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Structural analysis and reinterpretation of an apparent Precambrian angular unconformity, central Manzano Mountains, New Mexico

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Abstract

The contact between a Precambrian metaclastic unit and a massive Precambrian quartzite in the central Manzano Mountains has previously been interpreted as an angular unconformity based on the discordance of what was interpreted as bedding across the contact. However, this work establishes that what was interpreted as bedding is a transposition layering, and that the discordance across the contact is a structural discontinuity rather than an angular unconformity. The rocks on either side of the contact have undergone at least three periods of deformation and appear to have the same deformation history, but different metamorphic histories. Correlative structural fabrics on both sides of the contact are almost perfectly realigned by a single rotation, which, combined with the different metamorphic histories on either side of the contact, strongly suggests a thrust fault with a rotational component of displacement as the cause of the discontinuity. The discontinuity postdates the youngest structural fabric correlated across the contact and predates the Pennsylvanian sediments that lie undisturbed across the contact to the north.

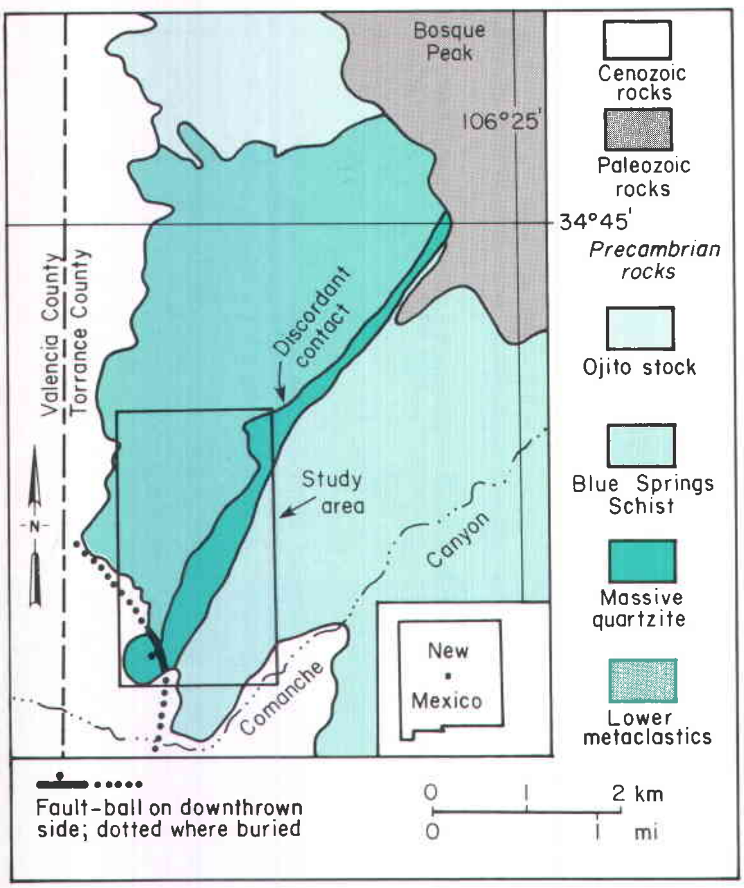

FIGURE 1—Location and regional geology of a portion of the central Manzano Mountains (adapted from Stark, 1956). The area studied in detail, and shown in Figs. 3 and 4, is outlined in black.

Introduction

The Manzano Mountains form a fault-bounded uplift bordering the eastern edge of the Rio Grande rift. The mountain range extends from Abo Pass to Escabosa, a distance of approximately 29 mi, and consists of multiply deformed Precambrian igneous and metamorphic rocks. The regional geology was summarized by Reiche (1949) and Stark (1956).

The study area for this report is located approximately 25 mi east of Belen, on the west side of the Manzano Mountains, and is contained within the NW¼ and SW¼ of the USGS Capilla Peak 7½ min quadrangle. The Precambrian rocks in the study area are divided into three mappable units based on Stark's (1956) work: lower metaclastics, massive quartzite, and Blue Springs Schist. This report is the result of a structural analysis of the contact between the lower metaclastics and massive quartzite immediately north of the mouth of Comanche Canyon in the central Manzano Mountains (Fig. 1; see Myers and McKay, 1972, for the most recent geologic map of the central Manzano Mountains). This contact has previously been interpreted as a Precambrian angular unconformity by Reiche (1949), Stark (1956), and Condie and Budding (1979) because of the discordance of what was interpreted as bedding across the contact. Based on the correlation and analysis of structural fabric elements and the comparison of metamorphic conditions on both sides of the contact, as well as evidence for faulting along the contact, the discordance across the contact is reinterpreted as a post-depositional structural discontinuity. ☞

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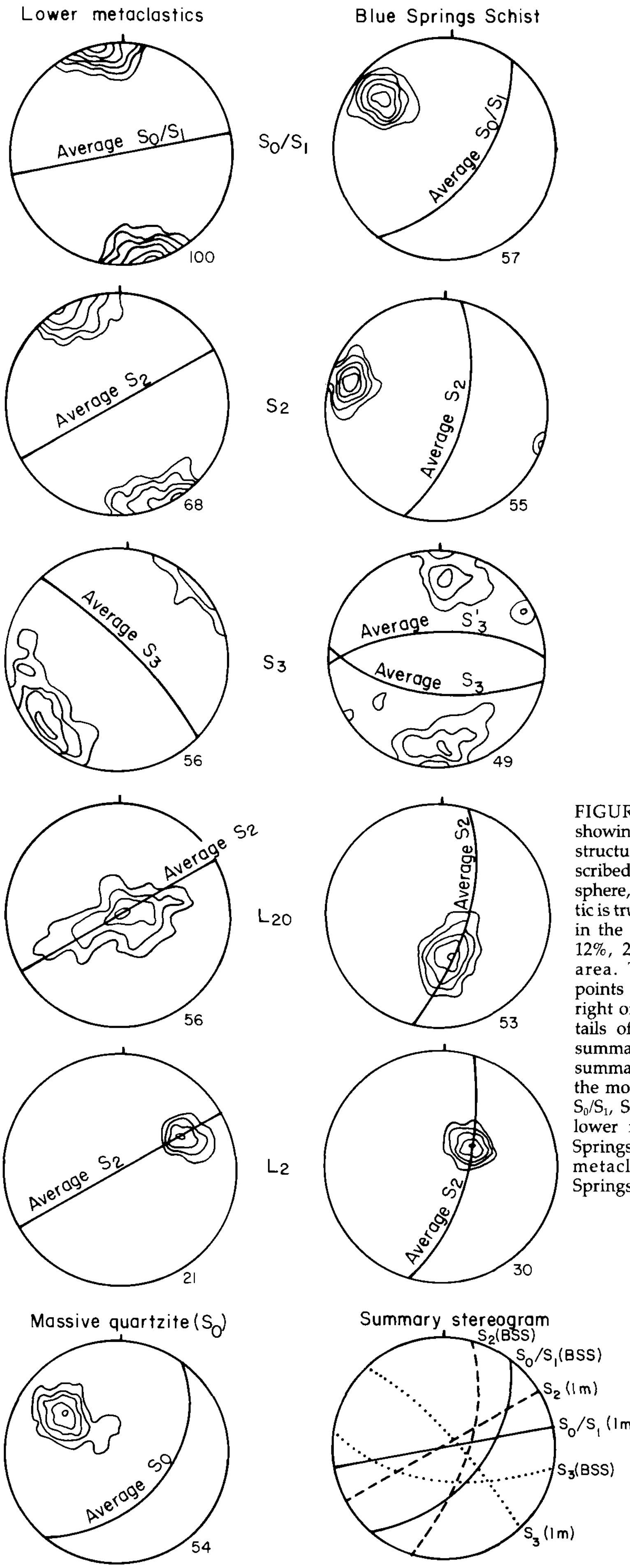

FIGURE 2—Stereograms showing the orientations of the structural fabric elements described in Table 1 (lower hemisphere, equal-area projections; tic is true north). Contours are in the sequence 1%, 3%, 6% 12%, 24%, and 48% per 1% area. The number of data points is shown at the lower right of each stereogram. Details of each stereogram are summarized in Table 2. The summary stereogram shows the modal orientations of the S_0/S_1, S_2, and S_3 fabrics in the lower metaclastics and Blue Springs Schist. **lm** = lower metaclastics; **BSS** = Blue Springs Schist.

TABLE 1—Definitions and descriptions of the mesoscopic fabric elements used in this study.

Element	Description
S_0	Bedding in the massive quartzite. Younging directions defined by crossbedding.
S_1	Dominant cleavage in the study area. Transposition layering in the lower metaclastics and Blue Springs Schist where it is included together with S_0 as S_0/S_1.
S_2	Cleavage ranging from a closely spaced crenulation cleavage to a well-developed schistosity. Overprints S_0/S_1 at an angle generally greater than 10°. Axial-planar to numerous mesoscopic folds. Shows a metamorphic differentiation in schists defined by alternating, closely spaced layers of quartz-rich and mica-rich rock.
S_3	Well spaced, nonpenetrative crenulation cleavage. Overprints S_0/S_1 and S_2 at an angle generally greater than 60°.
S_3'	Well spaced, nonpenetrative crenulation cleavage in Blue Springs Schist. No correlative counterpart in the lower metaclastics.
L_{20}	Observed and calculated intersection lineation of S_0/S_1 and S_2.
L_2	Stretching lineation observed on S_2 surfaces. Defined by preferred orientation and alignment of elongated chlorite and muscovite. Interpreted as representing the direction of maximum finite elongation during the second deformation event (D_2).

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Lithologies, bedding, and stratigraphic facing

The lower metaclastics are composed of interlayered brown to gray schist, gray phyllite, metavolcaniclastic rocks, and minor meta-arkose, amphibolite, and white to gray quartzite. Lithologic layering defined by Fe–Ti oxide concentrations in the quartzite and metavolcaniclastic layers is folded by rootless, intraformational, isoclinal folds with axial-plane foliations parallel to the compositional layering. Discontinuous pods and stringers of the compositional layers are common, as are isolated, isoclinal, fishhook-shaped fold noses with axial planes parallel to the compositional layering. Thus, the dominant layering in this unit is a transposition layering.

The massive quartzite is composed of white, gray, and occasionally blue or red, crossbedded quartzite. Quartz grains that range from 0.1 to 1.0 mm in size form 99% of the rock with only trace amounts of muscovite, Fe–Ti oxides, and tourmaline. In some areas discontinuous layers, ranging from 1 to 10 cm thick, contain concentrations of euhedral magnetite crystals up to 2 cm across. Primary bedding is well defined by Fe–Ti oxide concentrations and relatively thin (1–10 cm) layers of pebbly and conglomeratic quartzite. Crossbedding is defined by concentrations of Fe–Ti oxides and, where interpretable, shows consistent younging to the southeast, toward the Blue Springs Schist. No folds or transposition features were recognized, and the well-defined bedding features are interpreted as representing original bedding orientation. In other words, the attitude and facing of individual bedding features truly reflect the attitude and facing of the whole stratigraphic unit.

The Blue Springs Schist is composed of green to brown schist and green to gray phyllite with interlayered white, gray, and green, rarely crossbedded quartzite. The layering in the Blue Springs Schist contains the same transposition features seen in the lower metaclastics. Therefore, the dominant layering in the Blue Springs Schist is also a transposition layering, and this transposition layering in the lower metaclastics and Blue Spring Schist is fundamentally different from the primary depositional layering observed in the massive quartzite.

Metamorphism

The schists and phyllites in the lower metaclastics contain quartz, muscovite, plagioclase, biotite, pseudomorphs of chlorite and muscovite after coarse (1 cm) staurolite, and rare garnet surrounded and embayed by retrograde chlorite.

Electron microprobe analyses of the embayed, relict garnets reveal what appear to be retrograde reaction rims. In the core of the garnet, up to within 10 microns of the rim, the garnet composition is consistent with the following average: $Al_{45}Sp_{41}Pyr_{10}Gr_4$. However, from within 10 microns of the rim up to the rim the composition changes gradually with Mn increasing and Fe and Mg decreasing, giving the following average: $Al_{38}Sp_{50}Pyr_8Gr_4$. The plagioclase in the same rocks is commonly sericitized, and optical properties reveal compositions more calcic than An_{10}.

The amphibolites in the lower metaclastics contain quartz, epidote, plagioclase, calcite, and zoned amphiboles. The amphiboles are zoned with blue-green hornblende cores surrounded by what are interpreted as retrograde rims of actinolite. The hornblende–actinolite boundaries are commonly sharp, but irregular. The plagioclase is highly sericitized and its composition is unknown. The calcite is considered to be retrograde because it occurs exclusively as isolated patches and stringers within the blue-green hornblende, and it is totally absent in the surrounding rims of retrograde actinolite. It is not clear whether the epidote is prograde or retrograde; however, much of it appears to be retrograde because it occurs in close association with highly sericitized, nearly obliterated plagioclase.

The pseudomorphs after staurolite, garnets with retrograde rims, calcic but sericitized plagioclase, and zoned amphiboles associated with retrograde calcite and epidote suggest that the lower metaclastics underwent lower amphibolite facies prograde metamorphism, followed by upper greenschist facies retrograde metamorphism.

Mineral assemblages in the Blue Springs Schist include chlorite–calcite–biotite and chlorite–chloritoid–biotite, both with muscovite and quartz, which suggests upper greenschist facies metamorphism. There is no evidence in the Blue Springs Schist of retrograde metamorphism. Thus, rocks with different metamorphic histories are juxtaposed at the contact between the lower metaclastics and massive quartzite.

Structural fabric elements

Definitions and descriptions of the mesoscopic fabric elements used in this report are given in Table 1. S_0/S_1, S_2, S_3, L_{20}, and L_2 are common in the lower metaclastics and Blue Springs Schist, but they were not recognized in the massive quartzite. Although a large population of fractures, some of which form conjugate sets, occurs in the massive quartzite, their relationship to the S_0/S_1, S_2, and S_3 fabrics in this study is not clear; therefore, they were not included in this report.

The transposition layering S_0/S_1 observed in the lower metaclastics and Blue Springs Schist appears to be a common phenomenon in the Precambrian rocks of New Mexico (e.g., Bauer, 1983; Callender, 1983; McCarty, 1983; Armstrong and Holcombe, 1982; Holcombe and Callender, 1982; Grambling, 1982; Grambling and Codding, 1982; Cavin et al., 1982; Connolly, 1982). Evidence documenting that an early deformation event led to the development of a widespread transposition layering in the central Manzano Mountains consists of: 1) rootless, intraformational, isoclinal folds with axial planes that are parallel to the compositional layering and cut by the later S_2 foliation; 2) discontinuous pods and stringers of the compositional layering and isolated, isoclinal, fishhook-shaped fold noses with axial planes parallel to the compositional layering, both of which are cut by the later S_2 foliation; 3) quartz-rich microlithons, seen in thin section, that are parallel to the compositional layering and cut by the later S_2 foliation; and 4) mica alignment, seen in hand specimen and thin section, that is parallel to the compositional layering and cut by the later S_2 foliation.

Isolated kink bands that overprint S_0/S_1 and S_2 occur locally in the lower metaclastics and Blue Springs Schist, but their rare occurrence makes them relatively unimportant for the overall structure.

Structural analysis

Stereograms of the various fabric elements in Table 1 are shown in Fig. 2. Orientation data for the stereograms of Fig. 2 are summarized in Table 2.

The S_0/S_1 fabric in the lower metaclastics is truncated at the contact with the massive quartzite (Fig. 3). It has been demonstrated that this fabric represents a transposition layering rather than bedding; ☞

TABLE 2—Summary of orientation data shown in Fig. 2. Planes are given as dip and dip azimuth. Lines are given as plunge and plunge azimuth.

Fabric element	Orientation data		Number of data
Lower metaclastics			
S_0/S_1	modal S_0/S_1	90, 168	100
S_2	modal S_2	90, 149	68
S_3	modal S_3	80, 46	56
L_{20}	modal L_{20}	vertical	56
	L_{20} girdle	90, 149	
L_2	modal L_2	41, 59	21
Blue Springs Schist			
S_0/S_1	modal S_0/S_1	62, 126	57
S_2	modal S_2	70, 105	55
S_3	modal S_3	66, 188	49
	secondary maximum S_3'	70, 00	
L_{20}	modal L_{20}	54, 165	53
	L_{20} girdle	70, 105	
L_2	modal L_2	65, 60	30
Massive quartzite			
S_0	modal S_0	50, 130	54

therefore, the truncation may be a structural discontinuity, due to a later-stage deformation, rather than an angular unconformity. The discordance of the S_2 and L_{20} fabrics across the contact are shown in Fig. 4, and similar relationships for S_3 and L_2 can be seen in the stereograms in Fig. 2. In fact, the lack of alignment across the contact of any of the structural fabrics of Fig. 2 strongly suggests post-S_3 deformation.

The orientations of the fabric elements in the lower metaclastics and Blue Springs Schist are compared in Table 3 before and after a 53° counter-clockwise rotation of the fabric elements in the lower metaclastics about an axis plunging 45° to azimuth 94°. The near-perfect alignment of all five fabric elements in the lower metaclastics with those in the Blue Springs Schist after rotation suggests that: 1) they are correlative and formed during the same deformation event, 2) they were aligned at one time, and 3) rotational displacement has occurred causing the present discordance of the various fabric elements in the two units.

The fact that the structural discontinuity is restricted exclusively to the lower metaclastics–quartzite contact strongly suggests movement along the contact. Field evidence for movement along the contact is summarized in Figs. 3, 4, and 5. Within 1–5 m of the contact the S_0/S_1 fabric in the lower metaclastics has rotated into alignment with the contact. Fig. 5 shows sixteen S_0/S_1 and seven S_2 data points that were collected in the narrow (1–5 m) zone near the contact.

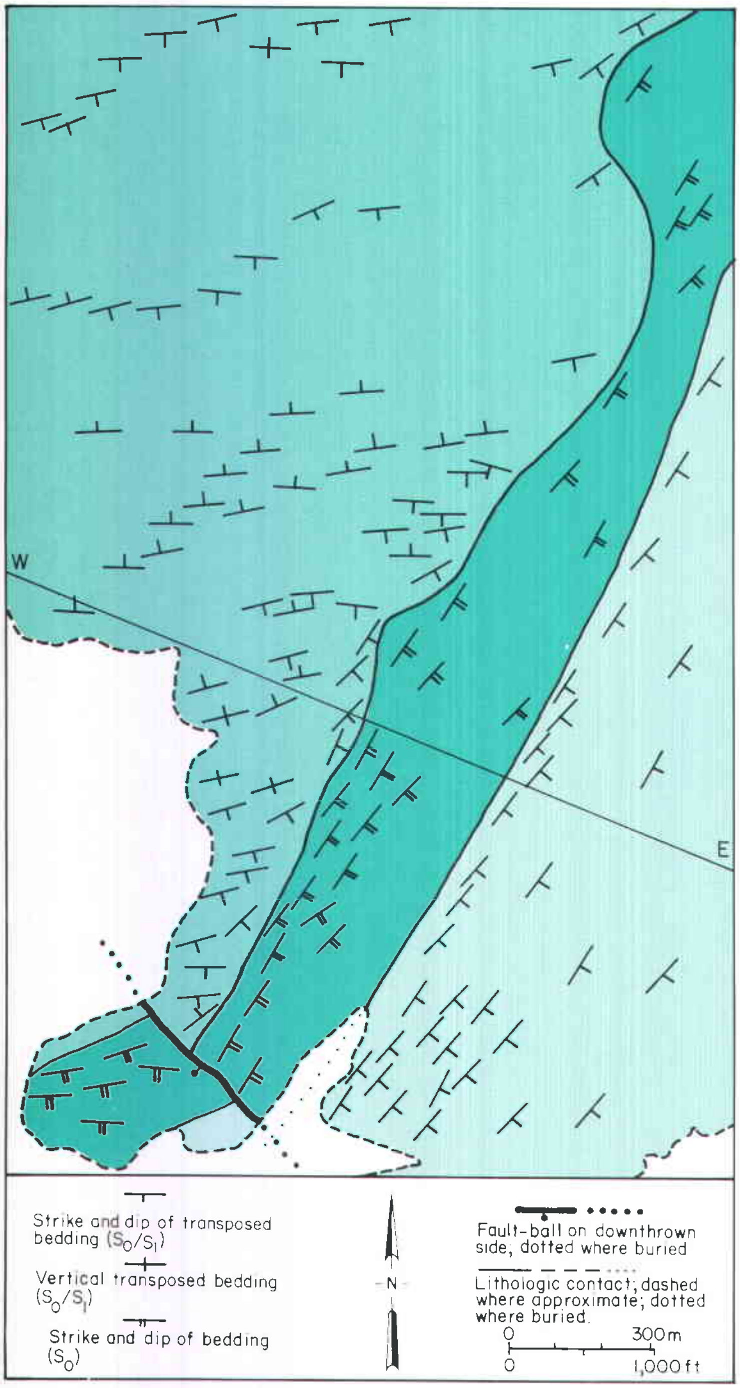

FIGURE 3—Map of the area outlined in Fig. 1 showing the spatial variation of the S_0/S_1 fabric in the lower metaclastics and Blue Springs Schist and the S_0 fabric in the massive quartzite. Dips are all steep and variations in dip values are summarized in the S_0/S_1 and S_0 stereograms in Fig. 2. The formations are named and color coded in Fig. 1. Generalized west–east cross sections are shown in Fig. 6.

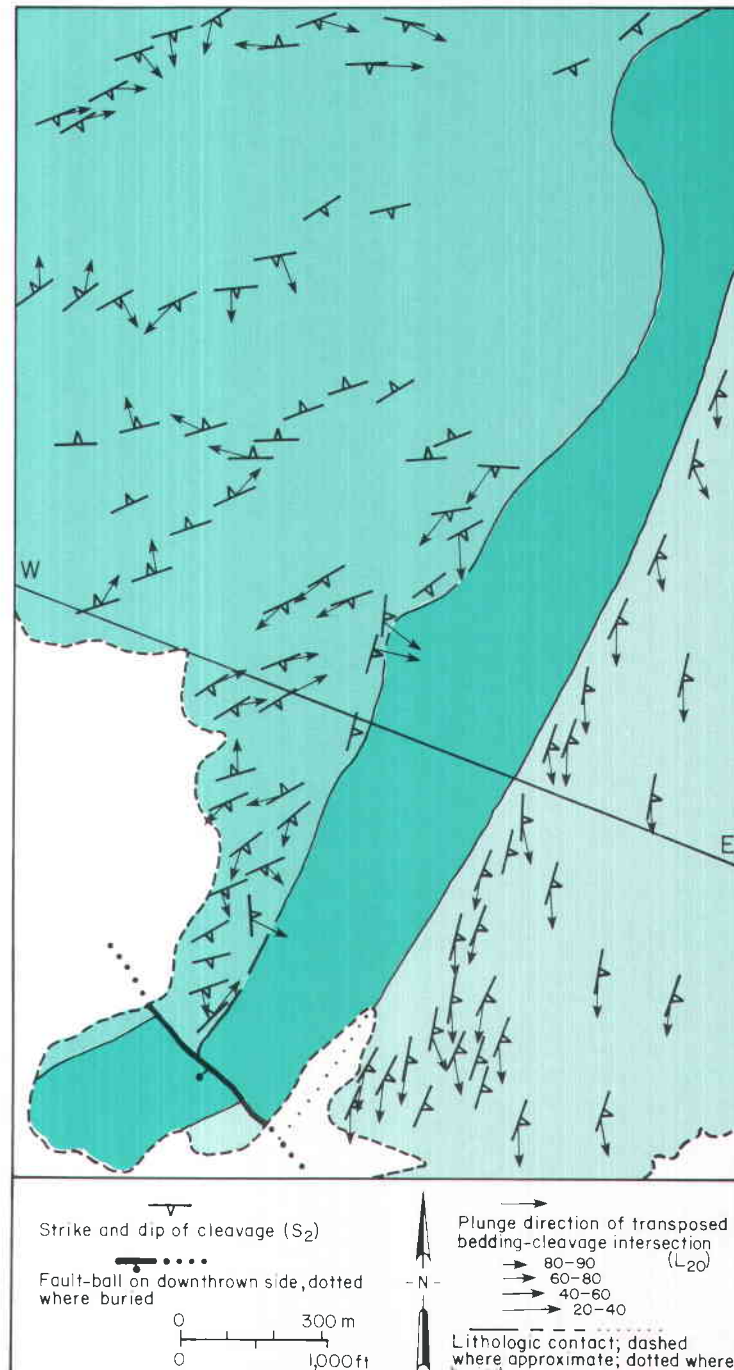

FIGURE 4—Map of the area outlined in Fig. 1 showing the spatial variation of the S_2 and L_{20} fabrics in the lower metaclastics and Blue Springs Schist. Dips are all steep and the orientation data are summarized in the S_2 and L_{20} stereograms in Fig. 2. The formations are named and color coded in Fig. 1. Generalized west–east cross sections are shown in Fig. 6.

These data points have been plotted onto the contoured S_0 stereogram of the massive quartzite, and they show that the S_0/S_1 fabric in the lower metaclastics near the contact is parallel to the contact. As the contact is approached, the lower metaclastics become highly silicified, but I have never been able to get close enough to the contact to find an actual movement zone. Thus, it is not clear whether the movement along the contact was brittle or ductile.

Discussion

Any structural explanation of the discontinuity along the lower metaclastics–quartzite contact must incorporate: 1) the rotation required to realign the correlative fabrics in the lower metaclastics and Blue Springs Schist (Table 3); 2) the faulting parallel to the contact with a component of left-lateral movement as implied by Figs. 3, 4, and 5; and 3) the different metamorphic conditions on either side of the contact.

Figs. 6A–D represent generalized west–east cross sections through the study area (Fig. 3) that show a sequence of hypothetical events that meet the above requirements and lead to the present structural, metamorphic, and topographic relationships. Fig. 6A represents post-S_3 time, just before faulting, during which upper greenschist facies metamorphic conditions prevailed. In Fig. 6B a ductile thrust fault with a 53° clockwise component of rotational displacement brought lower amphibolite facies rocks (lm_2) in contact with upper greenschist facies rocks (lm_1, mq, and BSS). It was during and after this faulting event that retrograde metamorphism occurred in lm_2. Reverse faulting combined with left-lateral displacement then occurred along the lower metaclastic–quartzite contact truncating the rotational fault and causing the S_0/S_1 fabric in lm_2 to rotate into alignment with the contact (Fig. 6C). Later erosion then led to the present structural, metamorphic, and topographic relationships (Fig. 6D).

This model relies on two hidden structural–metamorphic features: the rotational thrust fault and the existence of upper greenschist facies metamorphic mineral assemblages in lm_1. The model is only intended to represent one possible kinematic solution to the problem.

The timing of the structural discontinuity can be constrained in three ways. First, the discontinuity postdates the S_3 fabric because that fabric is realigned after rotation (Table 3). Second, the discontinuity predates the Pennsylvanian sediments that lie undisturbed across the contact to the north (Fig. 1). This second constraint requires that the discordant relationships across the lower metaclastics–quartzite contact observed in the study area continue to the north. Reconnaissance mapping to the north suggests that the structural and metamorphic relationships are the same; therefore, I consider this constraint valid. Third, the discontinuity probably predates the S_3' fabric in the Blue Springs Schist (Fig. 2 and Table 2) as follows. The S_3' crenulation cleavage in the Blue Springs Schist has no correlative counterpart in the lower metaclastics. If S_3' predates the discontinuity, then it should also appear in the lower metaclastics. However, if S_3' postdates the discontinuity, it is possible that rather than crenulating the lower metaclastics it would reactivate and tighten the S_0/S_1 fabric because the angle between the two fabrics is so small (Table 2). As seen in Table 2, S_3' in the Blue Springs Schist intersects S_0/S_1 in the lower metaclastics at an angle of less than 15°, supporting the interpretation that S_3' postdates faulting. Bell (1986) discussed the mechanisms and processes of the reactivation of earlier foliations. Alternatively, S_3 and S_3' may simply be conjugate crenulation cleavages with S_3' not developed in the lower metaclastics.

Previously, the contact between the lower metaclastics and massive quartzite has been interpreted as the contact between two separate structural terranes with different deformation histories (Reiche, 1949; Stark, 1956; Condie and Budding, 1979). These workers recognized two periods of deformation to the north of the contact and only one to the south. However, I recognized at least three periods of deformation that are completely correlatable across the contact. Grambling (1982) has also recognized at least three periods of deformation in the Blue Springs Schist, and Bauer (1983) has recognized

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TABLE 3—Comparison of correlative fabric elements after a 53° counterclockwise rotation of the fabric elements in the lower metaclastics about an axis plunging 45° to azimuth 94°. Planes are given as dip and dip azimuth. Lines are given as plunge and plunge azimuth.

Fabric element	Lower metaclastics (Before rotation)	Lower metaclastics (After rotation)	Blue Springs Schist	
modal S_0/S_1	90, 168	61, 123	modal S_0/S_1	62, 126
modal S_2	90, 149	70, 104	modal S_2	70, 105
modal S_3	80, 46	66, 188	modal S_3	66, 188
modal L_{20}	vertical	54, 165	modal L_{20}	54, 165
modal L_2	41, 59	63, 62	modal L_2	65, 60

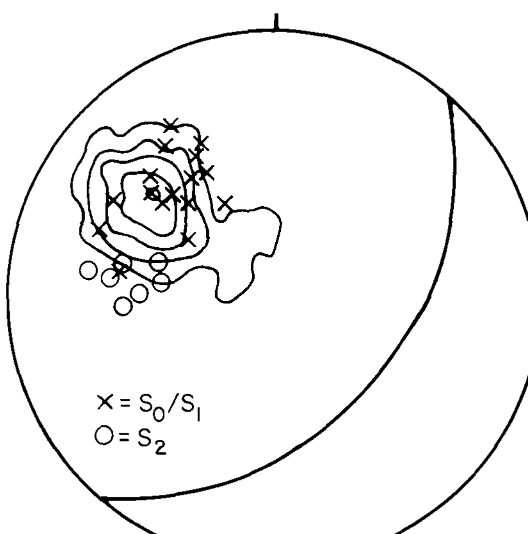

FIGURE 5—Stereogram showing 16 S_0/S_1 (X), and seven S_2 (O) data points from the lower metaclastics that were collected near the contact with the massive quartzite. They are overprinted onto the contoured S_0 stereogram for the massive quartzite; tic is true north.

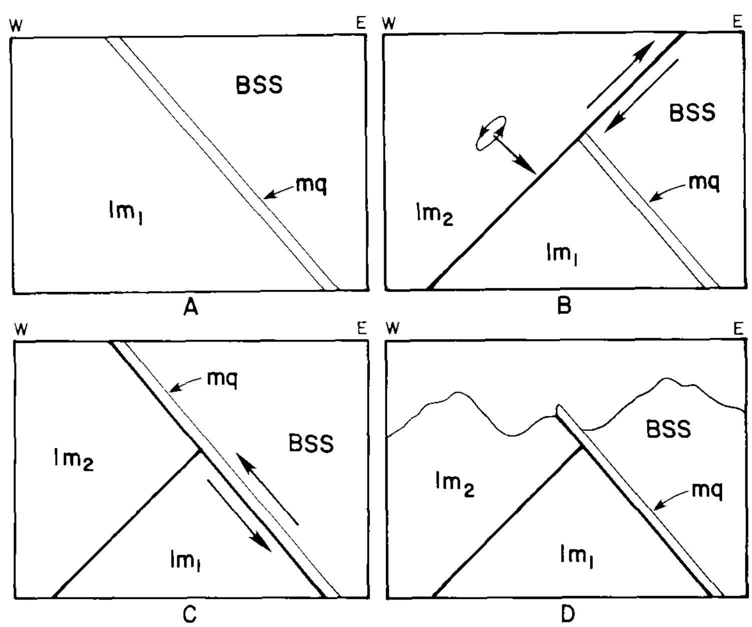

FIGURE 6—Generalized west–east cross sections through the study area (see Fig. 3 or 4 for location) showing a hypothetical sequence of events leading to the currently observed structural, metamorphic, and topographic relationships. The sequence is explained in the discussion section. **lm_1** = lower metaclastics with upper greenschist facies peak metamorphism; **lm_2** = lower metaclastics with lower amphibolite facies peak metamorphism; **BSS** = Blue Springs Schist with upper greenschist facies peak metamorphism; **mq** = massive quartzite with upper greenschist facies peak metamorphism.

at least three periods of deformation in the southern Manzano Mountains.

Conclusions

Field observations and structural and metamorphic analyses suggest that the discordance observed across the contact between the lower metaclastics and the massive quartzite in the central Manzano Mountains is a structural discontinuity rather than an angular unconformity. This conclusion is based on five observations: 1) microscopic and mesoscopic similarities between the fabric elements correlated across the contact, 2) identical crosscutting geometric relationships displayed by the fabric elements on each side of the contact, 3) evidence for movement along the contact, 4) different metamorphic histories across the contact, and 5) the fact that the correlated fabric elements across the contact can be nearly perfectly realigned by a single rotation. These observations strongly suggest a rotational thrust fault as the major cause of the discontinuity across the contact between the lower metaclastics and the massive quartzite, followed by faulting along the lower metaclastics–massive quartzite contact.

Timing of the discontinuity is uncertain, but it probably postdates the third deformation fabric (S_3) and predates the Pennsylvanian sediments that lie undisturbed across the discontinuity to the north.

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When Kirtley F. Mather died at the age of 90, in May 1978, he left a completed transcript of his latest book *The permissive universe*. This volume is a splendid last testament and final statement of Dr. Mather's belief that science and religion complement and support each other in all facets of our daily lives. The book is exceptionally well documented and is the culmination of a lifetime of observation and thought. As a pioneer in petroleum exploration, a very early and continuous member of the American Association of Petroleum Geologists, a Fellow of the U.S. Geological Society, and an active lay church leader, Professor Mather distilled his philosophy from fieldwork in many parts of the world, from 30 years of teaching at Harvard University (1924–1954), from careful testimony at the Scopes trial in 1925, and from wide-ranging lectures on the social and political condition of modern society. He was a winner of numerous gold medals, awards, and honorary degrees and, during the last seven years of his life, he was a Visiting Professor of Geology at the University of New Mexico. In the words of Stephen Jay Gould, who wrote the foreword, he "used the richness of his personal experience to inform the present and offer wise advice for the future." *The permissive universe* is available for $14.95 per copy plus $1.00 for postage and handling from: the University of New Mexico Press, Albuquerque, New Mexico, 87131. Royalties from sales go to the Department of Geology and Geography at Denison University, Dr. Mather's undergraduate alma mater.