Geologic Map of the Tres Ritos Quadrangle, Taos County, New Mexico

By

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New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 145

Scale 1:24,000

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DRAFT

Report on the Geology of the
Tres Ritos Quadrangle, Taos County, New Mexico.

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Description and Interpretation of map units

Quaternary Rocks

DESCRIPTION

Qal/Qf

Stream channel and valley-floor alluvium, and active floodplains (Holocene?)-Light-to-medium brown; loose, poorly to well-sorted; rounded-to-subangular; thin-to-thick bedded or massive; sand, pebbles, and boulders. Light-brownish sand, gravelly sand, and sandy gravel with minor mud and silt underlies modern ephemeral channels. Gravel is generally poorly sorted, subangular to subrounded pebbles. Sand is generally coarse- to very coarse-grained, poorly to moderately sorted, and subrounded to subangular. Estimated thickness of deposits associated with ephemeral channels is 1-5+ m. Thickness of alluvium under the Rio Pueblo is unknown. Several fan-shaped accumulations of alluvium have been mapped separately from Qal. These deposits are likely of similar age as Qal and have been mapped separately based solely on their morphology. These fans are found at the mouths of tributaries and seem to indicate delivery of sediment in excess of the 'main' streams ability to transport it.

Qc

Quaternary Colluvium

Colluvial deposits have not been mapped on this Quadrangle but most of the map area is covered by ~1-5 meters of brown-to-nearly black; loose; very poorly sorted; rounded-to-angular; massive-to-very crudely bedded; sandy-silty conglomerate and pebbly silty sand. This material is clearly colluvial based on its landscape position and the random orientation of larger clasts within a matrix of usually dark, organic-rich fines. Informal surveys of windthrow (movement of 'soil' by toppling of trees) indicate that this process is presetly active throughout the map area. What effect historic logging, Quaternary climate change, or recent weather trends have had on this process are unknown, but it seems safe to presume that windthrow has been active throughout the

Quaternary. We suggest that this process, along with frost heave and creep are jointly responsible for the ubiquity of Qc throughout the quadrangle.

Qlb

Quaternary landslide deposits with intact blocks of Tertiary basalt flow(s) (late Pleistocene to Holocene?) Quaternary landslide deposits with intact blocks of Tertiary basalt flow(s) and abundant, subangular-to-angular basalt blocks. Found on slopes below the Vadito basalt.

Qg

Undifferentiated Quaternary gravel deposits. Commonly buff-to-brownish, rounded-to-well rounded, crudely bedded, uncemented, quartzite-rich conglomerate and sandy conglomerate. These deposits are rarely preserved on a mappable scale on this quadrangle, although small accumulations of rounded stream cobbles are occasionally found on hillslopes along the valley of the Rio Pueblo.

QTg

Quaternary (and late Pliocene?)

Poorly sorted sand and gravel deposits, typically with layers containing large rounded boulders of Proterozoic quartzite. Found on high erosional pediment surfaces, and commonly forms colluvial veneer on underlying units. Maximum thickness of 10 m. Broadly similar deposits cover large areas on the nearby Penasco (Bauer et al., 2003), El Valle (Aby et al., 2005), Trampas (Bauer et al., 2005), and Truchas (Smith et al., 2004) quadrangles and are discussed further in those reports. No rigorous, regional correlation of QTg deposits has been conducted and no direct age control is available. These deposits are therefore grouped together solely on their geomorphic position. On this Quadrangel QTg deposits are confined to one small area overlying Tb near the western edge of the map area. These gravels are composed of Proterozoic quartzite (~90%) and Paleozoic sandstone (~10%) with minor amounts of other Paleozoic rock types.

INTERPRETATION

The Quaternary and late Pliocene geologic and geomorphic history of the map area is undoubtedly complex and a full discussion is outside the scope of this report. QTg deposits represent the oldest mappable Quaternary stream gravels, although accumulations of rounded stream cobbles below Tb flow remnants indicate that an axial stream flowed along the valley of the ancestral Rio Pueblo at ~5.7 Ma. The general lack of preserved stream terraces along this valley, along with the occurrence of isolated , rounded cobbles on some hillslopes, indicates that hillslope processes have been sufficiently active to remove any terraces that have formed. The present valley floors of the 'main' streams (Rio Pueblo and Rio Grande del Rancho) contain a fairly continuous cover of Qal. In higher-order drainages Qal deposits are often too thin or narrow to be mapped. Exceptions to this generalization include tributary confluences and/or relatively wide, gentle reaches that seem to be controlled by lithology (e.g. meadows overlying shale).

Tertiary Rocks

‘Vadito basalt’

Tb

DESCRIPTION

The basalt flows in the southwest part of the quadrangle are gray where weathered and black on fresh surfaces, strong, vesicular, **olivine tholeiite basalt**. These flows are up to approximately 10 m thick. No exposure of the lower contact of these flows has been found, but pebble-to-boulder gravel is often found on slopes immediately below the basalt. These 'deposits' have not been mapped due to their poor exposure and location below steep basalt cliffs.

INTERPRETATION

These basalt flow(s) where first mapped by Cope 1875, noted by Cabot (1938), and suggested to correlate with flows of the Ocate Volcanic field (the 5.65 Ma Cerro Vista flow, Olmstead, 2000) by Smith (2004). A recent date of 5.67 Ma on part this flow (on the Penasco Quadrangle) adds credence to this interpretation (Bauer et al., 2003).

We have found two small, previously unmapped remnants of this flow south of the Rio Pueblo (Sec. 7 T22N R13E). One of these remnants is in place while the other has apparetly been displaced by mass movement based on its elevation. These flow remnants seem to have buried 'stream' gravels and help to confirm that the source of the flows was to the east and that the flow followed an 'ancestral Rio Pueblo'. These gravels are the oldest known axial fluvial gravels in this area and indicate that a sizeable stream flowed through a confined river valley ~5.7 Ma.

INCISION RATE ESTIMATES

The incision rate calculated from the present position of the Vadito basalt flow remnants and their age is approximately 36 m/my (0.036mm/yr). This value is somewhat lower than average rates in New Mexico (50-200 m/my: Pazzaglia and Hawley, 2004) and rates calculated for the northernmost Santo Domingo Basin (90-250 m/my:Aby, 1996). This is probably because regional incision began in this area sometime after 5.67 Ma. Incison of the Rio Pueblo in the map area probably did not begin until sometime after ~3 Ma since ~3 Ma basalts cap Black Mesa/La Mesita west of Velarde (and provided a base level datum for the Rio Pueblo/Rio Embudo system at that time). Taking the start of incison as ~3 Ma results in an incision rate in the map area of ~70m/my. Recent mapping (Bauer et al., 1997, 2003) in the southernmost San Luis Basin has shown the presence of a ~1.27 Ma ash layer interbedded with Quaternary fan deposits (Taos Southwest Quadrangle) and post-Sevilleta Basalt alluvium (within landslide blocks on Trampas Quadrangle). A similar ash has recently been found interbedded with 'ancestral Rio Grande' deposits during reconnaissance on the Carson Quadrangle (Aby). If the preservation of this ash is construed as evidence of aggradation at this time then incision of the Rio Pueblo could not have begun prior to ~1.27 Ma. Using this age estimate increases the incision rate to ~ 178 m/my.

Picuris Formation

Introduction

Aby et al. (2004) subdivided the Picuris Formation informally into a lower conglomerate member, a middle tuffaceous member and an upper volcaniclastic member {which is likely equivalent to the Chama-El Rito Member of the Tesuque Fromation (Galusha and Blick, 1971; Aby and Koning, 2004)}.

The lower conglomerate member was first mapped by E.D. Cope as "drift conglomerate" during the Wheeler surveys (Cope, 1875). This interpretation is understandable as the unit often has a distinctly 'diamict' appearance, particularly in the poor, natural exposures likely available at that time. Cabot (1938) in a regional study included the lower conglomerate member in the 'Picuris Tuff'.

Rehder (1986) completed a master's thesis that introduced the term Picuris Formation and divided the formation into a lower and upper members separated by the Llano Quemado breccia (a volcanic/volcaniclastic, near-vent (?) breccia found only north of this quadrangle). Rehder's lower member is equivalent to the lower conglomerate member of Aby et al. (2004). Rehder's (1986) upper member is composed of both the tuffaceous middle member and upper volcaniclastic member of Aby et al (2004). Aby et al. (2004) noted that these members are likely more complexly interlayered in the northern Picuris Mountains (where Rehder's study was focused) than in the southern Picuris Mountains where they are clearly superposed and are further from their source in the Latir Volcanic field (Lipman et al., 1986).

DESCRIPTION

Tpu

upper volcaniclastic member

Red to purple; very friable to nonfriable; very poorly to moderately well sorted; poorly rounded to rounded, thickly to thinly bedded, carbonate-cemented, **pebble and gravel conglomerate.** In the small area of exposure on this quadrangle, pebble-sized clasts are Tertiary volcanic (95%) and rounded Precambrian quartzite(5%), based on a single clast count. Most contacts between beds are abrupt and basal contact of coarser beds commonly scoured. Upper and lower contact are not exposed.

Tpmc

Cemented part of middle tuffaceous member

The upper part of the middle tuffaceous member is commonly strongly cemented with silica in the southern Picuris Mountains (Aby et al., 2004). This upper part of the middle member also commonly contains abundant clasts of Proterozoic rocks, as opposed to the rest of the middle member which contains only sparse lenses of such clasts. Only one small exposure of this unit is found on this quadrangle just northwest of the Rock Wall. Readers are referred to Aby et al. (2004) and Bauer et al. (2003) for a complete description of this unit.

Tpm

Middle tuffaceous member

The middle tuffaceous member is a yellowish-white; friable; moderately-to-well sorted; subangular to subrounded; massive or thinly-to-very thickly bedded, mostly weakly carbonate cemented; silty, vfl-cl, **tuffaceous sandstone**. Recent dating of a primary ash fall in the lower part of this member on the Penasco Quadrangle (immediately west of the Tres Ritos Quad) indicates deposition was occuring at ~25 Ma (Bauer et al., 2003, Peters, 2005). This date is equivalent to the age of the Amalia Tuff of the Latir Volcanic Field (Smith et al., 2002) and is assumed to represent ash-fall from that caldera-forming eruption. Clasts from the middle member range in age from ~23-28 Ma (Aby et al, 2004).

Tpl

Lower conglomerate member

The lower conglomerate member is whiteish, yellowish, yellowish-green, greenish, tan, and/or reddish; very friable; poorly-to-very poorly sorted (sometimes bimodal); rounded-to-subangular; thinly-to-very thickly bedded and sometimes massive(?); uncemented-to-moderately cemented, **sandy-to-silty boulder-to-pebble conglomerate with minor sandstone and pebbly sandstone**. The well-to-moderately-well rounded clasts in the lower member are commonly fractured and in float have a distinctive appearance due to the resulting combination of angular and rounded faces. Contacts are commonly mapped in float. The lower contact is placed at the first accumulations of diverse Proterozoic clasts (Quartzite, Pilar slate, +/- schist). The lower member is very poorly exposed on most of the Quadrangle except in roadcuts along NM 514 west of the “Rock Wall'. In the southern Picuris mountains the lower member is approximately 200 m thick and may be up to 300-400 m thick in the western Picuris mountains (Aby et al., 2004).

Pebbles in the conglomerate are composed mostly of Proterozoic quartzite and smaller amounts of Pilar Slate (Table 1). The conglomerate displays a general fining-upward trend with very large (up to 2 m+) boulders at the base and poorly-to-moderately sorted, sandy, pebble-to-cobble conglomerate near the top. Some large boulders near the base of the section are granitic, in contrast to the predominance of quartzite clasts in most pebble counts (Table 1). Some individual beds within the lower conglomerate member along NM 518 also contain Tertiary volcanic clasts. These volcanic clasts are both under and overlain by Proterozoic clast dominated beds and seem to form a relatively thin interval (or intervals). **Several of these clasts have been submitted for geochemical and geochronologic analysis.**

INTERPRETATION

Tpu
upper volcaniclastic member

The upper volcanicastic member is composed mostly of debris shed from the Latir Volcanic Field (Aby et al., 2004). Basal beds are commonly dominated by volcanic clasts (as here) while higher in the section quartzite clasts are more common. To the south and west the upper member underlies and interfingers with the Dixon member of the Tesuque Formation. A basalt clast from the base of this member on the Penasco Quadrangle is ~19.8 Ma.

Tpmc
Cemented part of middle tuffaceous member

Only a very small outcrop of this unit is exposed on this quadragle. Readers are referred to Aby et al. (2004) and Bauer et al. (2003) for an interpretation of this unit. Cementation of this unit is probably related to devitrification of fine grained glass.

Tpm
Middle tuffaceous member

The middle tuffaceous member of the Picuris Formation is thought to represent fluvial and debris-flow deposits derived from the Latir Volcanic Field near Questa, NM (Aby et al., 2004; Bauer et al., 2003). Primary ash-fall presumably derived from the Amalia Tuff eruption (based on similarity of age) indicates deposition was occuring at ~25 Ma. Dated clasts from the middle member range in age from ~23-28 Ma, indicating that deposition continued until sometime after 23 Ma (Aby et al, 2004). A ~27.9 Ma ash exposed in highly deformed outcrops on the Ranchos de Taos Quadrangle and inferred to immediately overlie the Llano Quemado Breccia (Aby et al., 2004) suggest that deposition of the middle member started at about this time in the northern Picuris Mountains area.

Tpl

Lower conglomerate member

The lower contact of the conglomerate member was incorrectly described by Aby et al. (2004) as an angular unconformity with Paleozoic rocks. More detailed examination of “Rock Wall” outcrops (see ‘rock wall’ at intersection of NM 75 and 518) shows that the Paleozoic and Tertiary rocks have conformable bedding attitudes (dip ~30 toward 270) except within a few meters of the contact where Paleozoic rocks dip up to 50 degrees to the west. This observation leads us to tentatively reinterpret this contact as a fault, although offset may be minor. The concordance of bedding attitudes in the Paleozoic and Tertiary units above and below the contact suggests that the contact may have originally been disconformable. Subsequent to approximately 30 degrees of westward tilting a fault propagated along this contact. At the Rock Wall there seems to be a few meters of relief on the lower contact, with Pennsylvanian sandstone standing higher than shale. Rather than a fault, the relations here could be interpreted as depositional and the 'tilting' of Pennsylvanian strata near the contact attributed to late Eocene hillslope processes. The contact exposed in this road-cut has not been examined closely due to the high probability of dislodging rocks onto the road below. Photographs of the Rock Wall exposures (and exposures of the middle tuffaceous member just to the west) are shown in Bauer et al. (2004; fig 3.17).

Ash layers from two locations (near Talpa and Pilar) in the lower conglomerate member have been dated in recent years at ~ 34.5 Ma (Aby et al., 2004). These ages indicate that parts of the conglomerate member were deposited during the end of the Laramide orogeny, which 'peaked' at ~ 50 Ma (Cather, 2004; fig. 2). The conglomerate member seems to have been sourced largely from the Picuris mountains (Aby et al., 2004), indicating that these mountains were a positive feature at that time as they are at present. The age of these ash layers also indicate that parts of the conglomerate member are coeval with deposition of the Vallejo Formation of the Northern Sangre de Christo mountains/San Luis Basin (Miggins et al, 2002)

Volcanic clasts in some thin beds of the lower member must be derived from volcanic units to the north. The closest primary volcanic deposits are those of the Latir Volcanic field near Questa (Lipman et al., 1986). Much of the pre-caldera volcanic activity in the Latir Field was intermediate-to-basaltic (Lipman and Reed, 1989), and so these pre-caldera rocks are the most likely source for the similar clast types in the lower member. However, the possibility exists that these clasts were derived from the more distant San Juan Volcanic Field. The bulk of the lower member is composed of quartzite and Pilar Slate clasts. Pilar slate and Tertiary volcanic clasts have not been found in the same beds. We interpret these relations to indicate interfingering of fluvial sediments derived from southern ('Picuris Mountins' =Quartzite +slate) and northern (Latir Field=Quartzite +Tertiary volcanic) sources.

Rhyolitic clasts equivalent to the ~ 28.3 Ma Llano Quemado Breccia (Aby et al., 2004) have been tentatively identified by us in road cuts along NM 518 on the Ranchos de Taos Quadrangle. If this is confirmed, then deposition of the conglomerate member continued until at least 28.3 Ma.

Paleozoic Rocks

Pennsylvanian

Introduction

The Pennsylvanian section on this quadrangle consists of a thick section of sandstone, shale, limestone and siltstone. Regionally these rocks have been variously named, subdivided and correlated (Read and Wood, 1947; Baltz and Read, 1960; Miller et al., 1963; Kues, 2001). Miller et al. (1963) divided the Pennsylvanian in the map area into a lower, mostly silicic Flechado Formation and upper, arkosic Alamitos Formation. Although this distinction was based partly on stratigraphic sections within the map area along the Rio Pueblo, these workers did not map this contact anywhere on their regional (~1:63,000 scale) map due to poor exposure. A master's thesis by Fekete (1988) indicates that the silicic/arkosic variations within these Pennsylvanian rocks are an artifact of diagenesis. This has been used to justify abandoning these formation names and 'lumping' of the entire Pennsylvanian section into the Sandia Formation (Soegaard, 1990), A relatively recent review of the Pennsylvanian system has, however, retained the nomenclature of Miller et al. (Kues, 2001). The type section of the Flechado Formation is located along the Rio Pueblo near Flechado Canyon (Miller et all., 1963). The contact between the Flechado and Alamitos Formations is entirely covered here, and no continuous exposure in the map area exposes a mappable contact between Arkosic and non-arkosic strata. As noted by Miller et al (1963) and confirmed by our mapping, feldspathic sandstones are sometimes found near the base of the Pennsylvanian section. For these reasons we have adopted the strategy of Miller et al. (1963) in mapping 'undivided Pennsylvanian' rocks. We have, however, attempted to distinguish a basal Pennsylvanian sandstone unit where possible. This mostly poorly exposed area does not seem appropriate to resolve long-standing debates about regional relations and disagreements of nomenclature.

DESCRIPTION

Ppu

Undivided Pennsylvanian

(Sandia Formation or Flechado and Alamitos Formations)

Poorly exposed; greenish, reddish, yellowish, buff, tan, black, and brown; very friable-to-firm; sandy-to-clayey; thinly-to-thickly bedded; poorley-to-moderately well cemented (?) **sandy-to-clayey siltstone, mudstone, and shale** interbedded with mostly greenish and brownish; firm-to-very strong; poorly-to-moderately well sorted; poorly-to-moderately well rounded; thin-to-very thickly bedded; moderately-to-very well cemented; quartzose, feldspathic, and arkosic**; silty-to-pebbly-sandstone and sandy conglomerate** and minor; thin-to-thick bedded; greyish and blackish **limestone**. Limestones contain a rich assortment of fossils (see below) and sandstones often have leaf fragments that have been altered to limonite. Contacts between beds are generally sharp, rarely with minor scour (less than ~20 cm). Lower contact is sharp, planar (?), and disconformable(?) where overlying Mississippian rocks and unconformable where overlying Proterozoic rocks. Lower contact is mapped at the top of the Del Padre

Sandstone or highest Mississippian carbonate, or at the base of the lowest sedimentary bed where Mississippian rocks are absent. Contact with younger rocks is commonly a fault, but in some cases is depositional. In some places, an originally depositional contact seems to have been faulted, and low angle(?) faulting of depositional contacts with substantial (10's of meters?) relief has produced complex map patterns (see Picuris Formation discussion). Lichen cover generally obscures sedimentary structures in available outcrops. Pebbles in conglomeratic beds are usually granitic and/or quartzite(?). White quartzite pebbles derived from the Ortega Quartzite are difficult to distinguish from vein quartz derived from Proterozoic granites and pegmatites. Conglomeratic parts in the lower part of the unit sometimes contain rare, sometimes banded pebbles of chert that are derived from the limestones of the Espiritu Santo Formation of the APG. Miller et al. (1963; Rio Pueblo section) measured an incomplete section 1756 m (5761.5 feet) thick along the Rio Pueblo at and east of the Commales Campground; they indicate an aggregate thickness of Pennsylvanian strata in this area of ~6000+ feet (1830+m). Pennsylvanian rocks in this area were deposited in the Taos Trough and are one of the thickest Pennsylvanian sections in New Mexico (e.g. Kues and Giles, 2004).

Ppb
Basal sandstone

Mostly white with some yellowish, brownish, and/or reddish/red streaks and staining; very hard; moderately well sorted; angular-to-moderately well rounded; medium-to-thick bedded (?); well-to-very well, silica-cemented quartz **sandstone, pebbly sandstone, and minor breccia(?**). This unit can be difficult to distinguish from the underlying Ortega Quartzite of the Hondo Group as induration is complete and both rock types break across grains (Aby et al., 2004). This unit can also be confused with the Mississippian Del Padre Sandstone as they occupy a similar stratigraphic position and are virtually identical in some hand samples. The basal Pennsylvanian sandstone has slightly more matrix; sparse, altered feldspar grains; generally poorer rounding of grains; and a less diverse range of (diagenetic?) colors than the Del Padre. Lower contact is mapped at the top of Proterozoic rocks. Upper contact is mapped at the top of the highest well-cemented sandstone. Partial removal of Mississippian carbonates regionally makes it likely that the basal Pennsylvanian sandstone directly overlies the Del Padre Sandstone in at least some areas. In such cases the two units would be effectively indistinguishable and the Del Padre sandstone would be included within the basal Pennsylvanian sandstone as mapped.

INTERPRETATION and DISSCUSSION

Undivided Pennsylvanian
(Sandia Formation or Flechado and Alamitos Formations)

Pennsylvanian sedimentary rocks were deposited in response to Ancestral Rocky Mountains (ARM) tectonics modulated by eustatic sea level changes (e.g. Kues and Giles, 2004). Eustatic sea level changes during the Pennsylvanian were of the same scale (i.e. ~100 m) as Quaternary sea level fluctuations (Soreghan and Giles, 1999).

The history of the nomenclature of Pennsylvanian rocks in this area has been somewhat complex (see Kues, 2001; Kues and Giles, 2004 for recent reviews). In the map area, the Pennsylvanian rocks have most recently been assigned to the Sandia Formation (e.g. Soegaard, 1990) or divided into the (lower) Flechado and (upper) Alamitos Formations (Miller et al., 1963). Miller, et al,'s (1963) division of the units was based on "...a significant increase in the percentage of feldspar ...or...by the first appearance of feldspar..." (Miller et al., 1963 p. 30). Due to poor exposure, the identification of a ' significant increase' in feldspar is impractical and was not attempted by Miller et al.(1963). Fekete (1988) examined thin sections from outcrops and from the Salmon Ranch A #1 well east if Mora. He found that the apparent increase in feldspar observed in outcrop is an artifact of diagenetic dissolution of feldspars. When "... secondary porosity created by the dissolution of feldspars and clays filling pores are counted as feldspars." these samples are not significantly different mineralogically from samples higher in the section. In the map area, feldspathic sandstones are found near the base of the Pennsylvanian section. Due to these considerations we have not attempted to map Miller et al's formations but have mapped undivided Pennsylvanian rocks.

During our mapping, we did note that conglomeratic sandstones in the lower part of the Pennsylvanian section often contain <1% dark chert clasts. These clasts sometimes show the banding distinctive of chert nodules derived from the Espiritu Santo carbonates. Unfortunately, this fact was not evident until a substantial portion of the map area had already been examined, and we have not had the opportunity to examine the basal Pennsylvanian on a regional scale. We would suggest that these clasts may provide a means for subdividing this thick sequence of rocks if they do indeed exist on a regional scale. In addition, mapping of the distribution of these chert clasts within the Pennsylvanian rocks may allow for interpretaion of the timing of 'stripping' of Mississippian rocks during the early Pennsylvanian.

The clastic Pennsylvanian rocks of the map area were clearly derived from highlands (the Uncompahgre and/or San Luis highlands) somewhere to the west (e.g. Kues and Giles, 2004) . The exact boundary of these highlands is not well defined due to burial by younger rocks as well as erosion and/or tectonic inversion associated with Laramide and/or Rio Grande Rift tectonism. The Picuris/Pecos fault system seems a likely structural boundary for these highlands, although relatively thin Pennsylvanian strata are known from west of this fault system (Kues and Giles, 2004). Additionally, Black (1984) shows apparently thick 'known Paleozoics' underlying Tertiary rocks in the Espanola Basin west of the Picuris-Pecos Fault although the exact location and thickness of these rocks are not given (due to proprietary considerations).

In the map area Pennsylvanian rocks were deposited in the Taos Trough. This structural basin subsided relatively rapidly and received large amounts of sediment from the adjacent highlands. Sedimentation was often sufficient to keep the basin at or above sea level, but relatively thin limestone beds (~10-20% of section; Miller et al., 1963) indicate frequent transgression of the sea across this area. Correlative rocks to the south (e.g. East of Santa Fe) are a thinner sequence with more limestone and indicate less subsidence there on what has been termed the Pecos Shelf (e.g. Kues and Giles, 2004) .

Ppb

Basal sandstone

The basal sandstone of the Pennsylvanian section of this map has previously been interpreted as an unusually thick part of the Del Padre Sandstone of the APG (Miller et al., 1963). However, fossils found in this section during our mapping of the El Valle Quadrangle (Aby and Timmons, 2004) confirm earlier speculation that these thick deposits are of Pennsylvanian age{Armstrong (1967) as summarized in Chapin (1981)}. Since the Del Padre Sandstone and the basal Pennsylvanian sandstone are easily mistaken for each other, our interpretation of their distribution relies heavily on the presence or absence of the Espiritu Santo Carbonates. An obvious flaw in this interpretation strategy is the differential removal of these carbonates (and the Del Padre Sandstone) prior to Pennsylvanian deposition.

Miller et al. (1963) identified an unusually thick (~50 m) sandstone in Osha Canyon west of the Mica Mine (note that there is another 'Osha Canyon' just west of the Comales anticline) as the Del Padre Sandstone. Based on its thickness and the absence of Espiritu Santo Carbonates in this area we identify this unit as Ppb. The presence of a basal Pennsylvanian sandstone that is nearly indistinguishable from the Del Padre Sandstone indicates that similar conditions obtained during Early Mississippian and Early Pennsylvanian time. Deposition of fairly pure quarts sandstones at these times presumably was related to deep weathering and active transport of sand from the trans-continental arch to the west.

FOSSILS

Fossil collections were made in several locations within the Pennsylvanian rocks (Ppu) with the help of volunteers and specimens were graciously identified by Dr. Barry Kues of the University of New Mexico. These data have only recently been compiled and only preliminary interpretations are presented here. Only Brachiopod species are listed here as these are the type used in age determinations. Volunteer collectors include: Julia Valdez, Christine and Beth Gonzales, Cindy Stone, Mary Pickett, Navarre Frede, Salome Aby, and Lorali Aby.

Site 1

Location: 444730 4003260 (NAD 27 Zone 13S) along Highway 518 approximately 250 m east of the 'Rock Wall'. This site is the same as Sutherland and Harlow's (1973) Locality 56.

Brachiopod Species: *Phricodothyris perplexa*, *Anthracospirifer* sp., *Composita* sp., *Crurithyris*? sp..

Sutherland and Harlow (1973) also identified *Antiquatonia portlockiana*, *Composita “ovata”*, *“Buxtonia”* sp., *Anthracospirifer* cf. *A. curvilateralis chavezae.*

Inferred age: late middle Desmoinesian.

Site 2

Location: 445700 4006740 along logging road parallel to drainage west of Highway 518 southwest of U.S. Hill. Strike of beds is subparallel to road and drainage.

Brachiopod Species: *Linoproductus* cf. p*latyumbonus*, *Antiquitonia* spp. *(*including *A. portlockiana?*, *A.* n. sp. A of Sutherland and Harlow, and *A.* cf. *crassicostata),* *Neospirifer* sp., *Composita subtilita*, *Anthracospirifer “occidentalis”*, *Neospirifer alatus(?)*, *Echinaria* sp., *Echinaria,* cf. *knighti*, *Composita subtilita.*

Inferred age: Most taxa indicate Desmoinesian age but *Antiquatonia* appear to be Missourian so the Desmoinesian/Missourian boundary is probably nearby.

Site 3

Location: 447250 4007085 on north side of hill southeast of U.S. Hill.
Brachiopod Species: *Neospirifer* sp. (*N. cameratus?), Composita subtilita, Antiquitonia* cf. *crassicostatus (?), Linoproductus* cf. *platyumbonus* (of Sutherland and Harlow), *Echinaria semipunctatus(?), Phricodothyris perplexa.*
Inferred age: Missourian

Site 4
Location: 448050 4006550 in road cuts along Forest Road 442. Composite collection from about 250 meters of section.
Brachiopod Species: *Phricodothyris perplexa, Neochonetes* sp., *Chonetinella* cf. *flemingi, Linoproductus* sp., *Composita?* sp., *Neospirifer* sp., *Anthracospirifer* cf. *curvilateralis chavezae, Antiquitonia* n. sp. A of Sutherland and Harlow, *Antiquatonia crassicostata.*
Inferred age: This is a combination of Desmoinesian and Missourian taxa indicating that the boundary is present somewhere in this section.

Mississippian

DESCRIPTION

Arroyo Penasco Group (APG)

The different parts of the Arroyo Penasco Group have been variously subdivided into formations and/or members by different workers (e.g. Baltz and Read, 1960; Miller et al., 1963; Armstrong and Mamet, 1990; Baltz and Meyers, 1999). We use the group/formation divisions of Armstrong et al. (1993). In this scheme the APG consists of two formations: the Early Mississippian Espiritu Santo and Late Mississippian Terrero Formations. The Espiritu Santo Formation is composed of a basal, clastic member (the Del Padre Sandstone) that is overlain and partly interfingers(?) with unnamed marine-to-supratidal(?) carbonates (the Espiritu Santo carbonates). The overlying Terrero Formation is divided into, from bottom to top, the Macho, Turquillo, Manuelitas, and Cowles Members. According to Armstrong and Mamet (1979) and Miller et al. (1963) only the Manuelitas and Cowles Members are present at the ‘Rio Pueblo Section’ north of the Rio Pueblo near the Commales Campground. According to Baltz and Meyers (1999) only the Cowles Member is present in this same section. Although there does not seem to be any agreement between these authors on the field criteria used to map the individual members they do all agree that they each contain limestone, whereas the immediately overlying Pennsylvanian rocks are clastic. In most of the map area exposure is too poor to identify individual members within these formations even if explicit field criteria were available. We have not attempted to map individual members, but have instead distinguished the Del Padre Sandstone from overlying Mississippian carbonates of both the Espiritu Santo and Terrero Formations.

Pmc

Mississippian Carbonates

The Espiritu Santo carbonates are mapped together with the overlying Terrero Formation here due to the thinness of these units, poor exposure, and the disagreements between published descriptions/stratigraphic sections (Miller et al., 1963; Armstrong and Mamet, 1979; Baltz and Meyers, 1999) . Some thin clastic and/or mixed marine/clastic beds within the Terrero Formation may be included. We provide separate descriptions of the Espiritu Santo Carbonates and members of the Terrero Formation based on published material below. The Mississippian section is in need of rigorously explicit mapping criteria and detailed regional correlation.

Terrero Formation

Introduction

The Terrero Formation consists of four members (from oldest to youngest): the Macho, Turquillo, Manuelitas, and Cowles (Armstrong and Mamet, 1987). Only the two upper members (Manuelitas and Cowles) are present in the Rio Pueblo stratigraphic section immediately north and northeast of the Rio Pueblo at the Commales campground according to Armstrong and Mammet (1979) and Miller et al., 1963. Baltz and Meyers (1999) show only the Cowles Member in this same section. We made no attempt was made to map the individual members. Available exposures suggest that the Terrero Formation has been removed in many locations during pre-or-early Pennsylvanian time.

Cowles Member

The Cowles member is composed of silt, calcareous silt, and silty limestone and is up to 18.9 meters thick regionally (Miller et al.,1963; Baltz and Meyers, 1999). In the Rio Pueblo section this member is reported to be either 10.3 m thick (Miller et al., 1963), 2.5 m thick (Armstrong and Mamet, 1979), or ~5 m thick (Baltz an Meyers, 1999). This variation may be the result of slightly different placement of stratigraphic sections (i.e. an actual variation in thickness) or may reflect variations in interpretation of unit boundaries. This unit is found only in the Sangre de Christo Mountains and rests 'paraconformably' on the Manuelitas Member (Armstrong and Mamet, 1979), or directly on the Espiritu Santo Carbonates (Baltz and Meyers, 1999). We map the upper contact of the Terrero Formation (the top of the Mississippian carbonates) at the base of the lowest locally continuous sandstone bed, which we presume to be Pennsylvanian age based on a general lack of sandstone in published descriptions of the upper Terrero Formation (i.e. Miller at al, 1963; Armstrong and Mamet, 1979, 1986, 1993;). In some cases the presence of less-well-recrystalized limestones with visible fossil fragments on fresh surfaces (presumed Pennsylvanian) has also been used to delineate the approximate location of the upper contact of the APG.

Manuelitas Member

Regionally, this unit is composed of 2-6 meters of medium-to-light grey, medium-to-very-thick bedded oolitic limestone (Miller et al., 1963), overlain in places by silty, pelloidal limestone (Armstrong and Mamet, 1987). This unit is 3 meters thick at the Rio Pueblo Section and rests unconformably on the Espiritu Santo Formation here (e.g. Miller et al., 1963).

Espiritu Santo Formation

Espiritu Santo Formation carbonates (late Tournaisian)

Espiritu Santo Formation carbonates are light grey on weathered surfaces and dark grey on fresh surfaces; fine grained (mostly recrystalized); well-to-moderately well sorted; thinly-to-very thickly bedded(?); massive; carbonate cemented **dolomite, dedolomite, and recrystalized limestone** (Armstrong et al., 1993). In the map area dolomite is rare. Large (~5 to 70 cm), generally dark (black, grey, whiteish and rarely brownish), banded chert nodules and irregularly shaped layers are distinctive. Weathered surfaces show numerous-to-rare shell fragments while fossil fragments are rarely visible on fresh surfaces. This member lies disconformably on the Del Padre Sandstone. The lower contact is mapped at the lowest limestone (non-sandstone) bed. The upper contact of the Mississippian carbonates (Espiritu Santo Carbonates + Terero Fm.) is not exposed in the map area. We have mapped the approximate upper contact above the highest limestone (or float thereof) and/or at the base of the lowest presumed Pennsylvanian sandstone bed (see below). In some cases the upper contact has been inferred from the apparent local thickness of the combined Mississippian carbonates.

"Where the rocks are not dolomitized, features such as microbial-stromatolitic mats, spongistromata mats, echinoderm wackestone, kamaenid birds-eye-rich lime mudstone, and oncholitic-bothrolitic mats are recognizable." (Armstrong et al., 1993). This member has some interbedded clastic layers, most(?) of which are "… identical in character to the underlying Del Padre Sandstone." (Miller et al., 1963). These layers have led to the interpretation that the Espiritu Santo Carbonates are, at least in part, laterally equivalent to the Del Padre Sandstone. Some parts of the Espiritu Santo carbonates are sandy limestone and/or calcarenite (Baltz and Meyers, 1999).

In the Rio Pueblo section of Miller et al (1963), Espiritu Santo carbonates are ~14 m thick (Miller et a., 1963, Armstrong and Mamet, 1979). These carbonates can be traced for approximately .7 km to the south on the east side of the 'Commales anticline' (our informal name) in float and small exposures. To the south of this point limestone is seen only intermittently in float and we infer that it has been removed in many places by erosion and/or dissolution sometime prior to Pennsylvanian deposition.

The banded chert nodules of the Espiritu Santo carbonates can be identified as pebbles in some conglomeratic sandstones of the Pennsylvanian section. Their presence there further indicates erosion of Mississippian rocks prior to and during Pennsylvanian time. Chert (and limestone) boulders are also present in the Macho Member of the Terrero Formation (Miller et al., 1963). The macho Member is thought to be a collapse breccia (Armstrong and Mamet, 1987); it is absent in the map area. Dissolution and/or erosion of the Macho Member may also have contributed recycled banded chert clasts to the lower part of the Pennsylvanian section. Espiritu Santo carbonates (and limestones of the Terrero Fm.?) are generally thicker-bedded, more massive, more recrystallized (fossil fragments are usually only visible on weathered surfaces where they have partially eroded out) and darker colored on fresh surfaces than Pennsylvanian limestones in this area.

Pmd

Del Padre Sandstone Member (late Tournaisian)

The Del Padre Sandstone Member of the Espiritu Santo Formation is a white, tan, yellowish, green, red, and/or mottled; fine upper-to-very coarse upper; strong-to-very strong; moderately-to-very well sorted; well rounded-to-subangular, thinly-to-very thickly bedded; (mostly) horizontally laminated-to-low angle crossbedded; quartz-overgrowth cemented **sandstone, pebbly sandstone, sandy conglomerate, and minor breccia(?)**. Contacts between beds are generally sharp and parallel although minor (<20 cm) scour is seen locally. Jointing is prominent in much of this member. In the Rio

Pueblo section this member is either ~19.5 m (Miller et al., 1963), ~17 m (Armstrong and Mamet, 1979) or ~8 m (Baltz and Meyers, 1999) thick. We did not measure our own section of the Del Padre, but our mapping suggests that the higher estimates are closer to the observed thickness. Exposure quality is good relative to other Paleozoic rocks (due to induration) but is variable in general. Even where exposure is relatively good, lichen cover commonly obscures sedimentary features and/or bedding in all ages of rocks. This member unconformably overlies Proterozoic rocks in much of the Sangre de Christo Mountains of northern New Mexico (e.g. Armstrong and Mamet, 1979). Miller et al. (1963) noted an unusually thick (~50 m) section of Del Padre Sandstone in Osha Canyon just west of the mica mine in the western part of the quadrangel. However, another of the unusually thick "Del Padre" exposures noted by them has recently been shown to contain Pennsylvanian fossils (Aby, Cather, Timmons and Hallet, 2004; Cather , et al., 2007). The exposures in Osha Canyon are therefore mapped as 'basal Pennsylvanian sandstone' by us here (see below). In areas of poor exposure, distinguishing the Del Padre Sandstone from the basal Pennsylvanian sandstone is likely impossible and the two are probably superimposed in some areas. We map the basal contact of the Del Padre at the lowest identifiable clastic beds. This designation can be subjective where the Del Padre overlies the Ortega Quartzite as this Proterozoic unit sometimes retains a granular texture and bedding in the Del Padre is apparently parallel to f1 foliation (bedding?) in the Ortega in at least some places. The upper contact is mapped at the top of the highest strongly cemented sandstone bed. We have relied heavily on the presence or absence of the Espiritu Santo carbonates in distinguishing the Del Padre Sandstone from the basal Pennsylvanian sandstone.

INTERPRETATION

Our interpretation of the Arroyo Penasco Group (APG) comes mainly from published, regional investigations. Armstrong et al.(1993, 2004) indicate a maximum, regional thickness for the Del Padre Sandstone of ~6m. However, the Rio Pueblo section exposes ~19.5 meters of this unit according to Miller et al.(1963), ~15 m according to Armstrong and Mamet (1979), and ~8 m according to Baltz and Meyers (1999). Espiritu Santo carbonates are ~13-14 m thick at Rio Pueblo (according to all authors), and this represents the thickest surface outcrop measured by Miller et al., (1963). Subsurface carbonates of the Arroyo Penasco Group, on the other hand, are up to ~180 m thick near the Texas/New Mexico boarder in Union County, NM; up to 60 m thick between Santa Rosa and Tucumcari; ~30 meters thick along the eastern side of the Sangre de Christo Mountains; and are absent elsewhere in the subsurface of northeastern New Mexico (Roberts et al, 1976). It is not explicitly stated by Roberts, et al (1976) that the Del Padre Sandstone is absent from the subsurface of Northeastern New Mexico, but only carbonates are shown in their map of 'pre-Pennsylvanian' rocks (Roberts et al., 1976, fig. 3). Baltz and Meyers (1999) do indicate that "...the Arroyo Penasco Group, probably including both formations, is present...east and northeast of Mora." but do not explicitly identify the Del Padre Sandstone there.

Overall, the pattern of deposition and thickness data suggests deposition of the APG during a tectonically inactive period (Armstrong et al., 1993; Pazzaglia et al., 1999) and transgression of the sea across a regional peneplane from the south and east

(Armstrong et al., 2004). The fact that the Del Padre Sandstone is thickest in the map area may be related to the proximity of the Picuris Pecos Fault System (Bauer and Ralser, 1995) or simply to 'random' variations in sedimentation and/or erosion. ‘Vertical fractures’ confined to the Espiritu Santo Formation carbonates and truncation of the upper contact of this unit indicate some deformation prior to Pennsylvanian-age deposition (Miller at al., 1963).

The original distribution of the APG was partly controlled by the topography of the ‘Trans-Continental Arch’ (e.g Armstrong et al., 1993). The present distribution seems to be controlled by crustal deformation and erosion during Late Mississippian to Early Pennsylvanian time (e.g. Armstrong et al, 1993) as well as later orogenesis (i.e Ancestral Rocky Mountain, Laramide, and Rio Grande Rift deformation) and erosion.

The APG was deposited in response to transgressions and regressions of the sea, possibly modulated by regional orogeny (e.g. Antler orogeny). Early Mississipian regression produced the ‘great’ unconformity beneath the APG. The textural and mineralogical maturity of the Del Padre Sandstone suggest reworking of deeply weathered Proterozoic and/or early Paleozoic rocks during subsequent transgression(?). Most sand in the Del Padre Sandstone is moderately-to-well rounded but some very well rounded sand (e.g in the Rio Pueblo section) may reflect eolian input. Transgression during early Mississippian time (coincident with the Antler Orogeny to the west) lead to deposition of the Espiritu Santo Formation. Regression lead to some alteration of these rocks by karst processes. In the map area, the Macho Member of the Terrero Formation may have deposited and then completely eroded and/or dissolved away as the Macho Member is found to the north and south (Miller et al., 1963). The final transgression(s) and regression(s) of this sequence lead to deposition and/or erosion of the Manuelitas and Cowles Members (Armstrong and Mamet, 1990). All of these changes of relative sea level are apparently inferred from the interpretation of regional stratigraphy and we are not aware of any correlation to specific, documented sea-level 'events'. These transgressions and regressions may therefore be attributed to either global eustatic changes and/or the distal effects of orogeny.

During Mississippian deposition the map area was in the equatorial region (e.g Kues and Giles, 2004, Stanton et al., 1988). Studies of carbonate mineralogy and biofacies comparisons in southern New Mexico have lead to interpretation of a temperate climate at this time (Fagerstrom, 1988). More recent isotopic studies have indicated a tropical climate (Stanton, et al., 2002). Neither study appears conclusive by itself.

Banded chert pebbles found in Pennsylvanian conglomerates/sandstones and derived from the Espiritu Santo Formation indicate that these rocks were deformed and eroded before and during the early part of Pennsylvanian deposition. Late Mississippian and early Pennsylvanian deformation is also indicated by the uneven removal of Mississippian rocks from northern New Mexico prior to Pennsylvanian deposition. This period coincides with the Ouachita orogeny in Texas (Kues and Giles, 2004), and it may be presumed that erosion at that time was in response to that event.

Deformation

LARAMIDE DEFORMATION

We presume that most folding of Paleozoic strata is due to Laramide tectonics that affected this area from ~80-36 Ma (Cather, 2004) as we know of no other major compressional tectonics in this area. Laramide deformation is affected in the map area by the presence of the Picuris-Pecos fault system which seems to have a Proterozoic-to Neogene history (Bauer and Kelson, 2004). Several faults of the Picuris-Pecos System have been named (Bauer and Kelson, 2004) and mapped to the north on the Ranchos de Taos Quadrangle (Bauer, et al., 1999). Although these faults clearly offset post-Laramide rocks (Picuris Formation), it is believed that at least some of them are reactivated Laramide structures (Bauer and Kelson, 2004). Most of these faults are shown bending to the west at the southern end of the Ranchos de Taos Quadrangle and they seem to converge in a structurally complex area in the northwestern corner of the Tres Ritos Quadrangle. Exposure is too poor here to resolve the precise location or nature of the many faults that apparently exist in this area (both Laramide and 'Rift-related'). South of this area the named faults of the Picuris-Pecos System are not apparent, and Proterozoic/Paleozoic contacts are not mappably offset.

The area north of the mica mine (in Section 24 and 25 T23N:R12E) is apparently composed of a set of east-west trending folds. The mica deposit itself (and associated Proterozoic units) is bunded by faults on at least two sides. Our interpretation of these faults as thrusts is somewhat speculative and is based on their association with and orientatin subparallel to the above mentioned folds. The area near the mica mine seems to be structurally high relative to the areas to the north and south based on the near complete absence of the Picuris Formation. Mappable faults south of the mica mine offset the post-Laramide Picuris Formation but may be reactivated Laramide structures. Sparse, small outcrops of Paleozoic rocks south of the Rio Pueblo along the western part of the map area do not preclude the presence of faults of the Picuris-Pecos system in this area. Bedding attitudes suggest that this entire area forms the western limb of the Comales anticline. However, since post-Laramide units are also tilted to the west here, some cryptic structure related to the Picuris/Pecos Fault System is probably also involved.

The Comales anticline itself has been suggested to be the northern extension of the Jicarilla fault (Miller et al., 1963) which places Proterozoic rocks over Paleozoic strata near the Truchas Peaks. The presence of Mississippian rocks around the margin of the Proterozoic rocks exposed in the core of this anticline indicate that the edges of this structure are not faulted. The dotted (inferred) part of the Del Padre Sandstone on the west side of this anticline (beneath the 'bed' of *this* Osha Canyon) may in fact be absent. If this is the case then some faulting may have occurred here.

Outcrops are rare north and east of the core of the Comales anticline, but this general structure seems to extend at least one mile north of the Rio Pueblo and as far east as the prominent 'dogleg' in the Rio Pueblo in the southeast corner of section 15 T22N:R13E. Just east of this 'dogleg' is a zone of complex deformation at many scales. Miller et al. (1963) mapped a 'poorly exposed, high-angle reverse fault' in this zone near the mouth of the Rito Sandoval. Paleozoic strata in this area are apparently composed of sandstone, shale, and limestone units between 15(?) and 50(?)m thick. This repetition of rock types may obscure structures here, but sandstone and limestone layers seem to cross the Rito Sandoval (and the trace of the fault mapped by Miller et al.) without major offset.

Miller et al. (1963) interpreted meter-scale folds in limestone east of Rito Sandoval (and visible looking north from the entrance to the Agua Piedra Campground) as 'drag folds'. Although we agree that a zone of relatively intense (or just well-exposed?) deformation exists in this area, we believe the folding seen is best explained as 'parasitic' folds caused by the variable rigidity of the different rock types (e.g. Limestone vs. shale). The prominently folded limestones also show small-scale (<1m), east-verging thrust motion along some fold axis. The trend and plunge of twenty-four fold axis in these outcrops were measured. Fold axis trend between 348 and 60 degrees (average ~12 degrees) and plunge between 0 and 22 (average 7) degrees with subequal numbers plunging north and south. These fold axis roughly parallel the axis of the Comales anticline, suggesting that they formed at the same time. Although exposures are rare north of the Rio Pueblo, rare road cuts in abandoned logging roads sometimes show similar meter-scale folds, and we presume that this type of deformation is found throughout this area.

A relatively thick section dominated by sandstone is present immediately west of this area and is well exposed along the north-south trending part of highway 518 from the dogleg to the Flechado campground. This relatively rigid rock forms the east edge of the mappable Comales anticline and may have acted to concentrate deformation to the east.

RIO GRANDE RIFT DEFORMATION

Deformation associated with development of the Rio Grande Rift is currently thought to have begun ~28 Ma based on extrusion of mafic magma at this time (e.g. Smith, 2004 and references therein). Cather (2004) indicates that Laramide deformation ended by ~36 Ma and 'incipient extension' may have occurred after this time. These constraints would allow for some deformation of the lower conglomerate member of the Picuris Formation by 'incipient extension', but the other members of this Formation can only have been deformed during Rio Grande Rifting proper. No good exposures of rift-related faults have been found, but their presence can be inferred from outcrop patterns and very small exposures of highly-weathered rock and/or gouge near some contacts. The faults thus inferred have a wide range of orientations. Westward tilting of the Picuris Formation and underlying Paleozoic rocks at the Rock Wall is apparently caused by an unexposed fault of the Picuris-Pecos Fault System west of this Quadrangle, but this tilting is consistent with the dips produced on the west limb of the Comales anticline south of the Rio Pueblo. These relations present an intriguing puzzle, as the Picuris Formation cannot have been deformed by the Laramide tectonics that are presumed to have created the Comales anticline.

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