Geologic Map of the Rosilla Peak Quadrangle, San Miguel, Santa Fe Counties, New Mexico

By

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Open-file Digital Geologic Map OF-GM 031

Scale 1:24,000

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Geology of the Rosilla Peak 7.5-minute quadrangle, Santa Fe and San Miguel counties, New Mexico

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Summary

Mapping within the Rosilla Peak quadrangle has been driven by three primary goals: 1) a better understanding of the Proterozoic geologic history of northern New Mexico, 2) an appraisal of the Paleozoic outcrops, and evidence for timing of brittle deformation and 3) an assessment of how structures in bedrock might influence issues of societal importance, such as groundwater resources and slope stability. Locations of sulfide mineralization have also been included on the map. $^{40}Ar/^{39}Ar$ dating of minerals from key units and petrographic study of mineral assemblages and microstructural relationships were completed in conjunction with field structural analyses, resulting in great advances in our knowledge of Proterozoic deformation and metamorphism.

We have documented two late Proterozoic deformation events, which we believe overprint older structures in the region. The oldest of these two events involved dextral strike-slip shear, recorded by a steeply dipping, roughly E-striking foliation, a shallowly plunging mineral lineation, and a variety of kinematic indicators present in units that range in age from ca. 1720 - 1480 Ma. Petrographic analysis indicates that this deformation occurred during amphibolite facies metamorphism, and continued during cooling to upper greenschist facies conditions. $^{40}Ar/^{39}Ar$ plateau ages of hornblendes record cooling through the amphibolite/greenschist facies transition at 1372 ± 12 Ma, providing a minimum age of this deformation event. This result supports previous work suggesting that ca. 1400 Ma metamorphism and deformation were regional in extent.

The second late Proterozoic event was quite different in character, and is recorded by fault-related breccias and associated, locally extensive, K-feldspar alteration of Proterozoic rocks. Typical $^{40}Ar/^{39}Ar$ spectra are characterized by ages from 800 to 1150 Ma, suggesting a Proterozoic cooling age, which predated faulting and potassium mineralization. However alteration and brecciation could have occurred any time between 800 – 1400 Ma. These data represent the first unequivocal documentation of Proterozoic brittle deformation in the region.

Nearly flat lying Paleozoic sedimentary rocks unconformably overlie the Proterozoic bedrock with a maximum thickness of over 680 m. The Holy Ghost syncline gently warps these rocks approaching the Picuris-Pecos fault zone from the east. Post-Paleozoic motion on the Picuris-Pecos fault zone juxtaposed Paleozoic rocks and Proterozoic basement. The inferred reverse motion has a dip-slip offset of at least 500 m. The fault zone consists of four faults and is at least 1 km wide.

The Picuris-Pecos fault and similar north-northeast-striking Paleozoic and younger faults are present throughout the quadrangle, and are generally spatially associated with zones of extensive fracturing. Springs are locally related to these faults, suggesting that they may serve as conduits for fluid flow in some areas. The faults locally underlie valley fill, indicating that they are potential pathways for aquifer recharge. The new map makes information on the location of such features available for water resource planning.

Mapped landslide deposits consist of blocks of Paleozoic rock in matrices of unlithified sand and gravel. There is no evidence of control of Proterozoic structures such as foliations on the

location of this colluvium, and we suggest that these structures do not affect slope stability in the Rosilla Peak quadrangle.

Introduction

The Rosilla Peak 7.5’ quadrangle is located approximately 25 km northeast of rapidly growing Santa Fe in the Santa Fe National Forest. The second largest river in New Mexico, the Pecos River, traverses the quadrangle from north to south. Rocks exposed in the southern Sangre de Cristo Mountains, particularly along the Pecos River, include Proterozoic bedrock which ranges in age from ca. 1720 to 1480 Ma (Bowring and Condie, 1982), providing a unique opportunity to evaluate the timing and character of Proterozoic deformation in New Mexico. Mapping and associated study of Proterozoic bedrock in the Rosilla Peak quadrangle has therefore focused on unraveling the Proterozoic metamorphic and deformational history of the region, but has also progressed with consideration of the impact of structures on groundwater flow and slope stability.

Bedrock in the quadrangle is also cut by the Picuris-Pecos fault, suggested to represent a long lived strike-slip and dip-slip fault zone from the Proterozoic to the Phanerozoic (Bauer and Ralser, 1995). Mapping of Paleozoic rocks has focussed on the effects of faulting in preserving these sequences and the timing of brittle deformation, which juxtaposed Paleozoic rocks against Proterozoic basement. The mapping is not yet complete. Newly discovered Latest Eocene intrusive dikes and sills were found in the Paleozoic sedimentary rocks and are probably more extensive (Melis et al., 2000). These rocks intrude into the Madera group as sills and dikes and might account for the regional elevated heat flow during the latest Eocene, resetting apatite fission tracks over a wide area. This has implications for uplift studies of the southern Sangre de Cristo Mountains.

Previous mapping in the southern Sangre de Cristo Mountains primarily focused on documenting economic deposits, concentrated in the Proterozoic Pecos complex, and has generally not included detailed structural analysis. Miller et al. (1963), who described two stratigraphic sections within the Madera group, performed extensive reconnaissance mapping of Paleozoic rocks. Two previous maps were field checked and subsequently incorporated into the attached map: Wyman’s (1980) 1:6,000 map of a large part of the Cow Creek Proterozoic mafic complex in the eastern Rosilla Peak quadrangle and Bauer et al.’s (1995) 1:6,000 map of a small area near Windy Bridge. Other previous studies, which were less detailed than needed for this effort or otherwise inadequate, include a 1:48,000 “geologic survey” of the Pecos Wilderness Area based on mapping by Miller et al. (1963), including part of the Rosilla Peak 7.5 minute quadrangle (Moench et al., 1988); detailed mapping of the Jones mine and Macho Creek Canyon east of the Picuris-Pecos fault (Riesmeyer, 1978), completed without a topographic base; and unpublished reconnaissance maps by Robertson and Moench (1979) and D. B. Codding, J. A. Grambling, I. Klich, D. C. Mathewson, and J. M. Robertson. The enclosed map therefore largely represents a new contribution by Erwin A. Melis, first author of this report.

Previous Work

Proterozoic rocks of the Rosilla Peak quadrangle include metavolcanic and metasedimentary rocks, mafic dikes, and amphibolites that were part of a volcanic arc accreted to the North American craton during the Early Proterozoic (Condie, 1982). The Proterozoic back-arc volcanic and associated plutonic rocks are termed the Pecos complex (Robertson and Moench, 1979; Robertson and Condie, 1989; Bauer et al., 1995). The oldest rocks of this arc, dated at 1720 ± 15 Ma (U-Pb date on zircon; Bowring and Condie, 1982) are a collection of metamorphosed mafic and felsic volcanic and sedimentary rocks referred to as the Jones Rhyolite complex (Riesmeyer, 1978). Three generations of granitoid plutons intrude the Jones Rhyolite complex, recording arc magmatism, accretion, and a subsequent thermal and deformational event. The oldest of these intrusions, the multiply deformed Windy Bridge tonalite, is 1718 ± 5 Ma old (U-Pb date on zircon, Bowring and Condie, 1982). It is geochemically similar to and probably the intrusive equivalent of rhyolites of the Jones Rhyolite complex (Robertson and Condie, 1989). Younger granitoids include the ca. 1650 Ma Indian Creek granite, the 1480 Ma Macho Creek granite (U-Pb dates on zircon, Bowring and Condie, 1982), and the undated Pecos granodiorite (Wyman, 1980).

Previous workers in northern New Mexico have used the variable development of structures in rocks of different ages in conjunction with metamorphic petrology and thermochronology to constrain the timing and character of Proterozoic deformation and metamorphism. A general consensus has been reached on two points: 1) rocks in northern New Mexico record deformation, metamorphism, and intrusion associated with the 1690 -1660 Ma Mazatzal orogeny (e.g., Bowring and Karlstrom, 1990; Bauer and Williams, 1994) and 2) deformation, metamorphism and intrusion also occurred ca. 1400 Ma, variably overprinting the older structures, but the tectonic processes responsible for this event remain unclear (e.g., Grambling et al, 1989; Nyman et al., 1994; Karlstrom et al., 1997). In part this is because it is so often difficult to separate fabrics developed during one event from those developed in the other. Whereas some workers have suggested that deformation associated with metamorphism and intrusion at ca. 1400 Ma was restricted to 1400 Ma plutons and pluton margins (e.g., Nyman et al., 1994), an increasing body of data suggests that structures of this age are regional in extent (Marcoline et al., 1999). For example, some of the regionally extensive fabrics previously attributed to Mazatzal-age shortening and amphibolite facies metamorphism in the Picuris and Tusas Mountains (Bauer, 1988; Williams, 1991), have been shown to be related to the younger event through dating of metamorphic minerals (Lanzirotti et al., 1996). Other workers have found structural and/or metamorphic evidence for 1400 Ma extension that has been interpreted as both regional in extent (e.g., Grambling et al., 1988, 1989; Pollock, 1994) and a local part of an overall compressional regime (Kirby et al., 1995).

In the Rosilla Peak quadrangle, Bauer et al. (1995) noted that the ca. 1720 Ma Windy Bridge tonalite is well foliated and locally mylonitic, while the foliation in the ca. 1650 Ma Indian Creek granite is poorly developed. They also noted a shear band foliation locally developed in the Windy Bridge tonalite, which they interpreted to record top-to-the-NW shearing on steeply south-dipping planes. Folds in foliation in the Windy Bridge tonalite plunge shallowly to the southwest, similar to fold axes of isoclinal folds documented by Grambling and Codding (1982) in the Rio Mora area north of the Pecos complex. Bauer et al. (1995) concluded that these structures recorded regional shortening, and noted the intriguing possibility that they might have developed, at least in part, during the ca. 1700 Ma Yavapai orogeny.

Faults cut many of the Proterozoic and Paleozoic rocks in the Rosilla Peak quadrangle (Wyman, 1980; Bauer and Ralser, 1995). The intrusive contact between the Indian Creek granite and the Windy Bridge tonalite, for example, has locally been faulted (Bauer et al, 1995). The Cow Creek and Picuris-Pecos faults are both major north to north-northeast striking, strike-slip faults that exhibit significant separation of Proterozoic rocks and structures and cut the Paleozoic sequence (Bauer and Ralser, 1995). The Picuris-Pecos fault has 37 km of right-lateral displacement (Miller et al., 1963), and Proterozoic units are locally attenuated near the fault. The fault is therefore interpreted as having initiated in the Proterozoic and been reactivated during younger tectonic events (Bauer and Ralser, 1995). Bauer et al. (1995) also noted the presence of many northwest-striking faults east of the Pecos River in the Rosilla Peak quadrangle and speculated that the straight parallel canyons west of the Pecos River were controlled by these faults. They also suggested that the northwest-striking faults were responsible for a number of springs, which form the western tributaries to the Pecos River south of Windy Bridge. Fault-parallel fractures were noted in all rocks. The three dominant fracture sets have the following orientations: 1) north-striking and vertical, 2) north-northwest-striking and vertical, and 3) northeast-striking and steeply southeast dipping (Montgomery in Miller et al., 1963; Wyman, 1980). Faults can act as pathways, barriers, or complex barrier/conduit systems with respect to fluid flow (e.g., Caine et al., 1996). The faults and fractures of the Rosilla Peak quadrangle therefore may affect aquifer recharge and groundwater flow.

Structures may have other impacts of societal interest as well. Previous studies have shown that foliations subparallel to hillslopes increase the possibility of hillslope failure (Goodman, 1993; Haneberg et al., 1998). Colluvial deposits that record hillslope failure were not previously mapped in the Rosilla Peak quadrangle, and the potential impact of fractures and foliations on slope stability has not previously been assessed.

The Rosilla Peak Quadrangle

Lithologic descriptions of rocks exposed in the Rosilla Peak quadrangle are provided in the map explanation, and additional information about age relationships between different units was given in the previous sections. In the next paragraph, we highlight new data on the lithologic units of the region and their contact relationships before discussing evidence for the timing and character of deformation and metamorphism.

A new lithologic unit was recognized and dated in the course of this study –rhyolite dike(s). The rock records a flow foliation, with aligned phenocrysts of biotite and plagioclase. $^{40}Ar/^{39}Ar$ dating of biotite indicates that the flow is Latest Eocene in age; the preferred age is 35.05±0.53 Ma. Field observations also clarified the relative age of the informally named (Wyman, 1980) and undated Pecos granodiorite with respect to other intrusive rocks of the quadrangle. The Pecos granodiorite occupies most of the upper Cow Creek area and some of the highest elevations near tributaries to the east of the Pecos River (refer to map). It intrudes amphibolites of the Jones Rhyolite complex as well as the Windy Bridge tonalite. The contact with the Indian Creek granite is generally intrusive, though locally faulted. Interfingering along the contact and the presence of rocks of intermediate composition between the two units might mean that they are cogenetic.

PROTEROZOIC GEOLOGY

Terminology Used in Microstructural Descriptions

Microstructural analysis has been used both to evaluate kinematic indicators and to provide constraints on metamorphic conditions during deformation. We have recognized three foliations that provide kinematic information in the Rosilla Peak quadrangle: composite S- (schistosity) and C- (shear) surfaces (cf. Berthé et al., 1979) and shear bands (cf. White et al., 1980 and Gapais and White 1982; extensional crenulation cleavages of Platt, 1979 and Platt and Vissers 1980; C´ foliation of Ponce de Leon and Choukroune 1980).

A variety of microstructures can be used to constrain conditions of metamorphism during deformation (cf. Boullier and Bouchez, 1978; Simpson, 1985; Paterson et al., 1989). For example, we have evaluated whether foliations in intrusive rocks formed in the solid state (when a given pluton was completely crystalline) or when partially molten. We have also looked for microstructures such as myrmekitic intergrowths on the margins of K-feldspar porphyroclasts, which record deformation at amphibolite facies conditions (Simpson and Wintsch, 1989); bulging grain boundaries that have been demonstrated to form through grain boundary migration in quartz at temperatures greater than 400 °C (Hirth and Tullis,1992); and deformation twins in feldspar, which also form by deformation at temperatures in excess of 400°C (Pryer, 1993).

Proterozoic ductile deformation

We have used the variable degree of development and orientation of foliations in rocks of different ages in the Rosilla Peak quadrangle to evaluate the Proterozoic ductile deformation history. All four plutons and the Jones Rhyolite complex contain a dominant foliation, which mainly strikes NE and dips steeply to the southeast or northwest, but the expression of the fabric and its distribution varies between units. These variations are discussed below, beginning with observations made in the oldest rocks and progressing to evidence from the Macho Creek granite.

Mafic and felsic volcanic rocks of the Jones Rhyolite complex exhibit a foliation that varies from well developed to poorly developed. Where rocks are not well foliated, they locally preserve primary structures such as pillows in basalts and quartz phenocrysts in rhyolites. The foliation is typically defined by the preferred dimensional alignment of late syntectonic chlorite or quartz. It generally strikes NE and dips steeply, but exhibits variations in orientation. The main foliation varies little in orientation between blocks defined by younger brittle faults; however, poles to foliation define a great circle girdle on an equal area net, suggesting that orientation variations are associated with folding about a moderately southwest plunging fold axis. We found no evidence of overprinting of the folded foliation by a new foliation. Where the foliation dips south, a near horizontal mineral lineation is common in rocks of the Jones Rhyolite complex, particularly in schists and amphibolites. Metamorphic muscovite porphyroclast systems associated with this lineation and foliation locally but consistently record dextral strike-slip shear. More commonly, the fabric is orthorhombic in symmetry, and therefore records coaxial rather than noncoaxial shear.

The ca. 1720 Ma Windy Bridge tonalite exhibits a solid-state foliation defined mainly by centimeter-scale, elongate (aspect rations up to 1:10) quartz domains and biotite-rich domains. Lineations are rare; where present they typically plunge shallowly (Bauer et al., 1995).

Petrographic observations indicate that quartz domains are typically ribbons of recrystallized grains, fine grains of plagioclase may be elongate and define an S-foliation, and C-planes represent the main macroscopically visible foliation. Where present, such kinematic indicators record dextral strike-slip shear. Variations in orientation and degree of development of foliation are similar to those described above for the Jones Rhyolite complex. Where the foliation is moderately well developed the rock is generally coarse-grained; where it is very well developed and locally mylonitic, the rock is fine-grained. Poles to foliation define a southwest-plunging fold axis. Tight folds in foliation centimeters to tens of centimeters in scale generally plunge moderately to the southwest, but west and northwest-plunging hinges have also been noted.

The ca. 1650 Ma Indian Creek granite is relatively poorly foliated, but exhibits the same general pattern of foliation variation as the older rocks in the area. The great circle girdle described by poles to this solid-state foliation in the Indian Creek granite indicates a fold axis that plunges steeply to the southwest, but is defined by fewer poles than fold axes in either the Jones Rhyolite complex or Windy Bridge tonalite. The Pecos granodiorite, which as mentioned above may be similar in age to the Indian Creek granite, is rarely foliated. We have not found kinematic indicators in either the granite or the granodiorite.

The ca. 1480 Ma Macho Creek granite varies from nondeformed to locally mylonitized. The main foliation is a solid-state fabric, which generally strikes NE and dips steeply to the southeast, but varies substantially in orientation within the map area. This variation is not regular, as in the older rocks, and there is no evidence of folding of the foliation in the Macho Creek granite. There are, however, locally excellent kinematic indicators. For example, near the Jones mine (refer to map), the granite is altered and mylonitized and exhibits a well developed, subhorizontal mineral lineation and steeply dipping foliations. A well deveoped shear band foliation and asymmetric K-feldspar porphyroclast systems record dextral strike-slip shear.

Metamorphism and Mineralization

Foliation development was accompanied by metamorphism. Mineral assemblages and microstructures have been used to constrain metamorphic grade. Details of these observations are provided in the following paragraphs.

In amphibolites within the Jones Rhyolite complex, growth of blue-green amphibole postdated garnet growth, and amphiboles were overgrown by chlorite. Both amphibole and chlorite are aligned within the foliation. In quartz-muscovite schists, muscovite postdated biotite growth and retrograde chlorite overgrew the muscovite. These observations indicate that deformation of the Jones Rhyolite complex initiated under lower amphibolite facies conditions and continued during cooling to the greenschist facies.

In the Windy Bridge tonalite, large clusters of biotite surround altered blue-green, metamorphic amphiboles. Epidote is a late syntectonic alteration phase. Microstructures evident in thin section include irregular, bulging quartz grain margins and fine-grained recrystallized plagioclase. Quartz microstructures are interpreted to record grain boundary migration. Feldspar recrystallization and grain boundary migration in quartz are consistent with deformation at upper greenschist / lower amphibolite facies conditions.

Amphibole compositions were determined using the NMBMMR Cameca SX-100 electron microprobe. Five amphiboles from the Windy Bridge tonalite are calcic amphiboles and can be classified as magnesio-hornblendes (Yavuz, 1999). Two amphiboles have appreciable aluminum and sodium-aluminum exchange for iron-silica suggesting that they are a product of amphibolite facies metamorphism (Spear, 1993). Anorthitic feldspar (An_{23-29}) from the same rocks are compositionally well past the peristerite gap, suggested as the boundary between the greenschist and amphibolite facies in basic rocks (Apted and Liou, 1983). The Windy Bridge tonalite thus preserves evidence for amphibolite facies metamorphism, which is overprinted by late epidote and biotite growth.

Microstructures in the Macho Creek granite include myrmekitic intergrowths along the margins of K-feldspar porphyroclasts and deformation twins, both of which are consistent with deformation under upper greenschist / lower amphibolite facies conditions.

In addition to metamorphism, rocks have locally been mineralized. This is particularly evident near the Jones mine (refer to map), where rocks of both the Jones Rhyolite complex and Macho Creek granite are both strongly deformed and altered. Rocks of the Jones Rhyolite complex are chloritized and cross-cut by quartz veins in this location; chalcopyrite is the common sulfide present in veins. The veins vary in orientation, and generally appear to post-date deformation and metamorphism. Massive sulfide horizons and sulfides associated with veins are also found elsewhere within the Jones Rhyolite complex and similar metavolcanic outcrops along the Pecos River and tributaries such as the Indian Creek and Macho Creek. The effect these sulfides may have on acidification of surface water has not been evaluated.

Thermochronologic constraints on timing of ductile deformation

There are a number of constraints on the timing of dextral strike-slip shearing: 1) Foliations recording strike-slip shearing cross-cut the ca. 1480 Ma Macho Creek granite. 2) Pegmatite and aplite dikes locally parallel the main foliation in the country rocks, but generally cross-cut and therefore post-date the foliation. $^{40}Ar/^{39}Ar$ dates on muscovite from one of these dikes indicates that it cooled through ~350°C at 1345.2±1.7 Ma. 3) $^{40}Ar/^{39}Ar$ plateau ages for blue-green amphiboles from the Windy Bridge tonalite record cooling below 450-550°C at 1372±12 Ma. Since the closure temperature for amphibole roughly coincides with the greenschist/amphibolite facies boundary, this also provides a minimum age of metamorphism. Dextral strike-slip shearing and associated metamorphism therefore occurred between 1480 and 1370 Ma.

Brittle Proterozoic Deformation

Faults in the Rosilla Peak quadrangle can be divided into two broad groups: 1) those that resulted in extensive brecciation and potassium metasomatism of the Windy Bridge tonalite and 2) those that do not have a metasomatic signature but typically are characterized by extensive fracture zones and, locally, breccias. Both sets dip steeply and strike NNE. The first set is present in the eastern part of the quadrangle near the Pecos River, where the faults do not cut the Paleozoic sequence. Breccias in these fault zones are well cemented, and consist of fine-grained rock that appears to be nearly completely replaced by K-feldspar and locally includes secondary tourmaline. The second set of faults is evident throughout the quadrangle and includes both normal and strike-slip faults. At least some of these, including the Picuris-Pecos and Cow Creek faults, cut Paleozoic rocks.

Valleys are located on the largest faults in the area, suggesting preferential erosion of fault zones. Valleys like the Pecos River and Cow Creek valleys are underlain by alluvium and provide a well drained surface for water to infiltrate. Rocks exposed on either side of these major faults are brecciated. Faults at the eastern end of Davis Creek Canyon were found to tap springs, suggesting they are serving as conduits for fluid flow. We infer that fractures and uncemented breccias are zones of enhanced permeability with respect to unfractured protolith.

Joint sets that are not related to fault zones are also evident in the quadrangle. The Indian Creek granite, for example, exhibits a regular pattern of N- and E-striking joint sets.

$^{40}Ar/^{39}Ar$ dates on K-feldspar provide constraints on the timing of potassium metasomatism associated with brecciation of Windy Bridge tonalite along NNE-striking brittle faults. Metasomatism and brecciation predate the cooling ages obtained for K-feldspar, as age spectra for all, unaltered and altered samples, yield ages consistent with slow cooling from 1100 – 800 Ma. Alteration took advantage of the pre-existing foliation in the rocks. Alteration is thus constrained to have occurred between 1370 – 800 Ma during the Middle Proterozoic and is the first unequivocal documentation of Proterozoic brittle deformation in the region.

PALEOZOIC SEDIMENTARY ROCKS

The Paleozoic sequence is split into Mississippian rocks associated with the Arroyo Penasco group, and Pennsylvanian sedimentary rocks associated with the Madera group. The Arroyo Penasco group is locally covered by slope debris and only shown were actual identification was possible. According to Baltz and Myers (1999) the Arroyo Penasco group consists of the Espiritu Santo formation and the Tererro formation. The type locality for the Tererro formation lies within the Rosilla Peak quadrangle, west of the hamlet of Tererro (Baltz and Read, 1960). These units are not differentiated in the field and are lumped together. Rocks are a basal sandstone overlain by sandy and cherty limestones up to 30m thick. Some of the rocks have a distinct quartzite like appearance. Thickness varies locally.

Sutherland (1963) split the (middle Pennsylvanian – early Permian) Madera group in two lithostratigraphic units: the La Pasada formation and the Alamitos formation, with most of both type sections exposed in the Rosilla Peak 7.5 minute quadrangle. The two formations are distinguished based on their feldspar content. The La Pasada formation is the lower gray limestone, while the Alamitos formation is the upper arkosic limestone, with a more proximal sediment source, and more sandstones and shales. This subdivision is not always useful in close proximity to the Picuris-Pecos fault. Fault blocks cannot be easily recognized and are included in this study as Pennsylvanian-Permian undifferentiated rocks. The type locality for the La Pasada formation is at Dalton Bluff in the Rosilla Peak quadrangle, and consists of six cliff-forming units of limestone, with variations in sand and fossil content. Sutherland (1963) obtained a total thickness of 297 m for the La Pasada formation. The Alamitos formation was measured in two sections: one in Alamitos canyon, within the Rosilla Peak quadrangle and one in the Pecos River valley. Its total thickness is 389 m. Most fossils within the Paleozoic section are brachiopods, bryozoa and fusilinids.

Phanerozoic deformation

Sutherland (1963) mapped one fold in the Paleozoic rocks: the Holy Ghost syncline. It is a non-plunging long-wavelength open fold, which parallels the Picuris-Pecos fault to the east. Bauer and Ralser (1995) suggested that the syncline formed in Laramide time associated with Laramide strike-slip faulting on the Picuris-Pecos fault, which has an overall cross-sectional geometry of a positive flower structure.

Faults in the Rosilla Peak quadrangle are numerous and mostly record dip-slip motion, juxtaposing Paleozoic rocks against Proterozoic basement. Offset is more than 500 m. Horsts of undifferentiated limestone are present in the fault zone. Some strike-slip slickensides were recorded within the Picuris-Pecos fault zone. Some normal faults were mapped east of the Pecos River. They cut Paleozoic rocks.

LATEST EOCENE PECOS RHYOLITE

The Pecos rhyolite is a new map unit and it intrudes Madera group sedimentary rocks as discordant sills and dikes. Morphologically it forms a small bench above the Pecos River, and at present unexplored locations in Indian Creek Canyon. The Pecos rhyolite intruded a couple of meters above the unconformity into the La Posada formation, suggesting there is structural control on the intrusion, and also suggesting that the intrusion is shallow, since Paleozoic rocks have a maximum thickness of 680 m. The contact of the rhyolite intrusion is very irregular with elevation and across strike. In some places it intrudes the limestone as small aphophasies, in others it appears more as a small intrusion. The stratigraphy of the Madera group is not disturbed except near the margins where bedding planes vary.

In the field this rock is white, with abundant phenocrysts of plagioclase, quartz, biotite and rare sanidine. It was first recognized during reconnaissance mapping by Paul Bauer in the Fall of 1994, and may correlate with rocks described by Ingrid Klich north of Elk Mountain (1983), and rocks found by Bob Osborn elsewhere in the southern Sangre de Cristo Mountains (personal communication). In the field it exhibits platy, subparallel fractures, which are shale-like to massive, and show no marked preferred orientation between outcrops. The rhyolite dike has an irregular map pattern and a chilled margin near the top of the unit. This intrusion cooled rapidly due to the aphanitic matrix of the rock. In thin-section this rock has a porphyritic texture, with up to 1 cm large phenocrysts of plagioclase feldspar, quartz and biotite are smaller, up to 0.3 cm. Microlites consist of plagioclase, sanidine, quartz and biotite, which are all trachytic. Around phenocrysts there is a deviation of the flow foliation, suggesting that during intrusion the flow of matrix crystals deflected around the phenocrysts. Muscovite phenocrysts are surrounded by a reaction rim of biotite. Whether the crystals are xenocrystic or simply an unstable phenocryst in the assimilating and intruding dike is unclear at this moment. If it is xenocrystic its source is most likely a muscovite-rich Proterozoic schist, none of which occurs in the field area. The biotite is fluorine rich (2 weight percent determined on the electron microprobe). This also suggests that the intrusion was shallow. Phenocrysts of plagioclase show oscillatory zoning and are glomerocrystic in thin-section. Quartz phenocrysts are rounded, embayed and resorbed, suggesting a prolonged existence during changing conditions in a magma chamber, before intrusion as a dike. The oscillatory zoning of plagioclase feldspar also supports a dynamic magma chamber, when phenocrysts where out of equilibrium with the magma due to the influx of fresh magma or due to changes in pressure during eruptions. Electron microprobe data shows that the plagioclase feldspar has Na-rich rims. Matrix and plagioclase phenocrysts have virtually identical compositions. The modal percentage of plagioclase and quartz in both matrix and as phenocrysts suggest that the rock is dacitic – rhyolitic in composition. Ingrid Klich described a similar intrusion in her thesis (1983). Her whole rock geochemistry suggests a rhyolitic composition.

The rhyolite intrusion was dated by the $^{40}Ar/^{39}Ar$ method at the New Mexico Geochronology Research Laboratory. Biotite was chosen for dating since the matrix sanidines are small (10-20μm). Step heating of biotite phenocrysts in the furnace yielded a plateau age of 35.05±0.53 Ma (2σ error). The plateau age is a meaningful age and the preferred age of the intrusion. An isochron of the data yielded an acceptable $^{40}Ar/^{36}Ar$ ratio, within error of the current accepted value for atmosphere (Jaeger et al., 1977). Also the isochron age of 34.34±0.71 Ma is within error of the plateau age. The plateau age is the preferred age for the intrusion of the Pecos rhyolite.

This unit is a distinct igneous intrusive unit that is the first such unit described and dated within the southern Sangre de Cristo Mountains. There may be more intrusive units like this throughout the southern Sangre de Cristo Mountains, since a large portion of the area has yet to be mapped in detail. The latest Eocene may yet prove to be a time when the southern Sangre de Cristo Mountains were intruded, these intrusions could be related to initiation of rifting. It is entirely possible that these dikes fed eruptive centers, although none has been found so far.

Local AFT ages between Terrero and Pecos fall in the range of 35 Ma and could also be interpreted to have been reset by reheating during magmatism associated with the early stages of Rio Grande rifting. These ages seem to record a later history than the older Laramide AFT ages from the rest of the Santa Fe Range (Kelley and Chapin, 1995). Care should be taken to interpret these ages as uplifts associated with Rio Grande rifting.

Landslides

Several landslide deposits were mapped in the Rosilla Peak 7.5 minute quadrangle. These deposits consist of poorly sorted limestone blocks and sand/silt mixtures. The landslides are several 100s of meters wide at the base, and toes have in places impinged on the Pecos River. The age of these colluvial deposits is not known, but W.C. Haneberg (personal communication, 1999) has identified similar features in the northern Sangre de Cristo Mountains. From aerial photographs, it is evident the landslides have slumped and rotated to assume their current positions over Proterozoic bedrock in the valley.

At no location were well foliated rocks found to present a landslide danger. Cliffs of Proterozoic bedrock are only present along New Mexico State Route 63 at the Windy Bridge Camp Ground. From that locality and along Route 63 two kilometers to the north sheer cliffs rise out of the Pecos River canyon. The cliffs are composed of jointed but unfoliated Indian Creek granite.

Discussion

We have documented evidence for a dextral strike-slip shearing event that initiated at lower amphibolite facies conditions and continued through cooling to upper greenschist facies temperatures ca. 1370 Ma. The absence of evidence of overprinting of an older foliation by a younger foliation has also been indicated. In addition, although kinematic indicators consistently record dextral shear, they are rare. The absence of strong asymmetry in the main fabric over most of the region studied may indicate that the majority of the deformation was accommodated by coaxial rather than noncoaxial shear. We have, however, noted that rocks older than the ca. 1480 Ma Macho Creek granite record evidence for folding of the main foliation about a southwest-plunging fold axis. In addition, the most uniformly deformed rocks are the Jones Rhyolite complex and the Windy Bridge tonalite, the oldest rocks in the area. These observations could be explained in two ways: 1) Deformation initiated prior to intrusion of the Macho Creek granite, so older rocks record a longer period of deformation. During this longer time frame, the earlier formed foliations might have locally folded, producing the spatial variations in orientation currently evident in the quadrangle. This is reasonable because spatial and temporal heterogeneity is to be expected with flow in natural materials. This explanation, however, requires further consideration of the orientations of fold axes that would be expected with progressive shear in which noncoaxial dextral shear is highly localized and the majority of the deformation is taken up by coaxial flow. 2) The oldest rocks in the area are more deformed because they have experienced more than one deformation episode. Overprinting relationships have not been observed either because the older foliation was locally reactivated or because fold hinges, which are rarely observed in the field, have been largely removed during the later shearing event. Folding of foliation thus records the imposition of structures accommodating dextral strike-slip shear on an older fabric. This explanation would also account for Bauer et al.'s (1995) observation of structures that locally record reverse shear on foliation in the Windy Bridge tonalite; the structures would pre-date the ca. 1400 Ma event. Further work is needed to determine which of these two explanations best describes the structural evolution of the region.

Evidence for 1400 Ma dextral strike-slip shear is not confined to the ca. 1480 Ma Macho Creek pluton and its margins, suggesting that deformation and metamorphism were regional in extent. Previous models of large-scale crustal extension (Grambling et al., 1986, 1988) or shortening (e.g. Nyman et al., 1994) during 1400 Ma metamorphism are not sufficient to explain the structures we observe in the Rosilla Peak quadrangle.

Proterozoic brittle deformation is constrained to have occurred between 1370 and 800 Ma as it predates the $^{40}Ar/^{39}Ar$ cooling ages of K-feldspar. It is unclear at this time when the brecciation and local alteration of the Proterozoic rocks too place. It could have been after metamorphism and deformation at 1400 Ma as advocated by Miller et al (1963) or it could have been associated with a ductile Grenville event at 10 00 Ma (Grambling and Dallmeyer, 1993; Heizler et al., 1997). Further careful work is needed to precisely date this Proterozoic brittle event.

Further faulting in the Rosilla Peak quadrangle is constrained to be post-Permian as Pennsylvanian-Permian sedimentary rocks are juxtaposed against Proterozoic basement along the Picuris-Pecos fault and the Cow Creek fault. Field evidence suggests no prior movement on these north-north-east striking faults, but slickensides locally record strike-slip shear, which could be associated with Laramide deformation. Evidence of Proterozoic strike-slip shear was not documented in the Rosilla Peak quadrangle and thus the controversy over the magnitude of Laramide vs. Proterozoic strike-slip shear could no be resolved (e.g. Bauer and Ralser, 1995). Apatite fission track ages from the southern Sangre de Cristo Mountains suggest that the mountain range was uplifted during the Late Cretaceous and does not show evidence of significant uplift during Rio Grande rifting (Kelley and Chapin, 1995). The normal faulting documented here could be insignificant but temporally associated with Rio Grande rifting.

Conclusions

The geologic map of the Rosilla Peak quadrangle provides a foundation for interpreting Proterozoic deformation and metamorphism as well as structures that might influence present day fluid flow and geologic hazards. We also have identified several brittle deformation episodes, and the occurrence of a Latest Eocene igneous intrusive rock. We summarize our main conclusions as follows:

1) Proterozoic rocks in the Rosilla Peak quadrangle record an episode of dextral strike-slip shear on NE-striking, steeply dipping foliation planes at ca. 1400 Ma.
2) Brittle faulting and associated brecciation and potassium metasomatism occurred on steep NE-striking faults between 1370 – 800 Ma. This is the first unequivocal documentation of Proterozoic brittle deformation in the region.
3) Latest Eocene igneous intrusives dated at 35.05±0.53 Ma
4) Breccia and fracture zones are spatially associated with younger faults in the quadrangle. The presence of springs along some of these faults suggests that they may, at least locally, serve as preferred pathways for groundwater flow.

5) Mesozoic and Cenozoic reverse motion on the Picuris-Pecos fault has at least 500 m of offset. Some kinematic indicators record strike-slip shear.

6) Although a number of landslide deposits have been mapped, we find no evidence to suggest that slope failure is associated with Proterozoic structures in the quadrangle.

7) Sulfide mineralization is locally evident in lithologic layers and veins within the Jones Rhyolite complex. The locations of these areas have been mapped to provide an assessment tool for future work in either exploration or water quality.

References

Apted, M. J. and Liou, J. G., 1983, Phase relations among greenschist, epidote-amphibolite, and amphibolite in a basaltic system: American Journal of Science, v. 283-A, p. 328-354.

Armstrong, A. K., and Mamet, B. L., 1990, Stratigraphy, facies and paleotectonics of the Mississippian system, Sangre de Cristo Mountains, New Mexico and Colorado and adjacent areas: New Mexico Geological Society Guidebook to 41st Field Conference, p. 241-249.

Baltz, E. H., and Read, C. B., 1960, Rocks of Mississippian and probable Devonian age in Sangre de Cristo Mountains, New Mexico: AAPG Bulletin, v. 44, p. 1935-1944.

Baltz, E. H., and Myers, D. A., 1999, Stratigraphic framework of upper Paleozoic rocks, southeastern Sangre de Cristo Mountains, New Mexico, with a section on speculations and implications for regional interpretation of Ancestral Rocky Mountains paleotectonics: New Mexico Bureau of Mines and Mineral Resources Memoir 48, 269 pp.

Bauer, P. W., 1988, Precambrian Geology of the Picuris range, north-central New Mexico: PhD dissertation, New Mexico Bureau of Mines and Mineral Resources, Open-File Report OF-325, 280 pp.

Bauer, P. W., Daniel, C. G., Lucas, S. G., Barker, J. M., and Kottlowski, F. E., 1995, Second-day road log, from Santa Fe to Pecos, Rowe, Bernal, Romeroville, and Mineral Hill: New Mexico Geological Society Guidebook to 46th Field Conference, p. 29-55.

Bauer, P. W., and Ralser, S., 1995, The Picuris-Pecos fault - Repeatedly reactivated, from Proterozoic (?) to Neogene: New Mexico Geological Society Guidebook to 46th Field Conference, p. 111-115.

Bauer, P.W., and Williams, M.L., 1994, Age of Proterozoic orogenesis in New Mexico: Precambrian Research, v. 67, p. 349-356.

Berthé, M. G., Choukroune, P. and Jegouzo, P, 1979, Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South Armorican shear zone. Journal of Structural Geology, v.1, p. 31-42.

Boullier, A.-M. and Bouchez, J.-L., 1978, Le quartz en rubans dans les mylonites: Bulletin of the French Geological Society, v. 7, p. 253-262.

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

Bowring, S. A., and Karlstrom, K. E., 1990, Growth, stabilization and reactivation of Proterozoic lithosphere in the southwestern United States: Geology, v. 18, p. 1203-1206.

Caine, J. S., Evans, J. P., and Forster, C. B., 1996, Fault zone architecture and permeability structure: Geology, v. 24, p. 1025-1028.

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

Gapais, D. and White, S. H., 1982, Ductile shear bands in a naturally deformed quartzite: Textures and Microstructures, v. 5, p. 1-17.

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

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

Grambling, J. A., and Dallmeyer, R. D., 1993, Tectonic evolution of Proterozoic rocks in the Cimarron Mountains, northern New Mexico: Journal of Metamorphic Geology, v. 11, p. 739-755.

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

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, Volume 235: Special Paper: Boulder, Co., Geological Society of America, p. 87-110.

Goodman, R. E., 1993. Engineering Geology: New York, John Wiley & Sons, 412 pgs.

Haneberg, W. C., Bauer, P. W., and Chavez, W. X., 1998, Multilevel geologic hazard assessment in the Rio Grande gorge, northern New Mexico, U.S.A., in Bobrowsky, P., editor, Geoenvironmental Mapping: Method, Theory and Practice: New York, International Union of Geological Sciences, p. 214-231.

Heizler, M. T., Ralser, S., and Karlstrom, K. E., 1997, Late Proterozoic (Grenville?) deformation in central New Mexico determined from single-crystal muscovite $^{40}Ar/^{39}Ar$ age spectra: Precambrian Research, v. 84, p. 1-15.

Hirth, G., and Tullis, J., 1992, Dislocation creep regime in quartz aggregates: Journal of Structural Geology, v. 14, p. 145-159.

Karlstrom, K. E., Dallmeyer, R. D., and Grambling, J. A., 1997, $^{40}Ar/^{39}Ar$ evidence for 1.4 Ga regional metamorphism in Mew Mexico: implications for thermal evolution of lithosphere in the southwestern USA: Journal of Geology, v. 105, p. 205-223.

Kelley, S. A., and Chapin, C. E., 1995, Apatite fission-track thermochronology of southern Rocky Mountain-Rio Grande Rift-western High Plains provinces: New Mexico Geological Society Guidebook to 46th Field Conference, p. 87-96.

Kirby, E., Karlstrom, K. E., Andronicos, C. L., and Dallmeyer, R. D., 1995, Tectonic setting of the Sandia Pluton: An orogenic 1.4 Ga granite in New Mexico: Tectonics, v. 14, p. 185-201.

Klich, I., 1983, Precambrian geology of the Elk Mountain – Spring Mountain Area, San Miguel county, New Mexico, MS Thesis, New Mexico Institute of Mining and Technology, Socorro, 147 pp.

Lanzirotti, A., Bishop, J. L., and Williams, M. L., 1996, A more vigorous approach to dating mid-crustal processes: U-Pb dating of varied major and accessory metamorphic minerals tied to microstructural studies: Geological Society of America Abstracts with Programs, v. 14, p. 453.

Marcoline, J., Heizler, M., Goodwin, L.B., Ralser, S., and Clark, J., 1999, Thermal, structural, and petrologic evidence for 1.4 Ga metamorphism and deformation in central New Mexico: Rocky Mountain Geology, 34, 3-16.

Melis, E. A., Harpel, C. J., Kelley, S. A., and Bauer, P. W., 2000, Latest Eocene felsic volcanic rocks from the southern Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society Proceedings Volume Annual Spring meeting, p. 30.

Miller, J. P., Montgomery, A., and Sutherland, P. K., 1963, Geology of part of the soutern Sangre de Cristo Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 11, 106 pp.

Moench, R. H., Grambling, J. A., and Robertson, J. M., 1988, Geologic map of the Pecos Wilderness, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map, MF-1921-B, scale 1:48,000.

Montgomery, A., 1953, Precambrian geology of the Picuris Mountains, north-central New Mexico, New Mexico Bureau of Mines and Mineral Resources, Bulletin 30, 89 pp.

Nyman, M. W., Karlstrom, K. E., Kirby, E., and Graubard, C. M., 1994, Mesoproterozoic contractional orogeny in western North America: evidence from ca. 1.4 Ga plutons: Geology, v. 22, p. 901-904.

Paterson, S. R., Vernon, R. H. and Tobisch, O. T., 1989, A review of criteria for the identification of magmatic and tectonic foliations in granitoids: Journal of Structural Geology, v. 11, p. 349-363.

Platt, J. P., 1979, Extensional crenulation cleavage: Journal of Structural Geol. v. 1, p. 95.

Platt, J. P. and Vissers, R .L. M., 1980, Extensional structures in anisotropic rocks: Journal of Structural Geology, v. 2, p. 397-410.

Pollock, T., 1994, Evidence for the relative timing and character of Proterozoic deformation and metamorphism in the Ladron Mountains, New Mexico: unpub. M.S. thesis, New Mexico Tech, Socorro.

Ponce de Leon, M. J. and Choukroune, P., 1980, Shear zones in the Iberian arc: Journal of Structural Geology, v. 2, p. 63-68.

Pryer, L. L., 1993, Microstructures in feldspars from a major crustal thrust zone: the Grenville front, Ontario, Canada: Journal of Structural Geology, v. 15, p. 21-36.
Riesmeyer, W. D., 1978, Precambrian geology and ore deposits of the Pecos mining district, San Miguel and Santa Fe counties, New Mexico, MS Thesis, University of New Mexico, Albuquerque, 215 pp.
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, Volume 235: Special Paper: Boulder, Co., Geological Society of America, p. 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 to 30th Field Conference, p. 165-173.
Simpson, C., 1985, Deformation of granitic rocks across the ductile-brittle transition: Journal of Structural Geology, v. 7, p. 503-511.
Simpson, C., and Wintsch, R. P., 1989, Evidence for deformation-induced K-feldspar replacement by myrmekite: Journal of Metamorphic Geology, v. 7, p. 261-275.
Spear, F. S., 1993, Metamorphic phase equilibria and pressure-temperature-time paths, Mineralogical Society of America Monograph series, Washington, D.C., 799 pp.
White, S. H., Burrows, S. E., Carreras, J., Shaw, N. D. and Humphreys, F. J., 1980, On mylonites in ductile shear zones: Journal of Structural Geology, v. 2, p. 175-187.
Williams, M. L., 1991, Heterogeneous deformation in a ductile fold-thrust belt: The Proterozoic structural history of the Tusas Mountains, New Mexico: Geological Society of America Bulletin, v. 103, p. 171-188.
Wilson, C. J. L., 1975, Preferred orientation in quartz ribbon mylonites: Geological Society of America Bulletin, v. 86, p. 968-974.
Wyman, W. F. 1980, Precambrian geology of the Cow Creek Ultramafic complex, San Miguel county, New Mexico, MS Thesis, New Mexico Institute of Mining and Technology, Socorro, 125 pp.
Yavuz, F., 1999, A revised program for microprobe-derived amphibole analyses using the IMA rules: Computers and Geosciences, v. 25, p. 909-927.

Rosilla Peak 7.5-minute Quadrangle Unit Descriptions

QUATERNARY

Qal Alluvium, that ranges from less than 1m to 6 m thick. Predominately sand and silt with local gravel or clay-rich beds. Some deposits are cobble-rich.

Qc Colluvium, <1 to 8 m thick, including debris flows, slumps, and landslides. Deposits are coarse-grained, poorly sorted, and poorly stratified.

TERTIARY

Erd Latest Eocene (35.05±0.53 Ma, $^{40}Ar/^{39}Ar$ date on biotite, this study) rhyolite-dacitic intrusive igneous rock, with flow-aligned phenocrysts of biotite, plagioclase feldspar, and rounded quartz. Plagioclase feldspar is clustered in glomerocrysts. Crystalline matrix consists of biotite, plagioclase and quartz. Commonly contains broken xenocrysts of muscovite. Rock is white very well lithified, and weathers to tabular blocks.

PALEOZOIC

Pu Undifferentiated Pennsylvanian and Permian sedimentary rocks that unconformably overlie the Proterozoic basement, and are mostly fault blocks along the Picuris-Pecos fault.

Pa Alamitos formation. Dominated by arkosic limestone, with significant portions of sandstone and shale of latest Desmoinesian – Virgilian age (Miller et al., 1963).

Plp La Pasada formation. Dominated by cyclic limestones, with lesser mudstone and quartz sandstone of Morrowan to middle Desmoinesian age (Miller et al., 1963).

Map Arroyo Penasco group. Made up of the Espiritu Santo formation (Osagean) and the Tererro formation (Meramecian and Chesterian) and consisting of sandstones, limestones and local coarse quartzites (Armstrong and Mamet, 1990). Often covered by slope debris and talus and up to 30 m thick locally.

PROTEROZOIC

Yp Pegmatite and aplite dikes, with a cooling age of 1.334 ± 0.001 Ga ($^{40}Ar/^{39}Ar$ date on coarse-grained muscovite, this study). Dikes have a simple quartz-feldspar-muscovite mineralogy, are generally subvertical, and are at most 1-2 meters thick.

Ygm Macho Creek granite. Megacrystic K-feldspar granite, dated by Bowring and Condie (1982) at ca. 1.48 Ga (U-Pb zircon crystallization age). The Macho Creek granite is peraluminous, with ~10% muscovite, ~10% biotite, and rare garnet. Major phases are microcline, plagioclase and quartz. The rock varies from nonfoliated to locally well foliated. Iron oxide staining and orange weathering are typical.

Xgi Indian Creek granite. Fine grained, equigranular, weakly to moderately well foliated K-feldspar granite, dated by Bowring and Condie (1982) at ca. 1.65 Ga (U-Pb zircon crystallization age). Rock is composed of biotite, quartz and K-feldspar. It weathers to orange and reddish-pink rounded blocks.

Xgf Felsite and fine-grained granite. Mainly composed of quartz, K-feldspar and minor biotite, with minor sodic plagioclase.

Xgp Pecos granodiorite. A coarse-grained, equigranular granodiorite, containing about 15% quartz, 30% plagioclase, 30% K-feldspar, and 10-15% hornblende and biotite. Hornblende is commonly altered to biotite and chlorite.

Xgw Windy Bridge tonalite, dated at 1.718 ± 0.005 Ga (Condie and Bowring, 1982; U-Pb zircon crystallization age). This unit is distinguished by quartz porphyroclasts up to 2-3 cm long, which compose as much as 35% of the rock, and locally gneissic fabric. Other minerals include plagioclase, which is a fine-grained, matrix-forming phase, and biotite after hornblende. Plagioclase is commonly sericitized, and epidote alteration is locally evident. Amphibolite xenoliths aligned in the plane of the foliation are common. The tonalite weathers to a orange-brown color.

Xam Amphibolite and mafic schist. Dark green to black, variably foliated, coarse- to fine-grained rock consisting largely of amphibole and plagioclase. Also contains sphene ± epidote ± garnet ± biotite. Chlorite has locally replaced biotite.

Xmv Metavolcanic unit. Includes rocks of the Jones Rhyolite complex, dated by Bowring and Condie (1982) at 1.720 ± 0.015 Ga (U-Pb zircon crystallization age). This unit consists mainly of metarhyolites, but also includes metamorphosed basalts, metasedimentary rocks, and banded iron formations. Commonly grey to orange in outcrop, the metarhyolite preserves relict quartz and plagioclase feldspar phenocrysts. Alteration to a quartz -muscovite schist is locally extensive; degree of fabric development varies. Often contains extensive mineralized zones with sulfides and iron oxides in large portions.

Xg Biotite granite-granodiorite in Cueva Canyon. Equigranular and unfoliated, with biotite, plagioclase- and K-feldspar, quartz as main mineral phases.