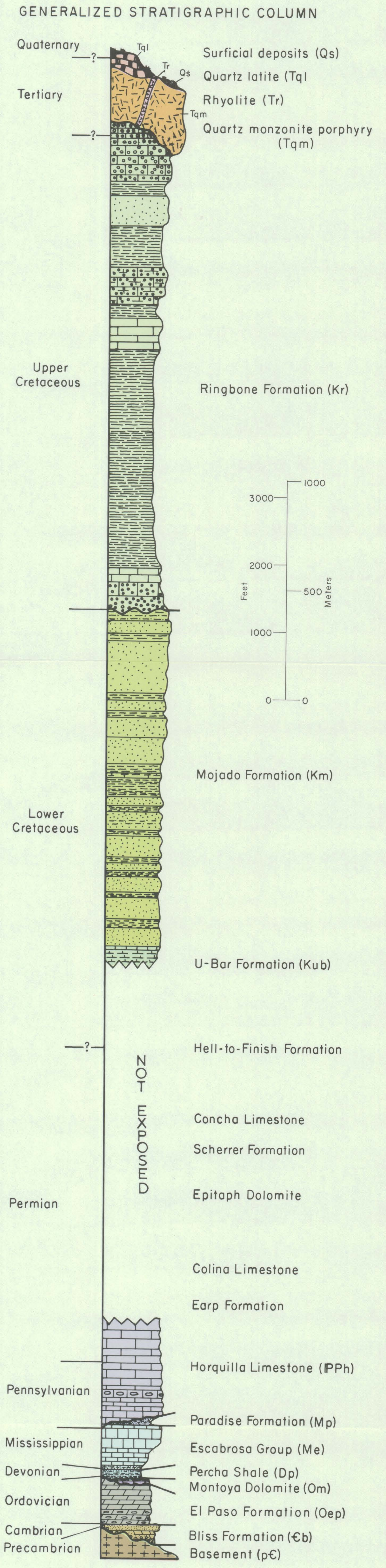
Spring

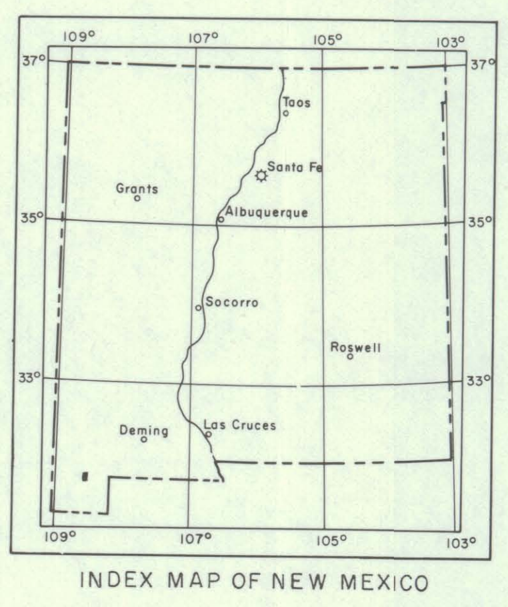
Mine

10
Locality discussed in text

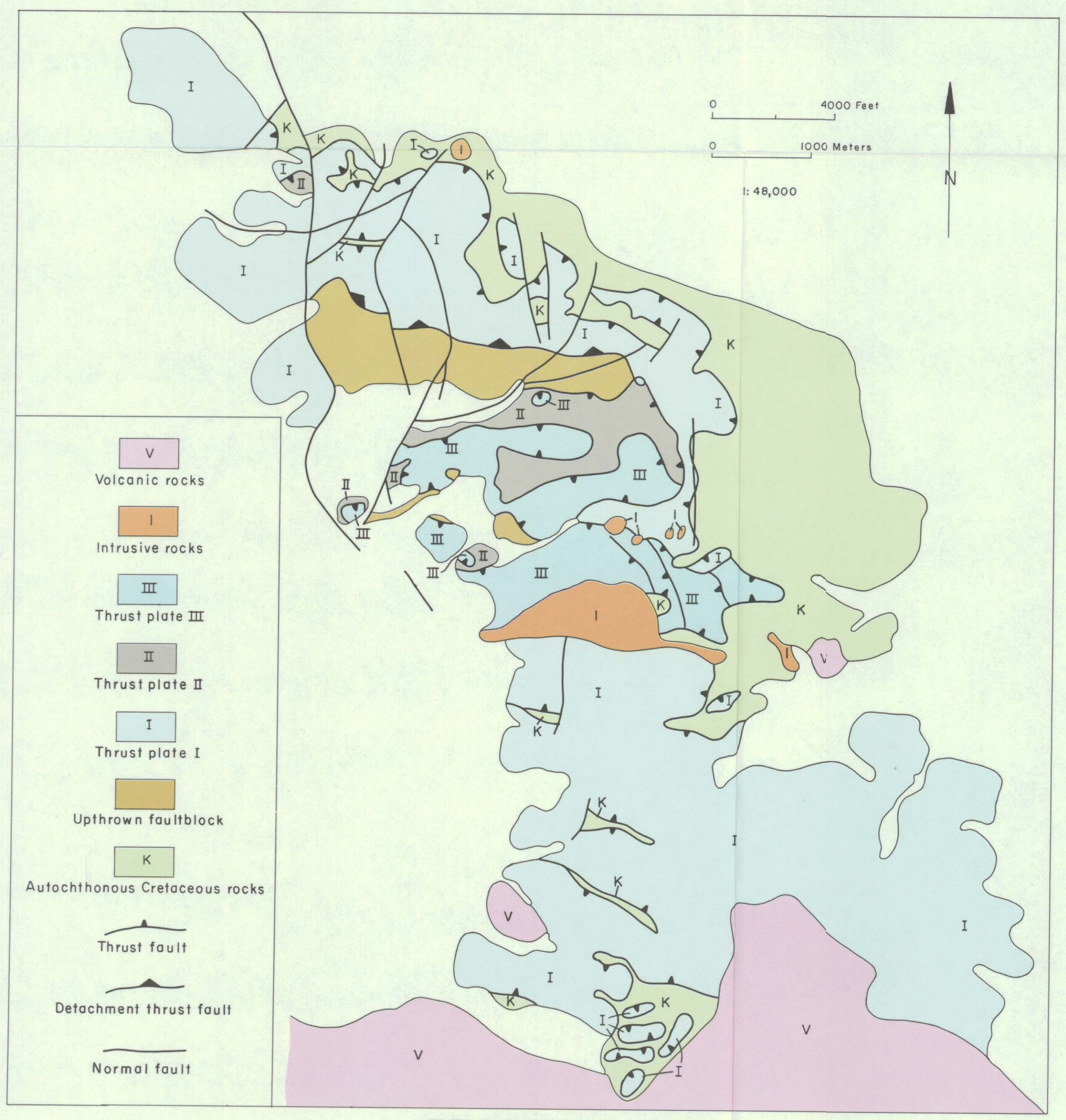


GEOLOGIC MAP

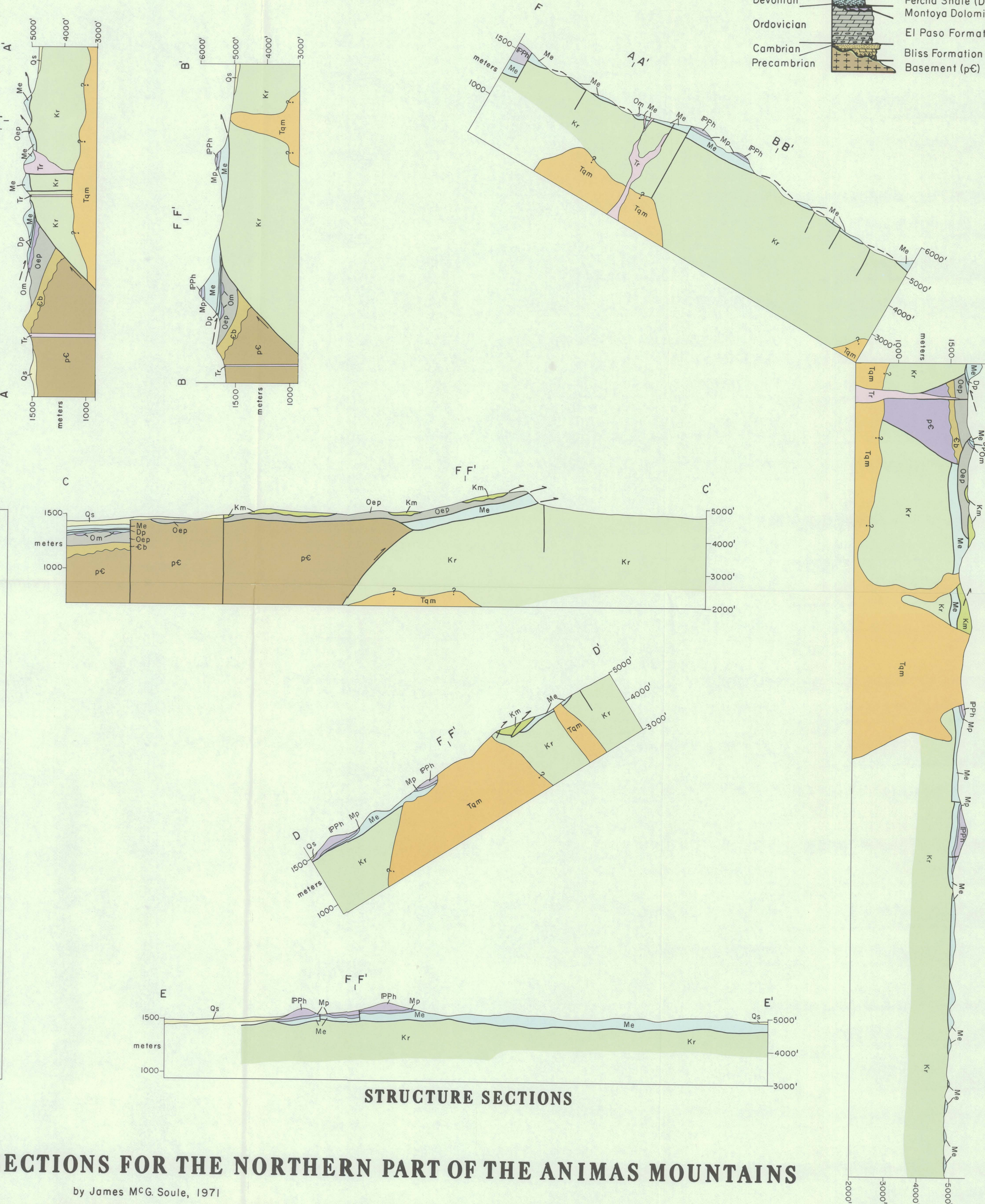




INDEX MAP OF NEW MEXICO



TECTONIC MAP



STRUCTURE SECTIONS

GEOLOGIC AND TECTONIC MAPS AND SECTIONS FOR THE NORTHERN PART OF THE ANIMAS MOUNTAINS

by James McG. Soule, 1971

J. M. Soule GEOLOGY NORTHERN ANIMAS MOUNTAINS New Mexico State Bureau Mines *Circular 125*