The relationship of the Proterozoic Hondo Group to older rocks, southern Picuris Mountains and adjacent areas, northern New Mexico

Christopher K. Mawer, J. A. Grambling, M. L. Williams, P. W. Bauer, and J. M. Robertson

1990, pp. 171-177. https://doi.org/10.56577/FFC-41.171

in:

Tectonic Development of the Southern Sangre de Cristo Mountains, New Mexico, Bauer, P. W.; Lucas, S. G.; Mawer, C. K.; McIntosh, W. C.; [eds.], New Mexico Geological Society 41st Annual Fall Field Conference Guidebook, 450 p. https://doi.org/10.56577/FFC-41

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

THE RELATIONSHIP OF THE PROTEROZOIC HONDO GROUP TO OLDER ROCKS, SOUTHERN PICURIS MOUNTAINS AND ADJACENT AREAS, NORTHERN NEW MEXICO

C. K. MAWER,[1] J. A. GRAMBLING,[1] M. L. WILLIAMS,[2] P. W. BAUER[3] and J. M. ROBERTSON[3]

[1]Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131;
[2]Department of Geology and Geography, University of Massachusetts, Amherst, Massachusetts 01003;
[3]New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

Abstract—At least three distinct Proterozoic rock packages are present in the southern Picuris Mountains and adjacent areas of northern New Mexico. These are: (1) an older (ca. 1765–1720 Ma) dominantly mafic metavolcanic assemblage or assemblages, examples being the Moppin, Pecos and Gold Hill Complexes, interpreted to have formed during arc-related volcanism; (2) a ca. 1700 Ma assemblage of dominantly felsic metavolcanic and metasedimentary rocks, the Vadito Group, interpreted to have formed during continental rift-related volcanism; and (3) a younger, essentially metasedimentary assemblage, the Hondo Group, a product of stable-shelf deposition. Felsic intrusive bodies cut both older assemblages but do not intrude the Hondo Group. The contact between Vadito and Hondo Groups has been investigated in detail; it is deformed strongly in most areas but appears to be depositional. The contact between the older mafic assemblage and the Vadito Group is everywhere tectonic. The Marquenas Formation, a key unit in the Precambrian stratigraphy of the southern Picuris Mountains, belongs to the upper part of the Vadito Group; it is not the stratigraphically youngest sequence in the Proterozoic rocks of northern New Mexico as Soegaard and Eriksson (1986) suggest.

INTRODUCTION

Proterozoic rocks of northern New Mexico are composed of a diverse assemblage of metavolcanic, metasedimentary and intrusive lithologies of various ages. Nearly all of these rocks have been deformed and metamorphosed, some more than once. Recently it has been recognized (Grambling et al., 1988, 1989a, b; Thompson et al., 1989) that several major tectonometamorphic breaks punctuate what was previously considered to be a more-or-less continuous Proterozoic stratigraphic sequence.

Information regarding the original character, stratigraphic succession, depositional environments and provenance of these Proterozoic rocks is sparse. Recently, Soegaard and Eriksson (1985, 1986) have reported significant new work that represents an important contribution to the Proterozoic sedimentary geology of the Hondo Group in northern New Mexico. They propose a regional stratigraphy and set of depositional environments for the entire Proterozoic succession of northern New Mexico, subdividing the supracrustal rocks into three stratigraphic units, the Vadito Group, the Ortega Group (now Hondo Group: Bauer and Williams, 1989) and the Marquenas Quartzite (now Marquenas Formation: Bauer and Williams, 1989). They interpreted the Vadito Group to be the oldest stratigraphic unit and described it as containing metamorphosed arc-related volcanic, plutonic and sedimentary rocks. Soegaard and Eriksson (1986) interpreted the Hondo Group to overlie the Vadito Group above an unconformable contact, with the unconformity marking a transition from arc volcanism to stable-shelf deposition. They further suggested that the Marquenas Formation developed by erosion of Vadito and Hondo rocks, making the Marquenas the youngest unit exposed in the Proterozoic strata of northern New Mexico.

New data support an alternative version of Soegaard and Eriksson's (1986) regional depositional and tectonic model. Bauer and Williams (1989) argue that the Marquenas Formation is located stratigraphically within the upper part of the Vadito Group. Furthermore, J. A. Grambling, M. L. Williams and C. K. Mawer (unpubl. data, 1986), Bauer (1988) and Bauer and Williams (1989) have shown that the boundary between Soegaard and Eriksson's (1986) Vadito Group and Ortega Group is generally tectonic rather than unconformable.

Because the original (primary) stratigraphic position of the Marquenas Formation and the exact nature of the present-day Vadito Group–Hondo Group contact are both critical to the development of a correct regional Proterozoic stratigraphy and tectonic history, we have reinvestigated the area near Cerro de las Marquenas in the southern Picuris Mountains where these relationships are well exposed. Based on our detailed mapping, structural analysis and sedimentologic, stratigraphic and geochemical studies carried out in the period 1976–1990, we offer the following comments and alternative interpretations to Soegaard and Eriksson's (1986) statements on: the nature of the "transition" from arc volcanism to stable-shelf sedimentation; the lateral continuity of the 1200–1500-m-thick Ortega Formation (previously Ortega Quartzite) and its overlying rocks; and the stratigraphic position of the Marquenas Formation.

A TRANSITION FROM ARC VOLCANISM TO STABLE-SHELF SEDIMENTATION?

The nature of the "transition" from arc volcanism to stable-shelf sedimentation in the Picuris Mountains, and elsewhere in northern New Mexico, is a critical piece of information in any regional tectonic synthesis. Soegaard and Eriksson (1986, pp. 56, 61) interpreted the contact between "Vadito" and Ortega (now Hondo) Groups marking this transition as a major unconformity. They suggested that juvenile arc volcanic rocks of the "Vadito" terrane were uplifted by the heat associated with syngenetic granitoid plutonism, were eroded, then cooled and subsided; and that a thick blanket of pure quartz sand (now the Ortega Formation) was deposited directly on this subsiding unconformity.

Our work indicates that the Ortega Formation was not deposited directly on arc-related rocks. Rather, the "Vadito" Group as defined by Soegaard and Eriksson (1986) actually consists of at least two compositionally and chronologically distinct volcanogenic assemblages. The earlier, dominantly mafic assemblage(s) formed during arc volcanism; the later, dominantly felsic assemblage, may have formed during a younger episode of rifting of pre-existing continental crust. The arc- and rift-related volcanogenic assemblages never lie in depositional contact. Their contact is everywhere tectonic, and given the presence of major tectonometamorphic breaks in the Proterozoic section of New Mexico (Grambling et al., 1986, 1988, 1989a, b; Grambling and Dallmeyer, 1990), it is impossible to say whether the mafic successions did, or did not, form basement to the felsic succession.

Soegaard and Eriksson chose to define the "Vadito" Group as a "heterogeneous succession of amphibolites, felsites and quartzites" with minor other metasediments. In doing so, they realized that they were combining the dominantly mafic "lower Vadito" with the dominantly felsic "upper Vadito" (Soegaard and Eriksson, 1986, p. 51). However, there are fundamental petrographic, geochemical and geochronoloigc differences between their lower and upper Vadito units—the two do not form a "succession." They formed at different times in different tectonic and depositional settings and are separated by ductile shear zones. What Soegaard and Eriksson (1986) term the "lower Vadito

Group," dominated by mafic supracrustal rocks and felsic plutons, equates to what we and others have recognized as a distinct mafic volcanic and volcaniclastic succession (or several successions), with local iron-formations, ca. 1765–1720 Ma, in which volcanic geochemistry is similar to that of modern oceanic arcs and associated back-arcs. In contrast, their "upper Vadito Group" correlates to the Vadito Group as defined by Bauer and Williams (1989), a younger (ca. 1700 Ma) succession dominated by felsic metavolcanic rocks and metasediments, with minor mafic metavolcanic rocks, in which the volcanic rocks display geochemical similarities to rocks formed in modern extensional basins or incipient rifts developed on continental crust (Figs. 1 and 2; Bowring and Condie, 1982; Reed, 1984; Silver, 1984 and oral commun. to J. A. Grambling, 1985; Wobus, 1985; Boadi, 1986; Condie, 1986; Williams et al., 1986; Grambling and Ward, 1987; Bauer, 1988; Grambling et al., 1988; Robertson and Condie, 1989; Robertson et al., in review).

The older volcanic succession is characterized by mafic to silicic, calk-alkaline volcanic-plutonic sequences such as the Moppin Complex (Tusas Range), the Pecos Complex (southern Sangre de Cristo Mountains), the Gold Hill Complex (Taos Range) and other smaller, unnamed occurrences (Fig. 1; see Bauer and Williams, 1989 for stratigraphic information; Barker, 1958; Barker and Friedman, 1974; Bingler, 1974; Robertson and Moench, 1979; Bowring and Condie, 1982; Reed, 1984; Boadi, 1986; Smith, 1986; Robertson and Condie, 1989). These apparent arc sequences make up a large part of the Proterozoic metavolcanic lithologies exposed in northern New Mexico.

In places, the ca. 1700 Ma metavolcanic-metasedimentary sequence structurally overlies the older arc sequence, but elsewhere the arc sequence structurally overlies the younger sequence (Fig. 2; Bauer, 1988; Gabelman, 1988; Grambling et al., 1988, 1989a, b). The younger sequence is regionally extensive and varies from 100 to about 2000 m in outcrop thickness. It includes the Burned Mountain Formation and associated quartz porphyries of the Tusas Mountains, the Vadito Group of the southern Picuris Mountains, the Glenwoody Formation, which underlies the Ortega Formation in the northwestern Picuris Mountains, and the metarhyolites and felsic metasediments of the eastern Rio Mora uplift (Fig. 1; see also Bauer and Williams, 1989). Geochemically similar metavolcanic rocks are also intercalated, probably tectonically, with the Ortega Formation in the Truchas Peaks and Rio Mora areas (Grambling and Ward, 1987; Grambling, in prep.).

In view of the fundamental lithologic and geochemical differences between the Vadito Group (as defined by Bauer and Williams, 1989) and the older volcanogenic sequences, as well as the tectonic nature of their contact, both should not be lumped under the term "Vadito Group." This term should be restricted to the younger, ca. 1700 Ma, felsic metavolcanic-metasedimentary sequence (Fig. 2), as recommended by Williams et al. (1986), Williams (1987) and Bauer and Williams (1989). The older, ca. 1765–1720 Ma, mafic metavolcanic-metasedimentary sequences should, for the time being, retain their local names such as Moppin Complex (Tusas range), Pecos Complex (southern Sangre de Cristo Mountains) and Gold Hill Complex (Taos Mountains). It may ultimately prove that all of these older mafic sequences are broadly cogenetic and represent a single, extended magmatic episode. However, present knowledge of their slightly different ages, slightly different lithologies and the tectonic boundaries that isolate each sequence make any such speculation risky at best.

The uppermost rocks of the Vadito Group include layers and lenses of crossbedded feldspathic quartzite roughly similar to lowermost Hondo Group rocks. In places where the Vadito-Hondo contact is relatively untectonized, as, for example, in the Tusas Mountains south of Kiowa Mountain, these uppermost Vadito crossbedded feldspathic quartzites grade upward into the micaceous basal beds of the overlying Ortega Formation. Weakly tectonized gradational contacts are exposed in other areas of the northern Tusas Mountains and in the eastern Rio Mora area (Fig. 1). These gradational contacts suggest that the Hondo and Vadito Groups were deposited conformably and represent an originally continuous stratigraphic sequence (Fig. 2). We recognize that the contact between Vadito and Hondo Groups is commonly somewhat tectonized but suggest this is due simply to the different mechanical behavior during ductile deformation of the dominant lithologies in each group, and the concentration of shearing strain at this pronounced mechanical anisotropy.

The Vadito-Hondo contact does not mark a transition from arc to stable-shelf deposition. Neither does it record the uplift and erosion of the Vadito Group section prior to Hondo Group deposition. Instead, the Vadito Group–Hondo Group contact represents a more-or-less continuous, conformable transition from an extensional (rifted?) continental margin or intra-continental setting to a slowly subsiding, stable-shelf environment. Preliminary U/Pb zircon studies (reported in Robertson et al., in review) suggest that the duration of the extensional phase was probably short.

LATERAL CONTINUITY OF THE HONDO GROUP

The basal formation of the Hondo Group is the Ortega Formation (formerly the Ortega Quartzite) which, except in its lowermost beds, averages about 98 modal percent quartz. Much of the discussion of Soegaard and Eriksson (1986, fig. 5) assumes that there are significant lateral variations in the primary stratigraphic thickness of this unit. Our work suggests otherwise. The quartzite is at least 850 m thick in the Tusas Range, where its top is not exposed; approximately 1500 m thick in the Picuris Mountains; at least 1200 m thick in the Truchas Peaks area, where its base is not exposed; and approximately 1200 m thick in its northern exposures along the Rio Mora (Fig. 1). The only place where the outcrop thickness of this quartzite is substantially less is along the southernmost portion of the Rio Mora exposures. Soegaard and Eriksson apparently interpreted this change in thickness as a primary feature developed along the southern edge of a depositional basin. We disagree. Along its southernmost exposures in the Rio Mora valley, the quartzite does thin abruptly, from 1200 m to 600 m across a map distance of 2 km, but the transition from thick to thinner quartzite coincides with the axial plane of a megascopic, isoclinal, almost-recumbent, first-generation syncline (Grambling et al., 1988).

The uncharacteristically "thin" quartzite lies in the overturned limb of this early fold (Grambling and Codding, 1982; Grambling et al., 1988) and exhibits extreme ductile strain. The strain is recorded by intensely flattened and sheared crossbedding, and by the local development of mylonitic zones. The rocks are cut by numerous ductile shear zones of thrust geometry (Grambling et al., 1988; Grambling, in prep.). We therefore interpret the abrupt southward thinning of the quartzite as a tectonic, not sedimentary, feature. It seems likely that the original southern margin of the Ortega Formation was considerably farther south: extremely thick meta-quartz arenites that may be extensions of the Ortega Formation are exposed in the Monte Largo Hills and the Pedernal uplift, 90 and 100 km southwest and south of the Rio Mora area, respectively (Fig. 1; Bauer and Williams, 1985; Grambling, 1986). Furthermore, quartzites similar to the Ortega Formation quartzites in texture, mineralogy and original sedimentary structures are common in the Manzano Mountains, over 100 km southwest of the Rio Mora area (Fig. 1). The correlation of these thick meta-quartz arenites to the Ortega Formation must remain tentative until their depositional ages are more closely constrained.

The Ortega Formation is overlain by a metapelite-dominated section: interbedded schists and thin quartzites of the Rinconada Formation, graphitic black phyllites of the Pilar Formation and various schists and calc-silicate rocks of the Piedra Lumbre Formation. This pelite-dominated section is remarkably similar wherever it is exposed, principally in the Picuris Mountains, Truchas Peaks area and along the Rio Mora (Fig. 1). Soegaard and Eriksson (1986, fig. 5) present the impression that this metapelitic section thins and becomes less complex from south to north. We have seen no supporting evidence for this. Our regional mapping reveals no large-scale lateral facies changes within these areas.

Thus, in summary, the Ortega and Rinconada Formations form a continuous stratigraphic succession in which the Rinconada Formation conformably overlies the Ortega Formation. Where not highly tectonized, over most of northern (and perhaps central) New Mexico these formations maintain a remarkably uniform stratigraphic thickness and

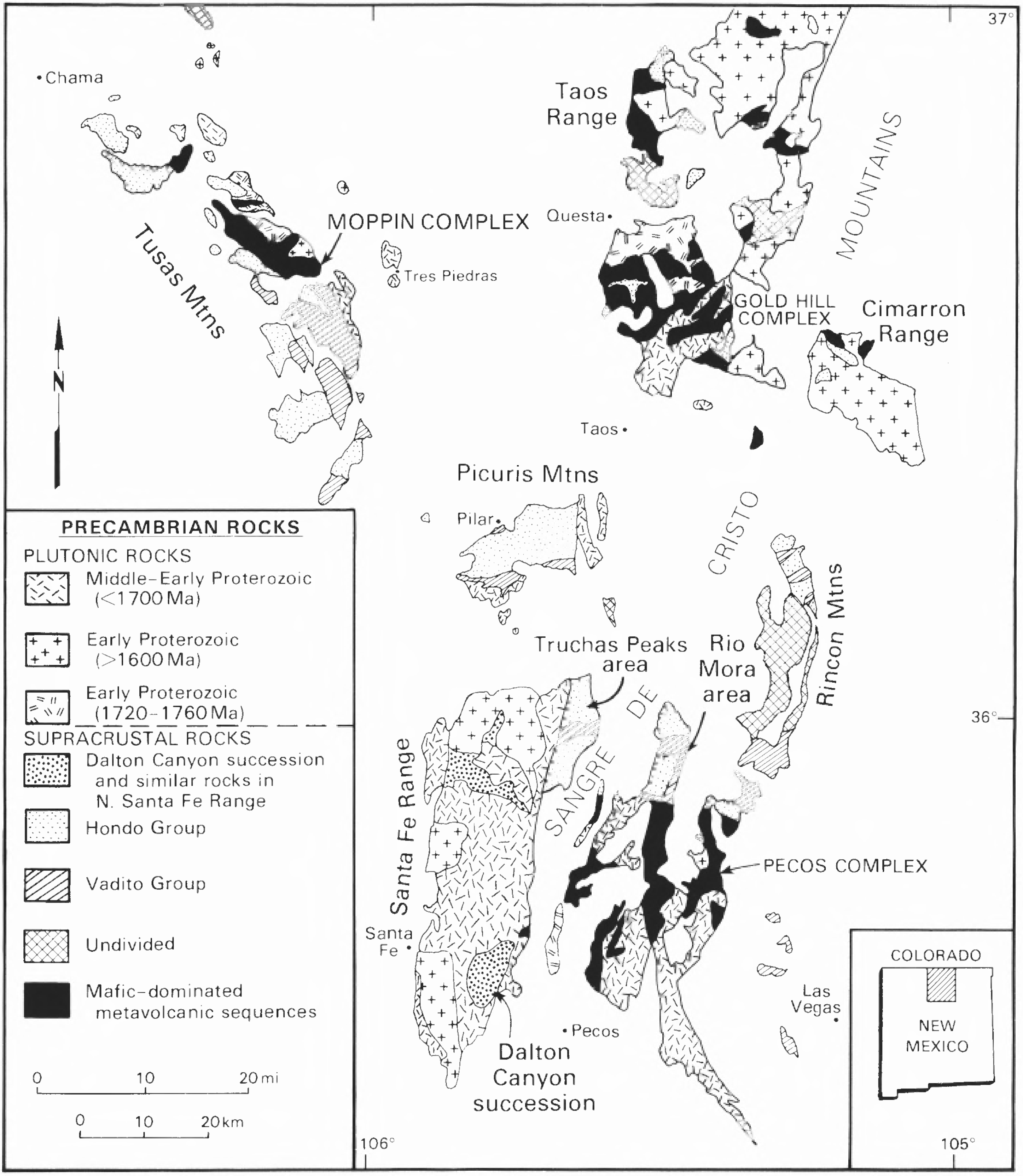

FIGURE 1. Location map showing outcrops of Precambrian metamorphic rocks discussed in text. Modified in part from Bauer and Williams (1989).

character. If major lateral facies changes do occur in this succession, then they occur on a scale much larger than northern New Mexico.

STRATIGRAPHIC POSITION OF THE MARQUENAS FORMATION

The primary stratigraphic position of the Marquenas Formation in the southern Picuris Mountains (Figs. 2 and 3) is critical to an accurate tectonic reconstruction of this region. The formation consists of approximately equal proportions of quartzite and metaconglomerate, and is about 500 m thick at Cerro de las Marquenas (Fig. 3). Soegaard and Eriksson (1986) suggest that the Marquenas Formation occupies the core of an isoclinal syncline with both Vadito and Hondo Groups stratigraphically beneath it, and is therefore the youngest unit in the Picuris Mountains. They based this interpretation on indirect evidence, principally the occurrence of two similar-appearing but reversely graded conglomerate sequences. We disagree with two of Soegaard and Eriksson's (1986) interpretations: that the Marquenas Formation is isoclinally folded, and that the Marquenas Formation is the youngest exposed unit in the Precambrian of northern New Mexico. The following discussion is based on detailed observations of the Marquenas Formation type section near Cerro de las Marquenas in the southwestern Picuris Mountains, in outcrops along strike to the east, in the Tusas Mountains and in the Rio Mora–Pecos area (Fig. 1).

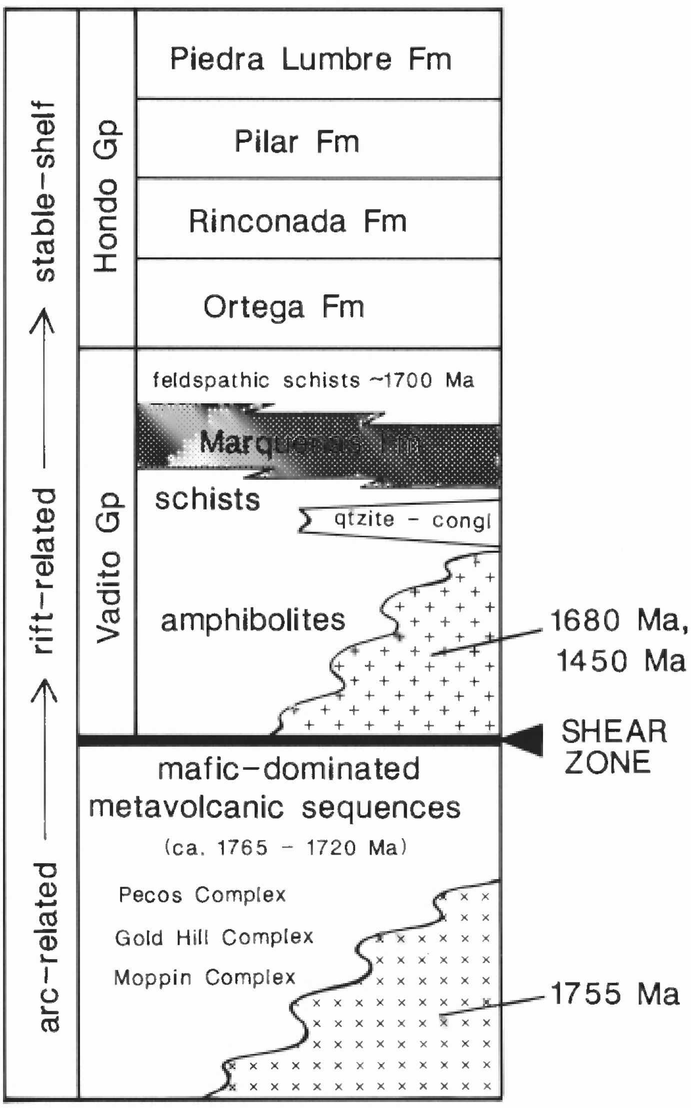

FIGURE 2. Generalized stratigraphic column for the Proterozoic rocks of northern New Mexico, indicating their interpreted depositional environments. The Marquenas Formation of the southern Picuris Mountains is stippled.

The southern half of the Marquenas Formation is well crossbedded, with crossbeds consistently younging north (see also Soegaard and Eriksson, 1986). We have found well-preserved, unambiguous, north-younging crossbeds across the entire formation at Cerro de las Marquenas, to within several meters of its tectonic contact with the Hondo Group (Fig. 4). Holcombe and Callender (1982, fig. 2) reported similar findings. It seems certain that the entire formation youngs north and lacks major internal folding, contrary to the suggestion of Soegaard and Eriksson (1986).

Conglomerates of the Marquenas Formation contain many quartzite clasts. Could these have been derived from erosion of Hondo Group rocks, and thus could the Marquenas Formation be stratigraphically younger than the Hondo Group? Such was the interpretation of Soegaard and Eriksson (1986). Clasts in the thickest conglomerate layers include well-rounded, slightly flattened cobbles and boulders of quartzite, up to 1 m across, intermixed with smaller clasts of felsic volcanic rock and quartz-mica schist. Based on a count of 600 clasts in outcrops of the basal conglomerate of the Marquenas Formation along N.M. Highway 75, 54% are metasedimentary quartzite, 40% are silicic metavolcanic rocks or quartz-muscovite schists and 6% are white vein quartz. Vein quartz and quartzite clasts are only slightly flattened, whereas fine-grained felsic and schistose clasts have aspect ratios averaging 11.6 to 5.4 to 1 (Fig. 5) and could easily be misidentified as matrix to the conglomerate. We suspect this may have led to the incorrect impression that over 90% of the clasts in these conglomerate exposures are gray quartzite (Soegaard and Eriksson, 1986). Several thin zones of conglomerate about 150 m higher in the section average 51% metasedimentary quartzite, 40% felsic schist and 9% vein quartz, based on a count of 170 cobbles. The northernmost zone of quartzite within the Marquenas Formation, about 50 m thick, has clasts conspicuously smaller than those in the southern conglomerate, with a maximum clast length of about 10 cm. These consist of 66% metasedimentary quartzite, 34% felsic metavolcanic rocks and schists and a few clasts of vein quartz, based on a count of 370 cobbles. Thus, cobbles in the Marquenas Formation conglomerates average only 50–65% metasedimentary quartzite.

If the clasts were derived from erosion of the Hondo Group, one would expect to see a large proportion of clasts similar to the Ortega Formation. That formation is a dominantly coarse-grained, completely annealed, pure quartzite and thus largely impervious to chemical weathering; clasts derived from it ought to be resistant to size reduction by abrasion. We have observed no Marquenas clasts that have dispersed aluminum silicates (or their sedimentary precursors), although aluminous quartzite forms the dominant rock type in the Ortega Formation. We have seen no clasts that contain the manganiferous andalusite viridine (or its sedimentary precursors), although this mineral is common in the uppermost Vadito and lowermost Hondo beds (Grambling and Williams, 1985). Although quartzites of the Ortega Formation and quartzites in the overlying Rinconada Formation are pervasively crossbedded, clasts of crossbedded quartzite are exceedingly rare in conglomerates of the Marquenas Formation. Counts of over 100 cobbles revealed less than 1% with internal crossbeds. It seems difficult to argue that clasts with aluminum silicate, manganiferous andalusite (or their sedimentary precursors) or crossbeds were preferentially destroyed during transport; in fact, the excellent preservation of schistose cobbles (deposited as shale cobbles?) in the Marquenas conglomerates indicates that more competent aluminous or crossbedded quartzite (sandstone?) clasts should not have been selectively destroyed.

Soegaard and Eriksson (1986) describe extremely rare "exotic pebbles" in the Marquenas conglomerates, including calc-silicate rock, black quartzite and garnet-biotite pelitic schist, and correlate these to specific units in the Hondo Group. Similar rock types do indeed exist in the Hondo Group, but they also exist in Vadito Group rocks south (and, we believe, conformably beneath) the Marquenas Formation. Calc-silicate beds exposed in the Vadito section immediately south of Cerro de las Marquenas are mineralogically identical to the Marquenas pebbles described by Soegaard and Eriksson. Beds of black quartzite are found sparsely throughout the Vadito section; some seem to have

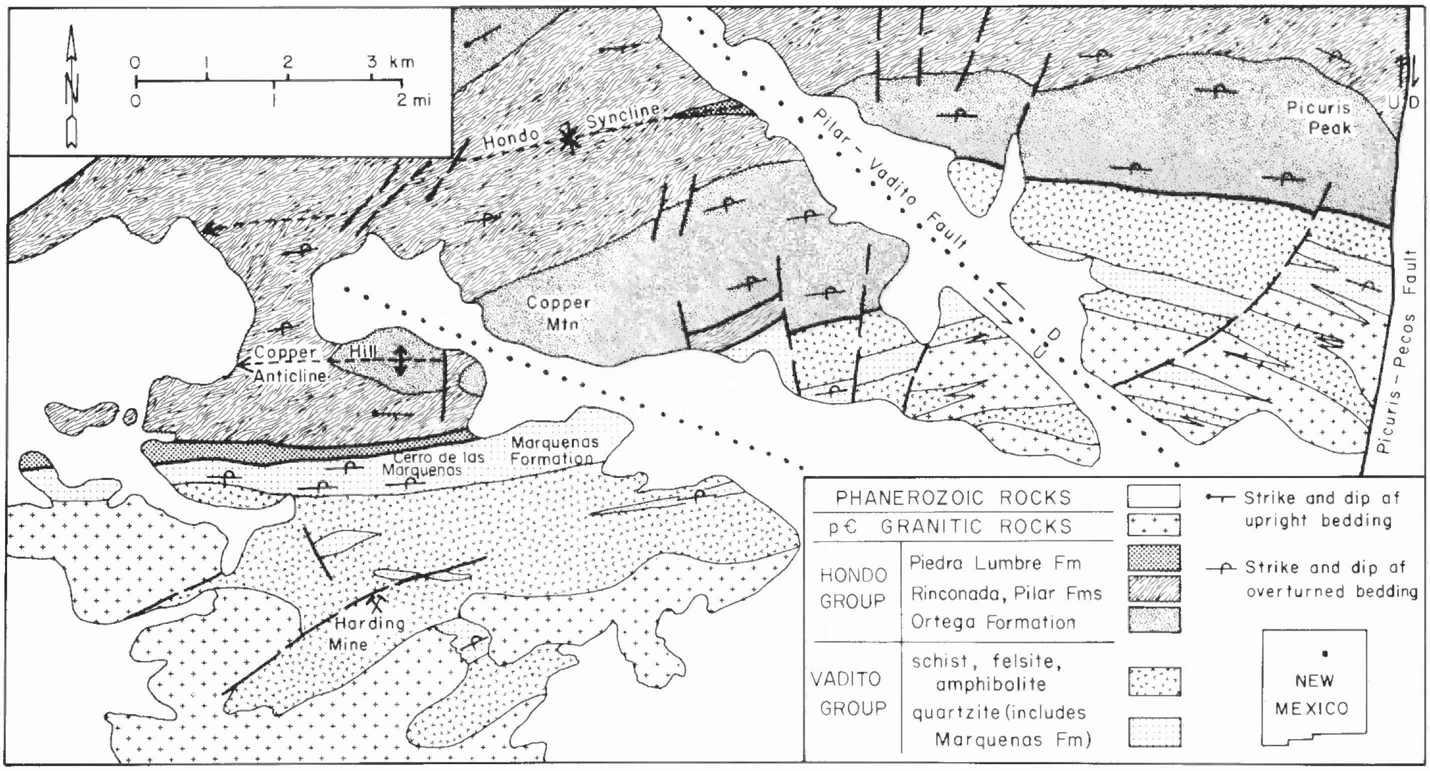

FIGURE 3. Generalized geologic map of the southern Picuris Mountains, New Mexico. Modified from Bauer (1988).

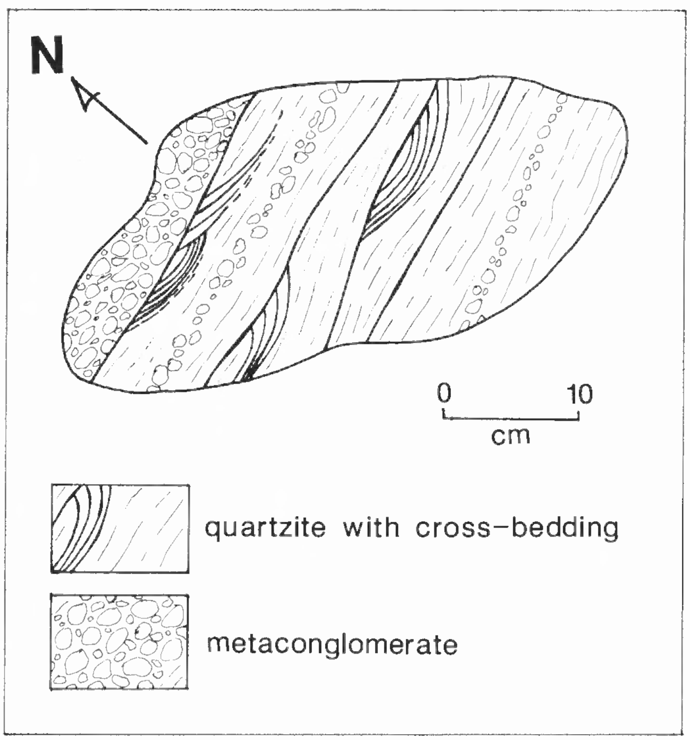

FIGURE 4. Field-outcrop sketch of north-younging trough crossbedding in the upper part of the Marquenas Formation, Cerro de las Marquenas, some 10 m south of its tectonic contact with the Hondo Group. Strata dip steeply southwards, view looks roughly east.

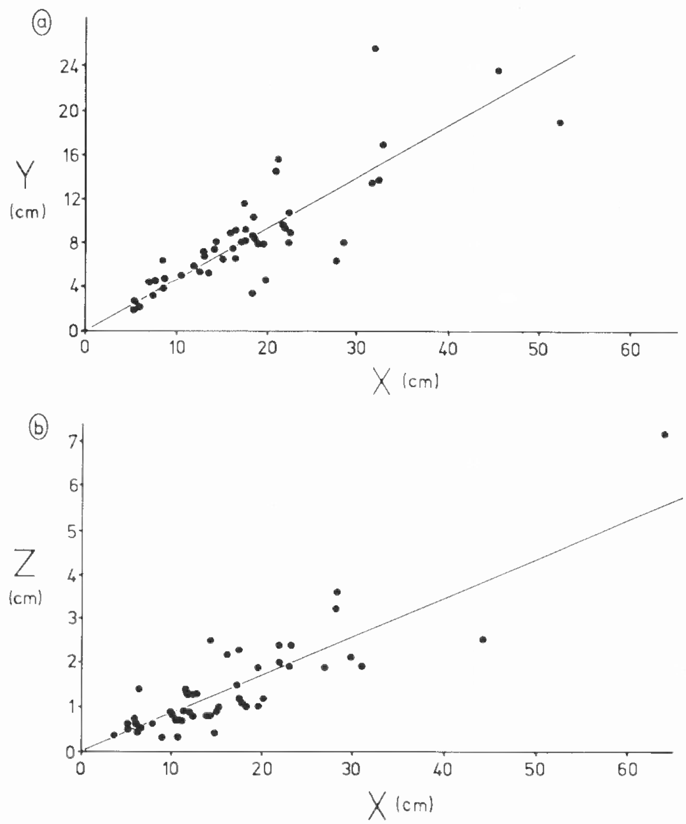

FIGURE 5. Axial ratios of deformed schistose cobbles in conglomerate of the Marquenas Formation, in outcrops along N.M. Highway 75. (a) longest dimension (X) vs. intermediate dimension (Y) for 50 schistose pebbles, measured on foliation surface. (b) longest dimension (X) vs. shortest dimension (Z) for 50 schistose pebbles, measured on joint faces perpendicular to foliation and parallel to extension lineation.

been chemical precipitates, whereas others are crossbedded and clearly derived from a detrital protolith. Pelitic schists containing garnet and biotite are common in Vadito exposures south of Cerro de las Marquenas. In our detailed clast-counting studies, we found several pebbles of fine-grained, foliated black metamorphic rock that resemble phyllites of the Pilar Formation (Hondo Group). Thin-section observation, however, showed these to have a mineralogy totally unlike the graphite-quartz-muscovite-oxide-sulfide mineralogy that characterizes the Pilar Formation. Instead, they consist of fine-grained intergrowths of tourmaline, muscovite, quartz and garnet. Thus, there is no compelling evidence to support the suggestion that some Marquenas Formation clasts were derived from the Hondo Group, and ample evidence to indicate the contrary.

The character of the contact between the Marquenas Formation and rocks clearly part of the Vadito Group is a critical piece of evidence. This contact has been interpreted as a fault (Soegaard and Eriksson, 1986, fig. 8). No such fault is exposed, but one may argue that it lies hidden south of Cerro de las Marquenas (Fig. 3) under a strip of roadfill about 50 m wide. Vadito Group rocks south of the roadfill contain thin beds of feldspathic schist, amphibolite, calc-silicate rock and rare marble. Outcrops north of the roadfill are dominated by conglomerates of the lower Marquenas Formation. However, isolated patches of weakly deformed calc-silicate rock, texturally and mineralogically similar to Vadito Group calc-silicates, cling to the southern edge of the conglomerate outcrops, and neither calc-silicate rock nor conglomerate along this contact are sheared. Both of these points suggest that there is no fault in the roadfill-covered interval. Furthermore, the Vadito Group section south of the Vadito-Marquenas contact includes quartzites (Figs. 2 and 3) that are lithologically similar to the Marquenas and, as does the Marquenas, contain north-younging crossbeds. These data indicate that the southern contact of the Marquenas Formation is not faulted, but is depositional, and that the Marquenas Formation is a conglomeratic quartzite in the upper part of the Vadito Group.

The northern contact of the Marquenas Formation is marked by a major, layer-parallel, ductile shear zone near Cerro de las Marquenas where the Hondo Group lies structurally beneath this inverted Marquenas sequence (Fig. 3; see also Holcombe and Callender, 1982; Bauer, 1988). The Marquenas Formation can be traced eastward along strike from Cerro de las Marquenas into the southeastern Picuris Range, where this major shear zone has climbed up-section beyond the top of the Marquenas Formation into a stratigraphically overlying section of Vadito Group feldspathic schists (Fig. 2; Bauer, 1988). This shear zone continues to form the boundary between Vadito Group and Hondo Group. In the southeastern Picuris Mountains, impure quartzite and associated conglomerate of the Marquenas Formation are interstratified with metavolcanic and metasedimentary beds that are identical to the Vadito Group rocks south of Cerro de las Marquenas (Bauer, 1988). Conglomerate beds are lenticular, discontinuous along strike and probably represent local channel deposits, consistent with the previous interpretations of Soegaard and Eriksson (1986) that the Marquenas Formation was deposited on a shallow alluvial plain. The Ortega Formation structurally overlies the Marquenas Formation in the eastern Picuris Mountains, though a thin interval of Vadito Group schists separates them. Here, crossbeds within the Marquenas Formation also consistently young northward, as do unambiguous sedimentary younging indicators in the overlying Ortega Formation. These relationships again indicate that the Marquenas Formation is older than the Ortega Formation, lies stratigraphically within the Vadito Group and was therefore not derived from cannibalization of Hondo Group lithologies.

The southern Picuris Mountains is but one of several areas where conglomerates with quartzite cobbles occur at or near the contact between Vadito and Hondo Groups. In the Tusas Mountains, the Big Rock Formation (Bauer and Williams, 1989), a distinctive, dominantly conglomeratic marker unit within the upper Vadito Group (Williams, 1987), contains abundant clasts of gray quartzite together with clasts of black quartzite, pelitic schist and calc-silicate rock. In both the southern and eastern Picuris Mountains, conglomerate layers with gray quartzite clasts occur sparsely in the lower 20 m of the Ortega Formation. Conglomerates with quartzite cobbles are found in discontinuous lenses along the Vadito-Hondo contact near the Rio Mora. Thus, quartzite-cobble conglomerates seem to be characteristic of the stratigraphic zone of transition from the Vadito Group to the Hondo Group. We suspect that all these conglomerates which are similar to the Marquenas Formation represent channel deposits developed in the upper part of the sedimentary-volcanic Vadito Group.

The provenance of the quartzite clasts in these conglomerates remains an important issue. We suspect that they were derived from an older crustal province, now removed tectonically (cf. Grambling et al., 1988, 1989a, b), and that they may have been metamorphosed prior to their accumulation in the sands of the Marquenas Formation. However, some well-rounded clasts in the Marquenas Formation are up to 1 m in diameter. The large size of these clasts has been used by Soegaard and Eriksson (1986) as evidence that their source terrane was not far away. This may have been true, at least for the interval during which the Marquenas Formation was deposited. As shown by Grambling et al. (1988, 1989a, b), however, major lateral transport of large crustal blocks occurred in central and northern New Mexico during Proterozoic time, and it cannot be assumed that presently adjacent lithological packages were adjacent, or even relatively proximal, during the time of deposition.

The sediment transport direction in the Marquenas Formation is also puzzling. Soegaard and Eriksson (1986) interpret crossbed data in the type Marquenas section to indicate northward transport, opposite to the southward transport direction they infer for Hondo Group rocks. Are these opposing transport directions real, or have they been tectonically modified? In either case, what is their tectonic significance? Could there have been an older quartzite south of the Picuris Mountains, which has been tectonically removed? If so, is it now exposed elsewhere in New Mexico? Or could there have been local, rift-related, topographic highs proximally south of the Marquenas depocenter? A plausible solution to this apparent dilemma could be that the Marquenas Formation represents rift-basin fill, while the Ortega Formation was deposited on a tidal- or wave-dominated, drift-stage shallow shelf in an epicontinental sea (G. A. Smith, written commun., 1990). The fluvial Marquenas sands and gravels would be transported seaward, while the Ortega shelf sediments could have been transported shoreward, thus explaining their opposing paleocurrent directions. Clearly, additional work is needed to resolve the questions posed above.

CONCLUSIONS

The basal Hondo Group unit, the Ortega Formation, composed dominantly of pure quartzite, may be interpreted to represent sedimentation on a tectonically quiet, but slowly subsiding, stable platform marginal to open water. The quartzite-dominated sequence shows minimal lateral variations in thickness and lithological character, at least across the area of Figure 1. This remarkable areal exposure of pure quartzite places major constraints on any tectonic model developed for Proterozoic tectonism of the region. The Ortega Formation did not develop on a cooling, subsiding volcanic arc. Instead, the arc-related volcanic rocks are in tectonic contact with all younger lithologies. A period of continental crustal extension immediately preceded quartzite deposition. The duration of this extensional phase is unknown, but was probably short.

The quartzites and conglomerates of the Marquenas Formation do not appear to have been derived from erosion and redeposition of Hondo Group rocks. This conclusion is based on clast population analysis, including consideration of the clasts' internal textural and mineralogical characteristics. Based on structural, sedimentologic and stratigraphic analysis, the Marquenas Formation is older than the Hondo Group, falling stratigraphically within the upper Vadito Group. The Marquenas Formation is probably related to the crustal extensional event that immediately preceded deposition of the massive quartzite of the Ortega Formation, the lowermost unit of the Hondo Group.

ACKNOWLEDGMENTS

Research into the structural geology and stratigraphy of Proterozoic rocks in northern New Mexico has been supported by the New Mexico

Bureau of Mines and Mineral Resources, the National Science Foundation (Grants EAR-8406572 to J.A.G. and T. H. Bell, and EAR-8816402 to J.A.G. and C.K.M.), Sandia National Laboratories (SURP Grant 86-5629, Task 7, to C.K.M.) and Anaconda Minerals, Inc. We thank Gary Smith (UNM) and Bill McIntosh (NMBMMR) for their careful reviews, and Steve Hayden (UNM) and C. J. Northrup (U. of Arizona) for their comments. M.L.W. and S. J. Seaman (Colgate University) are currently carrying out mapping, and major and trace element geochemical studies, on Vadito Group rocks in northern New Mexico to better define their tectonic setting and petrogenetic distinctions from the older mafic successions.

REFERENCES

Barker, F., 1958, Precambrian and Tertiary geology of the Las Tablas Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 45, 105 pp.

Barker, F. and Friedman, I., 1974, Precambrian metavolcanic rocks of the Tusas Mountains, New Mexico: major elements and oxygen isotopes: New Mexico Geological Society, Guidebook 25, pp. 115–117.

Bauer, P. W., 1988, Precambrian geology of the Picuris Range, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 325, 259 pp.

Bauer, P. W. and Williams, M. L., 1985, Structural relationships and mylonites in Proterozoic rocks of the northern Pedernal Hills, central New Mexico: New Mexico Geological Society, Guidebook 36, pp. 141–145.

Bauer, P. W. and Williams, M. L., 1989, Stratigraphic nomenclature of Proterozoic rocks, northern New Mexico—revisions, redefinitions, and formalization: New Mexico Geology, v. 11, pp. 45–52.

Bingler, E. C., 1974, Precambrian rocks of the Tusas Mountains: New Mexico Geological Society, Guidebook 25, pp. 109–113.

Boadi, I. O., 1986, Gold mineralization and Precambrian geology of the Hopewell area, Rio Arriba County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 111 pp.

Bowring, S. A. and Condie, K. C., 1982, U-Pb zircon ages from central and northern New Mexico: Geological Society of America, Abstracts with Programs, v. 14, p. 304.

Condie, K. C., 1986, Geochemistry and tectonic setting of Early Proterozoic supracrustal rocks in the southwestern United States: Journal of Geology, v. 94, pp. 845–864.

Gabelman, J. L., 1988, Precambrian geology of the upper Brazos Box area, Rio Arriba County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 171 pp.

Grambling, J. A., 1986, Crustal thickening during Proterozoic metamorphism and deformation in New Mexico: Geology, v. 14, pp. 149–152.

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

Grambling, J. A. and Dallmeyer, R. D., 1990, Proterozoic tectonic evolution of the Cimarron Mountains, north-central New Mexico: New Mexico Geological Society, Guidebook 41.

Grambling, J. A., Smith, R. F. and Bowring, S. A., 1986, A structural-metamorphic discontinuity in the central Taos Range, New Mexico: preliminary data: Geological Society of America, Abstracts with Programs, v. 18, p. 357.

Grambling, J. A. and Ward, D. B., 1987, Thrusting of the Pecos greenstone belt over younger supracrustal rocks, Rio Mora area, New Mexico: Geological Society of America, Abstracts with Programs, v. 19, p. 278.

Grambling, J. A. and Williams, M. L., 1985, The effects of Fe^{3+} and Mn^{3+} on aluminum silicate phase relations in north-central New Mexico, U.S.A.: Journal of Petrology, v. 26, pp. 324–354.

Grambling, J. A., Williams, M. L. and Mawer, C. K., 1988, Proterozoic tectonic assembly of New Mexico: Geology, v. 16, pp. 724–727.

Grambling, J. A., Williams, M. L., Mawer, C. K. and Smith, R. F., 1989, Metamorphic evolution of Proterozoic rocks in New Mexico; *in* Daly, J. S., Cliff, R. A. and Yardley, B. W. D., eds., Evolution of metamorphic belts: Geological Society of London, Special Publication 43, pp. 461–467.

Grambling, J. A., Williams, M. L., Smith, R. F. and Mawer, C. K., 1989, The role of crustal extension in the Metamorphism of Proterozoic rocks in northern New Mexico; *in* Grambling, J. A. and Tewksbury, B. J., eds., Proterozoic geology of the Southern Rocky Mountains: Geological Society of America, Special Paper 235, pp. 87–110.

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, pp. 138–149.

Reed, J. C., Jr., 1984, Proterozoic rocks of the Taos Range, Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society, Guidebook 35, pp. 179–185.

Robertson, J. M. and Condie, K. C., 1989, Geology and geochemistry of Early Proterozoic volcanic and subvolcanic rocks of the Pecos greenstone belt, Sangre de Cristo Mountains, New Mexico; *in* Grambling, J. A. and Tewksbury, B. J., eds., Proterozoic geology of the Southern Rocky Mountains: Geological Society of America, Special Paper 235, pp. 119–146.

Robertson, J. M. and Moench, R. H., 1979, The Pecos greenstone belt: a Proterozoic volcano-sedimentary sequence in the southern Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society, Guidebook 30, pp. 165–174.

Robertson, J. M., Grambling, J. A., Mawer, C. K., Bowring, S. A., Williams, M. L., Bauer, P. W. and Silver, L. T., in review, Precambrian geology of New Mexico; *in* Reed, J. C., Jr., Bickford, M. E., Houston, R. S., Link, P. K., Rankin, D. W., Sims, P. K. and Van Schmus, W. R., eds., Precambrian-conterminous U.S.: Decade of North American Geology, Volume C-2.

Silver, L. T., 1984, Observations on the Precambrian evolution of northern New Mexico and adjacent regions: Geological Society of America, Abstracts with Programs, v. 37, p. 256.

Smith, S. S., 1986, Precambrian geology of the Jawbone Mountain area, Rio Arriba County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 99 pp.

Soegaard, K. and Eriksson, K. A., 1985, Evidence of tide, storm, and wave interaction on a Precambrian siliciclastic shelf: the 1,700 m.y. Ortega Group, New Mexico: Journal of Sedimentary Petrology, v. 55, pp. 672–684.

Soegaard, K. and Eriksson, K. A., 1986, Transition from arc volcanism to stable-shelf and subsequent convergent-margin sedimentation in northern New Mexico from 1.76 Ga: Journal of Geology, v. 94, pp. 47–66.

Thompson, A., Grambling, J. A. and Mawer, C. K., 1989, Proterozoic tectonic assembly of southwestern North America: evidence from ductile shear zones in the Manzano Mountains, N.M.: Geological Society of America, Abstracts with Programs, v. 21, p. A215.

Williams, M. L., 1987, Stratigraphic, structural and metamorphic relationships in Proterozoic rocks from northern New Mexico [Ph.D. dissertation]: Albuquerque, University of New Mexico, 138 pp.

Williams, M. L., Grambling, J. A. and Bowring, S. A., 1986, Redefinition of the Vadito Group, an extensive felsic volcanic-sedimentary sequence in the Proterozoic of northern New Mexico: Geological Society of America, Abstracts with Programs, v. 18, p. 422.

Wobus, R. A., 1985, Changes in the nomenclature and stratigraphy of Proterozoic metamorphic rocks, Tusas Mountains, north-central New Mexico: U.S. Geological Survey, Bulletin 1571, 19 pp.

A HIT AND A MISS. While road logging near Amalia, one of the committee members had the misfortune of running down a large elk. In this post-tragedy photo, a poised Miss Hoffman of the Bureau of Mines (who also serves as part-time insurance claim adjuster and hairdresser) points out the damage to one of the Bureau fleet. Photo by P. W. Bauer.