Geologic Map of the McCartys 7.5-Minute Quadrangle, Cibola County, New Mexico

By

Colin T. Cikoski[1], Paul G. Drakos[2], and James W. Riesterer[2]

[1] New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801

[2]Glorieta Geoscience, Inc., P.O. Box 5727, Santa Fe, NM 87502-5727

June, 2017

New Mexico Bureau of Geology and Mineral Resources
Open-File Geologic Map OF-GM 265

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement G16AC00287 and the New Mexico Bureau of Geology and Mineral Resources.

New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

Table of Contents

1. Introduction

1.1. Geologic and geographic setting

The McCartys quadrangle lies a few kilometers (km) east-southeast of the town of Grants along I-40 in northwestern New Mexico. Over half the quadrangle lies on Pueblo of Acoma land, while the remainder is a mix of private ranch land, BLM, and minor state of New Mexico land. The Rio San Jose river valley roughly bisects the quadrangle along an east-west transect. The northeast quarter of the quadrangle lies mainly on the broad, low-relief southern piedmont of Mount Taylor, and is traversed south-southeastward by Rinconada Creek. The northwest quarter of the quadrangle is dominated by Horace Mesa, a broad "prong" of the Mount Taylor highland capped by Plio-Pleistocene basalt flows. The south half of the quadrangle consists of low sandstone-capped mesas separated by broad alluvial valleys. Elevations ranges from about 1,854 meters (m) above mean sea level (amsl) where the Rio San Jose exits the quadrangle to a high of about 2,336 m amsl on Horace Mesa.

Geologically, the quadrangle lies in the Acoma Sag section of the Colorado Plateau along the eastern limb of the McCartys syncline (Woodward, 1982), along or just south of the Jemez lineament and to the south of the Mount Taylor volcanic field and east of the Zuni-Bandera volcanic field. The majority of the quadrangle is underlain by clastic Mesozoic strata capped by a variable thickness of Pliocene to Holocene basalts and Quaternary alluvial cover. Structural relief is generally low.

1.2. Previous work

Early studies concerning the McCartys area include the reconnaissance work of Dutton (1885) and mapping of the Mount Taylor coal field by Hunt (1936). A concerted geologic mapping and stratigraphic study effort was performed in the 1960's through 1980's by the United States Geological Survey (USGS) in support of uranium resource development. Maxwell (1977) mapped the McCartys quadrangle during this period, utilizing the stratigraphy established previously by Dutton, Hunt, and mappers on surrounding quadrangles as well as by new research by Landis et al. (1973). Hook et al. (1983) and Molenaar (1983) would subsequently further refine the Cretaceous stratigraphy above the Dakota Sandstone.

Largely simplified in earlier geologic studies, the Cenozoic section received renewed interest in the 1980's and 1990's as a part of larger-scale studies of the volcanic and landscape history of the Mount Taylor and Zuni-Bandera areas (e.g., Drakos et al., 1991; Laughlin et al., 1993). Refinement of this chronology continues sporadically to this day (e.g., Cascadden et al., 1997; Channer et al., 2015; Dunbar and Phillips, 2004; Goff et al., 2015; Laughlin and WoldeGabriel, 1997).

More recent geologic mapping efforts by the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) concentrated on the Mount Taylor area (synthesized by Goff et al., 2015) and subsequently proceeded down the Rio San Jose from Grants. This report synthesizes these previous studies with original geologic mapping from the 2015-17 seasons to provide an up-to-date geologic product for the McCartys quadrangle.

1.3. General terminology notes

Geologic terms are after Compton (1985), soil terms after Birkeland (1999), carbonate horizon stages after Gile et al. (1966) and Machette (1985), and color notation after Munsell Color (2009). Coordinates are given in Universal Transverse Mercator (UTM) coordinates after the NAD83 Zone 13S datum.

1.4. Acknowledgements

We thank J. Michael Timmons, Geologic Mapping Program Manager at the NMBGMR, and the USGS STATEMAP program for funding to conduct this study. We thank the Governor and Council of the Pueblo of Acoma for permission to work on pueblo lands. Steve Juanico (Water Rights Office), Franklin Martinez (Department of Natural Resources), and Emilio Torivio (Department of Natural Resources) were instrumental in obtaining permission to work on Pueblo of Acoma lands. We also thank Chris Gutierrez, manager of the Diamond G Ranch, for permission to work on his ranch lands. Cartography was provided by the NMBGMR map production group, coordinated by Phil Miller. Stereonet figures were generated using Stereonet 8 by R. W. Allmendinger and N. C. Cardozo (Allmendinger et al., 2012; Cardozo and Allmendinger, 2013).

2. Middle-Late Cenozoic Geology

2.1. Alluvial deposits

Mapping of surficial deposits follows the style and terminology developed by Grimm (1983), Drakos et al. (1991), Osburn et al. (2009), and Cikoski et al. (2016). Quaternary sediments include fluvial terrace, alluvial fan deposits, and valley floor alluvium. Quaternary deposits contain a predominance of volcanic clasts of mixed lithologies, secondary Cretaceous sandstone clasts, and minor chert pebbles. Fan units Qf1-Qf4, mapped in the northeastern part of the Quadrangle and north of the Rio San Jose, form the distal part of a fan complex at the mouth of canyons draining the south side of Mt. Taylor, including Rinconada Canyon on the McCartys Quadrangle. Deposition of the Water Canyon fan east of the McCartys Quadrangle, which began by early Pleistocene time (correlative fine-grained deposits exhibit reversed polarity; Drakos et al. (1991)), record incision into the volcanic edifice, erosion of the amphitheater on Mt Taylor, and episodic piedmont aggradation, incision, and stabilization (Drakos and Riesterer, 2013). The piedmont has been extensively dissected since initial fan deposition, therefore Qf1 and Qf2 surfaces are preserved as relatively small remnants. Qf1 deposits underlie fan surfaces 30 to 35 m above local base level west of Rinconada Creek and are approximately 13 m thick with a basal contact on the Twowells Tongue of the Dakota Sandstone (map unit Kdt). Qf2 deposits are up to 8 m thick and include a partially stripped surficial soil with an A-Btk-Bk profile, buried soils, and multiple depositional units, indicating deposition over a relatively long time period (FIGURE 3-1). Qf3 is preserved as a single isolated fan remnant within the McCartys Quadrangle west of Rinconada Creek. Much of the modern piedmont in the distal part of the fan complex is composed of Qf4 surfaces. Qf4 deposits exhibit weakly developed soils indicating a likely Holocene age for this deposit (FIGURE 3-2). Aggradation of the modern piedmont including Qf4 is likely a result of aggradation along the Rio San Jose valley associated with eruption of the 0.38 to 0.128 Ma Laguna flow (Lipman and Menhert, 1979; Champion et al., 1988) and the 0.325 Ma Laguna Pueblo flow (Channer et al., 2015), which flowed eastward down the Rio San Jose drainage from the Zuni-Bandera volcanic field to the west.

Deposits underlying terrace surfaces along Rio San Jose are preserved as isolated erosional remnants along the modern Rio San Jose drainage. Qt1 (not preserved as a mappable unit on the McCartys Quadrangle) includes axial Rio San Jose gravel and tributary gravel facies approximately 7 m thick, and overlies the Cubero Sandstone Tongue of the Dakota Sandstone (map unit Kdc) on Woods Mesa south of the Rio San Jose on the adjacent Cubero Quadrangle. Qt2 is a strath terrace approximately 6.5 m thick with local channels up to 10 m thick comprising sandy gravel deposits overlying the Paguate Tongue (Kdp) north of the Rio San Jose. Qt3 includes two small erosional remnants overlying the Cubero Tongue of the Dakota Sandstone and the Mancos Shale.

Valley floor alluvium in tributary drainages is composed primarily of fine-grained sand, silt and clay with gravel lenses, weakly-developed surficial soils, and buried soils distinguished primarily by A horizon development (FIGURE 3-3). Thickness of various alluvial deposits, based on well log data (Risser and Lyford, 1984) and outcrop descriptions ranges from 5-20 m in tributary drainages to 30 to 50 m under the Rio San Jose valley floor. Rio San Jose alluvium includes coarse-grained sandy gravel sections and is interbedded with a 12 m to 18 m thick basalt flow (likely the Laguna Pueblo flow; cf., Channer et al., 2015), encountered 6 m to 25 m below the valley floor (Risser and Lyford, 1984).

The fan and terrace units described above are not present south of the Rio San Jose on the McCartys Quadrangle. Unit Qpal likely represents an early Pleistocene pediment deposit derived from source areas to the south. Lumber and Conejo Canyons appear to have eroded along predominant east- and northeast-oriented fracture sets in the Twowells and Paguate Tongues of the Dakota Sandstone (**FIGURE 3-4**). Arroyo incision into canyon floors tributary to the Rio San Jose is recent (less than 100 years old), as shown by juniper trees now suspended on root pedestal above the modern arroyo floor (**FIGURE 3-5**). Slopes below mesa tops are commonly mantled by slopewash deposits (unit Qasw), which are up to 6 m thick and exhibit a well-developed carbonate horizon (**FIGURE 3-6**), indicating deposition over a relatively long time period of as much as 100,000 years.

The Pliocene and Quaternary deposits and associated geomorphic surfaces in the Mt. Taylor area record a history of long-term incision interrupted by periods of deposition and formation of geomorphic surfaces during times of base level stability. In contrast to the overall Pliocene-Quaternary history, the late Quaternary has been characterized by alternating periods of erosion and deposition. Approximately 200-300 m of incision into the Pliocene pediment surface underlying the high basalts along the southern flank of Mount Taylor has occurred between 2.5 Ma and the present time, likely in response to regional uplift (cf., Drakos et al., 1991). Periods of erosion and deposition during the late Quaternary are likely in response to climatic fluctuations, continued regional uplift, and/or episodic volcanism in the Zuni-Bandera volcanic field periodically blocking drainages (Drakos and Riesterer, 2013).

2.1.1. Soils

The semiarid climate of the Grants-Laguna area and the regional carbonate dust influx has favored the development of carbonate soils. Soils were described based on methods described in Birkeland (1999). Carbonate morphology and Bt horizon development are the morphologic characteristics which best distinguish soils in the Grants-Laguna area. Carbonate soils in the study area and the adjacent Cubero Quadrangle (Cikoski et al., 2016) exhibit Stage I through III carbonate morphology (terminology after Gile et al. (1966) and Machette (1985)). Colors range from 5YR to 2.5Y, soil structure ranges from massive to strong subangular blocky or prismatic, and clay film morphology ranges from absent to thin, with common coatings on ped faces.

2.2. Igneous Geology

Exposed within the McCartys quadrangle are Plio-Pleistocene basalts of the Mount Taylor volcanic field, Pleistocene-Holocene basalts of the Zuni-Bandera volcanic field, a late Oligocene dike, and several undated dikes likely associated with one or more of these igneous periods.

The oldest exposed igneous rock is the Acomita dike (unit Tbda) of Laughlin et al. (1983), a north-northwest-trending basaltic andesite dike that can be followed for approximately 10 km across this quadrangle and into neighboring quadrangles. On the McCartys quadrangle, it is aphanitic to weakly porphyritic, with rare fine (commonly <1 mm across) phenocrysts of fine plagioclase and lesser pyroxene. Very locally, megacrysts (or xenocrysts or crystal aggregates) of plagioclase up to 1 cm across, anhedral, rounded, and oblate in shape, are found. The dike is generally poorly exposed, forming rounded ridges in the southern and central portions of the quadrangle, and only locally cropping out in the northern part of the quadrangle in Tafoya Canyon. Where exposed, the dike is commonly strongly jointed. Where the dike is thin, the jointing is principally subvertical or steeply-dipping and parallel to dike margins; where thick, the jointing is commonly perpendicular to dike margins and columnar, and likely related to cooling.

Locally, thin sills extend out from the dike margins into surrounding wall rock units, usually where intruding shales. Aldrich et al. (1986) report a K-Ar age of 30.7 ± 1.4 Ma for the dike (**Table 1**). Mesozoic strata are offset down-to-the-southwest by up to about 8 m across the dike, indicating the dike collocates with a fault. Offset is apparent across nearly the entire extent of the dike within the quadrangle. It is not clear the relative timing of slip and dike intrusion.

Plio-Pleistocene basalts associated with the Mount Taylor volcanic field, located mainly to the north of the quadrangle, cap Horace Mesa in the northwest quarter of the quadrangle. Extensive $^{40}Ar/^{39}Ar$ dating by Goff et al. (2015) indicate the field as a whole extends from the Lower Pliocene into the Lower Pleistocene. Within the McCartys quadrangle, the basal flow in the southeast corner of Horace Mesa has been dated twice, to 2.72 ± 0.1 Ma by the $^{40}Ar/^{39}Ar$ method (Channer et al., 2015) and to 3.24 ± 0.17 Ma by the K-Ar method (Laughlin et al., 1993; **Table 1**), placing the lowest flow on Horace Mesa in the Upper Pliocene; the upper flows have not been dated.

Up to three flows may be distinguished beneath Horace Mesa based on flow breaks. However, the lower two are identical in texture and mapped together (unit Tbp). The lower two, plagioclase-pyroxene porphyritic flows only crop out along the southeastern portion of the on-quad Horace Mesa, as well as beneath a nearby, unnamed mesa to the east. In one location along the eastern flank of Horace Mesa (approximately 253940 m E, 3888690 m N), a buttress unconformity is exposed separating the basalt from Cretaceous strata, with a strike of N40E and dip of 68° to the SE. The restricted extent of the flows and exposed steeply-dipping buttress contact suggest the flows filled a paleocanyon carved into the underlying Cretaceous strata. The upper, mainly aphanitic flow (unit QTbf) is more extensive, capping most of Horace Mesa and the adjacent unnamed mesa. A roughly circular break in the basalt occurs around 253180 m E, 3888060 m N, where Cretaceous strata occur at the surface underlying a topographic basin. This break is inferred to have been a topographic high during the eruption of QTbf, causing the flow to divert around this area. Subsequent erosion preferentially removed the softer Cretaceous strata, eroding the former hill or cuesta to a basin. Basalt flows are cut by northeast-trending normal faults with up to about 50 m of offset.

Basalts of the Zuni-Bandera volcanic field are represented at the surface by the El Calderon (Qbc) and McCartys (Qbm) flows (names after Maxwell, 1986), which can be followed westward up the Rio San Jose valley then southward into the El Malpais to centers to the southwest of the quadrangle. Each is weakly porphyritic, bearing fine phenocrysts of olivine and pyroxene. The younger McCartys flow is largely exposed with primary flow features well-preserved, while the older El Calderon flow is blanketed by a variable thickness of eolian and alluvial sediments. Both have been the subject of multiple attempts at age dating. The age of the McCartys flow is well-constrained to 2.4 to 3.9 ka (Laughlin et al., 1994; Dunbar and Phillips, 2004; **Table 1**), while the age of the El Calderon flow is less well-constrained, with accepted estimates between 34.7 and 128 ka (Champion et al., 1988; Laughlin et al., 1993; Cascadden et al., 1997; Dunbar and Phillips, 2004; **Table 1**). In addition to these flows at the surface, at least one basalt flow is commonly encountered in wells drilled along the Rio San Jose between the El Malpais and the town of Laguna (cf., Risser and Lyford, 1983, 1984). Channer et al. (2015) obtained $^{40}Ar/^{39}Ar$ ages on Zuni-Bandera basalts at the surface and from dill holes, and acquired nearly-identical ages for the Laguna Pueblo flow cropping out by the town of Laguna (322 ± 1 ka) as for a basalt encountered in a drill hole drilled in the Rio San Jose valley just west of the quadrangle boundary (325 ± 4 ka). Based on this observation, it is plausible that the basalt occurring in the subsurface intercalated into Rio San Jose alluvium is the Laguna Pueblo flow (Qblp, shown on cross-section A-A').

Finally, several thin, variably plagioclase-pyroxene±olivine porphyritic dikes (QTbpd) occur in the southeastern corner of the quadrangle. These dikes are west-northwest- to north-northwest-trending, and could be associated with emplacement of the Acomita dike, or could be radial dikes extending outward from the Mount Taylor volcanic field.

3. Cretaceous geology

We reviewed the history of the Cretaceous stratigraphy in this general region in our report on the geology of the Cubero quadrangle (Cikoski et al., 2016), and more detail on the stratigraphy can be found there. In a very broad sense, the Cretaceous system consists of interbedded sandstones, shales, lesser mudstones-siltstones, and a few limestones associated with the Western Interior Seaway. The Cretaceous section is capped by a substantial unconformity, and no rocks younger than the Crevasse Canyon Formation are preserved on this quadrangle.

3.1. Mancos Shale

The Mancos Shale in this area consists of multiple tongues of poorly-exposed gypsiferous shales with rare sandy shales and trace sandstones, limestones, and sparry gypsum beds. The Mancos intertongues with all the other Cretaceous units. Nomenclature is based largely on stratigraphic location, and is after Hunt (1936), Landis et al. (1973), and Hook et al. (1983). We additionally employ an undivided upper Mancos Shale unit (Kmu) in the poorly-exposed hills along Rinconada Creek, where stratigraphic location is unclear.

Most tongues consist of gypsiferous shales with lesser siltstones and absent to rare sandy shales, overlying a sharp basal contact with an underlying sandstone unit and grading upsection into an overlying sandstone unit. Exceptions to this description are the Bridge Creek Limestone beds of the Rio Salado Tongue (unit Kmb), Semilla Sandstone Member (Kms), and Mulatto Shale Tongue (Kmm). The Bridge Creek Limestone beds (after Hook et al., 1983) consist of interbedded shales, limy shales, and fine-grained carbonate grainstones and packstones, which weather to a distinct pale yellowish brown color (2.5Y 7/1 and 8/2-8/3 measured) that can often be used to map the unit through poorly-exposed slopes. Limestones and limy shales are thickly laminated to thinly bedded, weathering to a platy residuum that is also distinctive. As used on this quadrangle, the Bridge Creek Limestone map unit includes all shales between the top of the Twowells Tongue of the Dakota Sandstone (Kdt) and the uppermost Bridge Creek bed.

The Semilla Sandstone Member (after Dane et al., 1968) consists mainly of concretionary shales with rare, thin sandstones. The sandstone beds are muddy, very fine- to fine-grained, and commonly internally planar- or cross-laminated. Sandstone bed thickness and abundance increase upsection, with the top of the unit consisting of a 2-m-thick, laterally-extensive interval of thinly-bedded sandstones. Underlying sandstone beds are typically lenticular, discontinuous, and often no more than a few centimeters thick. Shales associated with these sandstones bear roughly spherical calcareous concretions up to 70 cm in diameter, in an abundance and size not seen in the remaining Mancos Shale units. Similar concretions were described by Dane et al. (1968) and Fleming (1989) for the shales of the Semilla Sandstone Member in other locations, and this may to be a regionally-common distinguishing feature. As a map unit, the Semilla Sandstone Member extends from the lowest Semilla sandstone bed to the highest Semilla sandstone bed, including all intervening shales, between the top of the Twowells Tongue of the Dakota and the base of the “F” tongue of the Gallup Sandstone (Kgf). The Juana Lopez Member, which overlies the Semilla Sandstone further east (C.T. Cikoski, Laguna quadrangle geologic mapping, in progress), was not recognized on this quadrangle.

The Mulatto Shale Tongue (after Hunt, 1936) intertongues with the Crevasse Canyon Formation, and contains notably more sandy mudstones and sandstone relative to underlying Mancos tongues. Thin beds of muddy sandstone are a major component of the map unit. As mapped, the unit includes all interbedded shales and sandstones between the thick sandstone intervals of the Borrego Pass Lentil (Kcb, below) and Dalton Sandstone (Kcda, above).

The undivided shale unit Kmu, used along Rinconada Creek, likely includes strata at least in part equivalent to the Whitewater Arroyo and Rio Salado Tongues of the Mancos, including the Bridge Creek Limestone beds, and possibly includes thin equivalents of the Twowells Tongue of the Dakota Sandstone. This map unit is only used where a lack of exposure precludes a more precise unit assignment. Correlation to the aforementioned Mancos tongues and Twowells Tongue is based on the elevation range across which the Kmu map unit occurs and exposures at the base of Horace Mesa along the west flank of the Rinconada Creek valley.

3.2. Crevasse Canyon Formation

The Crevasse Canyon Formation consists of the interval of dominantly non-marine sedimentary rocks between the underlying Gallup Sandstone and the overlying Point Lookout Sandstone (Allen and Balk, 1954; the latter unit does not occur on this quadrangle). It is subdivided here after Sears (1925), Sears et al. (1941), and Allen and Balk (1954), with the addition of the Borrego Pass Lentil of Correa (1970), which was formerly referred to informally as the “stray” sandstone.

In a broad sense, the Crevasse Canyon Formation consists of interbedded sandstones, mudstones, shales, and local coal seams that here constitute a transgressive-regressive sequence. In ascending order, the sequence consists of the heterolithic Dilco (Coal) Member, sandstones of the Borrego Pass Lentil, shales of the Mulatto Tongue of the Mancos Shale, sandstones of the Dalton Sandstone, and finally the heterolithic Gibson (Coal) Member. The heterolithic members (Dilco, Gibson) consist of interbedded siltstones, shales, sandstones, and local coal seams. Sandstone-dominated members (Borrego Pass, Dalton) consist of very fine- to medium-grained, cross-stratified, quartz-rich sandstones with trace siliceous pebbles. The Borrego Pass and Dalton commonly form continuous sandstone cliffs or ledges that can be mapped through the landslide blocks and colluvium on the flanks of Horace Mesa. In contrast, the Dilco and Gibson Members, as well as the Mulatto Tongue, are poorly-exposed and commonly buried by colluvium. Their locations are often inferred from mapping of the Borrego Pass and Dalton.

The basal contact with the underlying “C” tongue of the Gallup Sandstone is sharp. The upper contact is not exposed on this quadrangle.

3.3. Gallup Sandstone

The Gallup Sandstone here consists of multiple tongues of dominantly marine sandstone that intertongues with the Mancos Shale. Molenaar et al. (1996) measured numerous sections throughout the San Juan basin, and based on this work proposed a set of regional correlations that distinguish six sandstone tongues, referred to by letters A through F, with A as the youngest and F as the oldest. Based on sections presented from the vicinity of this quadrangle, we infer that their tongues C, E, and F are present on this quadrangle.

Each tongue consists of one or two intervals of upsection-coarsening, very fine- to fine- or medium-grained, quartz-rich sandstones. The C and F tongues each consist of a single interval, while the E tongue commonly consists of two intervals. Beds grade upsection from muddy, indistinctly-bedded, and locally bioturbated to clean, well-bedded, and commonly cross-stratified. Basal contacts for each interval are gradational, while top contacts are sharp.

The top of the Gallup Sandstone is placed at the base of the lowest non-marine strata of the Crevasse Canyon Formation.

3.4. Dakota Sandstone

The Dakota Sandstone in this area consists of multiple tongues of dominantly marine sandstone that intertongues with the Mancos Shale in the lower portion of the Cretaceous section. Nomenclature is after Pike (1947), Owen (1966), and Landis et al. (1973). The basal Encinal Canyon Member of Aubrey (1988) was not found in outcrop.

The upper three sandstone tongues (Cubero (Kdc), Paguate (Kdp), and Twowells (Kdt)) each consist of upwards-coarsening sequences of very fine- to fine- and locally medium-grained quartz-rich sandstone. Beds tend to grade upsection from muddy and massive to clean and well-bedded and commonly cross-stratified. Basal contacts are gradational, and upper contacts are sharp. Sandstones are locally fossiliferous, and locally bear burrow structures. The Cubero Tongue, where exposed, is of fairly constant thickness across the quadrangle. In contrast, the Paguate Tongue thins in outcrop considerably in the flanks of Canipa Mesa, and pinches out just south of the quadrangle boundary. The Twowells Tongue may pinch out in the northeast of the quadrangle, as it could not be found in outcrop in the valley along Rinconada Creek; if the Twowells is present, it is thinned, and included with the undivided Mancos Shale unit Kmu.

The lowermost member of the Dakota Sandstone, the Oak Canyon Member, consists of interbedded shales and sandstones. It is commonly subdivided into upper (Kdou) and lower (Kdol) map units, with the lower unit including all the sandstone intervals and intervening shales, and the upper unit including all the shales above the uppermost sandstone interval and below the Cubero Tongue. Shales are similar in description to the Mancos Shale. Sandstones are very fine- to medium-grained, quartz-rich, planar or lenticular-bedded with common cross-stratification.

The base of the Dakota Sandstone, a profound regional unconformity, was not found in outcrop in the quadrangle.

4. Structure

Structure consists of normal offset along a continuous north-northwest-trending fault, normal offset along several northeast-trending faults, strike-slip offset along northeast-trending faults, and a variety of small-magnitude, but mappable, monoclinal folds and normal faults of a variety of trends.

The lone north-northwest-trending normal fault collocates with the Acomita dike and is likely related to that feature, although the relative order of events, fault offset and dike intrusion, is not clear. The fault has a low magnitude of offset, at most about 8 m down-to-the-west, but appears continuous across the entire quadrangle. Where exposed, the fault dips steeply (78 to 87°) westward. No slip vector-indicators were observed in exposures.

The northeast-trending normal faults are most apparent in the northwest corner of the map area, where they offset the basalts atop Horace Mesa, indicating at least some slip since the Plio-Pleistocene. At least one fault appears to be continuous southwestward across the Rio San Jose valley into the Cretaceous section; no offset of the alluvium or Holocene McCartys flow is apparent along this trace, however. Map patterns and outcrops indicate fault planes dip 54 to 66°, mainly to the southeast but locally to the northwest, with offsets of Horace Mesa basalt units up to about 50 m. Notably, the magnitude of slip across the fault crossing Tafoya Canyon appears to be greater in the Cretaceous section as compared to the Plio-Pleistocene basalts capping Horace Mesa; offsets of Cretaceous strata was estimated in the field at 16 to 20 m down-to-the-southeast, while the upper flow (QTbf) is offset only about 2 m. This indicates that normal offset along northeast-trending faults occurred both prior to and following eruption of the Plio-Pleistocene basalts capping Horace Mesa.

Three northeast-trending faults in the southern half of the quadrangle are interpreted to have strike-slip offset: the Black Mesa Road, Airport Road, and Canipa Spring faults. Strike-slip is inferred for the first two faults based on outcrop evidence, and for the third based on map patterns. Right-lateral strike-slip is apparent in an outcrop of the Black Mesa Road fault circa 256165 m E, 3882900 m N (NAD83 UTM). Here, the main fault and main-fault-parallel fractures have an average attitude of N42E/75SE, offset strata in the dip-slip direction down-to-the-southeast, and bear striations that rake, on average, 26° from the southwest (**Figure 5-1**), indicating a slip vector with a substantial right-lateral component. The outcrop also bears several small-offset fractures with average attitude of N58E/74SE bearing striations with average rake angle of 31° from the southwest (**Figure 5-1**). Offset across these fractures is right-lateral and down-to-the-southeast, synthetic to the main fault. The synthetic sense-of-slip and shallow acute angle between the strike of the main fault and that of the synthetic fractures (16°) suggests these small-offset features are Riedel shears (R-shears), and the clockwise (looking down) difference in strike attitudes from the main fault to the R-shears again suggests right-lateral slip across the fault. Finally, an additional set of very small-offset fractures with average attitude of S36E/72SW and probable left-lateral offset is also apparent in this outcrop (**Figure 5-1**); the vector of slip across these fractures is not entirely clear, but their attitude and probable left-lateral sense of offset would be consistent with conjugate Riedel shears (R'-shears) associated with a right-lateral strike-slip fault.

An outcrop of the Airport Road fault circa 250640 m E, 3879750 m N suggests left-lateral, down-to-the-northwest oblique-slip. The main fault trend and main-fault-parallel faults have an average attitude of S43W/89NW, with down-to-the-northwest dip-slip offset apparent in the subhorizontal sandstone beds on either side of the fault zone. Striations were found on one main-fault-parallel fracture with an average rake angle of 60° from the southwest (**Figure 5-2**), which, combined with the sense of dip-slip, would indicate left-lateral, down-to-the-northwest oblique-slip. In addition, within the fault zone are a set of down-to-the-southwest-tilted fault blocks, with tilting facilitated by normal faults with an average attitude of N46W/51NE (FIGURES 5-2 AND 5-3), suggesting a component of northeast-southwest-directed extension at least in this part of the fault zone. This outcrop occurs immediately northeast of a bend in the trace of the fault, from north-northeast-trending (southwest side of the bend) to more northeast-trending (northeast side of the bend). Such a bend would be a releasing bend in a left-lateral fault, which could result in minor extensional structures such as the titled blocks observed here.

Strike-slip offset is inferred for the Canipa Spring fault based on the occurrence of the Canipa Spring monocline at a bend in the trace of the Canipa Spring fault. The Canipa Spring fault is not well exposed, but the trace is well-constrained, and circa 258420 m E, 3879680 m N the fault makes a set of bends; from southwest to northeast, the fault bends from northeast-trending to east-trending then back to northeast-trending. The Canipa Spring monocline is also not well exposed, but bedding attitudes collected on Dakota sandstone beds indicate a shallow monocline occurs in this area as well, with subhorizontal strata to either side of beds dipping up to 6° to the east-northeast. Directly within the bend of the Canipa Spring fault trace, bedrock is not exposed, but the topography, here upheld by the Cubero Tongue of the Dakota Sandstone, also shows a monocline-like trend, with subhorizontal slopes to either side of a gentle northeast-aspect slope that occurs in the bend in the fault trace. Outcrops and bedding attitudes observed further southeast, both on- and off-quad, suggest that the Canipa Spring monocline does not continue far from the Canipa Spring fault trace, suggesting the two structural features are related. We suggest that the Canipa Spring monocline could be the product of local northeast-southwest-directed compression at the bend in the Canipa Spring fault. Such compression would result from left-lateral offset across the fault.

Small magnitude monoclines and normal faults of a variety of attitudes occur through the southern half of the quadrangle. Faults have east-northeast to east-southeast trends, with striations indicating nearly pure dip-slip (rakes of 80 to 90° from the strike direction). Faults dip to both the north and south, and displacements are <5 m. One fault in the southeast corner of the map decreases in magnitude upsection, becoming a small monocline. Additional small monoclines are found with north-northeast- to north-trends, and these may also overlie small-offset faults. A continuous “hinge,” mapped as the anticlinal bend of a monocline, can be followed east-southeastward across McCarty Mesa and into Cedar Hill; across this small-magnitude fold, beds steepen from subhorizontal on the south to gently (~2°) dipping to the north-northwest through north-northeast on the north. Although each of these features is small in magnitude, they are included on the map for their lateral continuity.

5. Hydrology

Hydrology was not a focus of this study. However, some observations of geologic controls on spring flow were collected.

5.1. Springs

Three named springs (Canipa, Conejo, and Lane spring) are located within the McCartys Quadrangle. Canipa Spring is a rheocrene spring that emerges from the Canipa Creek alluvium where the Canipa Creek drainage crosses the Acomita dike. Discharge from Canipa Spring is apparently controlled by shallow groundwater flow moving upward along the dike. Flow toward the spring may be influenced by the Canipa Spring monocline, which folds Cretaceous strata just up-gradient (south) of the spring imparts a local shallow east-northeastward dip to the base of the alluvium. Discharge from the spring was estimated to be 1-5 gallons per minute (gpm) in March, 2017.

Conejo Spring is a hillslope or contact spring that discharges at the contact between the Twowells Tongue of Dakota Sandstone and the underlying Mancos Shale on the south wall of Cañon del Conejo. A secondary small seep is present in the Mancos shale approximately 30 m west and 6-7 m downslope (north) of the Conejo Spring orifice. Abundant tufa blocks present in outcrop and as float in the vicinity of Conejo Spring and the unnamed seep indicate that spring discharge in this area has persisted for an extended period of time. Combined discharge from Conejo Spring and the unnamed seep was estimated at less than 0.5 gpm in March, 2017.

Lane Spring is a hillslope or contact spring located south of Tafoya Canyon on the east flank of Horace Mesa. Spring flow discharges from colluvium covering the hill slope, but Mancos shale is exposed in the vicinity of the spring and is likely the control on spring discharge, with discharge probably occurring at the contact between the Gallup Sandstone and the underlying Mancos Shale. A second spring is located approximately 70 m north-northwest of the Lane Spring location shown on the McCartys quadrangle. Combined discharge from the two springs, estimated at the point where they discharge to the stock tank, is 1.5 to 2 gpm.

6. References cited

Aldrich, M. J., Chapin, C. E., and Laughlin, A. W., 1986, Stress history and tectonic development of the Rio Grande rift, New Mexico: Journal of Geophysical Research, v. 91, no. B6, p. 6199-6211.

Allen, J. E., and Balk, R., 1954, Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Bureua of Mines and Mineral Resources, Bulletin 36, 192 p.

Allmendinger, R. W., Cardozo, N. C., and Fisher, D., 2012, Structural Geology Algorithms: Vectors & Tensors, Cambridge, England, Cambridge University Press.

Aubrey, W. M., 1988, The Encinal Canyon Member, a new member of the Upper Cretaceous Dakota Sandstone in the southern and eastern San Juan basin, New Mexico, *in*, "Revisions to Stratigraphic Nomenclature of Jurassic and Cretaceous Rocks of the Colorado Plateau": U.S. Geological Survey, Bulletin 1633 A-C, p. 57-69.

Birkeland, P. W., 1999, Soils and Geomorphology, Third Edition, Oxford, Oxford University Press, 430 p.

Cardozo, N. C., and Allmendinger, R. W., 2013, Spherical projections with OSXStereonet: Computers and Geosciences, v. 51, no. 0, p. 193-205.

Cascadden, T. E., Geissman, J. W., Kudo, A. M., and Laughlin, A. W., 1997, El Calderon cinder cone and associated basalt flows, *in* Maberry, K., *ed.*, "Natural History of El Malpais National Monument": New Mexico Bureau of Geology and Mineral Resources, Bulletin 156, p. 41-51.

Champion, D. E., Lanphere, M. A., and Kuntz, M. A., 1988, Evidence for a new geomagnetic reversal from lava flows in Idaho: Discussion of short polarity reversals in the Brunhes and late Matuyama polarity chrons: Journal of Geophysical Research, v. 93, p. 11667-11680.

Channer, M. A., Ricketts, J. W., Zimmerer, M. J., Heizler, M. T., and Karlstrom, K. E., 2015, Surface uplift above the Jemez mantle anomaly in the past 4 Ma based on $^{40}Ar/^{39}Ar$ dated paleoprofiles of the Rio San Jose, New Mexico, USA: Geosphere, v. 11, no. 5, p. 1384-1400.

Cikoski, C. T., Drakos, P. G., and Riesterer, J. W., 2016, Geologic map of the Cubero 7.5-minute quadrangle, Cibola County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-File Geologic Map OF-GM-256, scale 1:24,000.

Compton, R. R., 1985, Geology in the Field, John Wiley & Sons, Inc., 398 p.

Correa, A. C., 1970, Borrego Pass Lentil, a new member of the Crevasse Canyon Formation, southern San Juan basin, New Mexico: The Mountain Geologist, v. 7, p. 99-102.

Dane, C. H., Kauffman, E. G., and Cobban, W. A., 1968, Semilla Sandstone, a new member of the Mancos Shale in the southeastern part of the San Juan basin, New Mexico: U.S. Geological Survey, Bulletin 1254-F, 21 p.

Drakos, P. G., Harrington, C. D., Wells, S. G., Perry, F. V., and Laughlin, A. W., 1991, Late Cenozoic geomorphic and tectonic evolution of the Rio San Jose and tributary drainages within the Basin and Range/Colorado Plateau transition zone in west-central New Mexico, *in* Julian, B., and Zidek, J., *eds.*, "Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado": New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, p. 149-157.

Drakos, P. G., and Riesterer, J. W., 2013, Water Canyon/Timber Canyon fan complex on the southeast flank of Mount Taylor, New Mexico, *in* Zeigler, K. E., Timmons, J. M., Timmons, S., and Semken, S. C., *eds.*, "Geology of the Route 66 Region: Flagstaff to Grants": New Mexico Geological Society, Fall Field Conference Guidebook, p. 175-179.

Dunbar, N. W., and Phillips, F. M., 2004, Cosmogenic 36Cl ages of lava flows in the Zuni-Bandera volcanic field, north-central New Mexico, U.S.A., *in* Cather, S. M., McIntosh, W. C., and Kelley, S. A., *eds.*, "Tectonics, Geochronology, and Volcanism in the Southern Rocky Mountains and Rio Grande Rift": New Mexico Bureau of Geology and Mineral Resources, Bulletin 160, p. 309-317.

Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau, *in* Powell, J. W., *ed.*, "Sixth Annual Report of the United States Geological Survey to the Secretary of the Interior, 1884-1885": U.S. Geological Survey, p. 105-198.

Fleming, T. F., 1989, New reference sections for the Semilla Sandstone Member of the Mancos Shale and their genetic implications: New Mexico Geology, v. 11, p. 1-7.

Gile, L., Peterson, F. F., and Grossman, R. B., 1966, Morphologic and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Goff, F., Kelley, S. A., Goff, C. J., McCraw, D. J., Osburn, G. R., Lawrence, J. R., Drakos, P. G., and Skotnicki, S. J., 2015, Geologic map of Mount Taylor, Cibola and McKinley Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-File Report OFR-571, scale 1:36,000.

Grimm, J. P., 1983, The late Cenozoic history of the Lobo Canyon drainage basin, Mount Taylor volcanic field, New Mexico, *in* Wells, S. G., Love, D. W., and Gardner, T. W., *eds.*, "Chaco Canyon Country": American Geomorphological Field Group, Field Trip Guidebook, p. 45-50.

Hook, S. C., Molenaar, C. M., and Cobban, W. A., 1983, Stratigraphy and revision of nomenclature of Upper Cenomanian to Turonian (Upper Cetaceous) rocks of west-central New Mexico, *in* Hook, S. C., *ed.*, "Contributions to Mid-Cretaceous Paleontology and Stratigraphy of New Mexico, Part II": New Mexico Bureau of Mines and Mineral Resources, Circular 185, p. 7-28.

Hunt, C. B., 1936, The Mount Taylor coal field, Part 2, *in* Sears, J. D., Hunt, C. B., and Dane, C. H., *eds.*, "Geology and Fuel Resources of the Southern Part of the San Juan Basin, New Mexico": U.S. Geological Survey, Bulletin 860-B, p. 31-80.

Landis, E. R., Dane, C. H., and Cobban, W. A., 1973, Stratigraphic terminology of the Dakota Sandstone and Mancos Shale, west-central New Mexico: U.S. Geological Survey, Bulletin 1372-J, 44 p.

Laughlin, A. W., Aldrich, M. J., and Vaniman, D. T., 1983, Tectonic implications of mid-Tertiary dikes in west-central New Mexico: Geology, v. 11, p. 45-48.

Laughlin, A. W., Perry, F. V., Damon, P. E., Shafiqullah, M., McIntosh, W. C., Harrington, C. D., Wells, S. G., and Drakos, P. G., 1993, Geochronology of Mount Taylor, Cebollita Mesa, and Zuni-Bandera volcanic fields, Cibola County, New Mexico: New Mexico Geology, v. 15, no. 4, p. 81-92.

Laughlin, A. W., Poths, J., Healey, H. A., Reneau, S., and WoldeGabriel, G., 1994, Dating of Quaternary basalts using the cosmogenic 3He and 14C methods with implications for excess 40Ar: Geology, v. 22, p. 135-138.

Laughlin, A. W., and WoldeGabriel, G., 1997, Dating the Zuni-Bandera volcanic field, *in* Maberry, K., *ed.*, "Natural History of El Malpais National Monument": New Mexico Bureau of Mines and Mineral Resources, Bulletin 156, p. 25-30.

Lipman, P. W., and Menhert, H. H., 1979, Potassium-argon ages from the Mount Taylor volcanic field, New Mexico: U.S. Geological Survey, Professional Paper 1124-B, 8 p.

Machette, M. N., 1985, Calcic soils of the southwestern United States, *in* Weide, D. L., *ed.*, "Soils and Quaternary Geology of the Southwestern United States": Geological Society of America, Special Paper 203, p. 1-22.

Maxwell, C. H., 1977, Preliminary geologic map of the McCartys quadrangle, Valencia County, New Mexico: U.S. Geological Survey, Open-File Report 77-380, scale 1:24,000.

-, 1986, Geologic map of El Malpais lava field and surrounding areas, Cibola County, New Mexico: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1595, scale 1:62,500.

Molenaar, C. M., 1983, Principal reference section and correlation of Gallup Sandstone, northwestern New Mexico, *in* Hook, S. C., *ed.*, "Contributions to Mid-Cretaceous Paleontology and Stratigraphy of New Mexico, Part II": New Mexico Bureau of Mines and Mineral Resources, Circular 185, p. 29-40.

Molenaar, C. M., Nummedal, D., and Cobban, W. A., 1996, Regional stratigraphic cross sections of the Gallup Sandstone and associated strata around the San Juan basin, New Mexico, and parts of adjoining Arizona and Colorado: U.S. Geological Survey, Oil and Gas Investigations Chart OC-143.

Munsell Color, 2009, Munsell Soil-Color Charts: Grand Rapids, MI.

Osburn, G. R., Kelley, S. A., Goff, F., Drakos, P. G., and Ferguson, C. A., 2009, Geologic map of the Mount Taylor 7.5-minute quadrangle, Cibola County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-File Geologic Map OF-GM-186, scale 1:24,000.

Owen, D. E., 1966, Nomenclature of Dakota Sandstone (Cretaceous) in San Juan basin, New Mexico and Colorado: American Association of Petroleum Geologists Bulletin, v. 50, p. 1023-1028.

Pike, W. S., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geological Society of America, Memoir 24, 103 p.

Risser, D. W., and Lyford, F. P., 1983, Water resources on the Pueblo of Laguna, west-central New Mexico: U.S. Geological Survey, Water-Resources Investigations Report 83-4038, 308 p.

-, 1984, Water resources on the Pueblo of Acoma, Cibola County, New Mexico: U.S. Geological Survey, Administrative Report (unpublished), 199 p.

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni basin, New Mexico: U.S. Geological Survey, Bulletin 767, 53 p.

Sears, J. D., Hunt, C. B., and Hendricks, T. A., 1941, Transgressive and regressive Cretaceous deposits in southern San Juan Basin, New Mexico, *in*: U.S. Geological Survey, Professional Paper 193, p. 101-121.

Woodward, L. A., 1982, Tectonic framework of Albuquerque country, *in* Wells, S. G., Grambling, J. A., and Callender, J. F., *eds.*, "Albuquerque Country II": New Mexico Geological Society, Fall Field Conference Guidebook 33, p. 141-145.

7. Tables

Table 1: Summary of geochronologic data for the McCartys 7.5' quadrangle

Unit	Age[1] (Ma)	±2σ[2]	Type[3]	Ref.[4]	Latitude	Longitude	Comments
Qbc	1.57	0.26*	K-Ar	L79			Too old (Laughlin et al., 1993); taken from ~3 miles east of Grants along I-40. *Unclear if published error is 1σ or 2σ
	0.128	0.033	K-Ar	CL88			
	0.054	0.1	K-Ar	L93	**	**	**Published lat/long are inconsistent with described location; location described as ~3 miles east of Grants along I-40.
	0.0347	0.003	36Cl	DP04	35.07°N	107.75°W	Weighted mean of 0 mm/kyr and 5 mm/kyr erosion rate assumptions
	0.115-0.120	--	PM	C97			Suggested to have erupted during the Blake geomagnetic polarity event
Tbp	3.238	0.17	K-Ar	L93	35.09°N	107.71°W	
	2.72	0.011	Ar/Ar	C15			Sampled basalt reported to overlie ancestral Rio San Jose gravels
Tbda	30.7	1.4	K-Ar	A86	35.03°N	107.62°W	
	Age[1] (ka)						
Qbm	2.97	0.12	14C	L94	34°56.01'N	107°50.33'W	
	3.01	0.14	14C	L94	34°56.01'N	107°50.33'W	
	2.5	1.1	3He	L94	35°05.16'N	107°46.52'W	
	2.4	0.6	3He	L94	35°05.16'N	107°46.52'W	
	3.9	1.2	36Cl	DP04	34°55.97'N	107°50.45'W	Weighted mean of 0 mm/kyr and 5 mm/kyr erosion rate assumptions

Notes

1: Age as published. No attempt made to normalize values. C-14 ages are not calibrated calendar ages.

2: Uncertainty as published, scaled to ±2σ where appropriate.

3: PM – age range suggested by comparison of radiometric ages and basalt flow paleomagnetic data to the paleomagnetic record; 14C ages date material from buried soils immediately underlying the flows; 3He and 36Cl are cosmogenic surface exposure ages; 40Ar/39Ar and K-Ar are crystallization ages.

4: A86 - Aldrich et al., 1986; C97 – Cascadden et al., 1997; C15 - Channer et al., 2015; CL88 – Champion and Lanphere, 1988; DP04 – Dunbar and Phillips, 2004; L79 - Laughlin et al., 1979; L93 – Laughlin et al., 1993; L94 – Laughlin et al., 1994.

8. Figures

Figure 3-1: Stratigraphic section measured through fan unit Qf2

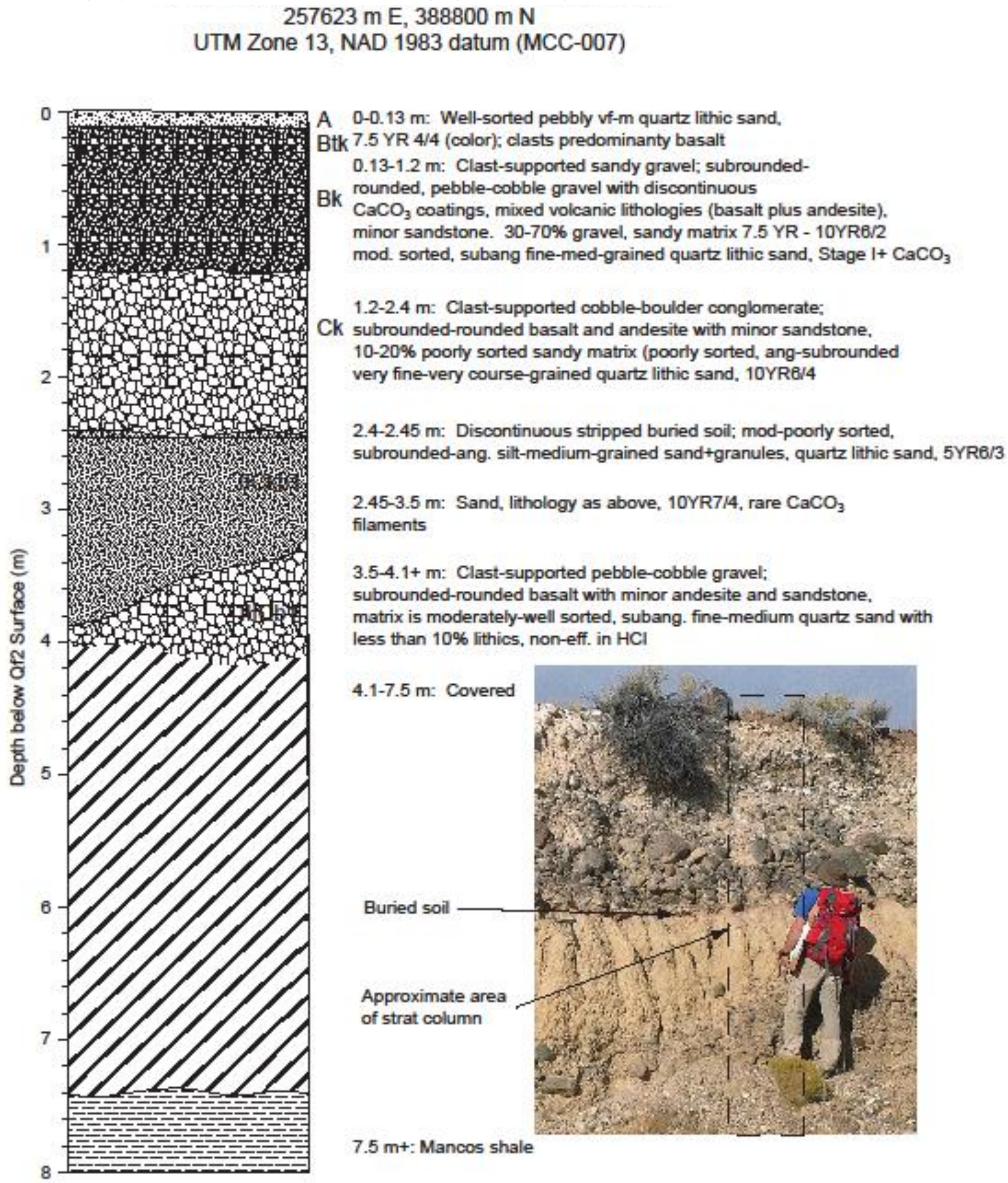

Figure 3-2: Stratigraphic section measured through fan unit Qf4

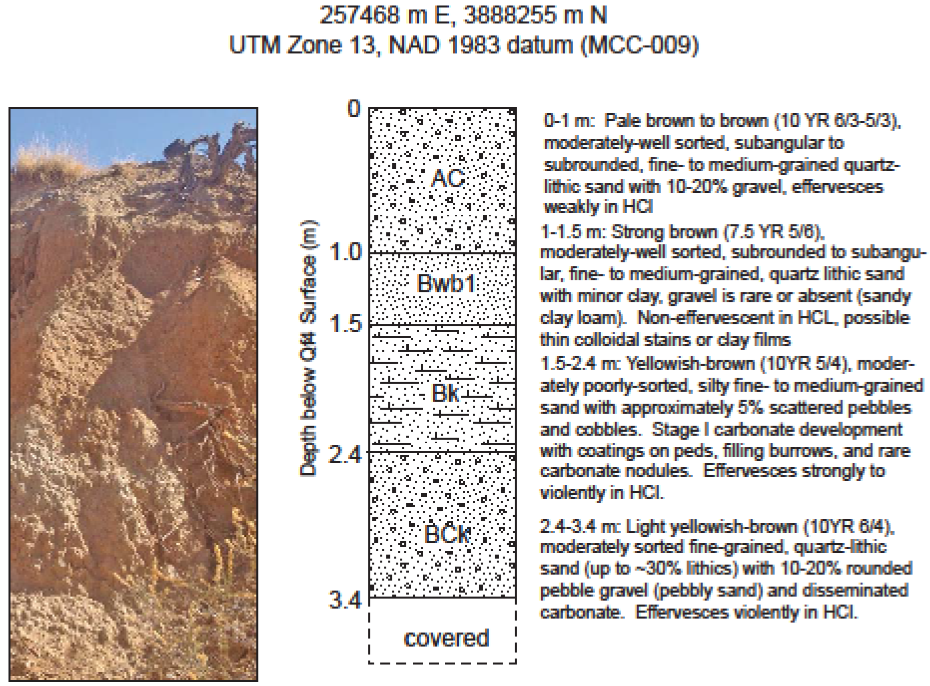

Figure 3-3: Stratigraphic section measured through Qal in Cañon Largo

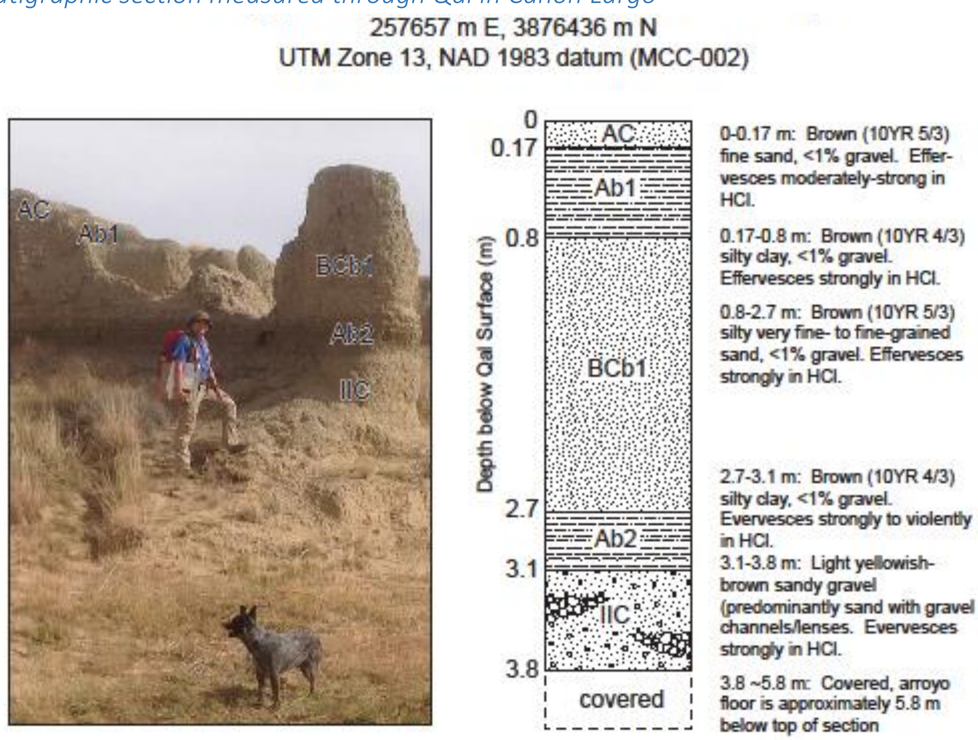

Figure 3-4: Fracture control in upper Cañon del Conejo

Northeast-oriented fractures in Paguate Tongue are parallel to orientation of canyon. Densely-fractured Two Wells Tongue forms canyon rim.

Figure 3-5: Recent arroyo incision in unnamed canyon west of abandoned airfield on McCarty Mesa

Figure 3-6: Stratigraphic section measured through Qasw in Cañon Largo

258279 m E, 3876775 m N
UTM Zone 13, NAD 1983 datum (MCC-003)

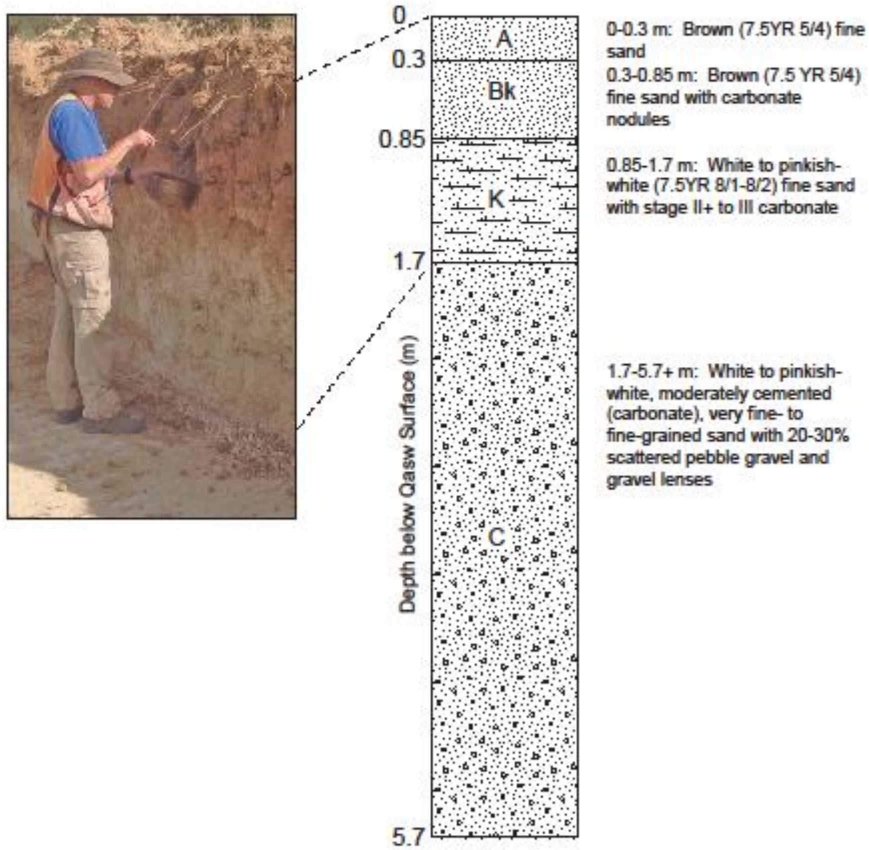

Figure 5-1: Stereonet of structural measurements in an outcrop of the Black Mesa Road fault.
Stereonet is an equal-area (Schmidt) southern hemisphere projection

Outcrop location: 256164 m E, 3882901 m N (UTM, NAD83, Zone 13S)

Up (U) and down (D) labels indicate sense of dip-slip offset apparent in map patterns of subhorizontal strata; sense of strike-slip offset is not apparent in map patterns, but inferred to be right-lateral from this structural data as described in the text.

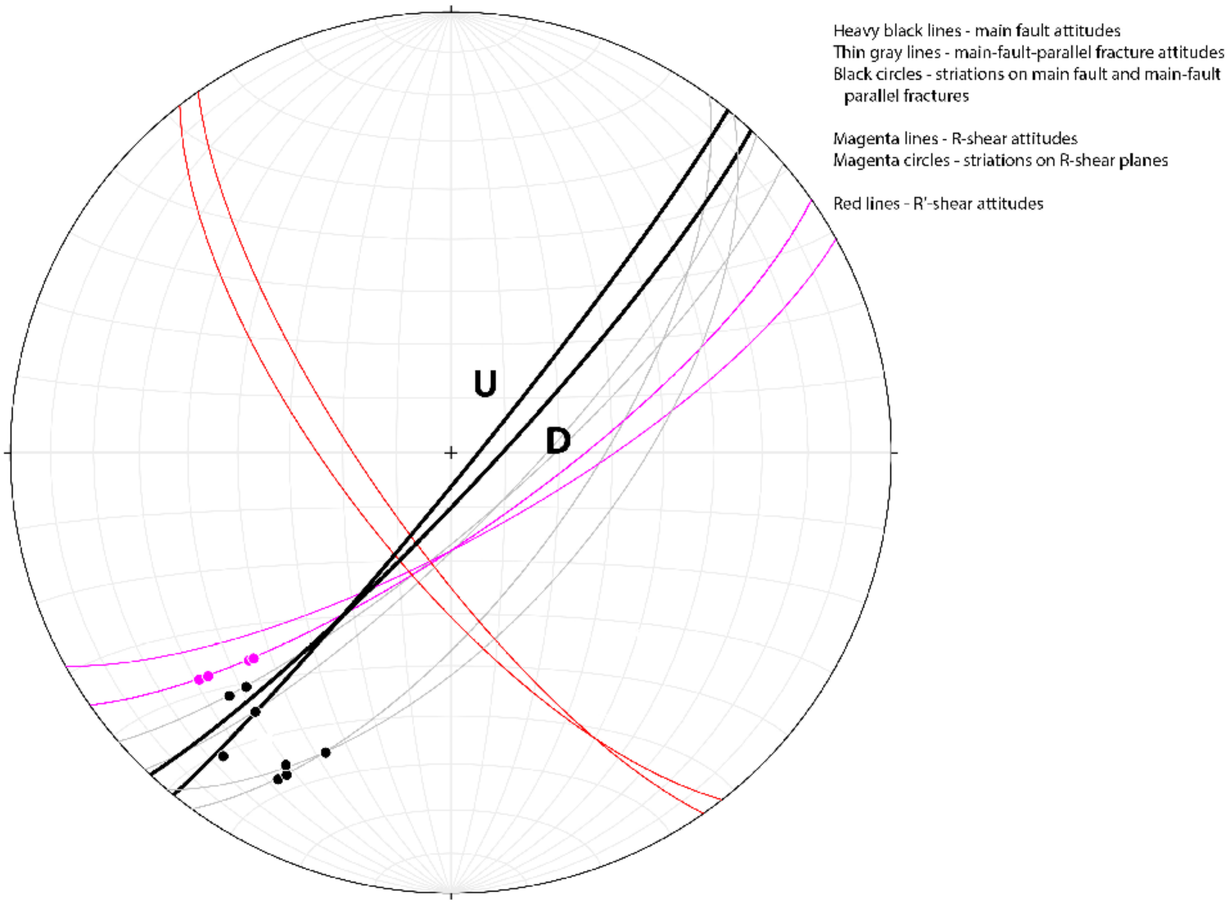

Figure 5-2: Stereonet of structural measurements in an outcrop of the Airport Road fault.
Stereonet is an equal-area (Schmidt) southern hemisphere projection

Outcrop location: 250639 m E, 3879754 m N (UTM, NAD83, Zone 13S)

Up (U) and down (D) labels indicate sense of dip-slip offset apparent in map patterns of subhorizontal strata; sense of strike-slip offset is not apparent in map patterns, but inferred to be left-lateral from this structural data as described in the text.

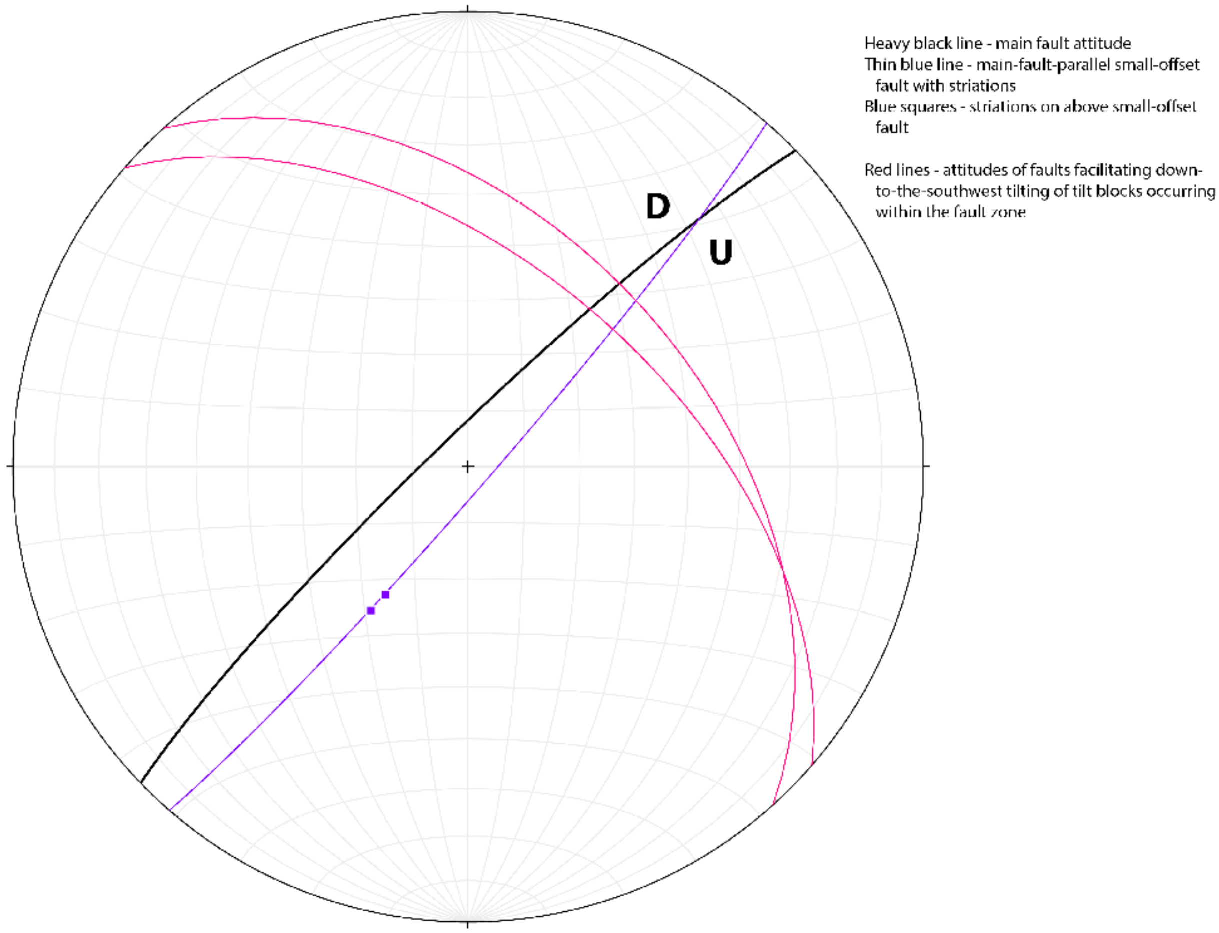

Figure 5-3: Photo of an outcrop of the Airport Road fault

Outcrop location: 250639 m E, 3879754 m N (UTM, NAD83, Zone 13S)

View is to the west-northwest. Red lines bound a set of tilted blocks occurring within the fault zone. Fault blocks are rotated down-to-the-southwest along a set of northwest-striking normal faults. These tilt blocks indicate a measure of northeast-southwest extension occurring along the fault zone at this location.