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1985, pp. 141-145. https://doi.org/10.56577/FFC-36.141

in:

Santa Rosa, Tucumcari Region, Lucas, S. G.; Zidek, J.; [eds.], New Mexico Geological Society 36 th Annual Fall Field Conference Guidebook, 344 p. https://doi.org/10.56577/FFC-36

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STRUCTURAL RELATIONSHIPS AND MYLONITES IN PROTEROZOIC ROCKS OF THE NORTHERN PEDERNAL HILLS, CENTRAL NEW MEXICO

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INTRODUCTION

The Pedernal Hills form an isolated, Precambrian-cored, north-trending structural high about 60 km east of Albuquerque on the eastern edge of the Estancia Valley (Fig. 1). The uplift represents a deeply eroded basement high of the "Ancestral Rocky Mountains" and is the southern termination of the Sangre de Cristo uplift of Laramide age.

Proterozoic metamorphosed sedimentary, volcanic, and plutonic rocks are exposed in the gentle, rolling, sparsely vegetated hills of the Pedernal. They are unconformably overlain by flat-lying, upper Paleozoic clastic sediments. The Precambrian units in the Pedernal Hills were first mapped by Gonzales (1968). Woodward and Fitzsimmons (1967) described the iron-rich quartzites in the northern Pedernal area. Armstrong and Holcombe (1982) studied the deformation, structure and chemistry of a sequence of complexly deformed metavolcanic rocks in the central Pedernal Hills.

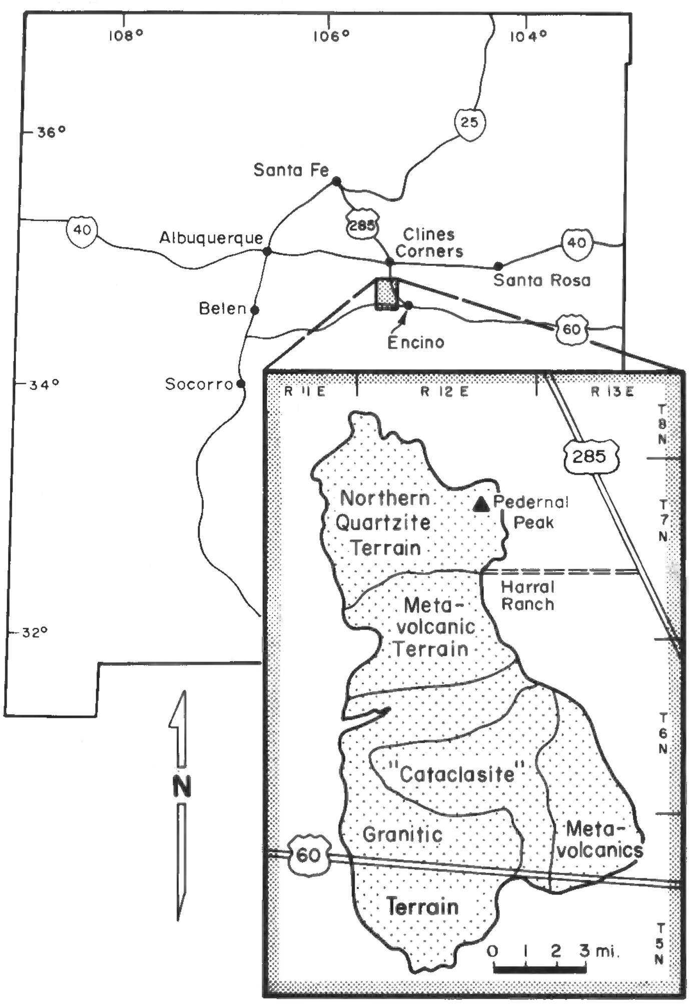

FIGURE 1. Location map and generalized geologic map (after Gonzales, 1968) showing approximate extent of Precambrian rocks in the Pedernal Hills, Torrance County, New Mexico. Northern metavolcanic terrain includes T-phase volcanics, M-2 volcanics and Crab Hill volcanics of Armstrong and Holcombe (1982). "Cataclasite" of Gonzales (1968) is highly strained quartz–biotite–feldspar schist with feldspar porphyroclasts.

Based on mineral assemblages in metavolcanic schists of the central Pedernal Hills, Armstrong and Holcombe (1982) concluded that metamorphic conditions ranged from lower to middle greenschist facies. The presence of staurolite (Gonzales, 1968) and kyanite in the quartzite of the northern Pedernal suggests that these rocks have experienced amphibolite-facies temperatures of at least 500°C and 3.75 kb. Rb/Sr ages of 1493 ± 30 m.y.B.P. and 1416 ± 100 m.y.B.P. have been reported for a metavolcanic rhyodacite and a deformed granite, respectively, from the Pedernal uplift (Armstrong and Holcombe, 1982). Armstrong and Holcombe (1982) suggested that these dates have been partially reset during metamorphism.

This report focuses on the northern part of the Pedernal uplift, which contains well exposed, massive, resistant orthoquartzites plus subordinate, less resistant mica schists. The contact between this metasedimentary terrain and the adjacent metavolcanic terrain is of particular interest. Studies of similar sedimentary–volcanic sequences elsewhere in New Mexico suggest that the contact between the metasediments and metavolcanics may not be a simple stratigraphic succession. Also of interest is the degree to which Pedernal stratigraphy and structure correlate with stratigraphy and structure of similar rocks exposed in the Manzano and Manzanita Mountains to the west, and possibly with other Proterozoic rocks in the southwestern United States.

ROCK UNITS AND TEXTURES

The Pedernal Hills can be divided into a northern metasedimentary terrain and a southern metavolcanic terrain. Structure and stratigraphy of the southern region have previously been described by Gonzales (1968) and Armstrong and Holcombe (1982), and will not be discussed in this report.

The predominant lithology of the northern Pedernal Hills is medium-grained, vitreous, resistant orthoquartzite. At its southern edge the quartzite is structurally overlain by schistose rocks. No conclusive sedimentary-facies indicators were recognized.

Quartzite

The quartzite of the northern Pedernal Hills is a white to light-gray, massive, vitreous, resistant unit with local black, hematite-rich layering. Gonzales (1968) estimated the thickness of the quarzite to be 2400 m, although he correctly suggested that this may be high, due to thickening by folding, shearing, and faulting.

Two main-fabric elements are observed in most quartzite outcrops. One is a penetrative foliation defined by micas aligned parallel to compositional layering. The second is a strong extension–lineation defined microscopically by elongate and aligned quartz grains. This lineation, rather than any foliation, is the dominant micro- and mesoscopic tectonite fabric in the quartzite. Most quartzite specimens display a mylonitic texture defined by aligned, elongate, highly strained quartz grains.

Schist

Two main schistose units are present in the southern part of the metasedimentary terrain: (1) fine-grained, greenish-gray, quartz–muscovite–chlorite schist and (2) very fine-grained, red/green/gray, well-laminated, quartzose schist. The quartzose schist appears to structurally overlie the quartz–muscovite–chlorite schist, although the two are complexly interfolded. Both units are dominated by a strong penetrative foliation, defined by aligned micas, that has been folded by numerous minor folds.

STRUCTURES

Compositional layering in the metasediments of the Pedernal Hills generally strikes east or northeast, with dips to the south or southwest. The dip of layering is extremely variable due to the presence of mesoscopic folds.

Structural fabrics within the quartzites are consistent with those of a mylonitic L-tectonite. Mesoscopically, fold hinges of small, isolated isoclinal folds and transposed, pencil-shaped rods of black hematitic layering are drawn out parallel to the well-developed extension lineation. Enveloping surfaces defining original layering are visible locally. In thin section, quartzites contain new, dynamically recrystallized, small quartz grains along the boundaries of highly strained old quartz grains which have interlocking, sutured boundaries (Fig. 2). In thin sections cut parallel to the extension lineation, quartz grains are elongated parallel to small, isolated muscovite grains. Sections cut perpendicular to the extension direction show an irregular mosaic of quartz grains without a preferred shape orientation, although the micas do define a weak foliation. Both section orientations show a good crystallographic preferred orientation of quartz grains, with the effect more pronounced in the parallel section. Such a fabric implies a deformation mechanism of intracrystalline slip in quartz during at least the final stage of deformation. Well-preserved mylonitic features, such as sutured grain boundaries, "mortar" structures and strain ribbons in quartz porphyroclasts, demonstrate the lack of post-kinematic recovery and recrystallization.

A specimen of muscovitic quartzite containing a tight fold, with its hinge subparallel to the mylonitic extension lineation, was sectioned perpendicular to the lineation. In thin section, the fold is vaguely defined by slight compositional variations and a folded-mica foliation (Fig. 3). This folded foliation indicates that a tectonite fabric existed prior to the event responsible for forming the tight fold. It is possible that the early foliation formed and then folded during a continuous deformational event (Bell and Hammond, 1984), rather than during two discrete deformations. No refolded folds were found.

Most schist outcrops show abundant, intense, disharmonic, noncylindrical, minor folding of the dominant foliation (Fig. 4) that is younger than the fold in quartzite described above. These small folds range from open to tight, with variable southwestern plunges. Especially well-preserved and pervasive in the laminated quartzose schist is a set of distinctive, fine, closely spaced extension lineations that are folded by minor folds whose hinges consistently trend at a high angle to the earlier extension lineation. These small folds are minor folds on a set of large, east-trending, overturned, tight folds that involve both the quartzite and the schist. The map-scale folds plunge gently to the west, with axial surfaces dipping steeply to the south, parallel to the contact between the volcanic and sedimentary terrains (Fig. 5). Folds of this generation are present throughout the quartzite terrain, but are considerably more open in profile. It is thought that these folds are more common and intense in the south due mainly to differences in mechanical properties and thicknesses between quartzite and schist. Weakly developed, minor crenulations locally overprint the dominant cleavage in phyllitic schists.

Quartzites are commonly laced with breccia zones on scales ranging from centimeters to 100 meters or more. Angular, internally lineated quartzite fragments ranging up to 40 cm in diameter are closely set in an undeformed, recrystallized(?) quartzite matrix (Fig. 6). These breccia zones are indicative of a more brittle phase in the deformation history, and are possibly related to the complex uplift history of the region.

The contact between the northern metasedimentary and southern metavolcanic terrains in the northern Pedernal Hills is poorly exposed. Field relations north and south of the contact suggest that the metasediments structurally underlie the metavolcanics. Armstrong and Holcombe (1982) described large-scale structures in the metavolcanic terrain to the south, with orientations identical to those recognized in this study area, suggesting that the two sequences are not distinct regions separated by a major tectonic boundary, but instead are adjacent, compositionally different, sequences which behaved differently during similar structural histories.

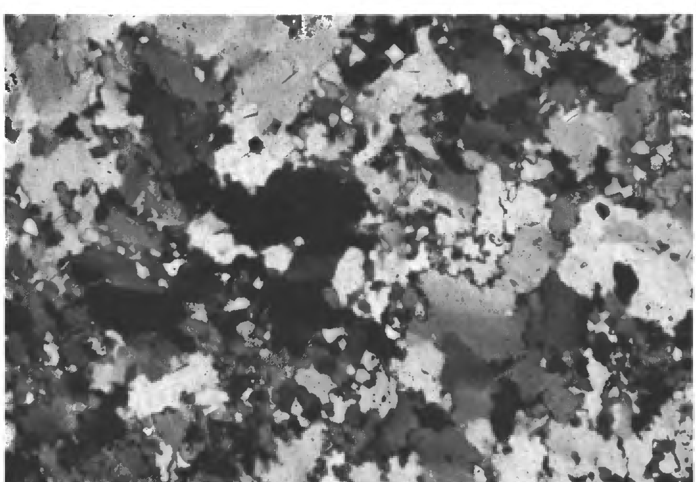

FIGURE 2. Photomicrographs of mylonitic L-tectonite quartzite from Pedernal Mountain. A, section cut parallel to the extension lineation and the foliation. Note alignment of elongate quartz grains, sutured grain boundaries, newly recrystallized fine quartz grains around large, older quartz grains and strain ribbons in quartz. Field of view is 2 mm across. B, section cut perpendicular to the extension lineation, showing very weak preferred-shape fabric of quartz grains. Field of view of 2 mm across.

DEFORMATIONAL HISTORY

Evidence for at least four fabric-forming events has been verified in the northern Pedernal Hills (Table 1). The oldest fabric recognized is a first generation (D_1) mica schistosity (S_1), observed in one thin section, folded by second generation (D_2) tight to isoclinal folds (F_2) in quartzite. The nature of this S_1 fabric and its associated deformation is unclear at present. D_1 and D_2 may be different phases of one mylonitic event. F_2 folds have an axial-plane cleavage (S_2) that is the dominant, though weak, cleavage in quartzites, and an intense extension lineation (L_2^2) that is the dominant fabric present in the quartzites. S_2 is approximately parallel to compositional layering in the northern part of the quartzite terrain. D_2 is a mylonitic event resulting in north–south extension under a constrictional-strain environment. The sense of D_2 shear has not been analyzed, but future work using crystallographic fabrics in quartz mylonites (Bouchez et al., 1983) is planned. D_3 is a folding event producing

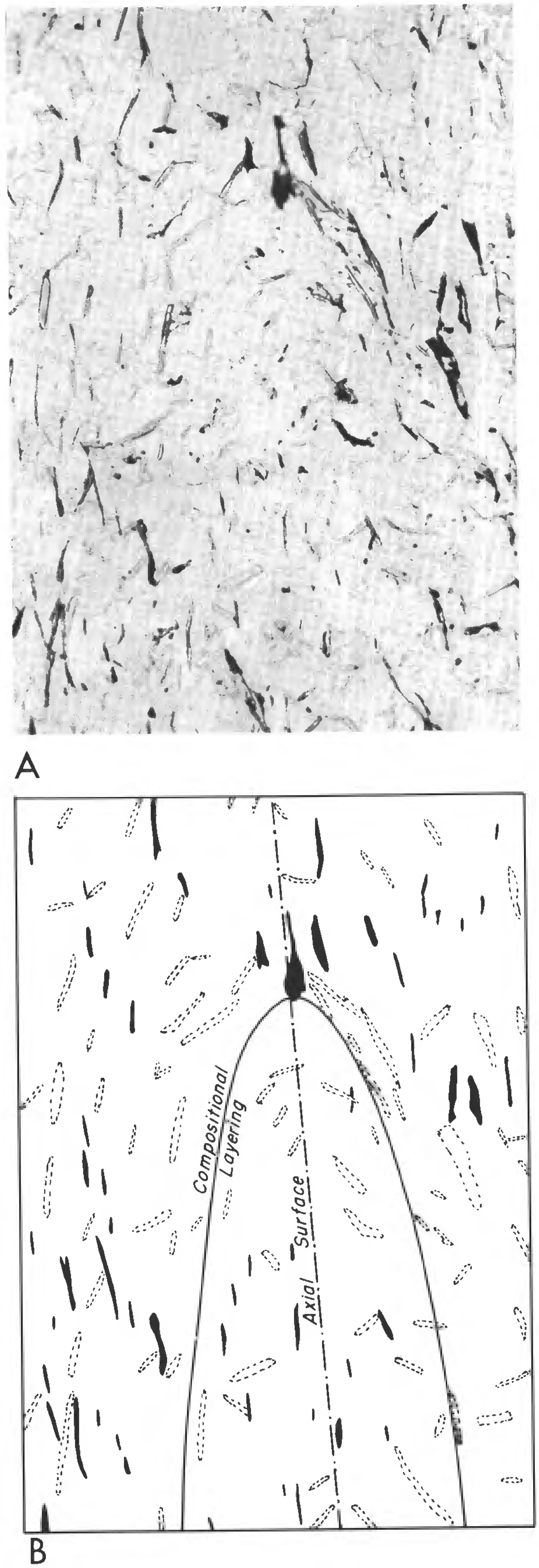

FIGURE 3. Photomicrograph and sketch of small (F_2) fold in muscovite quartzite from Pedernal Mountain area. Mica grains define both the S_2 axial surface to the fold (black micas in sketch), and the S_1 mica foliation folded by the fold (dashed micas in sketch). Field of view is 1 mm across.

FIGURE 4. Minor upright F_3 folds in phyllitic schist from the southern metasedimentary terrain.

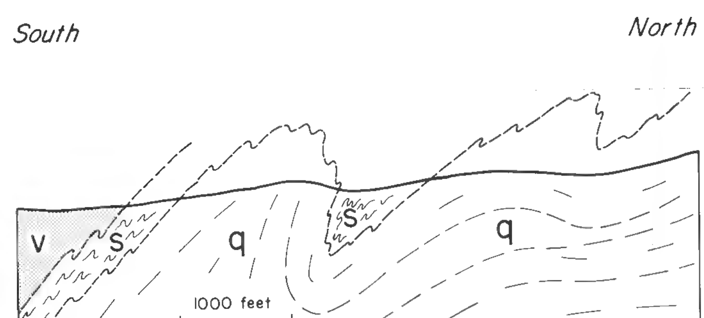

FIGURE 5. Schematic cross section of the contact region between the northern metasedimentary terrain and the southern metavolcanic terrain of the Pedernal Hills. Large F_3 folds plunge gently west. No vertical exaggeration. V = metavolcanics of the central and southern Pedernal Hills; S and Q = schist and quartzite metasediments, respectively, of the northern terrain.

FIGURE 6. Quartzite breccia from the southern metasedimentary terrain. Angular, lineated quartzite clasts of variable size are set in a medium-grained quartzite matrix. Lens cap is 5 mm across.

tight, east–west-trending, overturned folds (F_3) in schists, with yielding to the north. D_4 is a nonpenetrative, local, crenulation-forming event (F_4) with moderately north-dipping axial surfaces (S_4).The timing and nature of the D_5 breccia-zone-deformation event is unknown.

Armstrong and Holcombe (1982) suggested a similar structural history in the southern metavolcanic terrain. They noted that the most distinctive feature of that area is the increase in structural complexity from north to south. This is consistent with the fabrics recognized in the northern terrain only in the sense that D_3 and D_4 are less readily visible in the quartzites, which are increasingly dominant to the north. The structural history of the northern Pedernal Hills is apparently as complex as that of the southern metavolcanic terrain.

TABLE 1. Summary of structural events recognized in the metasedimentary terrain of the northern Pedernal Hills.

D_1:	S_1	- Slaty cleavage observed in one thin section of quartzite. Parallel to compositional layering. overprinted by F_2 folds. May represent an early stage of mylonitic event.
D_2:	S_2	- Slaty cleavage. The dominant fabric element in schists. A constrictive plus minor flattening deformation in quartzites. Sub-parallel to compositional layering.
	F_2	- Small, tight to isoclinal folds in quartzite. Accompanied by local transposition of compositional layering. Hinges are parallel to a strong extension lineation.
	L_2^2	- Strong extension lineation. The dominant fabric element in quartzites. Parallel to F_2 fold hinges in quartzites, and approximately normal to F_3 fold hinges in schists. With F_3 folds unfolded, this lineation trends about N40E with a low plunge.
D_3:	S_3	- Finely spaced crenulation cleavage dipping S to SE.
	F_3	- Open to tight, rounded folds in schists. Typically disharmonic and non-cylindrical at outcrop scale. Gently SW plunging.
	L_2^3	- Intersection lineation of S_2 and S_3, defined by a fine crenulation lineation on S_2 surfaces. Moderately W plunging.
D_4:	S_4	- Crenulation cleavage dipping steeply N.
	F_4	- Local, small crenulations in schists.
D_5:	Formation of breccia zones.	

DISCUSSION: CORRELATIONS AND CONJECTURE

The stratigraphy and structure of the metavolcanic/metasedimentary sequence of the Pedernal Hills closely resemble those of rocks exposed in the Manzano and Manzanita Mountains to the west. The phyllitic schist and the laminated quartzose schist are identical to lithologies mapped as Blue Springs Formation by Bauer (1983) in the southern Manzanos and by Grambling (1982) in the central Manzanos. Bauer (1983) found that the laminated quartzose schist lies stratigraphically above the phyllitic schist. A correlation of the Blue Springs Formation with the schists of the Pedernal Hills suggests that the stratigraphy is right-side-up in the Pedernal Hills, and therefore that the quartzite is younger than the schist. In the Manzanos, the Blue Springs Formation is underlain by the quartzites and schists of the Sais Formation (Bauer, 1983). Thus, the Pedernal quartzite may be correlative with the Sais Formation. The southern Manzano Mountains metasedimentary rocks lie structurally beneath the dominantly metavolcanic Sevilleta Formation (Bauer, 1983). The same relationship seems to hold in the Pedernal Hills. The nature of the contact between the metavolcanic and metasedimentary terrains in the Pedernal Hills is unknown, but correlative structures across the contact suggest a continuous stratigraphy. In the southern Manzano Mountains the two terrains appear to be in fault contact (Bauer, 1983), although structures in both terrains are similar in orientation and style. Proterozoic rocks in both the Manzano Moutains (Bauer, 1983; Grambling, 1982) and the Manzanita Mountains (Cavin, 1985) are multiply deformed, including an early mylonitic event followed by map-scale folding. It is conceivable that the rocks in the Manzano–Manzanita chain and the Pedernal Hills have undergone the same deformational episodes. Based on both stratigraphic and structural similarities, it is tentatively proposed that these two Proterozoic rock sections are correlative.

An unpublished U/Pb zircon date for a felsic metavolcanic rock from the Sevilleta Formation of about 1650 m.y.B.P. (S. A. Bowring, oral comm. 1985) suggests that, if the Manzano Mountain metasediments are stratigraphically as well as structurally below the Sevilleta Formation, the metasediments are older than about 1650 m.y.B.P. In the Rio Mora area (Grambling and Codding, 1982), the Picuris Range (Bauer, 1984), and the Tusas Range (Williams and Wobus, 1984) of northern New Mexico a major metasedimentary terrain (the Ortega Group) sits stratigraphically above a major felsic metavolcanic terrain (the Vadito Group). U/Pb zircon dates at the top of the Vadito Group yield ages of around 1700 m.y.B.P. (L. Silver, oral comm. 1985, referenced in Grambling and Williams, in press), and the Ortega Group metasediments thus are younger than 1700 m.y.B.P.

In summary, in northern New Mexico a quartzitic metasedimentary sequence younger than about 1700 m.y.B.P. overlies a felsic volcanic suite. In central New Mexico a quartzitic metasedimentary sequence apparently older than about 1650 m.y.B.P. underlies a second, felsic volcanic suite. The available data allow speculation that the quartzite terrain of the northern Pedernal Hills may be between 1650 and 1700 m.y.B.P. in age and may be a stratigraphic equivalent of the Ortega Quartzite. This proposition is highly speculative, but research into these problems continues.

ACKNOWLEDGMENTS

We thank J. Callender and J. Grambling for reviewing the manuscript, and R. Harral for generously permitting us access to the Pedernal Hills. Fieldwork was partially supported by the Department of Geology, University of New Mexico.

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Punta de Gallegos (photo: S. G. Lucas).