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TRANSPOSITION STRUCTURES IN PRECAMBRIAN ROCKS OF NEW MEXICO

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INTRODUCTION

Precambrian rocks in New Mexico have been the subject of geologic study for almost 100 years. Early reconnaissance work tended to draw together diverse lithologies into relatively simple stratigraphic groups, and to correlate these groups over large areas of the state, particularly in northern New Mexico. Although many workers noted the highly deformed character of Precambrian rocks in New Mexico, with a few notable exceptions (such as Bingler, 1965), little notice was taken of the stratigraphic problems inherent in complexly deformed rocks. Recent detailed structural analysis in northern New Mexico has cast doubt on some early stratigraphic correlations, mainly because certain contacts interpreted as being stratigraphic may be tectonic (Holcombe and Callender, 1982). The major types of tectonic contacts that produce pseudostratigraphic relations in complexly deformed rocks are low-angle faults and transposition layering. This brief note discusses the latter Phenomenon, which is common in many Precambrian terrains in New Mexico. Although field evidence for low-angle faults is accumulating, the presence of regional low-angle faults of Precambrian age in New Mexico is hypothetical and will be discussed only briefly here.

TRANSPOSITION

Transposition is a tectonic process by which a curviplanar or linear structural element is changed from an initial orientation to a new orientation discordant to the original. Although transposition of lineations may have regional significance in New Mexico (see Bingler, 1965), only transposition of curviplanar surfaces will be discussed here. Transposition commonly accompanies tight to isoclinal folding of interlayered sequences of varying competency and thickness (for example, thin sandstones and thick shales, thick quartzites and thin schists, and so forth). Folded sequences of this type yield disharmonic folds of varying wavelength (fig. 1). The initial curviplanar element may be stratigraphic bedding, compositional layering, foliation, or any other curviplanar feature; most commonly transposition involves bedding or an early axial-plane cleavage.

The initial orientation of folded stratigraphic layers is generally approximated by the enveloping surfaces of the folds (fig. 1). During tight to isoclinal folding, the limbs of the folded layers are brought approximately into parallel with the axial planes of the folds, whereas the axial planes are oblique or perpendicular to the enveloping surfaces (fig. 2a). As folding and shortening continue, progressive flattening and slip occur within or subparallel to the axial planes, causing attenuation of the limbs of the folds and isolation of the fold noses (fig. 2b). Ultimately a new lenticular layering develops parallel to the axial planes of the folds, and the isolated noses of the original folded layers are fragmented and dispersed, rotated into parallelism with the axial plane, or stretched into tectonic lenses (fig. 2c). The net result is a tectonic pseudostratigraphy that mimics stratigraphic bedding but is at a high angle to original layering. In addition, if the folds are asymmetric, the short limbs may be completely attenuated, yielding a pseudostratigraphy in which all layers show the same direction of younging (see Turner and Weiss, fig. 4-11, p. 94). For a more complete discussion of transposition, with many additional examples of the geometric forms developed, see Sander (1970), Knopf and Ingerson (1938), Turner and Weiss (1963), Whitten (1966), and Hobbs and others (1976).

The pseudo-bedding developed by transposition may be extremely difficult to distinguish from original stratigraphic layering. Transposition layering commonly is characterized by schistosity or cleavage parallel to stratigraphic layering, lenticular compositional bands, and local fish hooks or very tight to isoclinal fold noses (fig. 3). Without the evidence of fold closures, or good control on younging directions, transposition layering commonly resembles relatively undeformed, lenticular sedimentary sequences in which mimetic mineral growth has taken place. However, by definition, transposed pseudostratigraphy lies at a high angle to the original orientation of layering, so the presence of transposition layering can yield erroneous paleogeographic or facies interpretations.

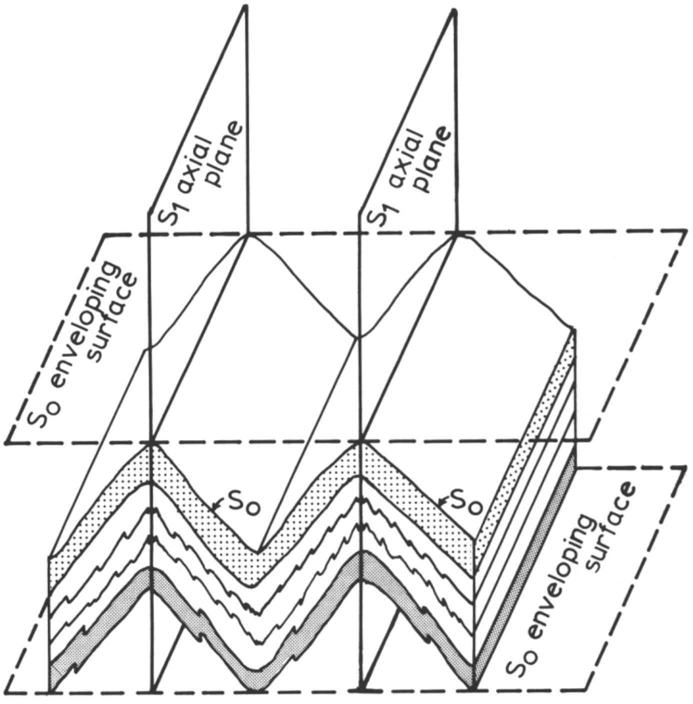

Figure 1. Symmetric, tight folds in a stratigraphic sequence containing beds (S_0) of varying thickness and competency, showing disharmonic folding, position of S_0 enveloping surface, and S_1 axial planes. The S_0 enveloping surface is a surface tangential to the hinges of the folds in a given S_0 surface.

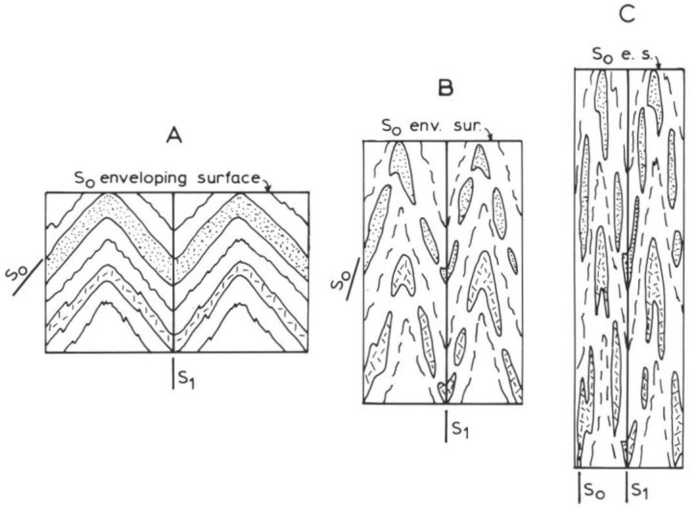

Figure 2. Progressive shortening of a stratigraphic sequence containing beds (S_0) of varying thickness and competency. Width of boxes indicates relative shortening; height, relative extension. A. Tight folding. B. Initiation of transposition, with attenuation of fold limbs and isolation of fold noses. C. Transposition layering, with lenticular tectonic pseudostratigraphy and flattened and isoclinal, rootless fold noses; note S_0 parallel to S_1. Redrawn after Willaims (1967).

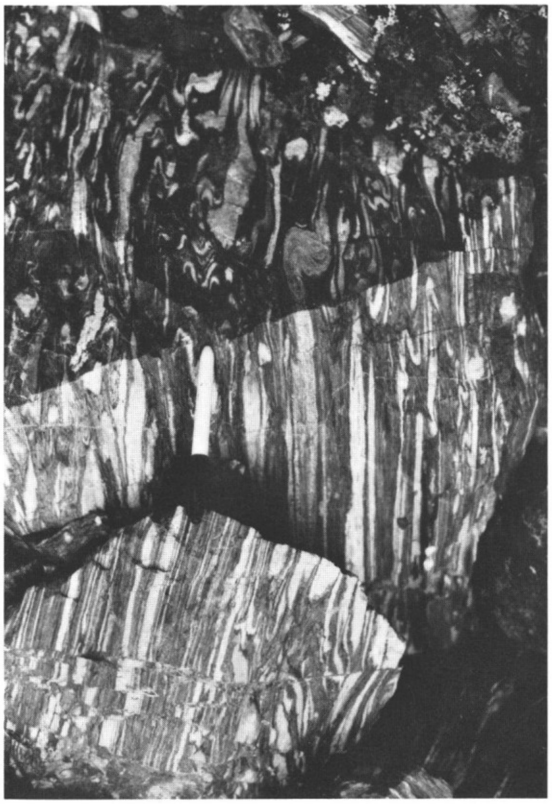

Figure 3. Transposition layering in "felsic volcanic rocks" (Condie, 1980) near Wheeler Peak. Marking pen is 130 mm long. Rock face at bottom of photograph shows typical tectonic pseudostratigraphy which characterizes transposition. Darker rock face at top of photograph is about at right angles to lower face and shows approximate profile plan of transposition layering, with abundant "fish hooks," fold noses, and discontinuous layers (compare to Figure 2).

EXAMPLES OF TRANSPOSITION IN NEW MEXICO

Numerous small-scale and local large-scale examples of transposition layering can be found in northern New Mexico. Figures 3-6 give a few illustrations at various scales. Additional examples of transposition are described and figured in Holcombe and Callender (1982), Grambling and Codding (1982), Cavin and others (1982), Connolly (1982), Bingler (1965), McCarty (1983), Bauer (1982), Grambling (1982), and Bowring and others (this guidebook). Particularly good examples of transposition layering which yields pseudobreccia or lenticular pseudostratigraphy are found in the Pedernal Highlands of central New Mexico (Armstrong and Holcombe, 1982). Similar fabrics have been observed everywhere in northern and central New Mexico where lithologic conditions are amenable (intercalated competent and incompetent layers of varying thickness) and where tight to isoclinal folding has deformed the sequence. These localities include the Tusas Mountains, Taos Range, Picuris Mountains, southeastern Sangre de Cristo Range, Santa Fe Range, Zuni Mountains, Sandia-Manzano-Los Pinos Mountains, Ladron Peak, and Magdalena Mountains. Many other locations throughout the state have similar lithologic and structural characteristics (see Fulp, 1982, Table 1), and probably also contain transposition layering.

THE S_0/S_1 PROBLEM

In the Precambrian of northern New Mexico, it is common to find lithologic layering (S_0), presumably formed by primary sedimentary or igneous processes, parallel to a pervasive early tectonite foliation (S_1), as defined by schistosity, mineral flattening planes, domainal slaty cleavage or even a spaced cleavage (Montgomery, 1953; Bingler, 1965; Holcombe and Callender, 1982; Armstrong and Holcombe, 1982; Grambling, 1982). The implications of tectonite foliation parallel to lithologic

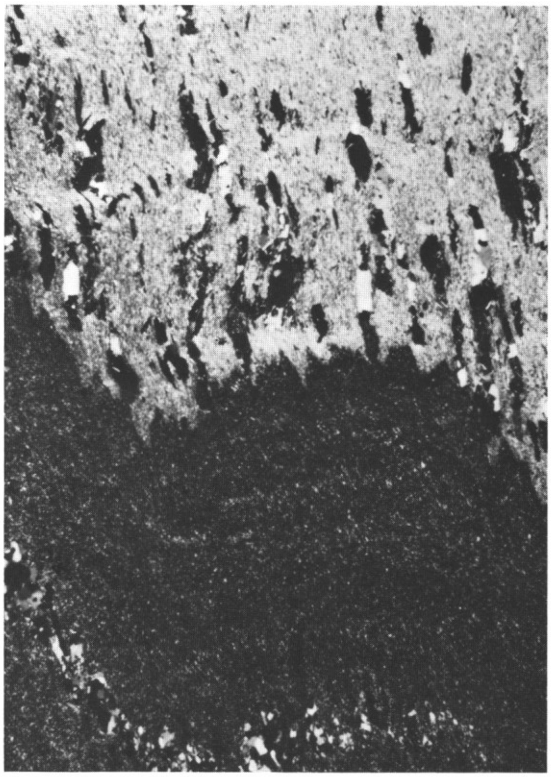

Figure 4. Microscopic transposition in Pilar Slate, Picuris Range, New Mexico. Long dimension of photograph is 16.8 mm. S_0/S_1 is marked by contact between light and dark layers in center of photograph. Fish-like bodies above S_0/S_1 in light layer are transposed quartz lenses that lie in S_2 cleavage.

layering have been the subject of debate for decades. This fabric probably formed by one of two relatively distinct processes (or a combination of both): 1) metamorphic recrystallization without penetrative deformation, mainly by mimetic recrystallization; or 2) a local to regional, tight to isoclinal folding event. The prevailing view is that the latter process is regionally most important (Hobbs and others, 1976). This is particularly true in northern New Mexico, where rootless fold noses, small-scale stratigraphic complexities and axial-plane flattening fabrics with the appropriate tectonite indicators suggest that folding has created S, parallel to So. It is fruitless to argue whether primary So and secondary, non-tectonite S, parallel each other in New Mexico; it is certainly possible locally. However, a useful working hypothesis for the Precambrian of at least northern New Mexico is that So-parallel foliation represents a regional, approximately isoclinal folding event (Bingler, 1965; Nielsen and Scott, 1979; Holcombe and Callender, 1982; Connolly, 1982; Grambling, 1982; Bauer, 1982; McCarty, 1983). Because tight to isoclinal folding is the appropriate environment for the formation of transposition layering, and also shear at small angles to axial-plane foliation (Ramsay, 1980), it might be expected that tectonically developed pseudostratigraphic layering would be the norm in those terrains where lithology permits the development of strong disharmonic folding.

SHEAR PROCESSES

Horizontal transport of lithologic units at the surface (overthurst belts) or at depth (mylonite zones) is accommodated mainly by simple-shear processes (rotational strain). On the other hand, regional shortening caused by intense flattening parallel to the axial planes of folds, which characterizes deformation in the cores of orogenic belts, is thought by many to be caused by pure shear (irrotational strain). If simple shear is superimposed on regional pure shear, a complex strain picture can develop (Ramsay, 1967, 1980). For significant strains (shortening or extension of 100 percent or more), the plane of slip may closely approximate the pure-shear flattening plane, that is, the axial plane of the folds (fig. 7), and the finite deformation path will involve both shear and flattening during progressive strain. A familiar example is the formation of thrust nappes in which the overturned limb of the recumbent, tight to isoclinal fold is attenuated and disconnected by shear approximately parallel to the axial plane of the fold. The implications of such coupled deformational environments for regional orogenesis are enormous; for recent examples, see Frost and Martin (1982), Hamilton (1982), Eaton (1982), and Ramsay (1982).

It is not clear if simple-shear processes of Precambrian age, and attendant horizontal transport, are regionally significant in New Mexico. Thrusting and nappe development have been postulated locally (Nielsen and Scott, 1979; Holcombe and Callender, 1982; Cavin and others, 1982). It is clear, however, that this type of deformation commonly accompanies intense flattening (Hobbs and others, 1976; Ramsay, 1980), and detailed work is needed to evaluate the magnitude of this process in New Mexico.

IMPLICATIONS FOR NEW MEXICO

It is probable that folding and shearing go hand-in-hand during orogenesis. In the process, original stratigraphic layers will be transposed and transported, yet the final deformed sequence may look like a simple stratigraphic section containing lensoidal competent layers (quartzites?) with consistent stratigraphic up directions, interlayered with highly deformed, stratigraphically meaningless incompetent layers (schists?, greenstone belts?) (fig. 6). Only detailed structural analysis and structural petrology can distinguish true stratigraphy from tectonic pseudostratigraphy. Most Precambrian rocks in New Mexico contain the

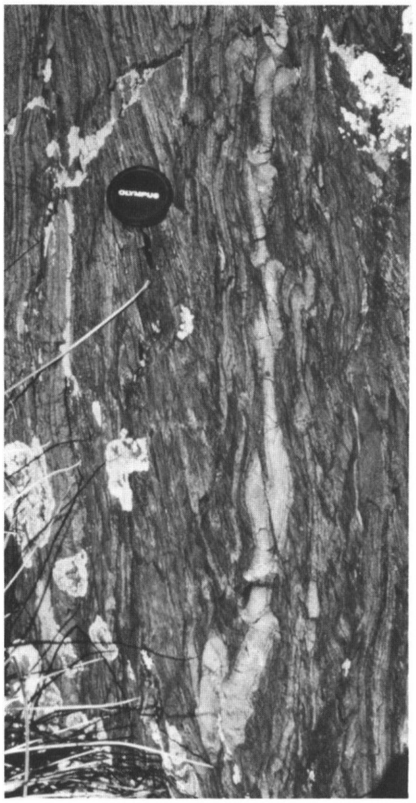

Figure 5. Incipient mesoscopic transposition in Blue Springs schist, Manzano Mountains. Lenscap is 52 mm in diameter. Light-colored, folded layer is S_0/S_1. Axial-plane schistosity (S_2) lies parallel to long axis of photograph.

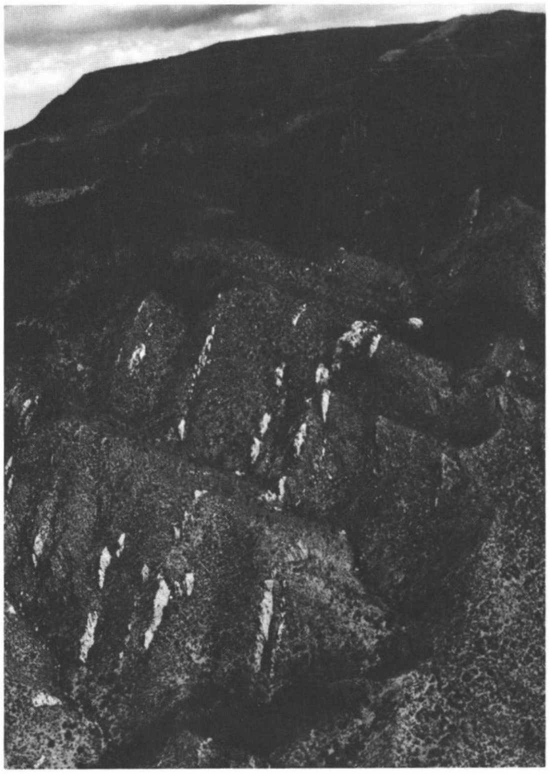

Figure 6. Map-scale transposition of light-colored quartzite layers in Manzano Mountains, near Comanche Canyon (see Myers and McKay, 1972). Bosque Peak is silhouetted on skyline. Distance between quartzite layers is about 100–500 m. Note fold closures and attenuated asymmetric fold limbs in quartzites.

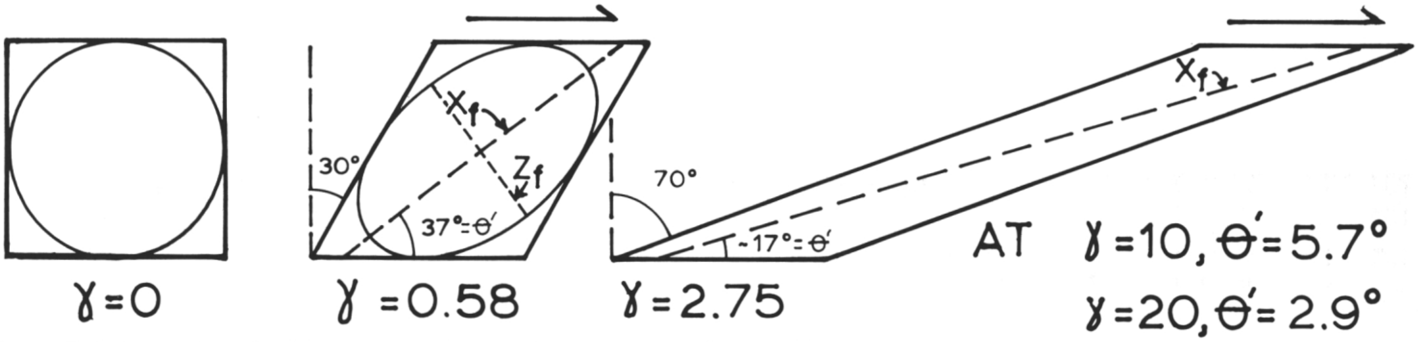

Figure 7. Relation of strain ellipse to shear in a simple-shear system. Left, undeformed state. Center, strain relations at a shear strain (γ) of 0.58 (angular shear of 30°); X_f=principal finite elongation; Z_f=principal finite shortening; θ' =angle between X_f and walls of shear zone. Right, strain relations at a shear strain of 2.75 (angular shear of 70°). Note that at high shear strains ($\gamma>10$), θ' is small; i.e., X_f is approximately parallel to shear zone walls, and Z_f (flattening) is approximately perpendicular. $\gamma=10$ corresponds to a ratio of elongation to shortening (X_f/Z_f) of about 100 (Ramsay, 1980).

appropriate lithologies to yield transposition layering, and most have a pervasive S, foliation parallel to what appears to be primary layering (S0).

CONCLUSIONS

Most Precambrian rocks in New Mexico contain a pervasive S, foliation parallel or subparallel to layering (SO, suggesting regional, early, tight to isoclinal folding. Many of the lithologic sequences probably have been transposed at least locally. The presence of large-scale shear subparallel to the axial planes of these early folds is also a possibility. It is probably premature to correlate Precambrian lithologic packages as stratigraphic units until more structural data is available, since regional tectonic pseudostratigraphic layering may exist in many of the basement terrains of New Mexico.

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