Precambrian geology and tectonics of the southern Manzano Mountains, central New Mexico

Paul W. Bauer

1982, pp. 211-216. https://doi.org/10.56577/FFC-33.211

in:

Albuquerque Country II, Wells, S. G.; Grambling, J. A.; Callender, J. F.; [eds.], New Mexico Geological Society 33 rd Annual Fall Field Conference Guidebook, 370 p. https://doi.org/10.56577/FFC-33

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

PRECAMBRIAN GEOLOGY AND TECTONICS OF THE SOUTHERN MANZANO MOUNTAINS, CENTRAL NEW MEXICO

PAUL W. BAUER
Department of Geology
University of New Mexico
Albuquerque, New Mexico 87131

INTRODUCTION

The Manzano Mountains of central New Mexico consist of a north-south elongate, eastward-tilted fault block on the eastern flank of the Rio Grande rift. The Manzanos extend northward to the Manzanita and Sandia Mountains and southward to the Los Pinos Mountains. Erosion in the southern Manzanos has removed all Phanerozoic cover from the Precambrian metaigneous, metasedimentary, and granitic rocks. Precambrian rocks are separated from Paleozoic sediments on the east by a high-angle, Laramide-style reverse fault, and are covered on the west by Cenozoic rift-fill sediments. The area which this report discusses is bounded on the north by Monte Largo Canyon and on the south by latitude 34°13' (fig. I). Exposure is excellent, showing well-developed tectonic fabrics and the common presence of metamorphic index minerals.

Precambrian rocks within this area have been divided into five major formations by Stark (1956). Stark recognized an older sequence of quartzites, mica schists, metasiltstones, and phyllites composing the Sais, Blue Springs, and White Ridge formations, and a younger succession of metarhyolite, amphibolite, and basic schist units of the Sevilleta and basic schist formations. Diverse lithology is present in most of these formations, although Stark's reconnaissance map at a scale of 1:48,00 does not reveal this. This area later was mapped by Myers and McKay (1976) at a scale of 1:24,000, and Precambrian lithology and structure were generalized. The present study of the southern Manzanos consisted of structural analysis and detailed lithologic mapping at a scale of 1:6,000 (fig. 2).

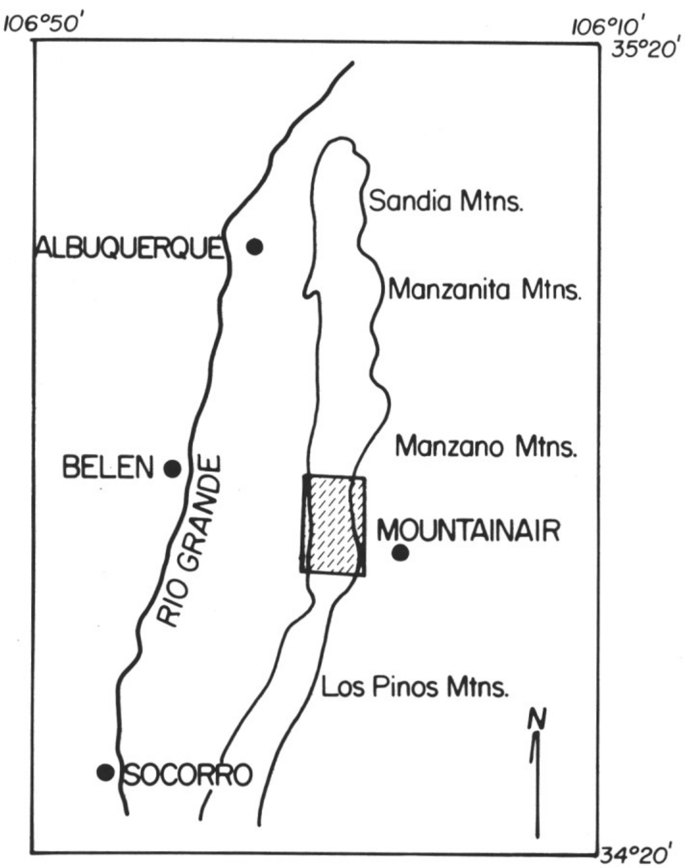

Figure 1. Location of the southern Manzano Mountains, New Mexico. Shaded region is study area.

The southern Manzanos are characterized by a strong N15°E-to-N40°E trending structural fabric consisting of compositional layering (S_0/S_1) and superimposed S-tectonite surfaces. Local incongruous areas of minor folding are present throughout. Extensive transposition masks original structure and stratigraphy in many areas.

Three ages of Precambrian folds are present in the area: two early episodes of tight to isoclinal northeast-trending folding (F_1 and F_2), and a later northwest-oriented open fold set with an associated crenulation cleavage (F_3). The only large fold in the Sandia—Manzanita—Manzano-Los Pinos chain is a tight, upright F_2 synform in the southern Manzanos. It trends N30°E with a nearly horizontal fold axis (Condie and Budding, 1979). The wavelength is at least 8 km, with an almost vertical axial surface; the axial trace approximately follows the center of the Sevilleta formation. The White Ridge formation is appreciably thinner on the western limb of this fold. Minor folds range in size from less than a centimeter to more than a kilometer in wavelength.

A high-angle, northeast-trending Phanerozoic fault, which generally parallels compositional layering, cuts Precambrian rocks (fig. 2). The only other significant fault is a high-angle, westward-dipping, northeast-trending, Laramide-style reverse fault along the eastern map boundary (fig. 2).

Regional metamorphism of the metasediments has been low to moderate (upper greenschist to amphibolite facies). A thermal aureole around the intrusive Priest quartz monzonite is characterized by increased grain size and the presence of abundant sillimanite in schists.

PRECAMBRIAN STRATIGRAPHY

The five major Precambrian units of the southern Manzano Mountains were originally recognized in the Los Pinos Mountains to the south by Stark and Dapples (1946). Stark (1956) traced these units northward into the southern Manzanos where he found, with a few exceptions, that lithologies remained much the same. Sais quartzite and Blue Springs schist have been mapped in the northern Manzano Mountains by Reiche (1949), where a series of older metaclastics unconformably underlies the Sais and Blue Springs (but see Blount, road-log segment I-D, this guidebook, for an alternative explanation).

Sais Formation

The Sais formation crops out along the eastern map boundary, where it is in fault contact with Paleozoic rocks and is intruded by the Priest quartz monzonite. The Sais can be divided into four major stratigraphic sub-units. From oldest to youngest these are: (1) blue-gray to pinkish blue-gray, commonly fractured, vitreous, massive to thinly-bedded, medium-grained orthoquartzite; (2) orange weathering quartz-muscovite schist; (3) red, maroon to purple, crossbedded, generally thin-bedded

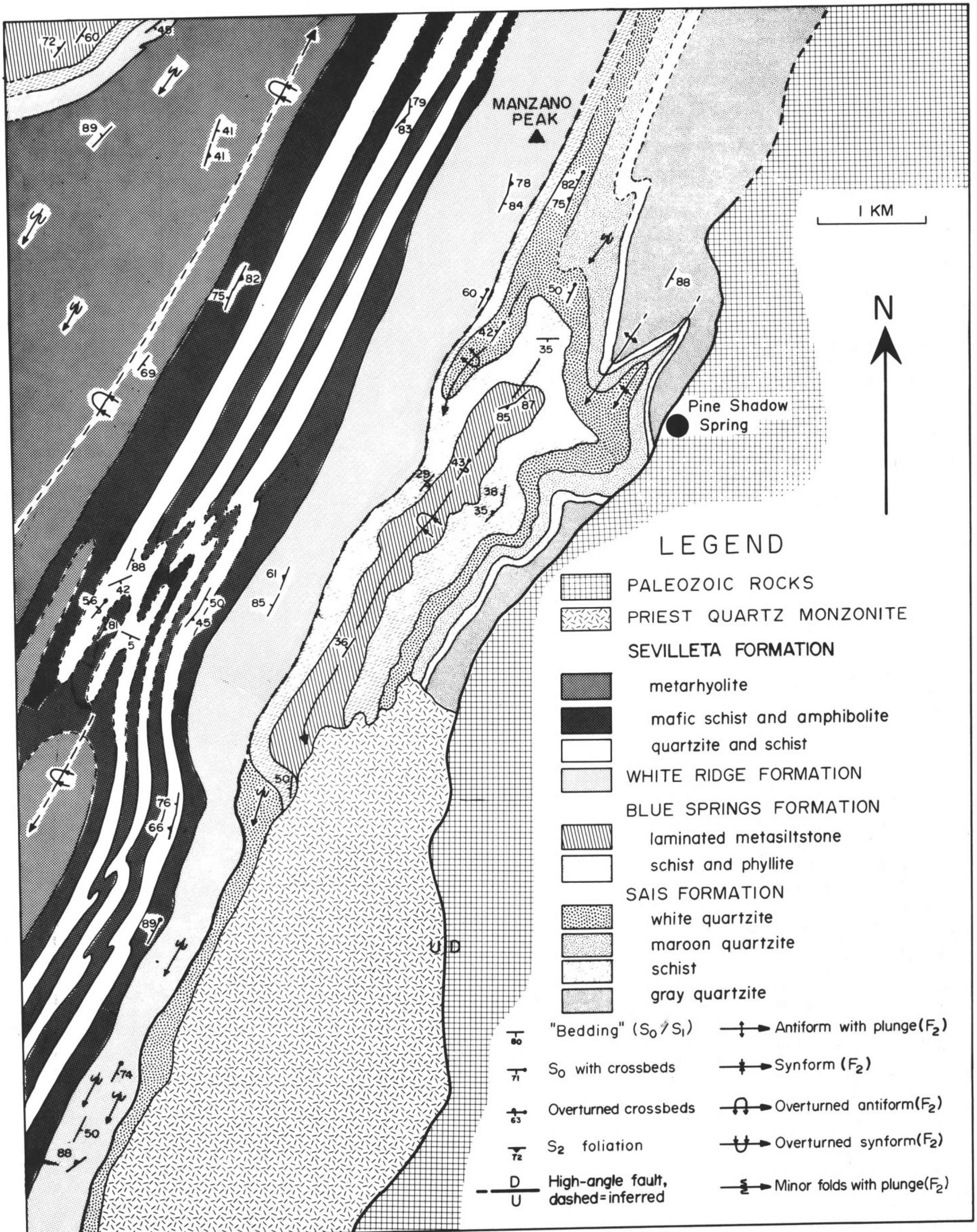

Figure 2. Generalized geologic map of the southern Manzano Mountains study area.

quartzite, commonly with mullion structures; and (4) white, resistant, massive-to-thin bedded orthoquartzites, including interbedded pink resistant quartzites and chlorite-sericite schists. Within these major subunits are numerous metaclastic facies such as brown-tan hematitic cliff-forming quartzite, pinkish massive vitreous quartzite with many thin hematitic layers, and thin-bedded micaceous quartzite with thin schistose layers.

Blue Springs Formation

The Blue Springs formation is a complex unit consisting of various interlayered metashales and metasiltstones. Three general lithologies may be recognized: (1) muscovite-chlorite schist, (2) phyllite, and (3) metasiltstone.

Muscovite-chlorite schist ranges from greenish-gray to dark gray. This unit is conspicuous due to the volume and persistence of lenticular and fishhook-shaped quartz veins, lenses, and pods. Elongation of these features parallel to the dominant schistosity, to fold noses, and to enveloping surfaces indicate that they are transposed quartz veins. These quartz stringers make up more than 40 percent of some outcrops. Well-developed foliations (S_1 and S_2) are generally preserved, commonly with an overprinted crenulation cleavage (S,). Phyllites are medium-grained quartz-muscovite rocks with smooth cleavage surfaces showing a distinctive sheen. Metasiltstones are fine-grained, siliceous, thinly laminated, colorful (pink, green, gray), and elegantly folded rocks. These may be metacherts instead of metasiltstones (see Grambling, this guidebook). Folds are generally small, tight to isoclinal, and characteristically disharmonic. In the southern area of exposure, adjacent to the Priest pluton, metasiltstones lose their distinctive laminae, appearing as dark, massive, fine-grained siliceous rocks.

Border facies of the Blue Springs formation adjacent to the Priest quartz monzonite are sillimanite schists containing sillimanite crystals up to 4 cm in length.

White Ridge Formation

The White Ridge formation appears in outcrop on both limbs of a large F, (?) synform. The eastern limb, which forms the highest peaks in the Manzanos, has an apparent thickness five times that of the western limb. The eastern half of the eastern limb of the White Ridge is composed dominantly of a sequence of resistant, vitreous, white to dark gray, medium to thinly-bedded orthoquartzites. Thin micaceous beds are common; pink and red quartzite facies occur locally. The western half of the eastern limb consists of less resistant, massive, orange-weathering micaceous quarzite with some interlayers of schist, basic schist, and metarhyolite. Compositional layering (S_0/S,) and cleavage (S_2) surfaces commonly are plated by a thin reflective mica layer.

The western limb consists of a sequence of reddish quartzite, muscovite-chlorite schist, resistant light-colored quartzite, and micaceous quartzite.

Sevilleta Metarhyolite and Basic Schists

The Sevilleta and basic schist formations consist of a stratigraphically and structurally complex association of metavolcanic, meta-plutonic, and metasedimentary rocks. These rocks lie near the core of a large syncline defined by Stark (1956).

The bulk of the sequence consists of metarhyolite which typically is pink to gray, blocky-fracturing, porphyritic with sub-rounded light-colored crystals of quartz and pink feldspar in a gray-pink groundmass. Textural and compositional variations occur locally. In places it is difficult to distinguish metarhyolite from red orthoquartzite, but metarhyolites contain 1-4 mm porphyroblasts of feldspar or quartz in an aphanitic groundmass and weather to a distinct pinkish color. Average mineral percentages of metarhyolite are orthoclase, 25 percent; plagioclase, 15 percent; quartz, 50 percent; biotite, 5 percent; plus rare crystals of magnetite, apatite, and zircon.

Intercalated with metarhyolite are sill-like units ranging from hornblende amphibolite to chlorite schist, with apparent thicknesses from a few centimeters to almost a kilometer. These units commonly show gradational contacts with adjacent metarhyolite. In places, mafic rocks interfinger with adjacent metasedimentary or metarhyolitic rocks. Mafic units may thicken, thin, fork, and pinch out along strike, although many may be followed continuously for several kilometers. A thick mafic unit may be expressed farther along strike by a number of thin units. A wide range of textural and compositional variations exist. Some of the common facies are: (1) feldspar-hornblende schist with small lenticular feldspar crystals, (2) coarse-grained metadiorite, (3) chlorite-hornblende amphibolite with large coarse-grained metadioritic pods and stringers, and (4) fine-grained black amphibolite. In places, fine- and coarse-grained plagioclase-hornblende facies form composite rocks.

Stark (1956) stated that primary igneous textures such as vesicles, amygdules, and ellipsoidal flow tops are seen in the Los Pinos Mountains, but none of the basic schists in the southern Manzanos show these features. However, fine-grained borders and stringers of mafic schist in adjacent rocks suggest that these may be sills.

A wide variety of metasedimentary rocks occurs within metarhyolite and amphibolite. Various quartzite facies are present. Garnet-muscovite schist is seen in several areas; chloritoid porphyroblasts up to 3 cm long are contained within some schists. Zones of magnetite schist are less common. A noteworthy outcrop of coarse-grained quartz mica schist contains smoothly rounded, oval to spherical inclusions of granite, quartzite, and aplite which look remarkably like rounded clasts. This lithology is about 5 m thick and occurs in only one area (see photo in Stark, 1956, plate 2). Clasts range in diameter from 1 to 20 cm; elongate clasts are oriented within foliation. Stark (1956) claimed that this unit has an igneous matrix since it grades above and below into rhyolite, and that inclusions may be pebbles from an older bed included in the magma. However, it is not clear that this cobbled unit grades into metaigneous rocks; many metasedimentary schists and quartzites are present throughout much of the Sevilleta formation.

STRUCTURE

Sedimentary Structures

Relict crossbeds, usually defined by thin, dark hematitic layers in quartzites, indicate stratigraphic tops in a number of localities. The best preserved crossbeds occur near the eastern map boundary in the red-maroon-purple unit of the Sais quartzite. They consistently indicate that the west-dipping beds are upright. This confirms Stark's age relationship of a younging sequence of Sais—Blue Springs—White Ridge—Sevilleta. Other unambiguous crossbeds in members of the White Ridge formation are not consistent; in fact, closely spaced crossbeds commonly show opposing tops, suggesting tight folding within the units.

Folds

Three ages of Precambrian folds are recognized.

1. F_1 is the earliest penetrative deformation recognizable, distinguished by isoclinal folds, transposed layers, and a strong axial-plane cleavage (S_1). F_1 fold noses are rarely observed in the field, although the S_1 cleavage is manifest in thin section. S_1 strikes about N30°E, generally dips at a high angle, and defines compositional layering (S_0).

2. F_2 is the second episode of penetrative deformation, characterized by tight to isoclinal folds, transposition, and a strong, axial-plane cleavage (S_2). Most of the folds seen in this area, both minor and map scale, are F, structures. Intersection lineations between S_0/S, and S, (L20) display significant scatter on a stereogram plot but show a definite

preferred orientation near S40°W, 60°. S_0/S_1 and S_2 are commonly nearly coplanar; only in or near F_2 fold noses does the vergence angle become appreciable.

3. F_3 is a late, northwest-trending event which overprints schistose rocks with a crenulation cleavage (S_3). The effect of this deformational event may simply have been to broadly warp rocks around a nearly horizontal northwest-trending axis as suggested by F_3 fold axes and rotated F_2 fold axes and intersection lineations. Figure 3 demonstrates the sequence of deformation indicated above.

This area is remarkable due to the prominence and variety of small minor folds. Folding is typically disharmonic due to the effects of ductility and thickness contrasts. Map patterns as well as hand specimens reflect this disharmony between folded layers. Very small examples of these patterns are commonly seen in the colorfully laminated siltstones of the Blue Springs formation (fig. 4). Minor folds in quartzites are generally larger. A splendid vertical exposure of quartzite in Estadio Canyon shows overturned isoclinal antiforms 12 m high with the intervening synforms apparently sheared out (fig. 5).

It is evident from outcrops that transposition has locally rotated compositional layering into the S_2 cleavage. The most striking examples occur in the dark, quartz vein-rich schist unit of the Blue Springs formation, where veins, hooks, pods, and lenses of quartz are strung out parallel to the schistosity of the ductile schist (fig. 6). Other obvious transposition textures are seen within amphibolite where felsic lenses have been rotated and elongated within a hornblende-rich matrix. It is not clear whether large-scale map patterns reflect the transposition seen in outcrops.

The southern Manzanos are dominated structurally by a large N30°E-trending F_2 synform. This fold has a wavelength of at least 8 km; its fold axis plunges gently to the southwest with the axial trace approximately following the center of the Sevilleta formation. Farther north, the synform becomes progressively overturned to the southeast (Stark, 1956). S_2 is consistently steeper than S_0/S_1 on the eastern limb, with the exception of local areas of minor F_2 folds whose axes commonly show deviations from that of the major synform.

East of the Montosa fault lies a large minor southwest-plunging F_2 syncline cored by Blue Springs formation. This fold appears isoclinal in map pattern; however, S_0 measurements indicate that this is a tight fold, eroded such that it appears isoclinal. A number of other large disharmonic F_2 minor folds occur in the northeast map area.

None of the cross-cutting granitic-aplitic dikes thought to be associated with the Priest intrusion are involved in Precambrian folding.

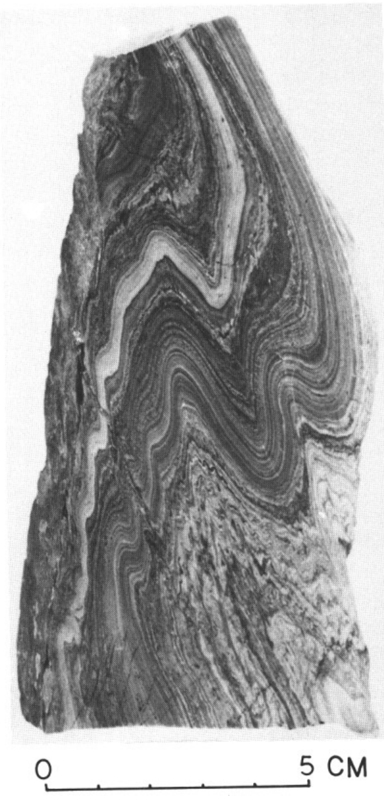

Figure 4. Typical disharmonic F_2 folds in a laminated metasiltstone of the Blue Springs formation.

Faults

Two approximately parallel faults are recognized in the region: (1) the Montosa on the east and (2) the Paloma to the west. The Montosa fault is a well-exposed, west-dipping high-angle reverse fault which separates Precambrian from Paleozoic rocks. Slip and separation are unknown along this fault. Paleozoic units are folded and locally overturned due to drag; breccia is common along the fault trace. Stark (1956) has traced the Montosa fault south of the Los Pinos Mountains where it cuts Cretaceous limestones but not Tertiary volcanics.

The Paloma fault is confined to Precambrian metasediments and generally parallels lithologic contacts. In the northern half of the map

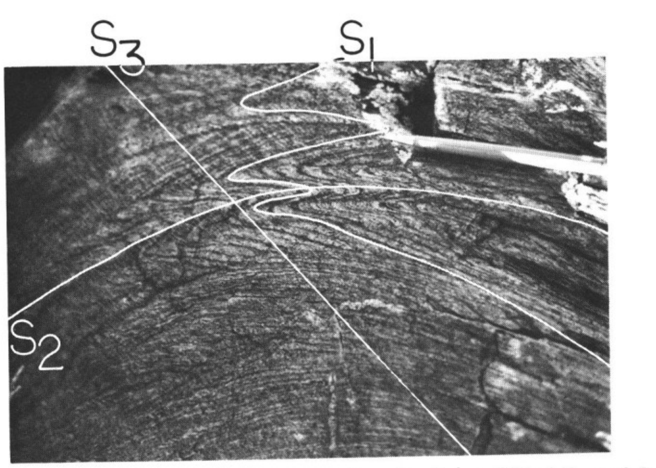

Figure 3. Outcrop of schistose quartzite showing refolded S_1 and S_2 surfaces. F_1 is isoclinal with no fold noses visible. F_2 folds are tight, and F_3 is a broad fold.

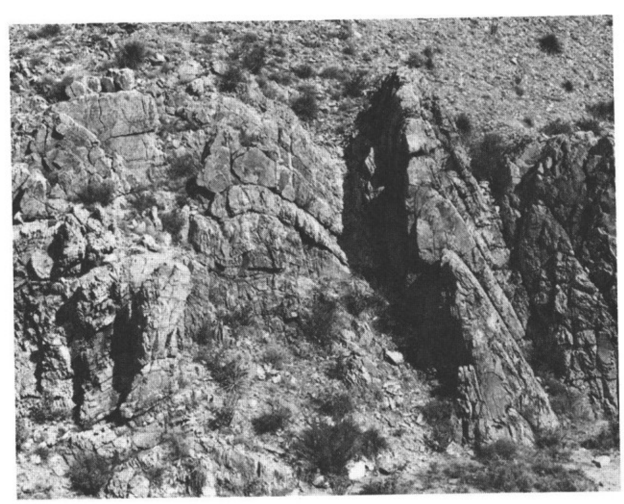

Figure 5. Overturned isoclinal antiforms with the intervening synform sheared out. Fold on right is 12 m high.

Figure 6. Transposed quartz veins in folded chlorite schist of the Blue Springs formation. Note the fishhook-shaped fold noses of quartz.

area, the fault follows S_o/S_1 and can be recognized only by careful structural measurements. In no locality within the map area is it possible to determine the sense of displacement along the fault, although Stark (1956) states that the two faults merge 5.5 km south of Capilla Peak and continue northward as the Montosa thrust.

Small localized faults probably associated with the major faults have offsets ranging from centimeters to meters. Lines of small fault scams in the alluvial fans to the west are Quaternary in age (Stark, 1956) and are probably related to the development of the Rio Grande rift.

GEOCHRONOLOGY

Bolton (1976) performed Rb-Sr whole-rock analyses on four samples of the Sevilleta metarhyolite and six samples of the Priest quartz monzonite in the southern Manzanos. He reports dates of 1,700±58 58 m.y. for the Sevilleta and 1,470±30 30 m.y. for the Priest. The Sevilleta date is the oldest isochron age for a siliceous metaigneous rock in central New Mexico (Condie and Budding, 1979). Recent U-Pb zircon data for metavolcanic rocks in central New Mexico by Bowring and Condie (1982) have yielded similar ages.

METAMORPHISM

Precambrian rocks have been regionally metamorphosed in the upper greenschist to lower amphibolite facies. Beers (1976) asserts that equilibrium temperatures and pressures for the Manzano and Los Pinos mountains range between 400 and 600°C and 3 to 6.5 kb. Electron microprobe data for garnet-biotite pairs for two schists from the Sevilleta formation yield temperatures of 480°C and 487°C assuming a pressure of 4 kb, using the geothermometer of Ferry and Spear (1978; D. Codding, personal commun., 1982). Schists typically contain quartz, muscovite, biotite, chlorite, and opaques with some assemblages additionally containing any of the following: staurolite, chloritoid, garnet, tourmaline, and alkali feldspar. Garnets commonly show rotational structures; chloritoid schists contain blocky chloritoid crystals up to 3 cm in length. Quartz grains exhibit equilibrium grain-boundary textures in some samples and cataclastic textures in the others. Basic schists and amphibolites contain hornblende, biotite, plagioclase, epidote, quartz, and opaques.

Intrusion of the Priest quartz monzonite into metaclastics formed a thermal aureole best seen in adjacent schists. Increased temperatures formed new minerals; most noticeably, sillimanite and muscovite were formed near the intrusive contact. Stark (1956) concluded, from mineral zones around the intrusion, that contact metamorphism was more dependent on original sediment composition than on proximity to the intrusive contact.

Table 1 presents a generalized Precambrian geologic history for the southern Manzanos based on observed structural fabrics.

TECTONICS

The key to understanding the complex structure and stratigraphy of this and similar areas lies in ascertaining the true nature of the S_1 fabric. Any supposition concerning S_1 will have to explain the following: (1) S_1 is parallel to compositional layering (S_o), (2) S_1 defines a strong

Table 1. Summary of major Precambrian events in the southern Manzano Mountains.

Event	Features	Possible age (b.y.)
Accumulation of clastic sediments in a broad sedimentary basin.	Crossbeds, hematitic layers and oxidation in sandstones indicates shallow water regime. Siltstones and pelitic sediments are deeper water facies.	
Bimodal volcanism with mafic sills and flows followed by thick rhyolitic flows.	Major volume of mafics intrudes metasedimentary rocks, although metarhyolites contain some amphibolite layers.	1.65-1.75 (Bolton, 1976)
Deformation (D_1)	Regional metamorphism; strong penetrative fabric; transposition layering; recumbent isoclinal folding.	
Deformation (D_2)	Continued or reactivated metamorphism; strong axial-plane cleavage; minor transposition; tight to isoclinal folding with vertical axial surfaces and gently plunging fold axes; approximate east-west compression.	
Deformation (D_3)	Broad folding with vertical axial surfaces, forming a crenulation cleavage in schistose rocks; northeast-southwest compression.	
Intrusion of post-tectonic Priest quartz monzonite.	Contact metamorphic aureole with sillimanite zone; granite, aplite, quartz dikes.	1.43-1.50 (Bolton, 1976)

schistosity, (3) rare folds thought to be F, structures are isoclinal and folded by F, and F,, and (4) Sp/S, is presumably a transposition layering, implying that Sp is not original stratigraphic layering. Due to insufficient data, a unique model for S, genesis does not exist, thus allowing for a number of intriguing conjectures. Three possibilities for F, deformation are: (1) horizontal compression resulting in large-scale recumbent folds and nappes, (2) horizontal compression involving intense shear with the formation of a sequence of stacked thrust sheets (Brown and others, 1981), and (3) some combination of the above two. Each of these deformations could form in various compressive tectonic settings, but it is important to note that the style of F, deformation seen in Precambrian rocks of New Mexico is not common in Phanerozoic rocks of the southwest. This suggests a very basic difference between Precambrian and Phanerozoic deformational environments in this area.

Several tectonic models of Proterozoic mountain-belt formation have been proposed in New Mexico. Condie and Budding (1979) and Condie (1982) have proposed two entirely different models for the evolution of the southwestern U.S. based on present-day tectonic processes. The early model compared Precambrian rocks of New Mexico with Phanerozoic eugeocline, miogeocline, and continental-rift assemblages. Similarities between Precambrian rocks and continental-rift rocks led Condie and Budding to conclude that Precambrian rocks of central and south-central New Mexico developed in an incipient-rift or multiple-rift system. In order to explain the observed lithologic assemblage, structural setting, and geochemistry of the igneous rocks, they proposed an active subduction zone lying to the west with associated back-arc spreading in the southwestern U.S. In support of this model they stated that evidence of major compressive polyphase deformation such as nappes and complex fold interference patterns are not observed in the Precambrian of New Mexico. They interpreted major folds as passive drape features. This model is inconsistent with the observed geology of the Manzano Mountains in several ways. At least three episodes of Proterozoic deformation are recognized in the southern Manzanos. In addition, complex fold interference patterns have recently been recognized in the central Manzanos (Grambling, this guidebook), in the Picuris Mountains (Holcombe and Callender, 1982), and in the Rio Mora area of the southern Sangre de Cristo Mountains (Grambling and Codding, 1982). The stresses implied for the formation of these structures must involve processes more catastrophic than those of draping Proterozoic sediments and volcanics over uplifted fault blocks as Condie and Budding have proposed.

Condie's later model (1982) is based on the following observations: (1) supracrustal rocks, which young toward the south, are intruded by Precambrian granitic plutons; (2) sequences of bimodal volcanics are overlain by quartzite-shale assemblages; and (3) geochemical and Sr-isotope data suggest "a variably depleted upper mantle source for basalts and a short-lived (<100 m.y.) lower-crustal source for granitic and felsic volcanic magmas (Condie, 1982, p. 37)." A model of southward-migrating arcs with successive basin closures and Andean-type orogenies producing 1,300 km of continental crust from 1.8 to 1.1. b.y. ago is suggested to explain the above observations. There are a number of inconsistencies between this model and the geology observed in the Manzano Mountains. If stratigraphic interpretations in the Manzanos are valid, the quartzite-shale assemblage is overlain by bimodal volcanics, not underlain by them. Another problem lies in the incongruity of forming northeast-striking isoclinal folds in a north-south compressive regime. Also, as Condie noted, calc-alkalic volcanics commonly associated with convergent plate boundaries are absent from the Proterozoic of the southwestern U.S.

Several authors have recently suggested that Precambrian tectonic styles may have been quite different from those of today, in response to evolving thermal regimes (Kroner, 1981; Hargraves, 1981; Goodwin, 1981). Such interpretations may better apply to observed geology of Proterozoic rocks of New Mexico.

ACKNOWLEDGMENTS

J. F. Callender and J. A. Grambling of the University of New Mexico and R. C. Holcombe of the University of Queensland, Australia provided invaluable guidance both in the field and in the classroom. J. F. Callender was kind enough to critically review the manuscript. D. B. Codding provided microprobe data, geothermometry calculations, darkroom facilities, and photographs.

This paper represents part of a study undertaken in partial fulfillment of a M.S. degree at the University of New Mexico. Field work and research expenses were supported in part by grants from the New Mexico Geological Society, the Geological Society of America, Sigma Xi, and the Student Research Allocations Committee at the University of New Mexico. The Geology Department at the University of New Mexico furnished field vehicles and research facilities.

REFERENCES

Beers, C. A., 1976, Geology of the Precambrian rocks of the south Los Pinos Mountains, Socorro County, New Mexico (M.S. thesis): New Mexico Institute of Mining and Technology, Socorro, 238 p.

Bolton, W. R., 1976, Precambrian geochronology of the Sevilleta metarhyolite and the Los Pinos, Sepultura, and Priest plutons of the southern Sandia uplift, New Mexico (M.S. thesis): New Mexico Institute of Mining and Technology, Socorro, 45 p.

Bowring, S. A. and Condie, K. C., 1982, U-Pb zircon ages from northern and central New Mexico: Geological Society of America Abstracts with Programs, v. 8, p. 304.

Brown, L. D., Oliver, J. E., and others, 1981, Deep crustal structure: implications for continental evolution, *in* Fyfe, W. S., ed., Evolution of the Earth: American Geophysical Union, p. 38-52.

Condie, K. C., 1982, Plate-tectonics model for Proterozoic continental accretion in the southwestem United States: Geology, v. 10, p. 37-42.

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

Ferry, J. M. and Spear, F. S., 1978, Experimental calibration of the partitioning of Fe and Mg between biotite and garnet: Contributions to Mineralogy and Petrology, v. 66, p. 113-117.

Goodwin, A. M., 1981, Precambrian perspectives: Science, v. 213, p. 55-61.

Grumbling, J. A. and Codding, D. B., 1982, Stratigraphic and structural relationships of multiply deformed Precambrian metamorphic rocks in the Rio Mora area, New Mexico: Geological Society of America Bulletin, v. 93, p. 127-137.

Hargraves, R. B., 1981, Precambrian tectonic style: a liberal uniformitarian interpretation, *in* Kroner, A., ed., Precambrian plate tectonics: Elsevier, New York, 781 p.

Holcombe, R. J. and Callender, J. F., 1982, Structural analysis and stratigraphic problems of Precambrian rocks of the Picuris Range, New Mexico: Geological Society of America Bulletin, v. 93, p. 138-149.

Kroner, A., 1981, Precambrian plate tectonics, *in* Kroner, A., ed., Precambrian plate tectonics: Elsevier, New York, 781 p.

Myers, D. A. and McKay, E. J., 1974, Geologic map of the southwestern quarter of the Torreon 15-minute quadrangle, Torrance and Valencia counties, New Mexico: U.S. Geological Survey Miscellaneous Geological Investigations map 1-820.

Reiche, P., 1949, Geology of the Manzanita and North Manzano Mountains, New Mexico: Geological Society of America Bulletin, v. 60, p. 1183-1212.

Stark, J. T., 1956, Geology of the south Manzano Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 34, 46 p.

Stark, J. T. and Dapples, E. C., 1946, Geology of the Los Pinos Mountains, New Mexico: Geological Society of America Bulletin, v. 57, p. 1121-1172.