Geologic Map of the Seboyeta Quadrangle, Cibola County, New Mexico

By

Steven J. Skotnicki, Paul G. Drakos, Fraser Goff, Cathy J. Goff, and Jim Riesterer

June 2012

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 226

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 10HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.

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INTRODUCTION

The Seboyeta quadrangle rests about 35 miles east of Grants, New Mexico, north of the Laguna Pueblo. The village of Paguate resides hear the southeast part of the map. The area also encompasses a portion of the Cebolleta Land Grant. The oldest rocks in the study area are Cretaceous. They include thick deposits of dark marine shale, interbedded with tan-colored beach and barrier-island sandstone and coal and sandstone units deposited in a marshy river system. These sediments record the transgression and regression of the ocean along the Cretaceous Western Interior seaway between about 84 and 99 million years ago (Molenaar, 1974). During the late Cretaceous/early Tertiary Laramide orogeny the region was uplifted and eroded, gently tilting the Cretaceous layers to the northeast by about 2-3° and creating a gently south-dipping peneplain (or pediment). Between about 3.3 and 1.2 Ma volcanic rocks of the Mount Taylor volcanic field erupted across this surface (Perry et al., 1990). The earliest rocks included rhyolite and trachydacite, but most of the eruptive products on the mesas are variations of basalt. The alignment of cinder cones in the Seboyeta quadrangle suggests they erupted along a buried fissure that is oriented northeast-southwest. For a good overview of the geology of the Mount Taylor volcanic field see the New Mexico Bureau of Geology's link at http://geoinfo.nmt.edu/tour/landmarks/mt_taylor/home.html.

ACKNOWLEDGEMENTS

We thank the staff of Laguna Pueblo for allowing us access to their lands within the Seboyeta quadrangle. We are grateful to Lee Maestas, President, Cebolleta Land Grant, for allowing us to perform this study on the Land Grant and for access to Chupadero and Seboyatita mesas. Specific thanks go to Jed Elrod, Ranch Manger, Silver Dollar Ranch, and Robert Alexander, Range Specialist, Laguna Pueblo. Phil Kyle (New Mexico Tech) kindly spent time with Fraser and Cathy Goff examining the Seboyeta Canyon basaltic vent. Dave Mann of High Mesa Petrographics, Los Alamos, made our thin sections. The State Map Program, jointly funded by the U.S. Geological Survey and the New Mexico Bureau of Geology and Mineral Resources, supported this project.

PREVIOUS WORK

Dane (19??) made detailed studies of the Mancos Shale in the eastern San Juan basin and was able to make correlations with other upper Cretaceous strata in northeastern New Mexico and eastern Colorado. Moench (1963a, b) mapped the Seboyeta 7.5' quadrangle and the Laguna 7.5' quadrangle to the south. Schlee and Moench (1963a, b) mapped the Mesita 7.5' quadrangle to the southeast and the Moquino 7.5' quadrangle to the east. Lipman and others (1979) made a 1:24,000 scale geologic map of the Mount Taylor quadrangle to the west, which was remapped by Osburn and others (2008). Additional quadrangles in the Mount Taylor volcano area have been recently completed by Goff and others (2008; 2010) and McCraw and others (2009).

SOME SPANISH WORD DERIVATIONS

Celosa – Jealous, suspicious, zealous (female)
Chivato – Young goat (male)
Chupadero – Anything that serves to pacify
Cubero – Cask or tub maker (?)
Encinal – Evergreen oak place
Prieta – Dark, black (female)
Seboyeta – Is it Anglicized from onions (Cebolleta) or is it related to fat (Sebo)?

CRETACEOUS ROCKS

Mancos Shale, Satan Tongue

The Satan tongue of the Mancos Shale is exposed only in the northeast part of the map along the northern part of Seboyeta Canyon. Because it is high above the canyon floor, and below the steep cliffs of volcanic rocks, it is difficult to access. There are only a few good exposures and each requires quite a climb to get to. Measured sections 1 and 20 show the stratigraphy of two good exposures. In each, the unit actually contains quite a few sandstone layers up to 3 and 7 meters thick. These sandstone beds are mostly fine-grained quartz, are thin- to medium-bedded, and commonly show faint planar cross-beds in sets up to 50 cm. **Photo 1** shows the thickest of the sandstone layers near the base of the unit (see measured section 20 for the location of the photo). The interbedded shale is dark gray and poorly exposed on slopes between the sandstone beds.

Point Lookout Sandstone, Hasta Tongue

The Point Lookout Sandstone forms the stratigraphically uppermost light gray sandstone cliff visible in the study area (**Photos 2 and 3**). Also, this unit is also only exposed in the northeast along Seboyeta Canyon, and exposures are not very accessible. It is a light gray, fine-grained quartz sandstone and contains rare darker lithic grains. The uppermost 5m shows planar cross-bedding in sets up to 1 m thick. Below the cross-bedded layers, bedding is mostly horizontal with some low-angle cross-beds, particularly in the lowermost 2-3 meters.

Gibson Coal member, Crevasse Canyon Formation

The Gibson Coal member is poorly exposed, except in two exceptional exposures on the west and south sides of Mesa Chivato (measured sections 2 and 20, respectively). The unit is composed of thick accumulations of shale that commonly contain dark brown and black layers of lignite coal up to about 2 meters thick or more. The coal is commonly interbedded on the millimeter to centimeter scale with lighter gray siltstone beds that give some exposures a weakly laminated appearance. Nearly all of the shale beds crumble easily and form slopes. Interbedded with the shale are several fine-grained quartz sandstone layers (**Photos 4 through 6**). Most are less than 1 meter thick, though some crumbly sandstone beds are up to 5 meters thick. Most sandstone beds are massive and show horizontal burrows along bedding planes, suggesting that these beds may have been bioturbated. Ripple marks are locally visible along bedding planes. Well-preserved plant impressions are visible in the upper half of the unit west of the mesa (**Photos 7 through 9**).

Dalton Sandstone member, Crevasse Canyon Formation

The Dalton Sandstone looks very similar to the Point Lookout Sandstone. It is a fine-grained quartz sandstone that contains minor dark lithic grains. Some beds appear massive to very weakly bedded. Other beds show planar cross-bedding in sets up to about 50 cm thick, particularly the uppermost 8 meters. The Dalton Sandstone forms a prominent light gray cliff. On the top of the cliff in measured section 20 is a thin orange-colored massive bed that contains what appears to be wood impressions (**Photo 10**). It is not clear if this bed is part of the Dalton Sandstone or the base of the Gibson Coal member. Below the base of the Dalton Sandstone the upper part of the Mancos Shale, Mulatto tongue, is interbedded with abundant thin- to medium-bedded fine-grained sandstone beds (**Photos 11 and 12**).

Mancos Shale, Mulatto Tongue

The majority of the Mulatto tongue of the Mancos Shale is dominated by quartz siltstone and very fine-grained platy beds of quartz sandstone. The Mulatto is characterized by an overall tan to ocher color. Shale is actually a very minor component of this unit. From a distance the unit is characteristically a muted pale greenish orange, which is distinct from the overlying lighter gray Dalton Sandstone and the underlying slope-forming Dilco Coal member. The Mulatto tongue contains at least two intervals that are dominated by thinly-bedded very fine-grained quartz sandstone. These intervals commonly form cliff ledges that show no distinct cliff-forming beds (**Photo 13**). Many of the thin platy beds throughout the unit contain molds and casts of brachiopods, the large bivalve *Inoceramus*, and darker shell fragments that resemble shell debris and echinoderm plates (**Photos 14 and 15**).

Dilco Coal member, Crevasse Canyon Formation

In the study area the Dilco Coal member is characterized by interbedded shale and thin sandstone layers. The shale beds commonly contain brown to black coal (**Photos 16 and 17**). The base of the Dilco coal member is characterized in most areas by a basal mottled sandstone layer 1-2 meters thick. This basal sandstone contains abundant horizontal tubular burrows up to about 1 cm in diameter. The burrows are filled with sandstone identical to non-burrowed areas, but for some reason are slightly more resistant than the surrounding matrix and stand out in relief, especially on the bottom of beds. Hematite preferentially stains certain areas within the sandstone and, together with the burrowed regions, gives the sandstone layer a mottled appearance, rusty orange color. The shale that immediately overlies this basal sandstone layer has eroded back, in places providing the basal sandstone layer with a resistant cap resting directly on top of the underlying Gallup sandstone. Some workers have lumped this basal layer into the Gallup Sandstone, which has led to different interpretations as to where to place the contact between the Gallup Sandstone and the Dilco Coal member. In this map and report, the contact is placed at the base of the basal sandstone layer.

Overlying the basal sandstone layer is a sequence of interbedded dark gray shale and very fine-grained yellow sandstone. The sandstone layers are typically between 0.5 and 2 meters thick, while the shale intervals are commonly between 3 and 7 meters thick. The interbedded sandstones are fine- to very fine-grained quartz, are thin- (<1 cm) to medium-bedded (between 1 and 10 cm), and commonly contain planar cross-beds in sets up to about 10 cm. The shales are typically dark gray to black and form weak, crumbly, slope-forming outcrops. Several of the intervals contain abundant dark, carbonaceous matter and layers of brown to black lignite coal several tens of centimeters thick. Locally, some shale layers contain

permineralized wood fragments up to 10 cm or more across, in addition to plant impressions and fossilized plant fragments (**Photos 18 through 20**).

Gallup Sandstone

The Gallup sandstone is a light tan-colored, fine- to very fine-grained quartz sandstone. It contains subangular to subrounded quartz grains and sparse dark lithic grains. The unit is typically horizontally bedded to massive. Planar cross-beds are common in sets up to 1-2 meters. The unit is well exposed from the southwest corner of the map to the northeast corner. It is best exposed near the mouth of Seboyeta Canyon where it forms a prominent cliff (**Photos 21 and 22, and Panorama 1**). Here, the overlying Dilco Coal member has eroded recessively so that the Gallup sandstone forms a flat bench. Near Bear Canyon the formation splits into two distinct sandstone layers separated by dark shale. Unfortunately this split cannot be measured further south because the Gallup Sandstone has been completely removed by erosion.

Mancos Shale and Interbedded Sandstones

Because the Mancos shale is crumbly, it erodes into slopes that are commonly mantled by basalt clasts or other material eroded down slope. As a result, good exposures are uncommon. The best, most continuous exposure of this unit is exposed near the southern margin of the map, where a ravine has dissected deeply into the landslide deposits exposing the underlying Mancos Shale below (see measured sections 12, 13, 18, and 19).

The Mancos Shale is dominated by dark greenish gray shale. Weathering at the surface has created a thin surface layer a few centimeters thick that is lighter gray in color, but the material underneath is typically darker colored. No obvious fossils were seen within the shale except for small carbonized fragments a few millimeters across that resemble fish scales, found near the bottom of measured section 14 in the Paguate open pit mine near the southeast corner of the map. The unit contains a distinctive fossiliferous bed about 4 meters above sandstone Kms_3, which contains abundant oyster shells (the shells are intact but separate ventral and dorsal halves). Almost everywhere the shale is cut by abundant very thin platy veins of selenite gypsum that weather out and litter the slopes with fragments locally up to as large as 10 cm across. It is possible that this gypsum represents remobilized sulfate originally disseminated within the shale. The shale also contains very distinctive concretions that preferentially form along specific stratigraphic horizons. There are at least two different types of concretions. The first, and most common, are septarian concretions/nodules up to a meter across that contain star-shaped coarse-grained calcite in their cores (**Photo 23**). Other septarian concretions contain more nodular calcite and exhibit dark orange colors (**Photo 24**). The second type of concretion is stratigraphically higher in the section and consist of light orange oblate spheroids up to 2 meters across. These concretions are composed of curious feathery fans that resemble chevron-shaped gypsum fans, but they appear to have been replaced by silica (see measured section 18). These fans crumble easily when struck with a hammer (**Photo 25**). In the lower part of the formation, a few meters above the top of sandstone layer Kms_3 is a characteristic bed about 2 meters thick that contains abundant oyster shells (**Photo 26**).

Two thin light gray massive beds were observed within shale in the ravine near the south edge of the map (**Photo 27**). Each bed is about 10 cm thick and is slightly more resistant that the interbedded

shale (see measured section 18). There are no apparent internal laminae and these two beds are interpreted to be possible tuff beds, altered to bentonite (?).

Within the lower part of the section, exposed only in the southeast corner of the map, are three relatively thick sandstone units interbedded with the Mancos Shale. Previous workers assigned labels to them of Kms_1 (**Photos 28 and 29**), Kms_2, and Kms_3 (**Photos 30 through 32**). This same terminology was used in this report.

Sandstone layer Kms_2 contains a very characteristic three-layer interval that forms a small four-meter-high cliff below the main cliff on which rests the village of Paguate (see measured sections 14, 15, and 16; and **Photo 32**). The lower most layer of this cliff is composed of very fine-grained quartz sandstone and siltstone that is thin- to medium-bedded, thick-bedded near top, and contains sparse thin dark calcite chips that may be shell fragments (**Photo 33**). It also contains sparse dark organic matter. Above this is a very think fossiliferous layer up to about 50 cm thick. The uppermost 0.35 m or so is planar laminated very fine-grained quartz sandstone. It contains abundant tubular burrows up to 1 cm diameter on top surface. Below this, the lowermost 15 cm is massive to horizontally bedded very fine-grained quartz sandstone that contains very abundant bivalve shell fragments. The bed fizzes strongly in HCl. The third uppermost layer of this lower cliff of Kms_2 is crumbly very fine-grained quartz sandstone, is mostly massive, and contains abundant burrows and oyster shell halves (**Photo 34 through 36**).

Sandstone Unit Ks

In the southern part of the quad, near the upstream end of the deep gully near the quad boundary, is a ledgy sandstone unit composed of thin beds of fine-grained quartz sandstone. This unit was mapped only in this one location, where it forms a small cliff a few meters high (**Photo 37**). It also contains locally abundant dark brownish gray fossil fragments of unknown origin (**Photo 38**)

TERTIARY ROCKS

Pebbles and Pre-volcanic Erosion Surface

On most slopes small rounded siliceous pebbles, though sparse, are ubiquitous (**Photo 39**). They are typically well rounded and range in size from less than 1 cm to over 10 cm across. They are composed of black, gray, and red chert, white vein quartz, light gray to purple quartzite, and rare granite. Nowhere are these pebbles visible in any of the exposed Cretaceous formations. They are found on the colluvium-covered slope just below the base of the Tertiary volcanic rocks, but not above. Because of this relationship it is likely that the pebbles are eroding out of a thin deposit immediately below the volcanic rocks. Since siliceous pebbles are very resistant to weathering and erosion they probably formed a lag on the pre-volcanic erosion surface (or pediment surface) that formed on the Cretaceous rocks. This erosion surface forms a planar surface that dips to the south about 2°, and forms a slight angular unconformity with respect to the underlying Cretaceous rocks which dip to the north-northeast by about 2°.

When standing on the northeast side of and looking across Seboyeta Canyon and Bear Canyon there appears to be a small amount of relief on the underlying Cretaceous rocks. Locally, the lowermost

basalt flows appear to truncate against paleo-topographic highs formed by the resistant sandstone layers of the Dalton and Point Lookout Sandstones.

Volcanic Rocks

Crumpler (1980a, 1980b), Perry et al. (1990), Hallett et al., (1997) and Fellah (2011) provide the most recent ideas on the magmatic evolution of the Mount Taylor volcanic field (MTVF) and Mesa Chivato. Volcanism in the Seboyeta quadrangle commenced with emplacement of Picacho Peak plug and dike at 4.49 Ma **(Figure 1).** This and other similar plugs and dikes are part of the Rio Puerco necks, which skirts the SE margin of the quad (Hallett et al., 1997). The plugs of Cerro de la Celosa (2.57 Ma) and Cerro Negro (3.39 Ma) intrude Cretaceous rocks just east of the quad boundary. Presumably, these plugs fed lava flows that have long since eroded away.

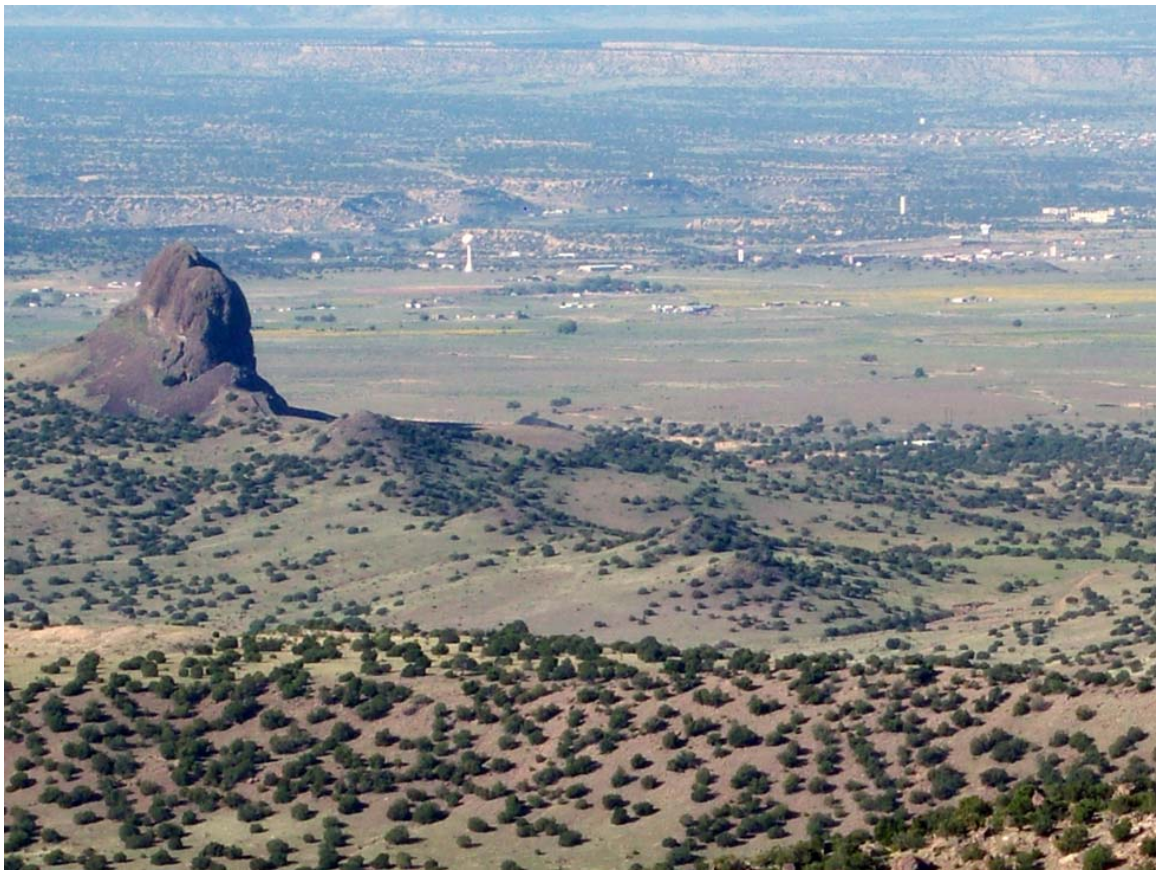

Figure 1: Photo of Picacho Peak, a "quartz" basalt plug and dike intruding Cretaceous rocks in southwestern Seboyeta quadrangle. Dated at 4.49 Ma, this intrusion also contains sparse dunite xenoliths.

The next volcanic eruption in the quad is an unusual alkali-olivine basalt filling a paleo-valley on the southwest margin of Encinal Mesa (Lipman and Moench, 1972). This is overlain by a widespread analcite basanite erupted at 3.26 Ma **(Figure 2)** that consists of one to three flow units filling a network of shallow paleo-valleys (Lipman and Moench, 1972; Lipman and Mehnert, 1979; Perry et al., 1990). Following this, fall deposits of Grants Ridge rhyolite tuff (3.26 Ma; Goff et al., 2008) were erupted from the Grants Ridge rhyolite center southwest of Mount Taylor. These aphyric pumice deposits, most of them reworked, remain as a few thin, highly eroded outcrops on top of the basanite.

From about 3.1 to 2.8 Ma, the first "high mesa basalts" (Lipman and Moench, 1972) were erupted from a variety of vents in the Mount Taylor-southwest Mesa Chivato area, covering most of the Cretaceous terrain and early valley-filling volcanics **(Figure 3).** These basalts are interlayered with slightly porphyritic rhyolite tuffs (unit Ttrt) originating from the early Mount Taylor complex (Osburn et al., 2009). Additional high mesa basalts were erupted until about 2.5 Ma. "High mesa" lavas form widespread caps on what we have informally named Encinal, Silver Dollar, Chupadero and Seboyatita mesas.

Figure 2: Photo of analcite basanite (Tbas, 3.26 Ma) overlying alkali-olivine basalt (Tmaob) west of "Encinal Mesa." These "early basalts" display distinctive texture and mineralogy **(Appendix 1).**

Figure 3: Photo of volcaniclastic sandstone beds (Tvss) underlying "high mesa basalt" (Tcopb) in ravine just west of "Encinal Mesa." Lower beds of this exposure are reworked rhyolitic tuffs (Ttrt and Tgrt).

The intermediate composition edifice of Mount Taylor stratovolcano formed from about 3.0 to 2.4 Ma (Goff et al., 2008, 2010; Osburn et al., 2009). On northwest Seboyeta quad, thick deposits of interbedded debris flows, mudflows, hyper concentrated flows and minor stream flow deposits represent eroded products of this volcanism as unit QTvs. Most of the cobbles and boulders in QTvs are porphyritic trachyandesite to trachydacite. We found two intermediate composition lava flows and several trachydacitic tuffs (Ttdt; **Figure 4**) within the sedimentary package. At the bottom of QTvs, we found several outcrops of volcaniclastic sandstone (Tvss) that is locally interbedded with older high mesa basalt (**Figure 3**). Probably 90% of QTvs is Pliocene in age and we mapped several tongues of these sediments interbedded with younger "high mesa" lava flows. However, the upper part of QTvs apparently extends into Pleistocene time (now defined as ≤2.5 Ma) because some of the deposits overlie lava flows dated at 2.65 Ma (unit Tmctb) and engulf another lava (unit QTfqxb) at a higher stratigraphic level.

Figure 4: Photo of reworked top of trachydacite pumice bed (Ttdt) in unit QTvs (UTM 0277663/3897487). Similar tuffs are dated at about 2.75 Ma elsewhere in the Mount Taylor region (Goff et al., 2008, 2010).

Figure 5: Photo of Cerro Ortiz and flow top of unit Qfqtb, the youngest lava within the Seboyeta quad (1.56 Ma).

The youngest volcanism in the Seboyeta quad is represented by lavas that have been previously called "late basalts" (Lipman and Moench, 1972). The youngest of these flows is unit Qfqtb, a distinctive "quartz" basalt that overlies unit QTvs and is dated at 1.56 Ma (Lipman and Mehnert, 1979). This flow originates from Cerro Ortiz **(Figure 5)** just north of the quad boundary, and extends 9 km to the south. Qfqtb overlies or abuts two other mafic flows that are probably Pleistocene in age; Qfob2 and Qmplb. The latter flow originates from Cerro Frio, well within the next quadrangle north. There are at least 10 Pleistocene-age flows north and west of Seboyeta quad (Goff et al., 2010). The youngest eruption identified in the immediate area of Mount Taylor is the Cerro Pelon cone and flow dated at 1.26 Ma.

An exceptional reference section of the different mafic lava types originally defined by Lipman and Moench (1972) is exposed in an unnamed canyon trending northeast off Bear Canyon **(Figure 6).** No other cliff exposures in the quad contain all type units and interbedded sediments. A thick flow (≤30 m) of "early" analcite basanite (unit 1) sits on Cretaceous rocks at the bottom of the section. This flow has a well-developed colonnade at the base overlain by a thick, rubbly entablature. Overlying the basanite are a few meters of reworked rhyolitic ash and volcaniclastic sandstone with a baked upper contact (units Tvss/Ttrt). This layer pinches out in either direction and is not shown on the geologic map. The next flow up (unit 2) is Tmotb, a medium-grained olivine basalt exemplifying initial "high mesa" basaltic volcanism. This flow is also overlain by thin local accumulations of volcaniclastic sediment (QTvs). Unit 3 in the photograph is Tfctb, a roughly 10-m-thick lava with distinct but sparse, black augite phenocrysts erupted from a nearby cinder cone. This younger "high mesa" basalt caps most of "Chupadero Mesa." Again, as much as 6 m of sediments (QTvs) locally overlie this flow. The uppermost lava (unit 4) is Qfqtb, the "quartz" basalt, which is 5 to 10 m thick. Unit Qfqtb is the type example of "late basalt" and the youngest mafic lava in Seboyeta quad.

Volcanic rocks in the Mount Taylor area are slightly alkalic. Few units contain primary quartz, although many of the mafic lavas contain quartz xenocrysts. Previous workers have variously classified the volcanic rocks as basalt-andesite-rhyolite to hawaiite-latite-trachyte-rhyolite (e.g., Baker and Ridley, 1970; Lipman and Moench, 1972; Crumpler, 1980a; 1980b; Perry and others, 1990; Hallett et al., 1997). For this map, we are using the widely accepted classification scheme of La Bas et al. (1986) and previously published chemical analyses to rename the volcanic units (Fig. 9). Thus, the alkali basalts (hawaiites) are called trachybasalts, basaltic andesites (muegerites) are called basaltic trachyandesites, andesites (latites) are named trachyandesites, and quartz latites are called trachydacite. The only volcanic rocks with no name changes are the rhyolites and basanites.

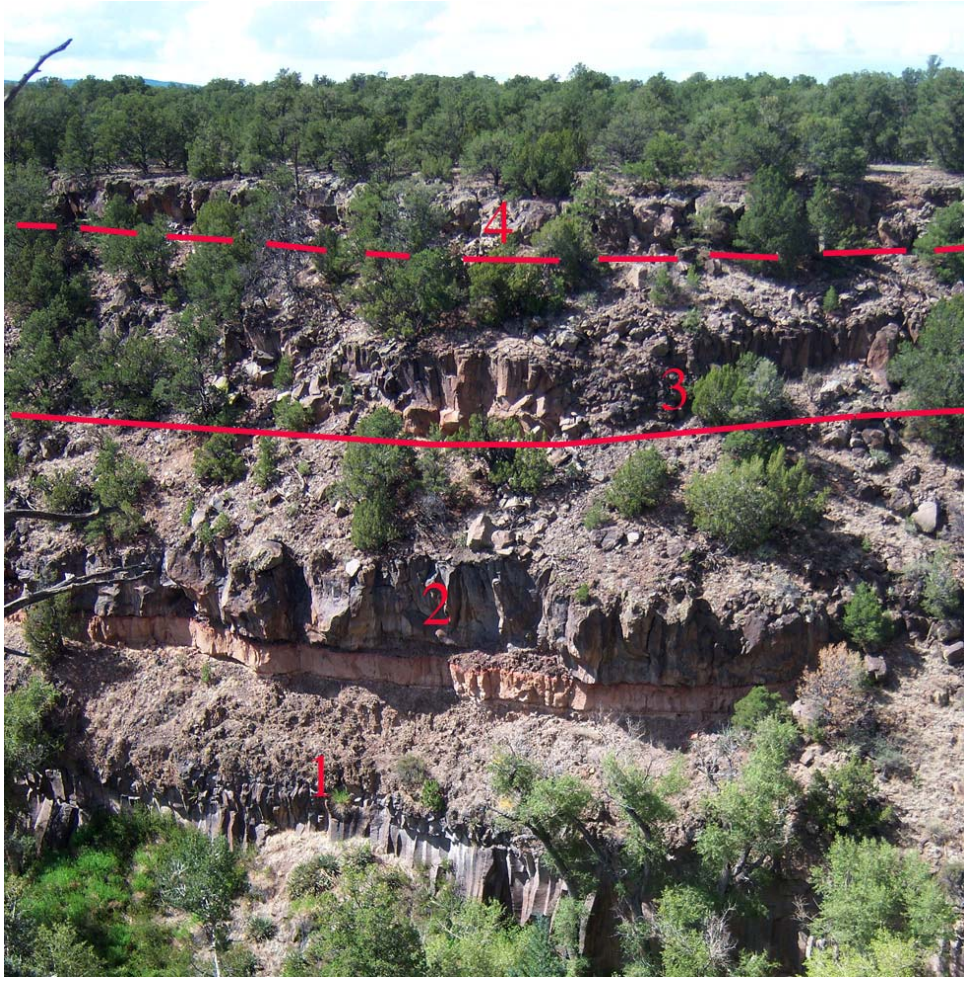

Figure 6: A reference section of volcanic rocks is exposed in unnamed ravine northeast of Bear Canyon (top of section is located at UTM 0277449/3894935, 7600 ft). Basal flow (unit 1) is analcite basanite dated at 3.26 Ma, part of "early basalt." Reworked rhyolitic tuffs above basanite are dated at roughly 3.0 Ma. Flow 2 is olivine trachybasalt equivalent to early "high mesa basalt" (about 2.9 Ma). Flow 3 is clinopyroxene-phyric trachybasalt, a late "high mesa basalt" with an age of roughly 2.7 Ma. Capping flow is "quartz" trachybasalt (1.56 Ma) equivalent to "late basalt." These lava names were originally defined by Lipman and Moench (1972) but were changed to a more complicated and less useful hierarchy by Lipman and Mehnert (1979). Dates are discussed in text and rock descriptions.

The latest comparison of chemical data for volcanic rocks in the southeastern Mount Taylor – southern Mesa Chivato area was presented in the Le Bas diagram of Hallett and others (1997: **Figure 7).** Most of the mafic rocks hover near the portion of the diagram where basalt, trachybasalt, and basanite intersect. Thus, it is not possible to positively name the mafic rocks without chemical

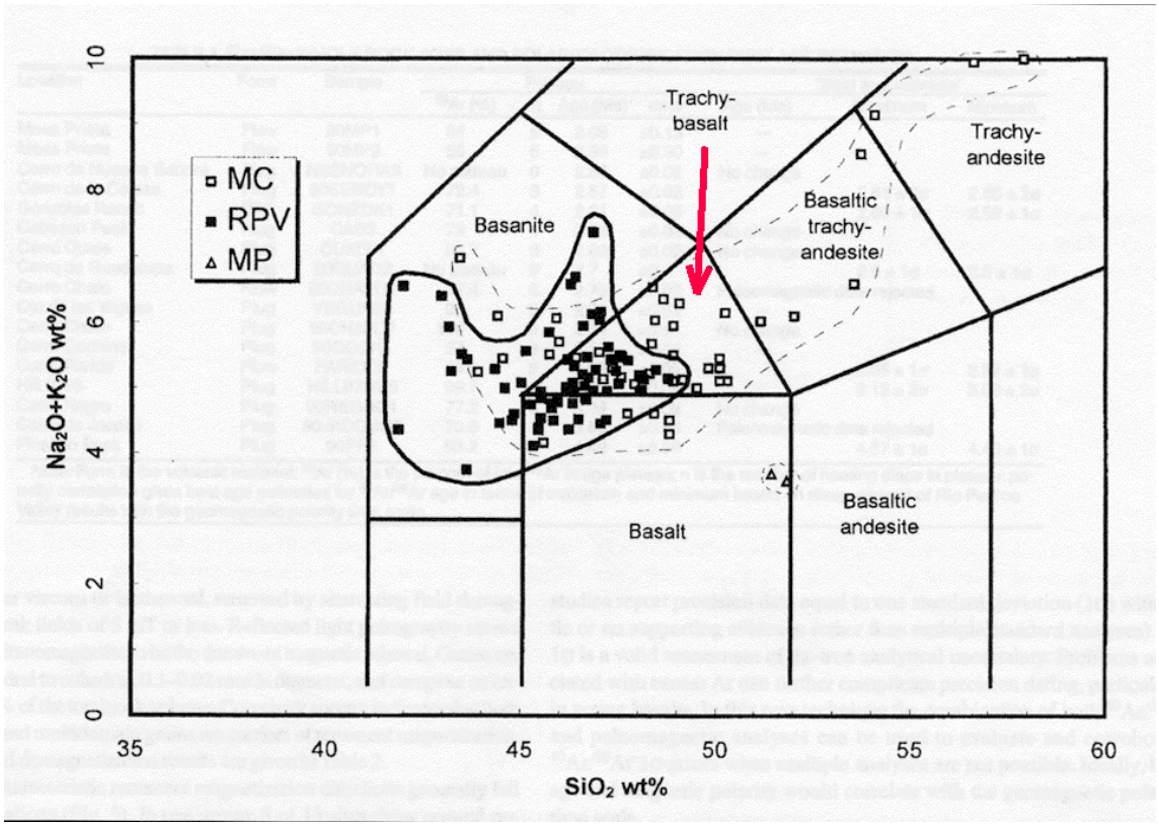

Figure 7: Total alkalis versus silica diagram of Le Bas et al. (1986) plotting rock compositions from the eastern Mount Taylor region; MC = Mesa Chivato, RPV = Rio Puerco Valley, MP = Mesa Prieta (modified from Hallett et al. 1997). Red arrow points at the field for trachybasalt (hawaiite) compositions. Data are from Lipman and Moench (1972), Crumpler (1980b), Perry et al. (1990) and Hallett et al. (1997).

analyses or thin sections of every unit. For this map we could reliably distinguish the analcite basanite from other lavas because of previous chemistry, spotted texture, blue-gray weathering and presence of groundmass analcite. Mafic lavas with abundant visible groundmass plagioclase were named trachybasalt (hawaiite). Commonly, the plagioclase in these lavas is aligned by flowage into a crude trachytic texture forming zones of platy texture. Dense black massive mafic lavas were named basalt.

The Seboyeta Canyon Vent

The youngest eruption in the Seboyeta quadrangle is probably the small, eroded basaltic vent on the east side of Seboyeta Creek about 1 km north of Seboyeta village (Unit Qctc; Fig. Add 1). This feature was first identified by Moench and Schlee (1967). Later it was described by Hallett (1994) who recognized the initial phases of the eruption as a tuff ring (maar volcano). Hallett and others (1997, figure 1) incorrectly show it as a volcanic neck. The vent consists primarily of three cycles of alternating massive basaltic hydromagmatic beds overlain by layers of coarse pyroclastic breccia and welded basaltic scoria (**Figures 8 through 11**). The cycles represent wet and dry phases during eruption. The hydromagmatic beds consist of fragments of quenched basalt of varying sizes mixed with abundant fragments of Cretaceous sandstone and rounded chert. Pale brownish yellow palagonite, a clay typical of

mafic hydromagmatic eruptions, is common in these beds. The pyroclastic breccia layers also contain fragments of Cretaceous sandstone and chert. An infill of lava cuts across the beds and layers of cycle 2 and forms a thin lava flow dipping south on the southwest side of the vent. The lava is covered by cycle 3 (uppermost) hydromagmatic and scoria layers. Two thin vertical dikes trending S30W cut cycle 1 deposits on the northeast side of the vent, visible along an abandoned trail. The lava, dikes, scoria and hydromagmatic fragments all consist of trachybasalt containing conspicuous phenocrysts and/or megacrysts of black clinopyroxene.

Cycle 1 (lowermost) deposits dip to the west under both the basal northeastern and southeastern exposures of the vent suggesting that the initial eruption covered a west-dipping slope on the wall of Seboyeta Canyon. Much of the west end of the vent is eroded away by Seboyeta Creek. If the eruption formed a surrounding apron of hydromagmatic beds typical of maar volcanoes (e.g., Fisher and Schmincke, 1984, p. 255), these are also eroded away. The location of this vent in the bottom of the canyon is significant because it indicates a late Quaternary age for the eruption. Thus, it is probably similar in age and stratigraphic position to the Laguna basalt flow (0.38 to 0.128 Ma, Lipman and Mehnert, 1979; Champion and Lanphere, 1988) located roughly 15 km to the southeast (see also Laughlin et al., 1993).

Figure 8: Photo looking east of eroded Qctc vent in Seboyeta Canyon: 1 = scoria layer of cycle 1; 2 = hydromagmatic beds of cycle 2; L = lava infill of vent; 3 = hydromagmatic beds of cycle 3; D = dikes cutting cycle 1 scoria beds. Cliffs in background are Cretaceous Gallup Sandstone.

Figure 9: Cathy Goff and Phil Kyle examine cycle 1 hydromagmatic beds and overlying scoria layers.

Figure 10: Cycle 1 mafic scoria with 0.7 m-long block of Cretaceous sandstone in Qctc vent.

Figure 11: Northwest trending dike cutting cycle 1 pyroclastic breccia on northwest side of Qctc vent; holes are paleomagnetic cores sampled by Hallett (1994), but only magnetic intensities are reported.

Volcaniclastic Deposits (Tvss)

The east side of Mount Taylor is mantled by a thick conglomeratic deposit that drapes downhill across the landscape into the western side of the Seboyeta quadrangle. Although the unit is deeply dissected by drainages, good exposures are rare. The best exposures are along its southern margin where the unit caps the edge of the prominent south-facing cliff along Encinal Mesa. Here the deposits are dominated by coarse conglomerate containing minor sandstone and tuffaceous sandstone. Where exposed, beds are typically up to a few meters thick and are characteristically non-bedded, exhibiting massive, chaotic internal structures. Clasts are typically subangular to subrounded from sand-size up to large boulders 2 meters across. The vast majority of clasts are composed of crystal-rich trachyte identical in composition to the trachyte exposed to the northwest on Mount Taylor (with minor basalt and pumice). The boundaries between beds, however, are very sharp and planar and are commonly defined by a recessively weathering basal layer of graded and cross-bedded pumice-rich sandstone, commonly between 10 and 20 cm thick. Where visible, the basal layers are commonly quite planar across the outcrop, but in some exposures they wrap around and across older beds and thus appear to form erosional scours in the underlying beds.

The chaotic, non-bedded textures within the beds suggest they were deposited by non-turbulent flow, which is consistent with debris flows or lahars. The cross-bedded pumice-rich basal sandstones were probably surge and/or pumice-fall deposits. Taken together, these volcaniclastic deposits were likely

the result of a series of explosive volcanic eruptions (pumice-rich sandstones) followed closely in time by lahar and/or debris flow deposits (the non-bedded conglomerate beds).

QUATERNARY DEPOSITS

Mapping of surficial deposits follows the style and terminology developed by Grimm (1985), Drake et al. (1991), Goff et al. (2008), and Osburn et al. (2009). The Plio-Pleistocene stratigraphy in Mt. Taylor area includes one Pliocene and one early Pleistocene pediment, and three widespread Quaternary units that lie above the modern flood plain or arroyo floor. In the Seboyeta Quadrangle, the Pliocene and early Pleistocene pediment deposits are poorly exposed and do not form mappable units. In adjacent areas, Pliocene deposits are limited to pediment and axial gravel deposits that cap erosional surfaces cut on Cretaceous sedimentary rocks, and are typically overlain by volcanic units. Pliocene deposits are generally coarse-grained and contain greater proportions of granite and quartzite clasts than are observed in Quaternary deposits (Drake et al., 1991).

Quaternary sediments mapped in the Seboyeta quadrangle include fluvial terrace, alluvial fan deposits, valley floor alluvium, and eolian deposits. Quaternary terrace and fan deposits contain a predominance of volcanic clasts of mixed lithologies, secondary Cretaceous sandstone clasts, and minor chert pebbles. Fan units Qf0-Qf4, mapped in the southwest corner of the Quadrangle, are the eastern part of the Water Canyon fan. Deposition of the Water Canyon fan, which began by early Pleistocene time (correlative fine-grained deposits exhibit reversed polarity; Drake et al (1991)), record incision into the volcanic edifice, erosion of the amphitheater on Mt Taylor and piedmont aggradation. The presence of multiple buried soils in Qf0 (**Figure 17**) record periods of landscape stability and soil formation in between episodes of aggradation during deposition of Qf0. The piedmont has been extensively dissected since Qf0 deposition, therefore Qf0 through Qf2 surfaces are preserved as relatively small remnants. Much of the modern piedmont in the vicinity of the Water Canyon fan is composed of the middle to late Pleistocene Qf3 surface, overlain in places by younger deposits. Aggradation of Qf3 (and overlying Qf4) is likely a result of aggradation along the Rio San Jose drainage associated with eruption of the Laguna flow at 0.38 to 0.128 Ma (Lipman and Mehnert, 1979; Champion et al., 1988), which flowed down the Rio San Jose drainage.

Deposits underlying terrace surfaces along Rio Paguate, Seboyetita Creek, and Seboyeta Creek comprise coarse-grained gravelly sediments. Qt2 is a fill terrace up to 12 m thick, and Qt3 is a strath terrace 2-3 m thick that is cut on the Cretaceous section (**Figure 11.5**). The valley floor alluvium is composed primarily of fine-grained sand, silt and clay with gravel lenses. Drill log data indicate a thickness of valley floor alluvium of 11 m near Encinal and 18 m near Paguate (Risser and Lyford, 1983). Recent aggradation of alluvial deposits has resulted in burial of older colluvial deposits in some drainages (**Figure 12**).

Figure 11.5. Qt3 strath terrace cut on Km near Paguate. Note stage II carbonate, reddened Bt horizon at top of gravel deposit.

The Pliocene and Quaternary deposits and associated geomorphic surfaces in the Mt. Taylor area record a history of long-term incision interrupted by relatively brief periods of base level stability. In contrast to the overall Plio-Quaternary history, the late Quaternary has been characterized by alternating periods of erosion and deposition. Approximately 200-300 m of incision has occurred into the Pliocene pediment surface between 2.5 m.y. and the present time, likely in response to regional uplift. 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 et al., 1991). Periods of temporary base level stability are reflected in the formation of Qf0-Qf3 at the mouth of Water Canyon and Encinal Canyon, and Qt2 and Qt3 along Rio Paguate, Seboyetita Creek, and Seboyeta Creek. The drainages in Seboyeta Quad, which are tributary to the Rio San Jose, incised 10-20 m below the modern valley floor. This was in response incision along the Rio San Jose, which cut a canyon 50-60 m below the modern valley floor (Drake et al., 1991).

Soils

The semiarid climate of the Grants-Laguna area and the regional carbonate dust influx have 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 that best distinguish soils in the Grants-Laguna area. Soils in the study area exhibit stage I through III carbonate morphology (terminology after Gile et al. (1981) and Machette (1985)). Colors range from 5YR to 2.5Y, soil structure ranges from massive to strong subangular blocky, and clay film morphology ranges from absent to thick, continuous (**Appendix 2; Table 1**).

STRUCTURE

The only structure is defined by the alignment of three mafic vents. We interpret this to be a buried fissure system with a NE-trend. However, we found no corresponding offset of lava units in the cliffs. So it does not appear to be an actual fault. Other than that, the Picacho Peak dike in the southwest corner of the map also has a NE trend. These northeast dike and fissure trends parallel those in both the Lobo Springs and Cerro Pelon quadrangles, and mimic the general NE trend of the Jemez volcanic lineament (Goff et al., 2008; 2010).

HYDROTHERMAL ALTERATION

Weak hydrothermal alteration was found in the older alkali-olivine basalt (Unit Tmaob) beneath the cliffs west of "Encinal Mesa." The alteration is pale red to yellow to green in color and consists of combinations of clay, silica, carbonate, Fe-oxides and possibly chlorite found in groundmass, fractures, cavities and vugs. We observed no hydrothermal alteration in other volcanic lavas or tuffs. We found no evidence for significant hot spring activity or subjacent deposition of epithermal ore deposits.

HYDROGEOLOGY

Numerous cold springs issue from either the base or near the base of the volcanic rocks. Many of these springs are found in the ravines of the major streams, commonly at or near a cliff of lowermost lava on Cretaceous rocks. The largest collection of cold springs occurs along middle Encinal Creek where it bends around the north side of vent Qfqgb (rough location UTM 027500/3896000, 7650 ft). This cluster of springs issue from the colonnade of the underlying basanite (Tbas; **Figure 8**). Presumably, the Cretaceous section occurs <20 m below these springs. Possibly, the northeast-trending buried fissure system contains dikes that impound water north of the vent. As mentioned before, we found no obvious evidence of a fault offset here but a small offset could easily be hidden in this area.

The village of Encinal has historically obtained water from the springs near the head of Encinal Canyon, which are reported to have a combined flow of about 100 gallons per minute (Risser and Lyford, 1983). Shallow groundwater supply targets include the thicker alluvial section along the Rio Paguate (utilized by the village of Paguate) and the Seboyeta Creek alluvium. Deeper water supply targets include the Dakota Sandstone and the Westwater Canyon member of the Mirrison Formation.

Figure 18: Photo of several cold springs entering middle Encinal Creek from colonnade of basanite (unit Tbas). This water supports growth of lush grasses and watercress over a distance of several hundred meters.

MINERALIZATION

Uranium mines (appear to be targeting the Morrison Formation) near Paquate

The Seboyeta quadrangle lies within the Grants uranium district, one of the largest uranium-mining areas in the world. The district is more than 85 miles wide and is divided into smaller, widely separated mining localities. Although no uranium mines lie within the quadrangle, immediately adjacent to the southeast edge of the map lie two of the largest open-pit uranium mines in the world—the Paguate and Jackpile mines. The northwestern edge of the Paguate mine just barely touches the southeast corner of the map. Exposed here at the edge of the open quarry is a cliff-face containing the lowermost sandstone unit of the Mancos Shale (unit $\mathbf{Kms_1}$). No other mineralization was seen in the quadrangle.

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UNIT DESCRIPTIONS

Quaternary Deposits

d **Disturbed by human action (Anthropocene).**

Qy **Younger alluvial deposits (Holocene).** Deposits of sand, gravel and silt in main valley bottoms; locally includes stream terraces, alluvial fans, and canyon wall colluvium; Late Holocene in age; maximum thickness of various alluvium deposits is uncertain but is at least 10 m. A well drilled in the NE ¼, SW ¼, SW ¼ of section 27, T 11 N, R 6 W (in Encinal Canyon) penetrated a total thickness of 11 meters of alluvium overlying Mancos shale. Alluvium in canyon bottoms and along major drainages is typically coarse-grained, cobble to boulder size sandy gravel of mixed volcanic lithologies and subordinate sandstone clasts. Alluvium in embayments adjacent to main drainages is typically finer-grained, silt and sand dominated deposits with pebble-gravel lenses and minor interbedded gravel beds. Valley floor alluvium and low terrace deposits are characterized by weakly-developed soils with 10YR-2.5Ycolor, none to minimal carbonate accumulation, and lack of Bt horizon development. As mapped, Qy also contains some units possibly equivalent to Qy4.

Qp **Playa deposits (Holocene and possibly also Pleistocene).** Mostly fine-grained deposits that fill small depressions in soil-covered basalt on the plateau and within the small volcanic maar in the northeast corner of the map.

Qt4 **Alluvial deposits underlying Qt4 terrace surfaces—**Deposits of sandy pebble to boulder size gravel underlying terrace surfaces located approximately 3 to 5 m above local base level (Figure 1). The only Qt4 deposits on the Seboyeta Quadrangle are located along Encinal Canyon, where deposits are in excess of 5 m thick (basal contact is not exposed). Soils developed in deposits underlying Qt4 surfaces are weakly developed, with 10YR-2.5Y color, Bw horizon development, none to minimal carbonate accumulation, (Table 1). Late Holocene (?) in age.

Qt3 **Alluvial deposits underlying Qt3 terrace surfaces—**Deposits of sandy pebble to boulder size gravel 1 to 3 m thick underlying strath terrace surfaces located approximately 6 to 24 m above local base level along Rio Paguate, Seboyetita Creek, and Seboyeta Creek drainages. Bt horizon is typically absent (stripped), with stage I to II carbonate horizon exposed at surface. Late Pleistocene (?).

Qt2 **Alluvial deposits underlying Qt2 terrace surfaces—**Deposits of sandy pebble to boulder size gravel underlying terrace surfaces located approximately 11 to 30 m above local base level. Surfaces typically have a slope greater than the adjacent valley floors, so elevation above base level can vary significantly for one depositional unit. Deposit thickness ranges from 2 to 12 m or more. Where preserved, soils are well developed, exhibit Stage II to III carbonate morphology, Bt horizon with 5YR to 7.5YR color. Likely middle to late Pleistocene in age.

Qf4 **Deposits underlying Qf4 fan surfaces—description is from Mt. Taylor quad.** Qf4 surfaces form part of the modern piedmont. Deposits of fine sand to coarse gravel; typically interbedded fine to medium sand and imbricated cobble-to-boulder-size gravel with individual gravel beds 1-3m thick. Qf4 deposits often bury Qf3 deposits and include buried soils (Figure 2, from Mt Taylor Quad). Total thickness 3 to 10 m or more. Where present, Qf3 buried soils are 1 to 5 m

below the Qf4 surface. Qf4 soils are characterized by A-Bw-C or A-Bk-C profiles with maximum Stage I carbonate morphology (Table 1), locally include buried A horizons. Middle to late Holocene. The large deposit in Seboyeta is covered locally by younger (Qy?) deposits.

Qf3 **Deposits underlying Qf3 fan surfaces—**Qf3 surfaces form part of the modern piedmont. Deposits of sandy pebble to boulder gravel of mixed volcanic lithologies and subordinate sandstone clasts. Total thickness is from 4.5 m to more than 7 m. Soils are partially eroded, but exhibit Stage III carbonate morphology, Bt horizon with 5YR to 7.5YR color where preserved (Figures 3 and 4, Table 1). Likely middle Pleistocene.

Qf2 **Deposits underlying Qf2 fan surfaces—**Deposits of subrounded to subangular sandy pebble to boulder gravel underlying remnant fan surfaces. Deposits range from isolated remnants that are less than 1 m thick to continuous surfaces where deposits are up to 19 m thick. Qt2 fan surfaces in the Seboyeta Quadrangle are approximately 12 m above local base level. Soils are typically stripped although stage I-II carbonate morphology is locally preserved. Early to middle Pleistocene?

Qf1 Deposits of subrounded to subangular sandy pebble to boulder gravel. Forms one small terrace remnant in the southwestern part of the map, just below the level of Qf0 deposits.

Qf0 **Deposits underlying Qf0 fan surfaces—**Deposits of subrounded to subangular sandy pebble to boulder gravel underlying remnant fan surfaces. Deposits are approximately 18 m thick (Figure 5). Qf0 fan surfaces on the Seboyeta Quadrangle are approximately 60 m above local base level. Multiple buried soils are present within the deposits including Bt soil with 5YR color, Bw soil with 10YR color, and multiple Bk soils with Stage II carbonate morphology (Figure). The surficial soil exhibits Stage III carbonate morphology, Btk horizons with 7.5YR to 10YR color. Early Pleistocene?

Qls **Landslide deposits.** Poorly sorted debris that has moved chaotically down steep slopes; slumps or block slides (toreva blocks) partially to completely intact, that have moved down slope; slumps and block slides usually display some rotation relative to their failure plane; thickness varies considerably depending on the size and nature of the landslide. As mapped includes colluvium and talus deposits that contains material deposited on slopes that originated as avalanches, debris flows, and reworked deposits of each. There appear to be deposits of different ages, some with well developed laminar caliche horizons.

Qg **Old alluvial deposits along Seboyeta Canyon.** These remnants are composed of very poorly sorted subrounded to angular debris composed mostly of basalt clasts. The deposits reside more than 400 feet above the modern drainage and most do not appear to be continuous with the more extensive landslide deposits. They appear to be remnants of deposits that are older than the landslide deposits. Locally, this unit may include Qls deposits.

Qes **Eolian deposits.** Typically 0.3 to 0.8 m thick deposit of silt and very fine sand forming sand sheet on Encinal Mesa. Characterized by thin (approximately 10 cm thick) late Holocene deposit overlying buried middle Pleistocene eolian deposit approximately 20 to70 m thick. Surficial soil is weakly developed with 7.5YR color, absence of carbonate morphology, and lack of Bt horizon

development. Buried soil is well developed, exhibits Bt horizon with 5YR color (Table 1). Underlying volcanic rubble has continuous carbonate coatings.

Volcanic Rocks of Southeastern Mount Taylor and Southern Mesa Chivato

Quaternary (Pleistocene)

Qctc **Young basalt in the bottom of Seboyeta Cyn.** The vent consists primarily of three cycles of alternating massive basaltic hydromagmatic beds overlain by layers of coarse pyroclastic breccia and welded basaltic scoria. The hydromagmatic beds consist of fragments of quenched basalt of varying sizes mixed with abundant fragments of Cretaceous sandstone and rounded chert. Pale brownish yellow palagonite, a clay typical of mafic hydromagmatic eruptions, is common in these beds. The pyroclastic breccia layers also contain fragments of Cretaceous sandstone and chert. An infill of lava cuts across the beds and layers of cycle 2 and forms a thin lava flow dipping south on the southwest side of the vent. The lava is covered by cycle 3 (uppermost) hydromagmatic and scoria layers. Two thin vertical dikes trending S30W cut cycle 1 deposits on the northeast side of the vent, visible along an abandoned trail. The lava, dikes, scoria and hydromagmatic fragments all consist of trachybasalt containing conspicuous phenocrysts and/or megacrysts of black clinopyroxene.

Qfqtb **Fine-grained quartz-bearing olivine trachybasalt—**Flows of dark gray, fine-grained trachybasalt containing sparse, but easily recognizable, small xenocrysts of quartz, and small sparse phenocrysts of olivine and black augite in groundmass of tiny plagioclase, olivine, augite, opaque oxides, and glass; many of the xenocrysts have pale green clinopyroxene reaction rims with host lava; olivine shows minor high-temperature iddingsite alteration; flows originate from Cerro Ortiz just north of quad boundary; flows overlie QTvs and Qfob2, and abut Qmptb; maximum observed thickness about 55 m; K-Ar date is 1.56 ± 0.17 Ma (whole rock; Lipman and Mehnert, 1979).

Qfob2 **Fine-grained olivine basalt—**Flows of dark gray to black, fine-grained basalt with sparse small phenocrysts of olivine in groundmass of plagioclase, olivine, augite, opaque oxides and glass; contains rare small quartz xenocrysts; olivine displays minor high-temperature iddingsite alteration; flows originate from the north; overlie Qmptb but underlie Qfqtb; maximum observed thickness is about 10 m.

Qmptb **Medium-grained plagioclase-phyric olivine trachybasalt—**Gray, medium-grained, sparsely porphyritic trachybasalt flows containing plagioclase phenocrysts ≤3 cm long in groundmass of plagioclase, olivine, augite, opaque oxides and glass; olivine shows very minor high-temperature iddingsite alteration; flows originate from Cerro Frio north of quad boundary; underlies Qfob2 but overlies Tfob; maximum observed thickness is about 15 m.

Quaternary- Tertiary (Plio-Pleistocene)

QTfob **Fine-grained olivine basalt—**Dark gray to black, fine-grained basalt flows with rare megacrysts of 0.25 cm resorbed plagioclase and sparse phenocrysts of small olivine in groundmass of plagioclase, olivine, augite, opaque oxides and glass; superficially resembles flows of unit Qfob2; flows apparently originate from the northeast; underlies Qmptb, Tfcpb, and Tfab; maximum observed thickness is about 35 m.

QTfqxb **Fine-grained, quartz- and xenolith-bearing olivine trachybasalt—**Dark gray to black, fine-grained, occasionally flow-banded, nearly aphyric trachybasalt flows; contain sparse small quartz xenocrysts with green clinopyroxene reaction rims; contains very rare, resorbed dunite xenoliths ≤4 cm in diameter and rare resorbed black augite megacrysts; groundmass consists of tiny plagioclase, olivine, augite, opaque oxides and glass; olivine displays minor high-temperature iddingsite alteration; one of younger flows in Seboyeta quad but is submerged in upper part of debris flows of QTvs; overlies Tmctb, and Tmcpb; maximum observed thickness about 20 m.

QTvs **Volcaniclastic sedimentary rocks—**Gray to tan to white debris flows, fluvial deposits and interbedded tuffs **(Ttdt and Ttrt)** shed from the Mount Taylor stratovolcano during growth. Debris flow component is most abundant near source (northeast part of quadrangle) and consists primarily of boulders and cobbles of angular to subangular trachydacite and trachyandesite in a volcanic sand matrix. Boulders form a lag deposit on surface of debris flows. Fluvial component contains rounded to subrounded cobbles including a higher proportion of basaltic clasts, especially to south. Tuffs are described below. Underlies a multitude of mafic flows and cones east of Mt. Taylor; interbedded with two intermediate composition flows along northeast margin of quad **(Tpota and Tbhtd).** Overlies a few older trachybasalts and basalts throughout much of the quadrangle. Maximum exposed thickness is >200 m.

Tertiary (Pliocene)

Tfptb **Fine-grained plagioclase-phyric olivine trachybasalt—**Flows of gray, fine- to medium-grained, slightly porphyritic trachybasalt containing 0.5 to 1.5 cm plagioclase phenocrysts in a groundmass of plagioclase, olivine, augite and opaque oxides; contains virtually no glass; flows originate from eroded vent with barely any cinders at north end of Silver Dollar Mesa; overlies QTvs, Tfqgb, and Tbas; maximum exposed thickness about 35 m.

Tmctb **Medium-grained clinopyroxene-phyric olivine trachybasalt—**Dark gray, medium-grained, slightly porphyritic trachybasalt flows with abundant small phenocrysts of black augite, plagioclase and olivine in a groundmass of plagioclase, olivine, augite, opaque oxides and glass; olivine shows high-temperature iddingsite alteration; occasionally displays spotted appearance; underlies QTfqxb and Tfptb; interbedded within QTvs; maximum exposed thickness about 35 m; K-Ar age is 2.65 ± 0.15 Ma (Lipman and Mehnert, 1979).

Tmcpb **Medium-grained clinopyroxene plagioclase-phyric olivine trachybasalt—**Flows of gray, medium-grained sparsely porphyritic trachybasalt having phenocrysts of plagioclase and black augite in a groundmass of plagioclase, olivine, augite, opaque oxides and glass. Flows are exposed along most of the upper Rio Paguate; underlies Qfqtb and QTfqxb; interbedded in QTvs abuts Tmctb; overlies Tmotb; maximum exposed thickness is about 25 m.

Tpota **Porphyritic olivine trachyandesite—**Light gray, highly porphyritic lava flow with abundant 0.5 to 2.0 cm phenocrysts of complexly zoned plagioclase, and tiny phenocrysts of olivine, augite, plagioclase and sparse biotite in a very fine-grained, devitrified groundmass of plagioclase and opaque oxides; olivine shows extensive iddingsite alteration; minor Fe-oxide staining in cracks; contains sparse enclaves of plagioclase-augite ≤12 cm in diameter; flow is massive to sheeted; unit forms thick viscous flow in NW corner of quad; interbedded in QTvs; maximum exposed thickness is about 75 m.

Tbhtd **Porphyritic biotite-hornblende trachydacite—**Light gray to pale pink, highly porphyritic lava flow containing conspicuous phenocrysts of plagioclase, biotite and hornblende in a fine-grained devitrified groundmass of plagioclase, sanidine, biotite, augite and opaque oxides. Flow is massive and is exposed as two low knobs interbedded in QTvs on unnamed ridge in western part of quad. Maximum exposed thickness is about 7 m.

Ttdt **Porphyritic trachydacite tuffs—**White to light gray beds of pumice and pumice-rich sediments interbedded in middle to lower parts of unit QTvs; pumice is highly vesicular containing sparse, small phenocrysts of plagioclase, augite ± sanidine, biotite, hornblende and quartz; tuffs originate from sources within Mount Taylor; beds are up to 5 m thick; $^{40}Ar/^{39}Ar$ dates on similar deposits to west and northwest range from 2.71 to 2.76 Ma (n=4; Goff et al., 2008, 2010).

Tfctb **Fine-grained clinopyroxene-phyric olivine trachybasalt—**Flows of gray, fine- to medium-grained slightly porphyritic trachybasalt containing sparse plagioclase phenocryst ≤1.5 cm long and very sparse phenocrysts of equant, black augite in a groundmass of plagioclase, olivine, augite, opaque oxides and minor glass. Olivine displays high-temperature iddingsite alteration. Flows originate from eroded cinder cone (Tfctc) and cover all of southern Chupadero Mesa. Flows underlie Qfqtb, QTvs and QTfob; flows overlie Tmotb and Tbas. Maximum exposed thickness is about 20 m.

Tfctc **Eroded cinder cone for lava flows of Tfctb.** Scoria and cinder deposits.

Tfcpb **Fine-grained, clinopyroxene porphyritic olivine basalt—**Flows of dark gray to black, fine-grained, porphyritic basalt with conspicuous black megacrysts of resorbed augite and small phenocrysts of plagioclase, olivine and magnetite in a groundmass of plagioclase, olivine, augite, opaque oxides and glass; olivine is extensively altered to high-temperature iddingsite; flows cover most of Seboyatita Mesa and apparently originate from the east; unit underlies QTfob and overlies QTvs, Tmpcb and Tfab; maximum exposed thickness is about 20 m.

Tfotb **Fine-grained olivine trachybasalt—**Dark gray, fine-grained trachybasalt flows with sparse phenocrysts of olivine, plagioclase and augite in groundmass of plagioclase, olivine, augite, opaque oxides and glass; flows originate from eroded hills of cinders and scoria **(Tfotc)** on southern Mesa Chivato; overlie Cretaceous rocks; maximum exposed thickness of flows is about15 m.

Tfotc **Eroded cinder cone for lava flows of Tfotb.** Scoria and cinder deposits.

Tmpcb **Medium-grained plagioclase-phyric trachybasalt—**Flows of gray, medium-grained porphyritic trachybasalt with phenocrysts of plagioclase and very small phenocrysts of olivine and augite in groundmass of plagioclase, olivine, augite, opaque oxides and glass; underlies Tfcpb and overlies Cretaceous rocks along northeast edge of Seboyatita Mesa; maximum exposed thickness about 15 m.

Tfab **Aphyric basalt—**Black, very fine-grained, aphyric basalt flows with tiny microphenocrysts of plagioclase, olivine, augite, opaque oxides and abundant glass; olivine displays extensive iddingsite alteration; flows originate from eroded cinder cone **(Tfac);** underlies Tfob and Tfcpb; overlies Cretaceous rocks; maximum exposed thickness of flows is about 40 m.

Tfqgb **Fine-grained quartz- and xenolith-bearing trachybasalt—**Flows of gray, fine-grained trachybasalt with rare quartz xenocrysts and very rare xenocrysts (0.5 to 2 cm) of pyroxene gabbro in a groundmass of plagioclase, olivine, augite, opaque oxides and glass; quartz may have pale green clinopyroxene reaction rims; gabbro is medium-grained and equigranular; highly eroded vent **(Tfqtc)** is mostly stripped of scoria and bombs; underlies Tfptb; interbedded in QTvs; overlies Tmpxb and Tbas; maximum exposed thickness of flow is about 15 m.

Tfqtc **Eroded cinder cone for lava flows of Tfqgb.** Scoria and cinder deposits.

Tmpxb **Medium-grained clinopyroxene-phyric olivine trachybasalt—**Gray, medium-grained, slightly porphyritic trachybasalt flows with sparse megacrysts of resorbed black augite in a groundmass of plagioclase, olivine, augite, opaque oxides and a little glass; olivine shows considerable iddingsite alteration; forms distinctive flows along southwest margin of Silver Dollar Mesa; probable source is low hill on east side of middle Encinal Creek; underlies QTvs and Tfptb; overlies Tcpob, Ttrt, Tbas and Cretaceous rocks; K-Ar date is 2.93 ± 0.12 Ma (whole rock; Laughlin et al., 1993).

Tvss **Volcaniclastic sandstone—**Gray to tan, fine- to course-grained fluvial sandstone containing small clasts and grains of quartz, plagioclase, olivine, augite, chert, pumice, and various types of basalt and intermediate composition volcanics; may contain thin beds of trachydacite or rhyolite tuffs too thin to map; occupies shallow channels cut into earliest lava flow surfaces in the region; underlies QTvs; interbedded with various older lava flows; overlies Tbas; maximum exposed thickness is about 35 m but usually is much less.

Tmotb **Medium-grained olivine trachybasalt—**Flows of gray to black, medium-grained, trachybasalt containing about 3% of ≤1 mm olivine phenocrysts in a slightly trachytic groundmass of plagioclase, olivine, augite, opaque oxides and glass; olivine is extensively altered to iddingsite. Flows originate from small exhumed cinder cone **(Tmotc)** on west side of upper Paguate Creek; underlies Tvss and several lava units; overlies Tbas and Cretaceous rocks; maximum exposed thickness is about 35 m.

Tmotc **Eroded cinder cone for lava flows of Tmotb.** Scoria and cinder deposits.

Tcpob **Medium-grained augite- and plagioclase-phyric olivine trachybasalt—**Gray, medium-grained, porphyritic trachybasalt flows with phenocrysts of plagioclase, olivine, sparse augite and magnetite in a groundmass of plagioclase, olivine, augite, opaque oxides and glass; olivine displays extensive high-temperature iddingsite alteration; augite phenocrysts are very sparse in some locations but porphyritic texture is quite distinctive; covers most of Encinal Mesa; flows originate from low hill of cinders **(Tcpoc);** underlies QTvs and Tmpxb; interbedded with Tvss and Ttrt; overlies Tgrt and Tbas; maximum exposed thickness about 20 m.

Tcpoc **Eroded cinder cone for lava flows of Tcpob.** Scoria and cinder deposits.

Ttrt **Porphyritic rhyolite tuffs—**White to pale pink beds of pumice, pumice-rich sediments and thin ignimbrites; pumice is highly vesicular containing sparse, small phenocrysts of sanidine and biotite ± hornblende, clinopyroxene and quartz; tuffs originate from sources within Mount Taylor; underlies QTvs and Tvss; interbedded with Tcpob; overlies Tbas; beds are up to 25 m thick near western margin of quadrangle; $^{40}Ar/^{39}Ar$ dates on similar deposits to west and northwest range from 3.08 to 2.79 Ma (n=3; Goff et al., 2008, 2010).

Tbas **Spotted aphyric analcite basanite—**Dark gray to bluish gray, fine-grained, nearly aphyric basanite flows with rare tiny phenocrysts of plagioclase and olivine in a groundmass of plagioclase, abundant olivine, augite, analcite, opaque oxides and glass; the analcite displays ocellar texture (Lipman and Moench, 1972); olivine shows intense, high-temperature iddingsite alteration; vugs, vesicles and cracks are commonly filled with opal/chalcedony, calcite and Fe-oxides; weathered surfaces are distinctly to vaguely spotted in outcrop; upper part of unit is massive to rubbly; lower part is columnar jointed; underlies all other Mount Taylor volcanic rocks except Tmaob; source is apparently within Mount Taylor; flows fill shallow paleo-valleys developed on top of Cretaceous rocks; maximum exposed thickness is about 45 m. K-Ar date is 3.26 ± 0.31 Ma (whole rock, Perry et al.,, 1990).

Tfqxd **Fine-grained quartz- and xenolith-bearing olivine basalt dike—**Dark gray, fine-grained, slightly porphyritic basaltic dike containing sparse small phenocrysts of olivine in a groundmass of plagioclase, olivine, augite, opaque oxides and glass; contains sparse small quartz xenocrysts with pale green clinopyroxene reaction rims and sparse xenoliths of dunite; olivine shows iddingsite alteration; dike extends northeast from Picacho Peak plug, which is just south of quad; intrudes Cretaceous (?) rocks; $Ar^{40/39}$ date on plug is 4.49 ± 0.08 Ma (groundmass; Hallett et al., 1997).

Cretaceous and Jurassic Rocks

Kmsa **Mancos Shale, Satan tongue.** Intgerbedded dark shale and less abundant very fine-grained quartz sandstone. Only exposed in the far northeast part of the map. See measured sections 1 and 20 for a more detailed description. About 65 meters thick but top is covered.

Kph **Point Lookout Sandstone, Hasta tongue.** Fine-grained quartz sandstone with rare darker lithic grains. Uppermost 5 meters shows planar cross-bedding in sets up to 1 m. Below about 5 meters bedding is mostly horizontal with low-angle cross-beds, especially in the lowermost 2-3 meters. Forms prominent light gray cliff. Thickness 45 meters.

Kcg **Gibson Coal member, Crevasse Canyon Formation.** Interbedded light orange very fine-grained quartz sandstone in massive to thinly bedded layers up to 4 meters thick and dark shale. The shale commonly contains dark brown to black lignite coal in seams up to 2 meters thick. Locally contains light gray fragments of fossilized wood. Thickness 95 meters.

Kcd **Dalton Sandstone member, Crevasse Canyon Formation.** Light tan-colored very fine-grained quartz sandstone. Grains are mostly subrounded quartz and light gray grains that appear to be either altered feldspar or argillite grains. Some beds appear massive to very weakly bedded. Other beds show planar cross-bedding in sets up to about 30 cm thick. Forms a prominent light gray cliff. See measured sections 2 and 20 for a more detailed description. Thickness 24 meters.

Kmm **Mancos Shale, Mulatto tongue.** This unit is composed mostly of very thinly bedded siltstone, and minor shale and fine-grained sandstone. The unit typically forms a steep resistant slope which contains two intervals of medium-bedded fine-grained sandstone. These two intervals form light tan cliffs composed of thin planar beds. Thickness 80 meters.

Kcdc **Dilco Coal member, Crevasse Canyon Formation.** Interbedded very fine-grained, well sorted yellow quartz sandstone and dark carbonaceous shale. Thin- to medium-bedded sandstone beds are typically mottled in appearance, contain abundant horizontal burrows up to 1 cm in diameter, and are between 0.5 and 1 meter thick. Quartz grains are subrounded. Minor biotite flakes. Low-angle planar cross-beds are locally common in sets up to 20 cm thick. Ripple marks are common on the undersides of some sandstone beds. Shale horizons are characteristically dark gray, contain abundant dark carbonaceous matter and brown to black lignite coal beds up to several tens of centimeters thick, and are between 3 and 7 meters thick. Shale beds also contain permineralizied wood fragments and leaf and seed molds.

Kg **Gallup Sandstone. Very fine- to fine-grained quartz sandstone** Light tan-colored, fine- to very fine-grained quartz sandstone. It contains subangular to subrounded quartz grains and sparse dark lithic grains. The unit is typically horizontally bedded to massive. Planar cross-beds are common in sets up to 1-2 meters. The unit is well exposed from the southwest corner of the map to the northeast corner. It is best exposed near the mouth of Seboyeta Canyon where it forms a prominent cliff. Here, the overlying Dilco Coal member has eroded recessively so that the Gallup sandstone forms a flay bench. Near Bear Canyon the formation splits into two distinct sandstone layers separated by dark shale. Unfortunately this split cannot be measured further south because the Gallup Sandstone has been completely removed farther south.

Km **Mancos Shale.** Thinly layered and laminated dark shale and quartz siltstone. Weathered surfaces are typically medium gray to light tan, but fresh surfaces are characteristically dark gray to dark grayish green. Locally contains thin very fine-grained sandstone layers a few tens of centimeters thick, septarian concretions up to 1 meter across, and one thin light gray bentonite layer 15 cm thick within the lower 1/3rd of the mapped unit within the study area. Lower part also contains one layer 1 meter thick composed of very abundant oyster fossils. Translucent to clear platy crystals of gypsum up to 10 cm long are common weathering out of

slopes. Sandstone layers contain sparse but ubiquitous very fine green-colored grains of unknown composition, the same size as the quartz grains.

Kms_3 **Sandstone.** Thin to medium bedded very fine grained quartz sandstone. Sparse darker lithic grains. Dark bivalve shell fragments up to 7 cm. Most beds appear massive. Low-angle planar cross-beds are visible in the upper 3 m. Darker lithics are locally mostly dark green in color common in dark laminae. Abundant bedding-parallel burrows above cross-beds. Forms cliff.

Kms_2 **Sandstone.** Upper part is thin to medium bedded very fine grained quartz sandstone. Sparse darker lithic grains. Dark bivalve shell fragments up to 7 cm. Most beds appear massive. Low-angle planar cross-beds are visible in the upper 3 m. Darker lithics are locally mostly dark green in color, common in dark laminae. Abundant bedding-parallel burrows above cross-beds. Forms cliff. Lower parties thin to medium bedded very fine grained quartz sandstone. Sparse darker lithic grains. Dark bivalve shell fragments up to 7 cm. Most beds appear massive. Low-angle planar cross-beds are visible in the upper 3 m of lower part. Darker lithics are locally mostly dark green in color, and are most common in dark laminae. Abundant bedding-parallel burrows above cross-beds. Forms cliff.

Kms_1 **Sandstone.** Very fine-grained to fine-grained quartz sandstone. Upper part is mostly massive. Abundant burrows on bed planes. Faintly to strongly laminated. Medium- to thick-bedded, with low-angle planar cross-bedding. Lower part is thin- to medium-bedded. Faint horizontal laminae. Flecks of dark organic matter. Crumbly. As mapped this unit contains beds of dark shale.

Kd **Dakota Sandstone (shown only in cross-section).**

Jm **Morrison Formation (shown only in cross-section).**

Jt **Todilto Formation (shown only in cross-section).**

Je **Entrada Sandstone (shown only in cross-section).**

APPENDIX 1

The following thin-section descriptions are of volcanic samples from the Seboyeta 7.5' Quadrangle, Mount Taylor Region (by Fraser Goff)

General Comments: Locations use US Geological Survey, Seboyeta 7.5 minute topographic quadrangle, UTM NAD 27 (1982) unless otherwise noted. Textures, petrology and rock names generally follow the examples in Williams et al. (1954). Rock names use classification schemes of Le Bas et al. (1986) for volcanic rocks.

Abbreviations: Kspar = generic potassium feldspar (variety noted if possible); plag = plagioclase, qtz = quartz, bio = biotite, hbd = hornblende, opx = orthopyroxene, cpx = clinopyroxene, ol = olivine; io = generic iron ore, mt = magnetite, ilm = ilmenite, gl = glass; HT-idds = high-temperature iddingsite (mainly reddish orange hematite and maghemite); ser = sericite, chl = chlorite, cc = calcite, ep = epidote, Fe-oxide = generic low-temperature secondary iron oxide(s).

F11-48: Medium-grained olivine trachybasalt (map unit Tmotb)
Location: 0276534/3897190, 7660 ft, bottom upper Bear Canyon by main Silver Dollar Rd.
Relations: Overlain by QTvs, bottom of unit not exposed here
Color & Texture: Gray to black, medium-grained, intersertal, slightly trachytic and vesicular
Primary: Contains about 3% of small ≤1 mm ol phenocrysts in groundmass of felty, semi-aligned plag, cpx, abundant tiny ol, io and minor gl
Secondary: Ol is altered to HT-idds; larger crystals have fresh core
Comments: This unit is observable both up and downstream
Petrographic Name: Medium-grained olivine basalt

F11-51: Porphyritic trachydacite pumice (Ttdt layer in QTvs)
Location: 0277885/3897419, 7700 ft, end of dirt road in overflow of "Trout Pond"
Relations: 3 to 5-m-thick discontinuous bed of pumice in volcaniclastic sandstone
Color & Texture: White, glassy, pumiceous, highly vesicular, and slightly porphyritic
Primary: Contains <1 % small phenocrysts of qtz, sanidine, dark green cpx and oxidized hbd; very minor plag; qtz and sanidine are broken and partially resorbed; gl is fresh
Secondary: Minor amounts of fine volcanic sandstone in some larger vesicles
Comments: Pumice fragments average 2-3 in in diameter; submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Slightly porphyritic dacite pumice

F11-52: Medium-grained plagioclase-phyric olivine trachybasalt (unit Qmptb)
Location: 0277059/3900757, 7995 ft, on main Silver Dollar Rd
Relations: Underlies Qfob2; overlies Tfob and abuts Qfqtb
Color & Texture: Dark gray, medium-grained, intersertal, slightly vesicular, sparsely porphyritic
Primary: Sparse plag phenocrysts ≤3 cm long in groundmass of plag, ol, cpx, io and gl; plag phenocrysts contain gl inclusions and display complex zoning
Secondary: Very minor HT-idds in ol
Comments: Somewhat distinctive flow originates from north; submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Medium-grained plagioclase porphyritic olivine basalt

F11-53: Fine-grained olivine basalt (unit QTfob)
Location: 0277773/3901850, 8060 ft, on low rise ¼ km west of Seboyetita Creek
Relations: Underlies Qmplb; abuts Tfac; overlies Tfcpb
Color & Texture: Dark gray to black, fine-grained, hyalopilitic to intersertal, slightly vesicular and sparsely porphyritic
Primary: Rare megacrysts of resorbed, complexly zoned plag and rare phenocrysts of ol in groundmass of felty plag, ol, tiny cpx, io and gl
Secondary: Minor HT-idds in ol
Comments: Flow originates from the north
Petrographic Name: Fine-grained sparsely porphyritic olivine basalt

F11-55: Fine-grained olivine basalt (unit Qfob2)
Location: 0276576/3902322, 8155 ft, along "Southwest Road"
Relations: Overlies Qmplb; underlies Qfqtb
Color & Texture: Dark gray to black, fine-grained, hyalopilitic to intersertal, slightly vesicular and porphyritic
Primary: Sparse ol phenocrysts in groundmass of plag, ol, tiny cpx, io and gl; contains rare small embayed qtz xenocrysts
Secondary: Minor HT-idds in ol
Comments: Resembles F11-53 in color and texture; can't tell them apart without field relations; flow originates from north
Petrographic Name: Fine-grained sparsely porphyritic olivine basalt

F11-56: Fine-grained quartz-bearing olivine trachybasalt (unit Qfqtb)
Location: 0276218/3901763, 8135 ft, along "Southwest Road"
Relations: Overlies Tfob2 and QTvs; youngest flow on quadrangle
Color & Texture: Dark gray, fine-grained, hyalopilitic, slightly vesicular and porphyritic
Primary: Sparse small phenocrysts of ol and black cpx in groundmass of tiny plag, ol, cpx, io and gl; contains sparse but noticeable qtz xenocrysts, some with pale green cpx reaction rims
Secondary: Minor HT-idds in ol
Comments: Qtz xenocrysts are distinctive; flow originates from Cerro Ortiz just north of quad; K/Ar date is 1.56 ± 0.17 Ma (whole rock; Lipman and Mehnert, 1979)
Petrographic Name: Fine-grained quartz-bearing olivine basalt

F11-57: Fine-grained, clinopyroxene porphyritic olivine basalt (unit Tfcpb)
Location: 0279714/3903314, 8000 ft, just north of quad boundary, W side Seboyeta Canyon
Relations: Overlies Tmpcb in canyon wall; underlies QTfob to west
Color & Texture: Dark gray to black, fine-grained, intersertal, slightly vesicular and porphyritic
Primary: Conspicuous black megacrysts of resorbed cpx and small phenocrysts of plag, ol and mt in groundmass of tiny plag, ol, cpx, io and gl
Secondary: Considerable HT-idds alteration of ol
Comments: Distinctive flow presumable originates from north or west
Petrographic Name: Fine-grained clinopyroxene megacrystal olivine basalt

F11-59: Aphyric basalt (unit Tfab)
Location: 0280311/3900626, 7830 ft, W side Seboyeta Canyon
Relations: Underlies QTvs and Tfcpb; overlies Cretaceous rocks
Color & Texture: Black, very fine-grained, aphyric, hyalopilitic, slightly vesicular
Primary: Groundmass contains tiny microphenocrysts of plag, ol, cpx, io, and abundant gl
Secondary: Minor HT-idds of ol
Comments: Distinctive flow originates from hill 8061 to west; submitted for $^{40}Ar/^{39}Ar$ date

Petrographic Name: Aphyric olivine basalt

F11-61: Fine-grained basanite (unit Tbas)
Location: 0279449/3897352, 7625 ft, in cliff exposure, W side Bibo Canyon
Relations: Overlies Cretaceous rocks; overlain by 10 m of Tvss with pumice layer of Ttdt(?)
Color & Texture: Dark gray, fine-grained, vaguely spotted, intersertal, nearly aphyric, slightly vesicular
Primary: Abundant microphenocrysts of ol in groundmass of plag, tiny cpx, io and tiny patches of analcite; spots contain more plag and analcite; les io
Secondary: Ol altered to HT-idds; some cc in vesicles
Comments: Fills shallow paleo-valley in Cretaceous rocks; spots and tiny ol are distinctive
Petrographic Name: Fine-grained analcite basanite

F11-63: Fine-grained, clinopyroxene phyric olivine trachybasalt (Tfctb)
Location: 0279418/3897327, 7700 ft, about 30 m above F11-61 in cliff wall
Relations: Overlies QTvs; lower of two flow units
Color & Texture: Gray, fine- to medium-grained, intersertal, slightly porphyritic and vesicular
Primary: Sparse phenocrysts of plag up to 1.5 cm long and very sparse phenocrysts of black, equant cpx in groundmass of plag, ol, cpx and io; very little gl; plag phenocrysts have complex zoning
Secondary: Minor HT-idds in ol
Comments: Flows cover SW Chupadero Mesa; originate from hill 7781; upper flow submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Medium-grained, clinopyroxene phyric olivine basalt

F11-68: Porphyritic trachyandesite (unit Tpota)
Location: 0272753/3901225, 8395 ft, N side unnamed ravine near W edge of quad
Relations: Thick flow-banded to massive flows submerged in QTvs
Color & Texture: Light gray, porphyritic, fine-grained pilotaxitic groundmass
Primary: Abundant 0.5 to 2.0 cm phenocrysts of complexly zoned and resorbed plag and small phenocrysts of ol, cpx, plag, mt, apatite, rare bio and sanidine in groundmass of felted plag and io. No glass, devitrified appearance; some plag contain many tiny resorbed cpx
Secondary: Minor HT-idds in ol; low-temperature Fe-oxides in cracks and spots
Comments: Ol is BIG surprise; lava contains enclaves of plag and cpx up to 5 in across; submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Porphyritic olivine trachyandesite

F11-70: Aphyric spotted basanite (unit Tbas)
Location: 0277203/3894190, 7505 ft, in cliff W side of Bear Canyon
Relations: Overlies Cretaceous rocks; overlain by Tfptb
Color & Texture: Dark gray to black, fine-grained, intersertal, vaguely spotted, practically aphyric
Primary: Abundant tiny ol in groundmass of plag, cpx, io, analcite and gl
Secondary: HT-idds in ol; cracks filled with chalcedony-opal and clay
Comments: Very similar to F11-61; submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Aphyric analcite basanite

F11-71: Fine-grained plagioclase-phyric olivine trachybasalt (unit Tfptb)
Location: 0277203/3894190, 7550 ft, top of cliff, W side of Bear Canyon
Relations: Overlies QTvs, Tfqgb and Tbas; flows cover top of Silver Dollar Mesa
Color & Texture: Gray, fine- to medium-grained, slightly porphyritic, sub-ophitic
Primary: Small 0.5 to 1.5 cm plag phenocrysts in groundmass of plag, ol, cpx (titanaugite) and io; virtually no gl
Secondary: No HT-idds!

Comments: Very fresh rock; submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Fine-grained plagioclase phyric olivine basalt

F11-74a/74b: Fine-grained, quartz- and xenolith-bearing olivine trachybasalt (unit QTfqxb)
Location: 0274710/3898611, 7990 ft, on slender ridge between two unnamed drainages
Relations: Submerged in QTvs; overlies Tmopb
Color & Texture: Dark gray to black, fine-grained, flow-banded, intersertal, nearly aphyric
Primary: Contains sparse resorbed qtz xenocrysts, small dunite xenoliths, and cpx megacrysts in groundmass of plag, ol, cpx, io and glass; qtz commonly displays pale green cpx reaction rims
Secondary: Minor HT-idds in ol
Comments: Distinctive rock but easily confused with Qfqtb if xenoliths and megacrysts not observed; dunite contains dark brown, translucent chromite blobs; possibly one of younger flows in quad
Petrographic Name: Fine-grained, quartz- and xenolith-bearing olivine basalt

F11-83: Medium-grained alkali-olivine basalt (unit Tmaob)
Location: 0272459/3894548, 7400 ft, in cliff SW side of Encinal Mesa
Relations: Overlies Cretaceous rocks; underlies Ttrt, Tcpob, and Tbas
Color & Texture: Dark brown, medium-grained, slightly porphyritic, spotted, sub-ophitic groundmass
Primary: Small sparse phenocrysts of ol and plag in groundmass of ol, plag, cpx (titanaugite), and io. No glass.
Secondary: Low-temperature Fe-oxides and clays (possibly chlorite) alteration of ol makes brown spots in lava; cc amygdules in some vesicles
Comments: Texture different, courser grained than F11-61/F11-70; submitted for $^{40}Ar/^{39}Ar$ date
Petrographic Name: Medium-grained olivine basalt

F11-85: Clinopyroxene and plagioclase phyric olivine trachybasalt (unit Tcpob)
Location: 0274535/3892006, 7380 ft, southern end of Encinal Mesa
Relations: Overlies Cretaceous rocks; covers entire southern end of mesa
Color & Texture: Gray to black, medium-grained, porphyritic, intersertal, slightly vesicular
Primary: Phenocrysts of plag, ol, sparse cpx and mt in groundmass of plag, oliv, cpx, io and gl
Secondary: HT-idds in ol
Comments: Distinctive porphyritic flow on this mesa; cpx phenocrysts *very* sparse in places
Petrographic Name: Medium-grained, clinopyroxene and plagioclase phyric olivine basalt

F11-87: Aphyric spotted basanite (Tbas)
Location: 0275241/3895767, 7615 ft, W side of upper Encinal Creek
Relations: Oldest lava in local area; underlies QTvs
Color & Texture: Dark gray to black, aphyric, intersertal, slightly vesicular
Primary: A few larger microphenocrysts of plag in groundmass of plag, ol, cpx (titanaugite), analcite, io and gl
Secondary: HT-idds in ol; clay in vesicles and cracks
Comments: Different, finer-grained texture than F11-83
Petrographic Name: Aphyric analcite basanite

F11-88: Medium-grained clinopyroxene-phyric olivine trachybasalt (unit Tmpxb)
Location: 0275694/3894203, 7460 ft, cliff along Encinal Creek
Relations: Overlies Tcpob and Tvt; underlies QTvs and Tfqgb
Color & Texture: Gray, medium-grained, intersertal, slightly porphyritic
Primary: Sparse megacrysts of resorbed cpx in groundmass of plag, ol, cpx, io and a little gl
Secondary: HT-idds in ol

Comments: Distinctive flow along lower SW cliffs of Silver Dollar Mesa: dated at 2.93 ± 0.12 Ma (Laughlin et al., 1993)
Petrographic Name: Medium-grained clinopyroxene phyric olivine basalt

F11-93: Fine-grained quartz- and xenolith-bearing olivine basalt dike (unit Tfqxd)
Location: 0272961/3889683, 6605 ft, dike extending NE of **Picacho** Peak plug
Relations: Intrudes Cretaceous rocks
Color & Texture: Dark gray, fine-grained, intersertal, slightly porphyritic
Primary: Small ol phenocrysts in groundmass of plag, ol, cpx (titanaugite) io and gl. Contains sparse xenocrysts of qtz with pale green cpx reaction rims and sparse resorbed dunite xenocrysts
Secondary: HT-idds in ol
Comments: Dunite contains small blebs of dark brown chromite; plug dated at 4.49 ± 0.08 Ma (Hallett et al., 1997)
Petrographic Name: Fine-grained, quartz- and xenolith-bearing olivine basalt

Photo 1. Outcrop of cross-bedded sandstone unit within Kmsa.

Photo 2. Outcrop of the upper part of the Point Lookout Sandstone below Mesa Chivato.

Photo 3. Outcrop of the lower part of the Point Lookout Sandstone below Mesa Chivato.

Photo 4. The upper part of the Gibson coal member is interbedded with this sandstone beds below Mesa Chivato.

Photo 5. A good exposure of the Gibson coal member in Seboyeta Canyon.

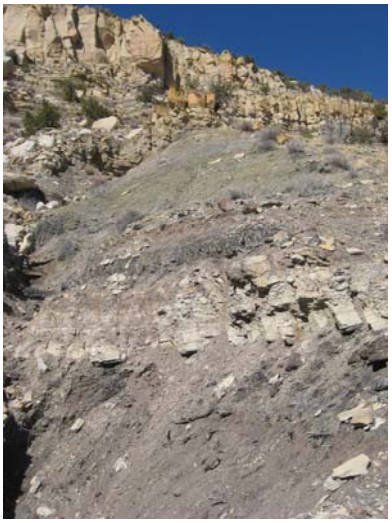


Photo 6. Interbedded shale, coal, and sandstone in the Gibson coal member.

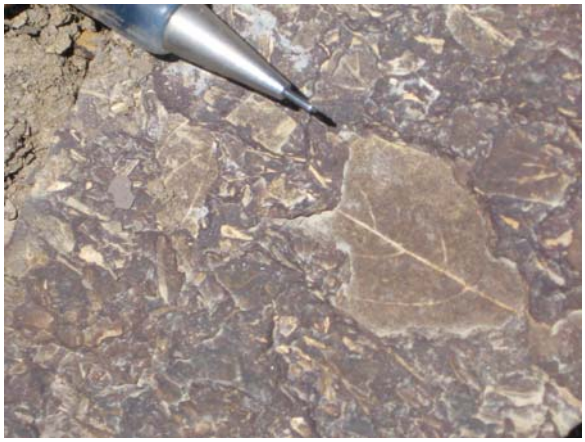


Photo 7. Plant fossils in the Gibson coal member in Seboyeta Canyon.

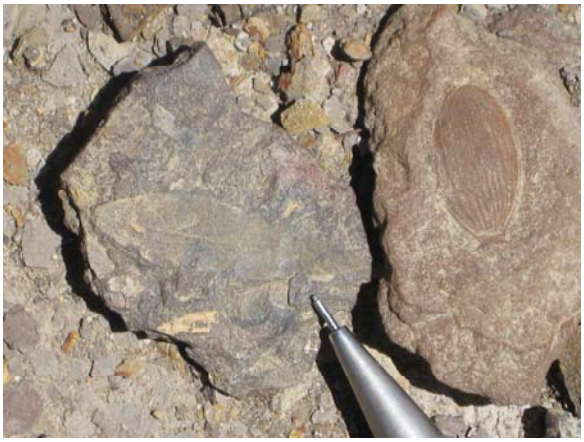


Photo 8. Plant fossils in the Gibson coal member in Seboyeta Canyon.

Photo 9. Plant fossils in the Gibson coal member in Seboyeta Canyon.

Photo 10. Top of Dalton Sandstone below Mesa Chivato showing what appears to be wood impressions.

Photo 11. Cliff exposure of the Dalton Sandstone below Mesa Chivato.

Photo 12. Below the Dalton Sandstone the Mancos Shale is interbedded with shale, south of Bibo Canyon, measured section 6.

Photo 13. Mulatto tongue of the Mancos shale south of Bibo Canyon.

Photo 14. Brachiopod moulds and casts are common in the Mulatto tongue beds.

Photo 15. Fragment of *Inoceramus* bivalve cast in the Mulatto tongue.

Photo 16. Interbedded shale and sandstone of the Dilco coal member.

Photo 17. The Dilco coal member is overlain by the Mulatto tongue of the Mancos shale south of Bibo Canyon.

Photo 18. Ripple marks and burrows are common in the Dilco coal member.

Photo 19. Permineralized wood fragments in the Dilco coal member.

Photo 20. Large bivalve impressions in the Dilco coal member.

Photo 21. The Gallup Sandstone forms a prominent cliff in the SW part of the map.

Photo 22. The Gallup Sandstone is overlain by the Dilco coal member and the Mulatto tongue of the Mancos Shale.

Photo 23. Septarian concretions are common in some layers of the Mancos Shale.

Photo 24. Large orange-weathering nodules in the Mancos Shale.

Photo 25. Feathery pseudomorphs in the Mancos Shale may be replaced gypsum.

Photo 26. Oyster-rich layer is exposed a few meters above Kms3.

Photo 27. Light gray beds in Mancos Shale near southern edge of map may be tuff.

Photo 28. Kms1 is interbedded with shale in the pit was near the SE corner of map.

Photo 29. Another view of Kms1 in the pit was outside the SE corner of the map.

Photo 30. Sandstone layer Kms3 near the south edge of the map.

Photo 31. Cross-beds within Kms3 west of Paguate.

Photo 32. Burrows are abundant on bedding planes within Kms3.

Photo 33. Lowermost sandstone unit in Kms2 contains three distinct layers.

Photo 34. Lower unit of photo 32 showing curving burrows and massive zone above.

Photo 35. Inverted teepee above burrow in laminated sandstone.

Photo 36. Middle layer of photo 32 is massive and contains abun. shell fragments.

Photo 37. Cliff exposure of Ks near the southern edge of map.

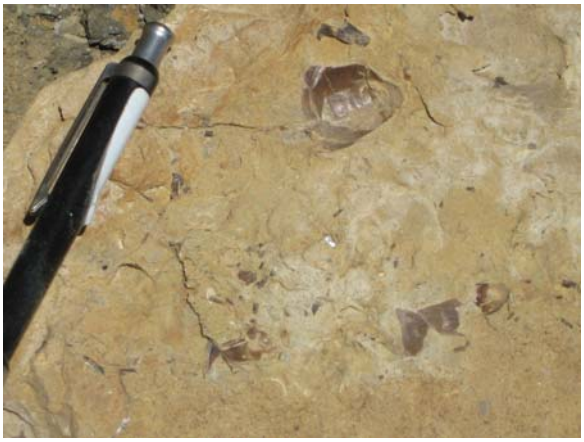


Photo 38. Close up of brown fossil fragments in Ks.

Photo 39. An assortment of siliceous pebbles found as float on the slopes.

Photo 40. Road-cut of the upper part of the Dakota Sandstone about 1 mile SE of Paguate.

Panorama 1. Looking southwest to northwest towards Mount Taylor. The prominent cliff is composed of Gallup Sandstone.

Table 1. Summary of soil morphology Seboyeta Quadrangle mapping (described by Paul Drakos)

Horizon	Depth (cm)	Gravel (%)	Dry Color (Matrix)	Moist Color (Matrix)	Texture	Structure	Dry Consist-ence	Wet Consist-ence	Argillans	$CaCO_3$	$CaCO_3$ Stage	Notes
Location: On high fan surface west of Encinal Canyon (Qf0). UTM Zone 13, 274164 m E, 3890665 m N, NAD 27. Described 7/8/1989												**Field location ID NMG-89-25**
A	0-4	25	10YR5/4	10YR3/2	sl	1f-msbk	so	ss,po	n.o.	es	-	Discontinuous to continuous coatings on clast bottoms
Btk1	4-15	20-30	8.75YR5/4	10YR4/4	scl	2m-msbk	sh	ss,ps	2n pocobr	es	I +	Continuous 1-5 mm coatings on clast bottoms. Discontinuous on sides and top
Btk2	15-23	40-50	7.5YR6/4	8.75YR5/4	scl	2msbk	h	ss,ps	1n pocobr	ev	I +	Continuous 1-5 mm coatings on clast bottoms. Discontinuous on sides and top. Filaments % 1mm nodules in matrix
Bk1b1	23-59	40-50	10YR7/3 w/ 10YR8/2 nodules	10YR7/4	ls	lumps of $CaCO_3$	h	ss,po	n.o.	ev	III	1-10 mm coatings on clast bottoms. Thin, generally continuous coatings on sides and tops. Matrix slightly hard to hard
Bk2b1	59-120+	60-70	10YR7/3	10YR6/3	s	m	lo-so	so,po	n.o.	ev	1+ or II	Continuous 1-5 mm coatings on clast bottoms. Discontinuous on sides and top. Matrix so-sh.
Location: On intermediate fan surface west of Encinal Canyon (Qf2). UTM Zone 13, 273049 m E, 3890316 m N, NAD 27 Described 7/26/89												**Field location ID NMG-89-29**
A	0-9	-	10YR5/4	10YR4/3	sl	1pl to m	lo	ss,po	n.o	e-	-	Clast coatings absent to thin, discontinuous on bottoms, sides, and tops. Some thin (2mm) chuncks of Av.
Btk1	9-27	50	8.75YR4/4	10YR4/4	scl	2-3msbk	sh-h	s,p	3-4nkpf pocobr	e	-	Thin, discontinuous coatings on clast bottoms
Bk1b1	27-50	50	10YR5/3	10YR5/4-4/4	sl	2f-msbk	so	ss,ps	n.o	es	I	Thin (2mm) coatings on clast bottoms. Discont. to absent on sides and tops
Bk2b1	50-85	60-70	10YR7/2	10YR6/3	s	m, some $CaCO_3$ chunks	sh-lo	so,po	n.o	ev	II	2-15 mm coatings on clast bottoms. Thin,discontinuous to continuous coatings on sides, absent to discontinuous on top
Bk3b1	85-120	60-70	10YR7/3	10YR6/3	s	m	lo	so,po	n.o	ev	1 +	Thin (2mm) coatings on clast bottoms. Discontinuous on sides
CBkb1	120-130+	70	10YR6/3	10YR4/3	s	m	lo	so,po	n.o	es	-	Thin coatings on clast bottoms
Location: Intermediate terrace surface in Seboyeta Cyn, SE of dry reservoir (Qt2). UTM Zone 13, 281781 m E, 3900251 m N., NAD 27 Described 10/28/2011												**Field location ID SEB-2011-27**
Bt1	0-40		5YR4/3	5YR3/4	scl	2-3msbk	sh	s,p	3nk-k, pfco, pobr	non	-	A horizon is stripped
Bt2	40-80		7.5YR4/6	7.5YR5/6	scl	2msbk, 2mk	sh	ss,ps	cobr	non	-	
Bk1	80-120		7.5YR8/1-10YR7/2	10YR7/3		m/csbk	so-sh	so,po	n.o.	ev	III-	
Bk2	120-150+		10YR6/4	10YR5/4	I	m	so-lo	so,po	n.o.	es	I+	
Location: On valley floor Qf3 fan surface between Castillo and Timber Canyons at 6600 ft, ~1000 ft west of Seboyeta/Mt Taylor Quad boundary. UTM Zone 13, 3890759m N., 269533m E., NAD 27 Described 11/4/2008												**Field location ID MT-2008-31**
A	0-5	10-20	7.5YR4/4	7.5YR3/4	sl	sg	lo	so,po	n.o.	non	-	Derived from weathering of Bt horizon?
Bt	5-25	20	5YR4/4	5YR4/4	scl	2mpr-2msbk	h	s,ps	2npobr	e	I	Partially stripped? Gravel = pebble-cobble size, subangular
K	25-75	50-60	7.5YR8/1	7.5YR8/1	s?	3m-cabk	vh	n.a.	n.o.	ev	III	
Bk	75+											Cobbly sandy gravel with disseminated carbonate in matrix
Location: Terrace in Encinal Canyon (Qt4). UTM Zone 13, 275533 m E, 3892661 m N, NAD 27. Described 6/2/2011.												**Field location ID SEB-2011-5**
A	0-30	40	10YR3/2	10YR2/2		m	lo	so,po	n.o.	non	-	
Bw	30-80	50	2.5Y3/3	2.5Y4/3		1csbk	so	ss,po	n.o.	non	-	Cobble to boulder gravel, predominantly basalt with 10%

Table 1. Summary of soil morphology Seboyeta Quadrangle mapping (described by Paul Drakos)												
Horizon	**Depth (cm)**	**Gravel (%)**	**Dry Color (Matrix)**	**Moist Color (Matrix)**	**Texture**	**Structure**	**Dry Consist-ence**	**Wet Consist-ence**	**Argillans**	**$CaCO_3$**	**$CaCO_3$ Stage**	**Notes**
C	80+	70	2.5Y5/4-4/4	2.5Y4/4		m	lo	so,po	n.o.	non	-	sandstone clasts
Location: Low surface exposed in arroyo below mouth of Encinal Canyon (Qal). UTM Zone 13, 275143 m E, 3890579 m N, NAD 27. Described 6/30/2011												**Field location ID SEB-2011-13**
A	0-40	-	10YR4/3	10YR3/3		1msbk-m	so-lo	so,po	n.o.	non	-	Silty very fine sand
Bwk	40-80	scattered	10YR5/3	10YR4/3		1-2 msbk	so	so,po	n.o.	es	I -	Very fine sand
C	80-330	channels	10YR5/3	10YR4/3		m	lo	so,po	n.o.	es to non	-	Very fine sand + scattered gravel
Location: Encinal Mesa eolian deposit (Qes). UTM Zone 13, 274952 m E, 3895101 m N, NAD 83. Described 5/23/2012												**Field location ID SEB-2012-10**
A	0-8	<5	7.5YR4/4	7.5YR3/4	si	1msbk	so-lo	so,ps	n.o.	non	-	si with minor gravel lag
Btb1	8-75	<2	5YR4/3	5YR4/4	sic	2-3msbk	sh	s,p	3mkcopobrpf	non	-	si with minor scattered basalt pebbles
												75+ = basalt rubble
Notes:												
[1]Age estimates based on relative soil development and comparison with soils in similar climate regimes and parent material for which age constraints are available. See Machette (1985), Drake [Drakos] et al. (1991)												
See key for explanation of symbols.												

Key to symbols used in descriptions of soil morphology (from Birkeland (1984) and McDonald (1996))

Structure

Grade	Size	Type	Other
1 = weak	vc = very coarse	sbk = subangular blocky	: = parting to (e.g. pr:pf)
2 = moderate	c = coarse	abk = angular blocky	
3 = strong	m = medium	pr = prismatic	
	f = fine	pl = platy	
		sg = single grain	
		m = massive	

Consistence

Dry	Moist	Wet - Stickiness	Wet - Plasticity
lo = loose	lo = loose	so = non sticky	po = non-plastic
so = soft	vfr = very friable	vss = very slightly sticky	vps = very slightly plastic
sh = slightly hard	fr = friable	ss = sticky	ps = slightly plastic
h = hard	fi = firm	s = sticky	p = plastic
vh = very hard	vfi = very firm		

Cutans

Abundance	Thickness/(Distinctness)	Location/Type	Type
n.o. = none observed	n = thin (faint)	po = along pores	man = mangans
	mk = moderately thick (distinct)		
v1 = very few (< 5%)		co = coating gravel, ped faces	skel = skeletans
1 = few (2 - 25%)	k = thick (prominent)	br = bridging grains	si = silans
2 = common (25 - 50%)		pf = along ped faces (as co + br)	
3 = many (50 - 75%)		pr:pf along prismatic ped faces	
4 = nearly continuous (75+%)		bk:pf along blocky ped faces	
		Lam = lamellae	
		Non-lam = interspace between lamallae	
		PI: ped interior	
		prfc: pressure faces	
		irg = irregular shape	

Horizon Boundary

Thickness	Topography	Carbonate effervescence in HCl
a =abrupt (< 2.5cm)	s = smooth	none = non-effervescent
c = clear (2.5 - 6cm)	w = wavy	e = slightly effervescent
g = gradual (6-12.5cm)	i = irregular	es = strongly effervescent
d = diffuse (> 12.5 cm)	b = broken	ev = violently effervescent

Texture

s = sand	sil = silt loam
ls = loamy sand	scl = sandy clay loam
sl = sandy loam	sicl = silty clay loam
l = loam	cl = clay loam

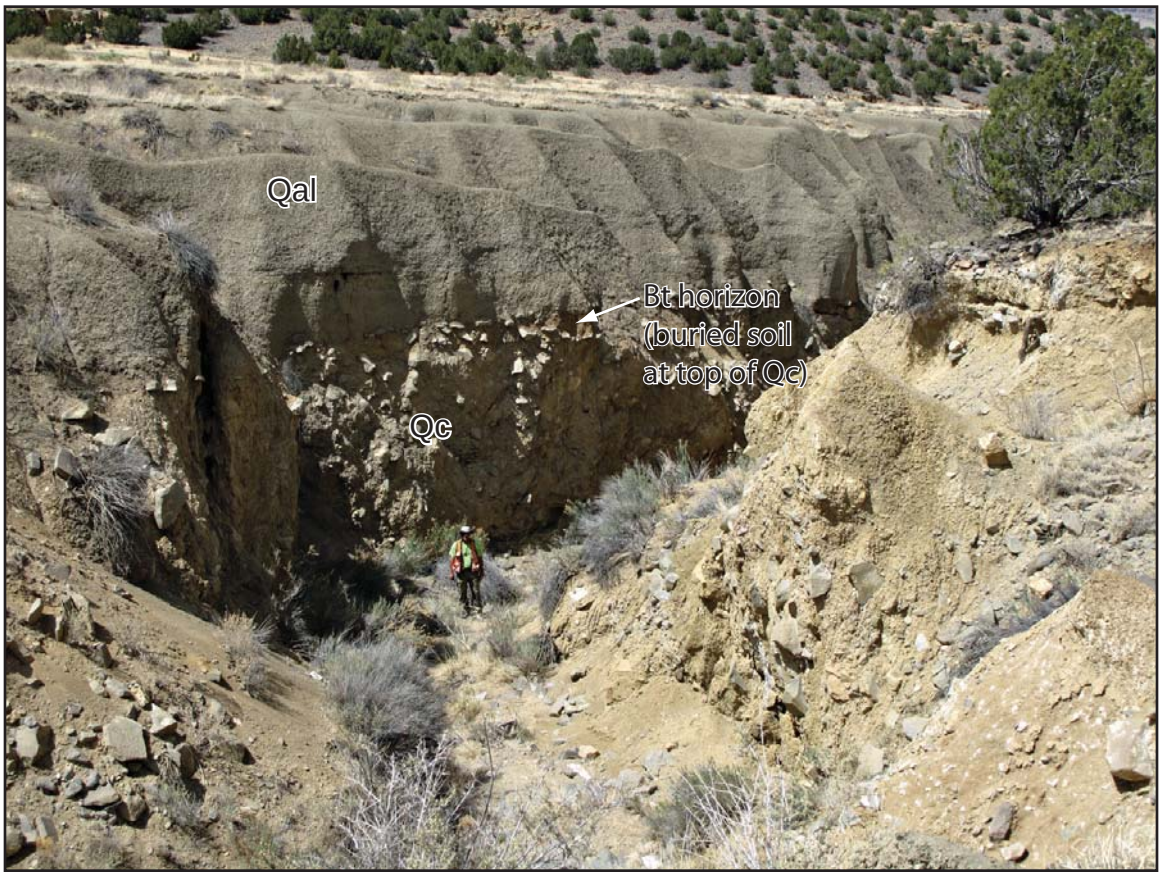
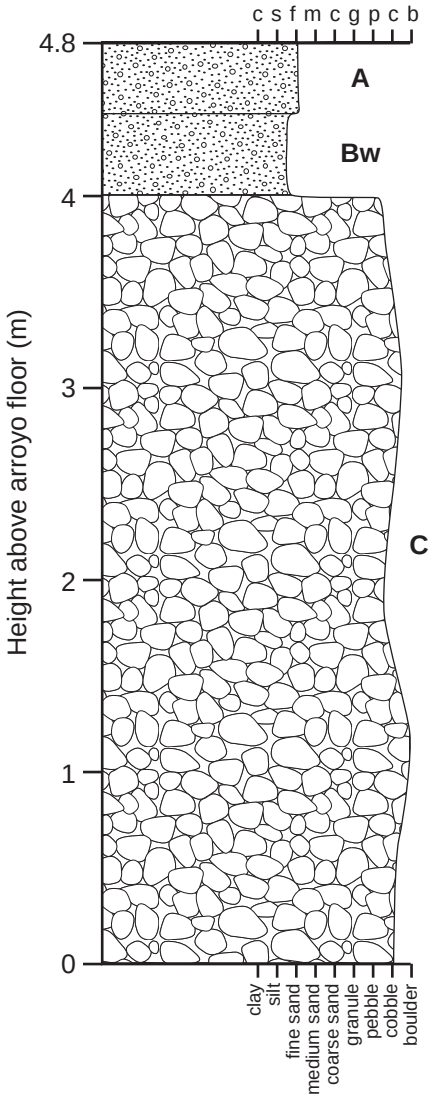


Figure 12. Qal overlies Qc along arroyo west of Paguate. Note sloping Qc contact, buried soil with Bt horizon at top of Qc. 281620m E, 3890110m N, NAD 1927.

Figure 13. Stratigraphic section measured through terrace unit Qt4
Base of Qt4 section located at 275533 m E, 3892661 m N
UTM Zone 13, NAD 1927 datum (SEB-11-5)



Lithologic Log

0-4 m: Clast supported, subangular, pebble to boulder gravel with interedded sandstone (~70% gravel). Clasts are basalt with 5-10% sandstone (no intermediate volcanics). Matrix color (dry) is 2.5Y5/4-4/4. Non effervescent in HCl

4-4.5 m: Silty sand (50%) and pebble gravel. Dry color is 2.5Y5/3. Non effervescent in HCl

4.5-4.8 m: Fine sand (60%) and pebble gravel, 10YR3/2 (dry). Non effervescent in HCl

Figure 14. Sketch of fan stratigraphy at MT-2008-54
UTM Zone 13, 3891843m N, 269614m E, NAD 27 (Mt Taylor Quad)

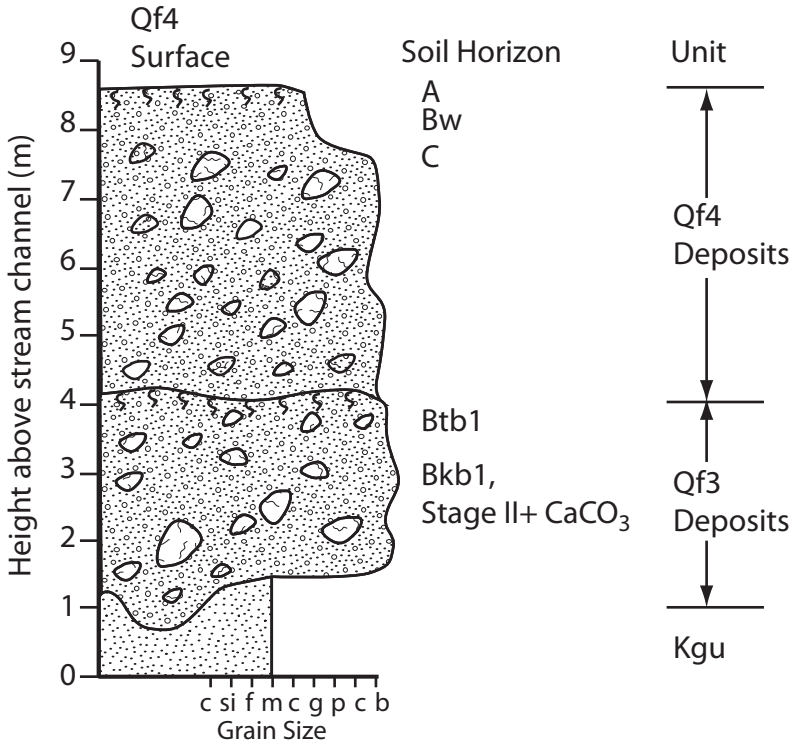
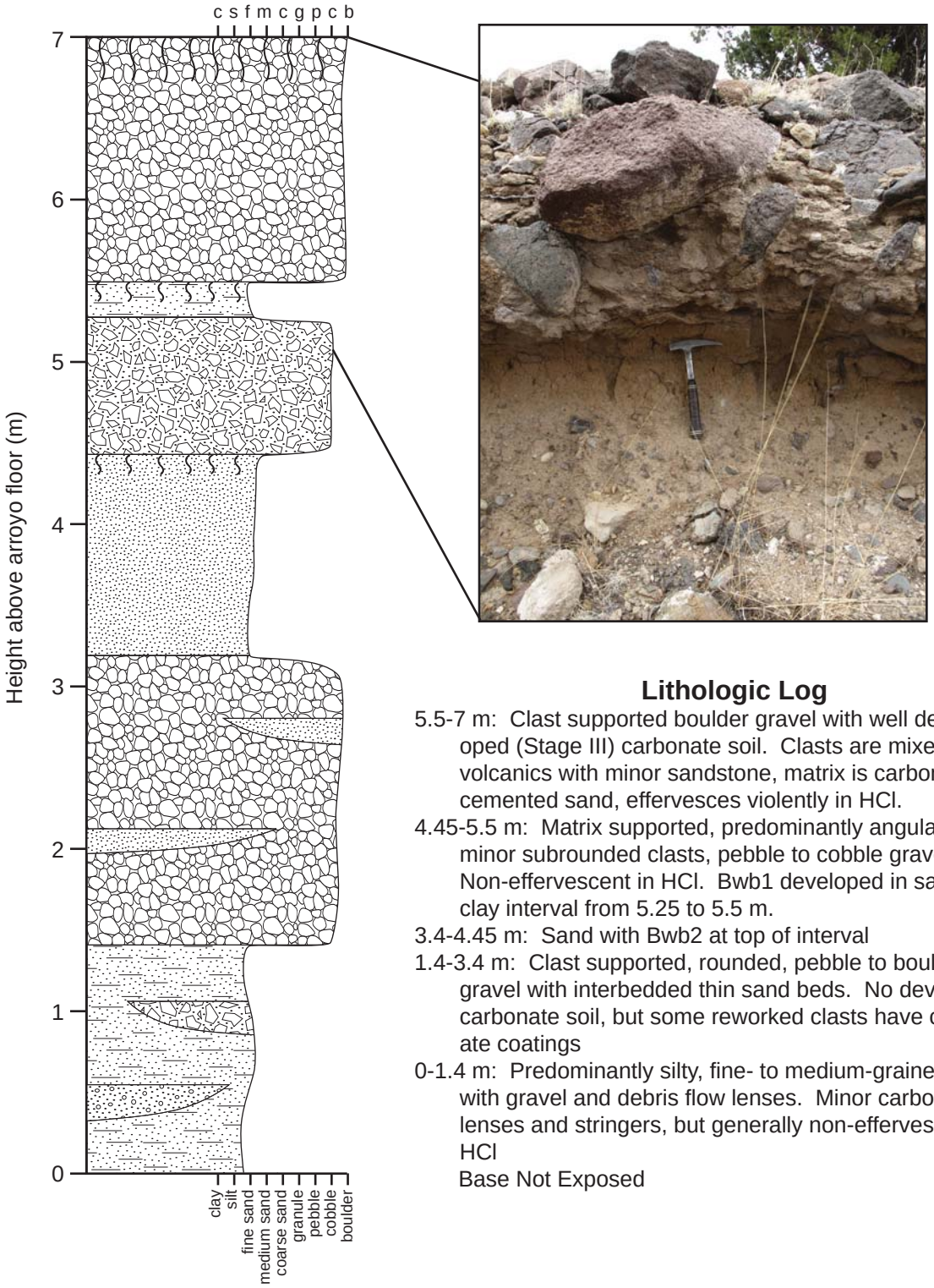


Figure 15. Stratigraphic section measured through fan unit Qf3
Base of Qf3 section located at 273040 m E, 3890728 m N
UTM Zone 13, NAD 1927 datum (SEB-2011-4)



Lithologic Log

5.5-7 m: Clast supported boulder gravel with well developed (Stage III) carbonate soil. Clasts are mixed volcanics with minor sandstone, matrix is carbonate cemented sand, effervesces violently in HCl.

4.45-5.5 m: Matrix supported, predominantly angular with minor subrounded clasts, pebble to cobble gravel. Non-effervescent in HCl. Bwb1 developed in sandy clay interval from 5.25 to 5.5 m.

3.4-4.45 m: Sand with Bwb2 at top of interval

1.4-3.4 m: Clast supported, rounded, pebble to boulder gravel with interbedded thin sand beds. No developed carbonate soil, but some reworked clasts have carbonate coatings

0-1.4 m: Predominantly silty, fine- to medium-grained sand with gravel and debris flow lenses. Minor carbonate lenses and stringers, but generally non-effervescent in HCl

Base Not Exposed

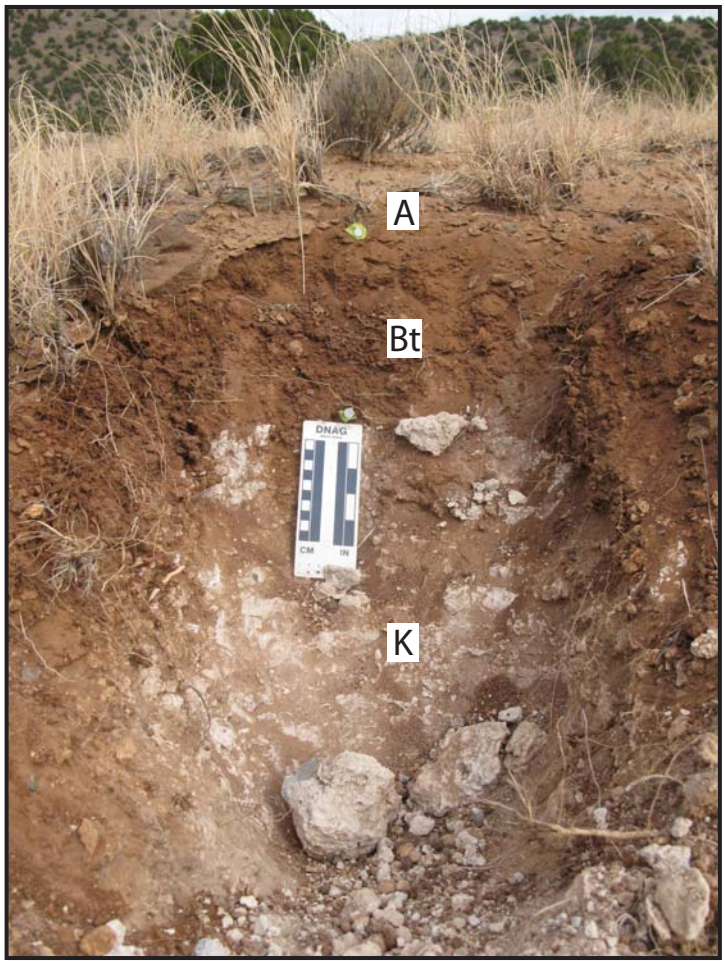
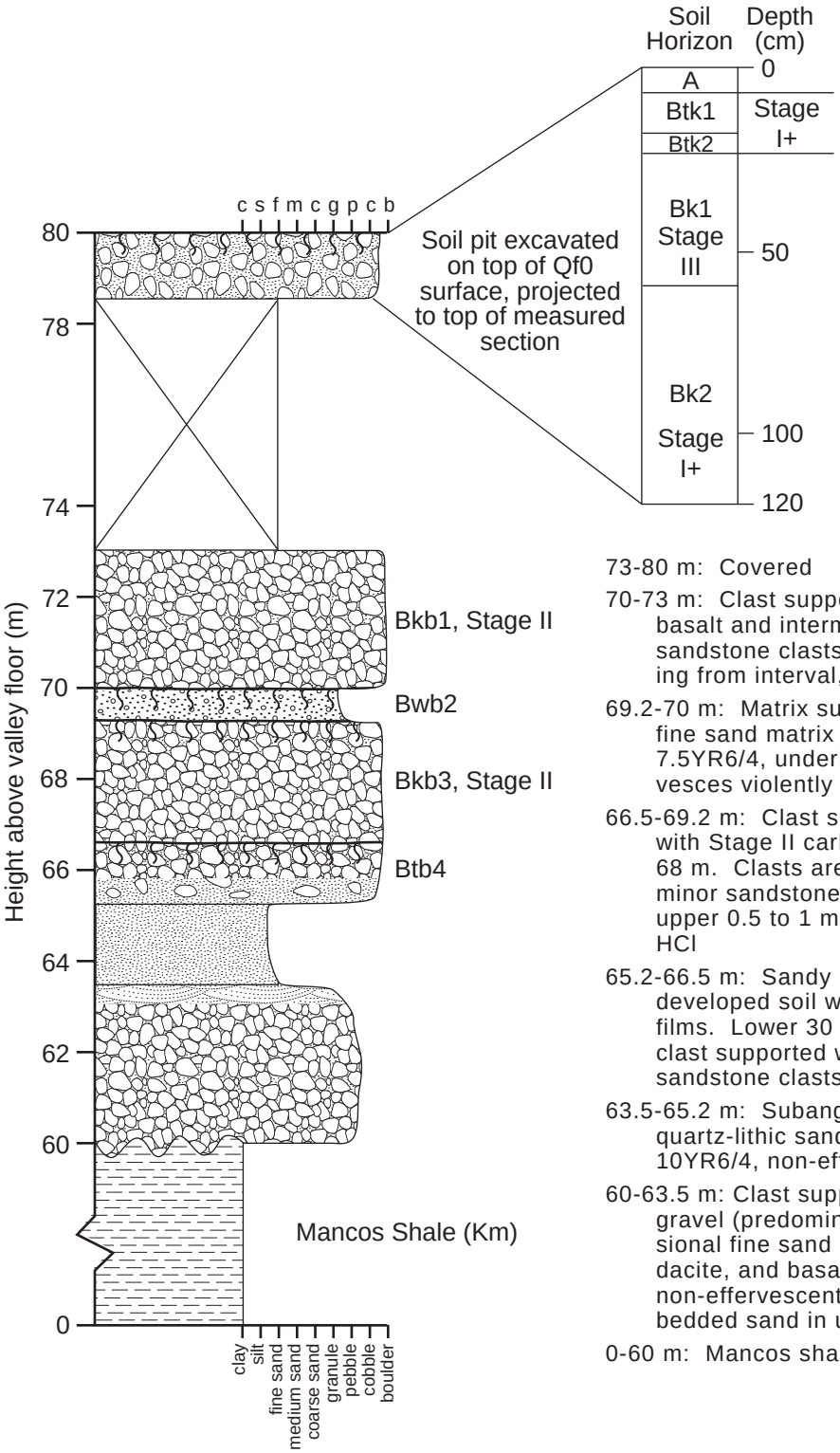


Figure 16. Soil developed in Qf3 deposits. Bt horizon is partially stripped; A horizon derived in part from weathered Bt, plus eolian fine sand.
Location 269533 m E, 38907 m N, UTM Zone 13, NAD 1927 (MT-2008-31).

Figure 17. Stratigraphic section measured through high fan unit Qf0
Base of Qf0 section located at 274065 m E, 3890369 m N
UTM Zone 13, NAD 1927 datum



Lithologic Log

73-80 m: Covered

70-73 m: Clast supported boulder gravel. Predominantly basalt and intermediate volcanic clasts with minor sandstone clasts. Carbonate coated clasts weathering from interval, effervesces violently in HCl

69.2-70 m: Matrix supported pebble to cobble gravel with fine sand matrix and Bw horizon at top. Bw horizon = 7.5YR6/4, underlying C horizon is 10YR5/4. Effervesces violently in HCl.

66.5-69.2 m: Clast supported boulder to cobble gravel with Stage II carbonate coating on clasts from 67.5 to 68 m. Clasts are predominantly mixed volcanics, with minor sandstone and dominant basaltic clasts in upper 0.5 to 1 m. 10YR7/4, effervesces violently in HCl

65.2-66.5 m: Sandy cobble to boulder gravel with well developed soil with Bt horizon, moderately thick clay films. Lower 30 cm is matrix supported, upper 1 m is clast supported with mixed volcanic clasts and minor sandstone clasts. 5YR5/6, non-efferevescent in HCl

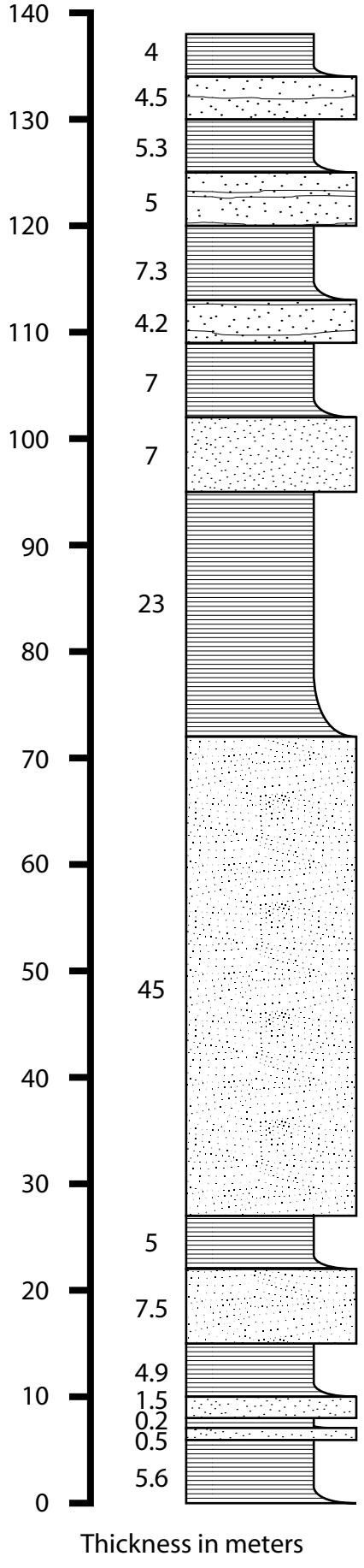
63.5-65.2 m: Subangular, very fine- to fine-grained quartz-lithic sand with scattered pebble gravel. 10YR6/4, non-effervescent in HCl

60-63.5 m: Clast supported sandy pebble to boulder gravel (predominantly pebble to cobble) with occasional fine sand interbeds. Clasts are andesite, dacite, and basalt with ~40% sandstone (10YR7/4, non-effervescent in HCl), planer and trough cross-bedded sand in uppermost part of interval

0-60 m: Mancos shale/covered

Measured Section 1

North end of Seboyeta Canyon



Mancos Shale, Satan tongue

Top of ridge covered with basalt rubble. Lowermost 4 meters contains float of rounded silicic pebbles.
Dark shale
Very fine-grained quartz sandstone.

Dark shale
Very fine-grained quartz sandstone.

Dark shale

Very fine-grained quartz sandstone.

Dark shale.

Very fine-grained quartz sandstone.

Interbedded shale and very fine-grained quartz sandstone beds up to 30 cm thick.

Point Lookout Sandstone

Very fine-grained quartz sandstone.
Planar cross-beds in sets up to 2 meters thick.
Forms steep cliff.

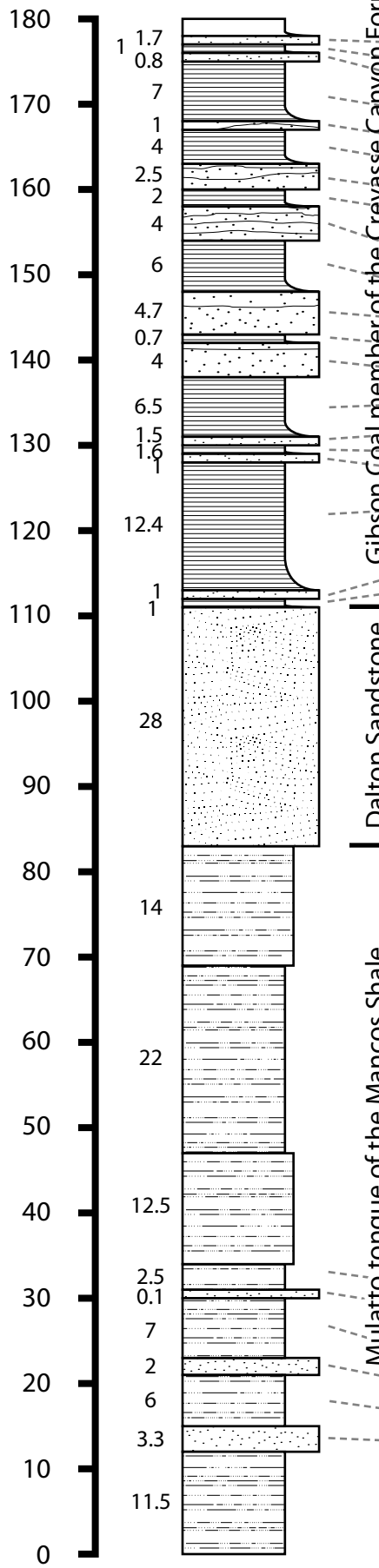
Gibson Coal member of the Crevasse Canyon Fm.

Dark shale.
Very fine-grained quartz sandstone.
Planar cross-beds up to 0.5 meters thick.

Dark shale.
Very fine-grained quartz sandstone.
Dark shale
Very fine-grained quartz sandstone.
Dark shale.

Measured Section 2

Near north end of Seboyeta Canyon



Gibson Coal member of the Crevasse Canyon Formation

Top of hill is covered with basalt rubble.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal. Top contains a light gray bentonite (?) layer up to about 10 cm thick that may be an altered tuff.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
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Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.
Very fine-grained quartz sandstone. Minor dark lithic grains.
Organic-rich shale. Contains some lignite coal.

Dalton Sandstone

Fine-grained quartz sandstone. Contains minor dark lithic grains. Some beds appear massive to very weakly bedded. Other beds show planar cross-bedding in sets up to about 30 cm thick. Forms a prominent light gray cliff.

Mulatto tongue of the Mancos Shale

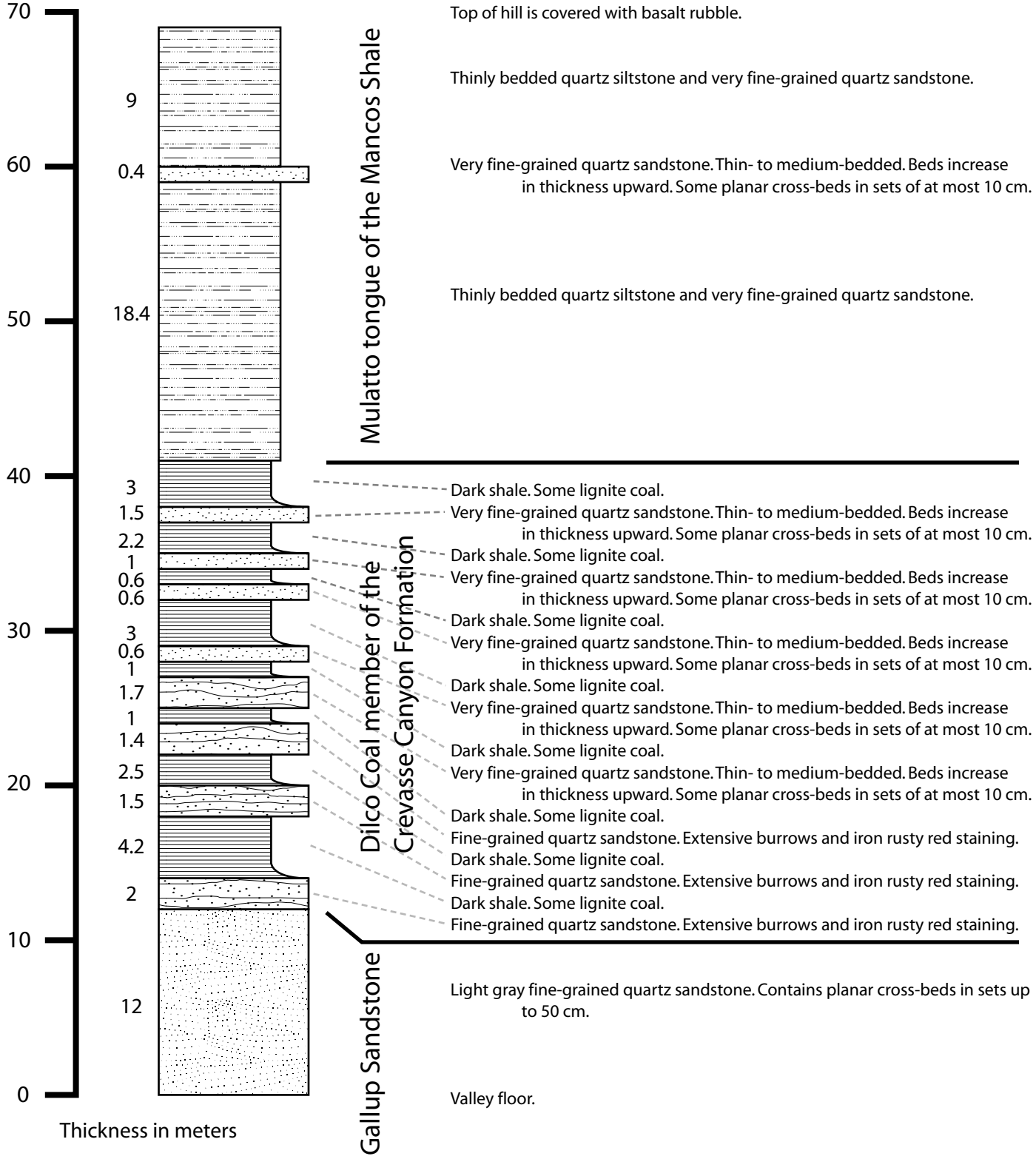
Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone. Beds are noticeably thicker than the beds below this interval and are between about 3 and 20 cm thick.

Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone.

Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone. Forms more resistant ledgy cliff. Cement is poikalitic and resembles gypsum. Contains brachiopod casts throughout. Uppermost 30 cm is strongly cemented and forms resistant cliff top.
Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone.
Thinly bedded fine-grained quartz sandstone, containing about 10% lithic grains. Contains casts of brachiopods up to 1.5 cm across and sparse crinoid stems.
Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone.
Thinly bedded fine-grained quartz sandstone, containing about 10% lithic grains.
Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone.
Very fine-grained quartz sandstone and siltstone. Forms resistant beds that show horizontal laminae. Some beds show planar cross-bedding in sets up to 15 cm. Minor burrowing visible.
Very thinly bedded platy, flakey, very fine-grained quartz sandstone and siltstone.

Measured Section 3

A little more than 1 mile northwest of Seboyeta.
on the east side of Seboyeta Canyon.



Top of hill is covered with basalt rubble.

Thinly bedded quartz siltstone and very fine-grained quartz sandstone.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Beds increase in thickness upward. Some planar cross-beds in sets of at most 10 cm.

Thinly bedded quartz siltstone and very fine-grained quartz sandstone.

Dark shale. Some lignite coal.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Beds increase in thickness upward. Some planar cross-beds in sets of at most 10 cm.

Dark shale. Some lignite coal.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Beds increase in thickness upward. Some planar cross-beds in sets of at most 10 cm.

Dark shale. Some lignite coal.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Beds increase in thickness upward. Some planar cross-beds in sets of at most 10 cm.

Dark shale. Some lignite coal.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Beds increase in thickness upward. Some planar cross-beds in sets of at most 10 cm.

Dark shale. Some lignite coal.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Beds increase in thickness upward. Some planar cross-beds in sets of at most 10 cm.

Dark shale. Some lignite coal.

Fine-grained quartz sandstone. Extensive burrows and iron rusty red staining.

Dark shale. Some lignite coal.

Fine-grained quartz sandstone. Extensive burrows and iron rusty red staining.

Dark shale. Some lignite coal.

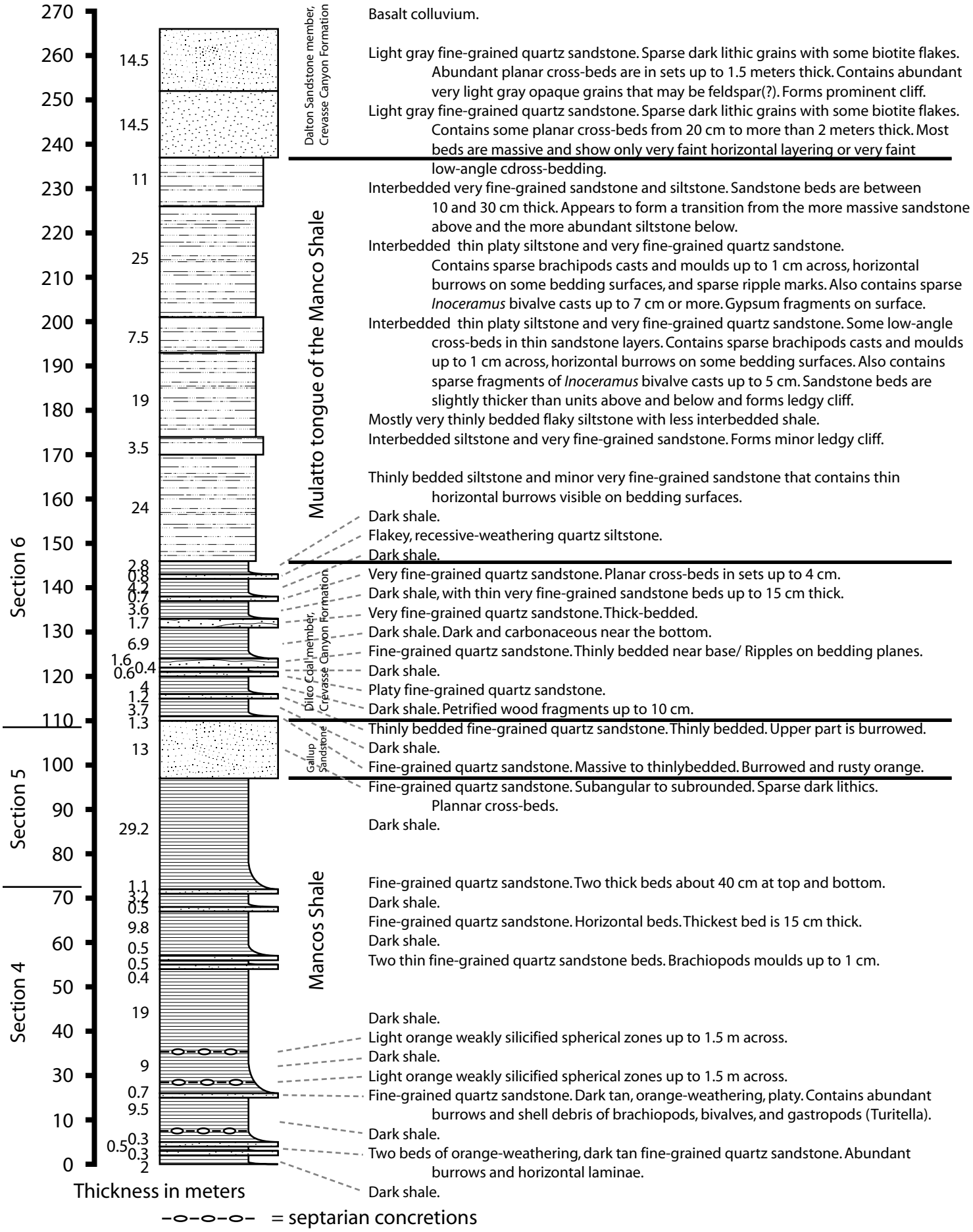
Fine-grained quartz sandstone. Extensive burrows and iron rusty red staining.

Light gray fine-grained quartz sandstone. Contains planar cross-beds in sets up to 50 cm.

Valley floor.

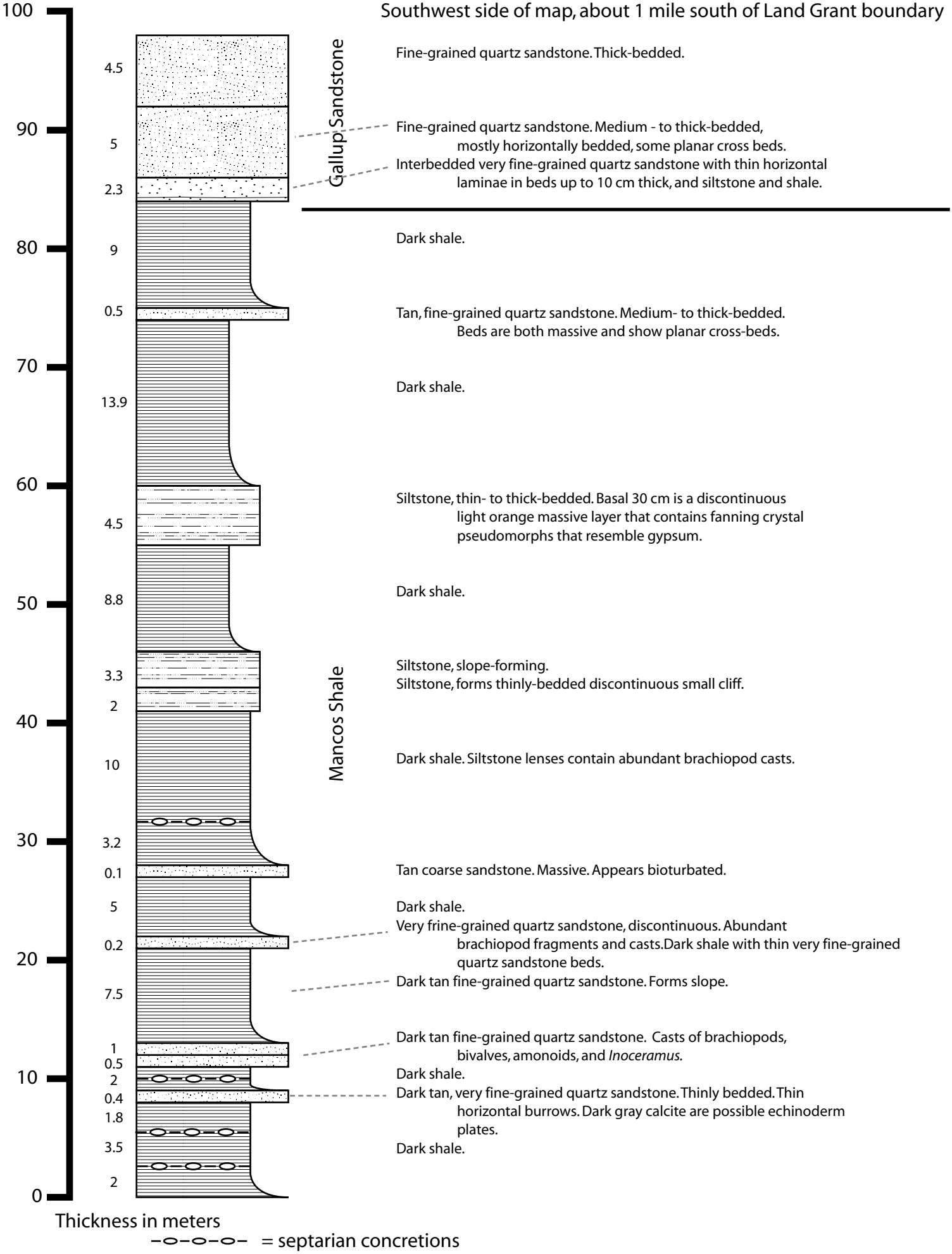
Measured Sections 4, 5, and 6

At the mouth of Bibo Canyon, just north of the lake



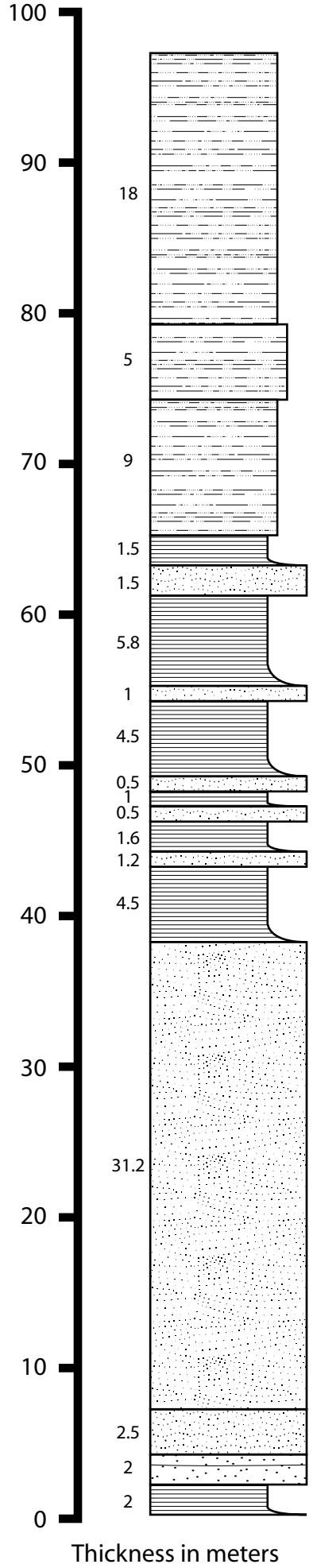
Measured Section 7

Southwest side of map, about 1 mile south of Land Grant boundary



Measured Section 8

Southwest side of map near Land Grant boundary



Mulatto tongue, Manco Shale

Interbedded siltstone and fine-grained quartz sandstone.

Sinstone and interbedded very fine-grained quartz sandstone. Forms small cliff.

Thinly bedded siltstone.

Dilco coal member of the Crevasse Canyon Formation

Dark shale.
Very frine-grained quartz sandstone. Massive and faint horizontal laminae.

Dark shale.

Tan fine-grained quartz sandstone.

Dark shale.
Light tan, very fine-grained quartz sandstone.
Dark shale.
Very fine-grained quartz sandstone. Massive to faintly bedded. Possible vertical burrows.
Covered slope.
Light tan very fine-grained quartz sandstone. Thin- to thick-bedded. Some planar cross-bedsin sets up to 20 cm thick.
Covered slope.

Gallup Sandstone

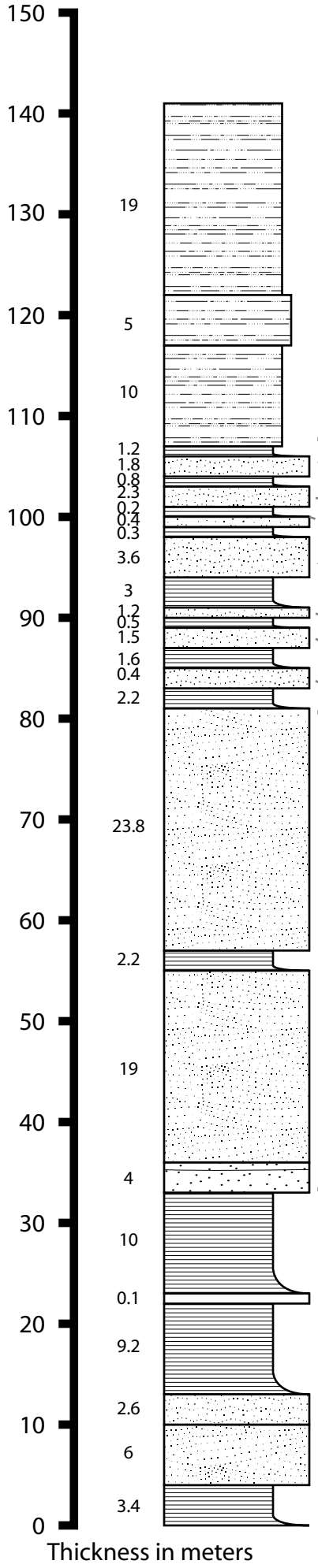
Light tan very fine-grained quartz sandstone. Thin- to thick-bedded. Planar cross-beds in sets up to 2 meters thick. Forms cliff.

Fine0grained quartz sandstone. Medium- to thick-bedded. Some low-angle planar cross-beds.
Interbedded very fine-grained quartz sandstone in beds up to 15 cm thick, and siltstone and shale.

Dark shale.

Measured Section 9

Est side of Encinal Creek, near UTM 276000, 3892000



Mulatto tongue, Mancos Shale

Thinly bedded siltstone and very fine-grained quartz sandstone. Slope.

Thinly bedded siltstone and very fine-grained quartz sandstone. Forms cliff.

Thinly bedded siltstone and very fine-grained quartz sandstone. Slope.
Horizontal burrows on some bedding planes.

Dilco coal member, Crevasse Cyn. Fm.

Dark shale.
Very fine-grained quartz sandstone.
Dark shale.
Very fine-grained quartz sandstone.
Dark shale.
Very fine-grained quartz sandstone.
Dark shale.
Very fine-grained quartz sandstone.
Dark shale.
Very fine-grained quartz sandstone.
Dark shale.
Very fine-grained quartz sandstone.

Gallup Sandstone

Dark shale.
Very fine-grained quartz sandstone.
Dark shale.

Tan, very fine-grained quartz sandstone. Horizontally bedded to massive.
Planar cross-beds in sets up to about 1 meter.

Covered slope.

Tan, very fine-grained quartz sandstone. Horizontally bedded to massive.
Planar cross-beds.

Thinly bedded tan very fine-grained quartz sandstone.

Mancos Shale

Dark shale.

Fine-grained quartz sandstone. Abundant dark organic matter.

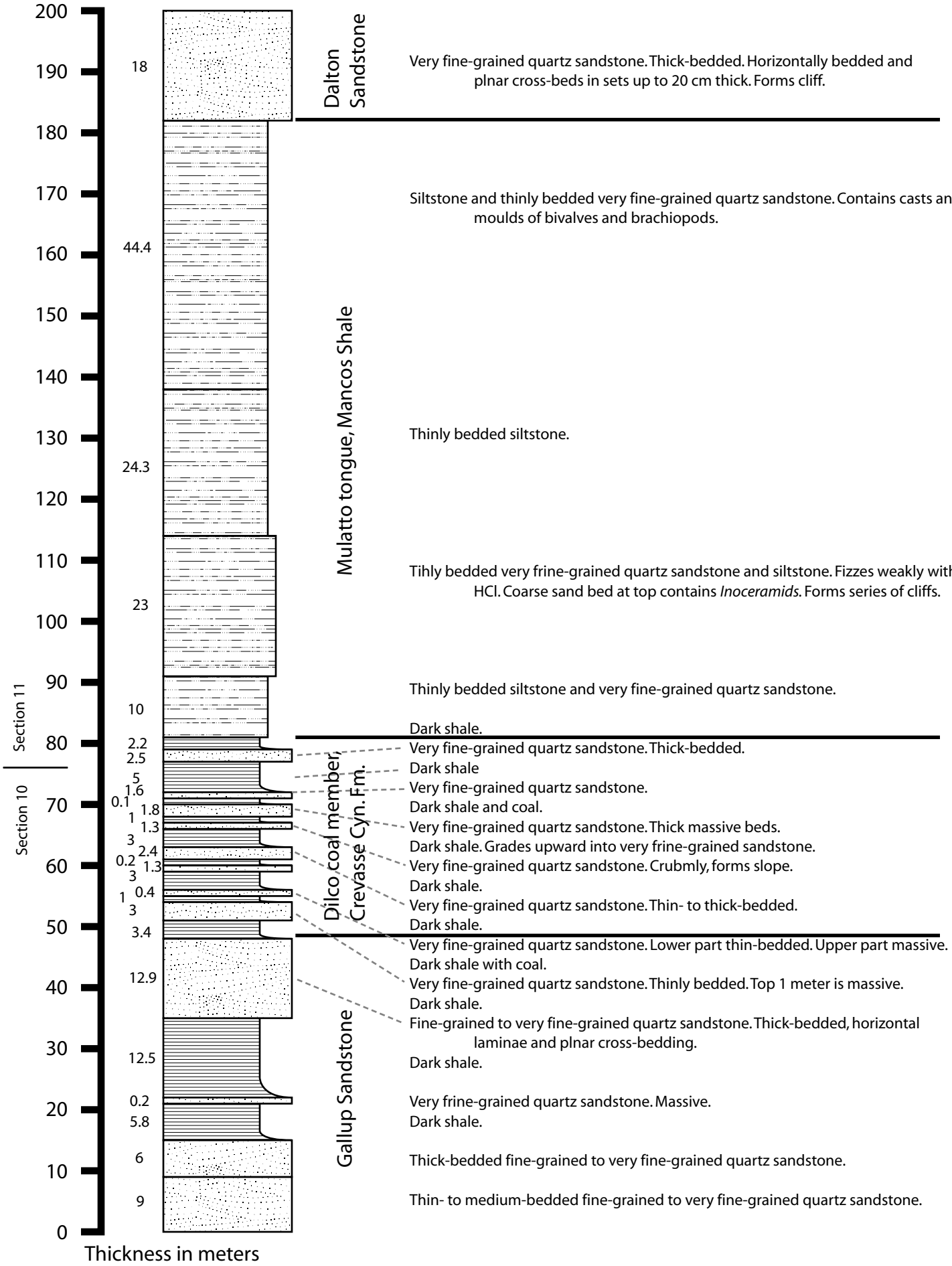
Covered slope with shale float.

Fine-grained quartz sandstone. Mottled, burrowed. Contains frgaments of bivalves,
pencil-shaped amonoids (?), coiled amonites up to 12 cm.
Tan, fine-grained quartz sandstone. Mostly thin- to medium-bedded. Planar cross-beds.

Dark shale.
Orange masses with crystal fans that resemble gypsum.

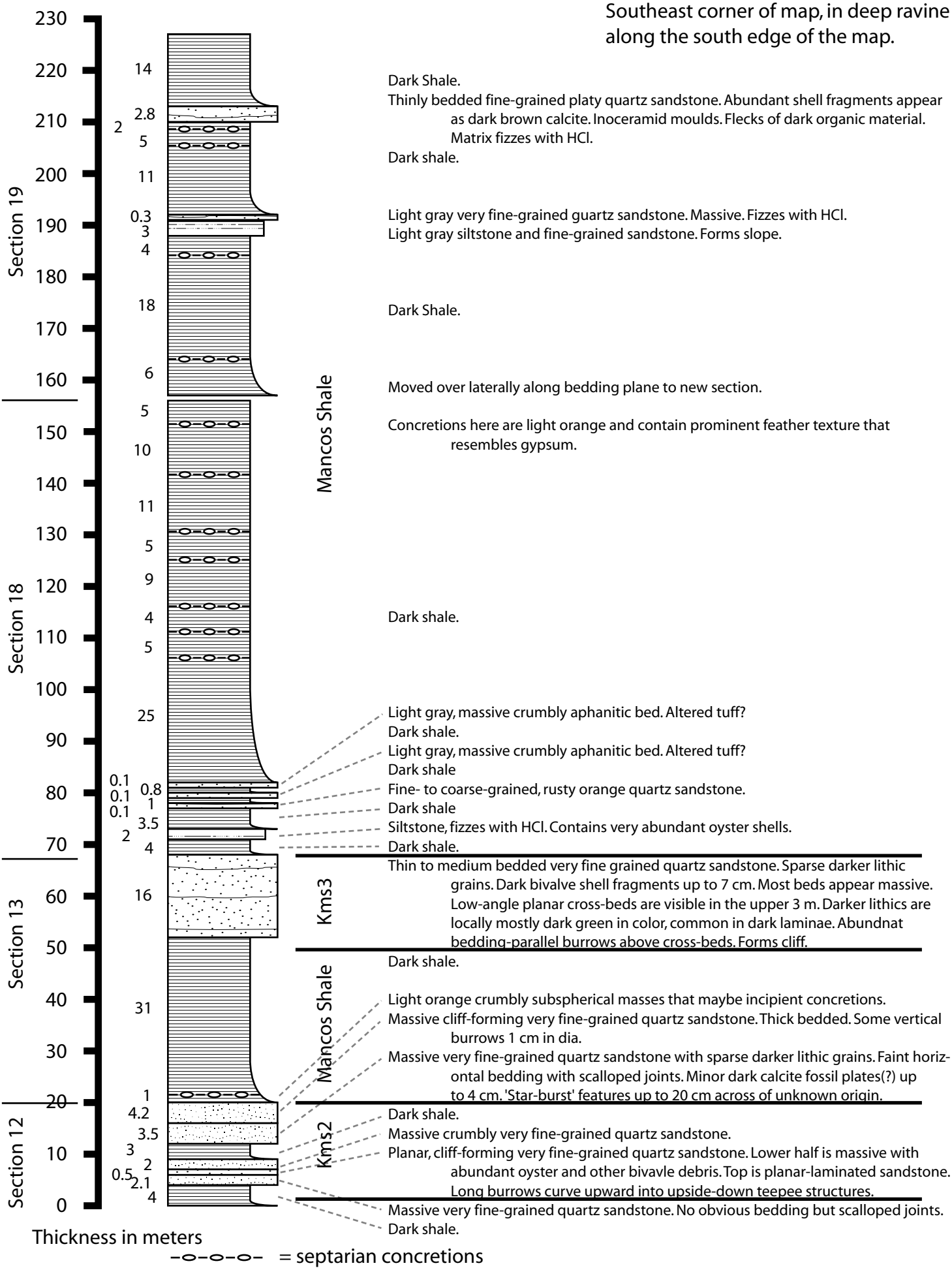
Measured Sections 10 and 11

In Bear Canyon near UTM 278500, 3893700



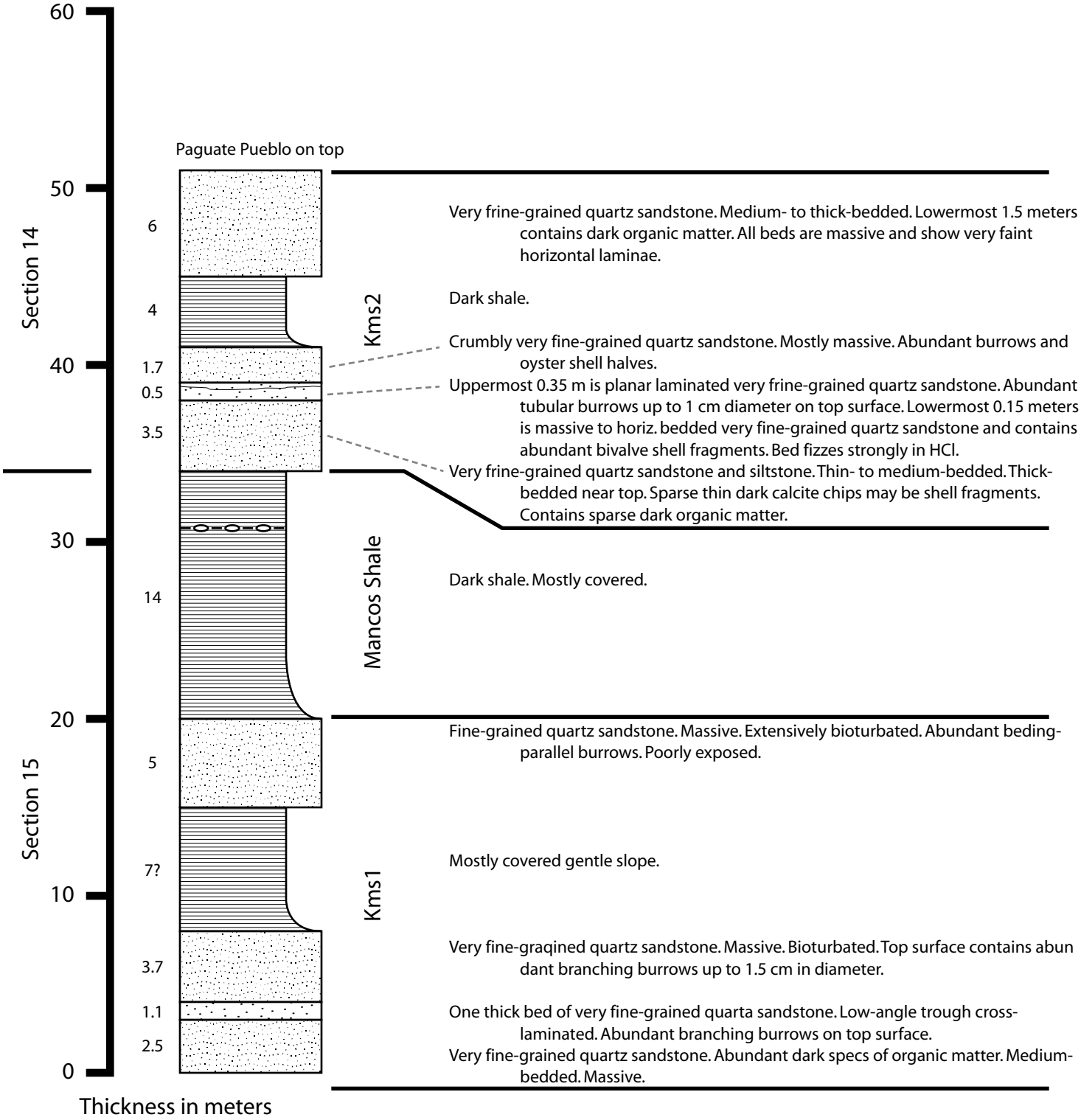
Measured Sections 12, 13, 18, and 19

Southeast corner of map, in deep ravine along the south edge of the map.



Measured Sections 14 and 15

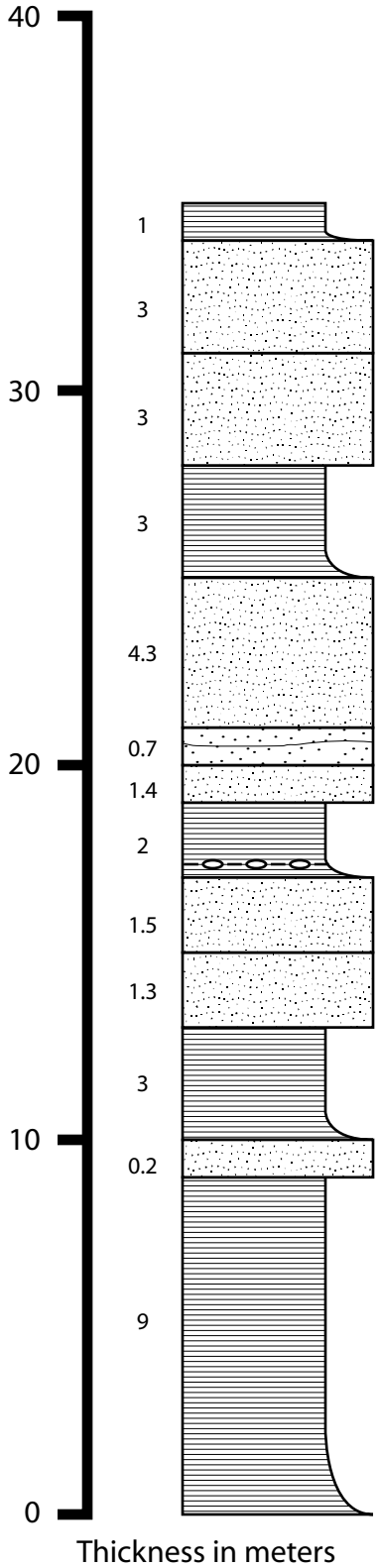
Immediately south of the Paguate Pueblo, and in the gully a few hundred feet to the south.



–o–o–o– = septarian concretions

Measured Section 16

Exposed in the NW side of the Paguate open-pit, immediately east of Section 15, just southeast of the Puate Pueblo.



Dark shale.

Fine-grained quartz sandstone. Massive. No obvious bedding. Abundant burrows.

Very frine-grained quartz sandstone. Thinly bedded. Crumbly.

Dark shale.

Very fine-grained quartz sandstone. Mostly massive. Abundant burrows on bed planes.

Very fine-grained quartz sandstone. Faintly to strongly laminated. Medium- to thick-bedded, with low-angle planar cross-bedding.

Very fine-grained quartz sandstone. Thin- to medium-bedded. Faint horizontal laminae. Flecks of dark organic matter. Crumbly.

Dark sandy shale. Septarian concretions up to 40 cm in diameter near base.

Very fine-grained quartz sandstone. Crumbly. Abundant dark flecks of organic matter.

Very fine-grained quartz sandstone. Planar laminated. Some low-angle planar cross-bedding. Thick-bedded.

Dark shale.

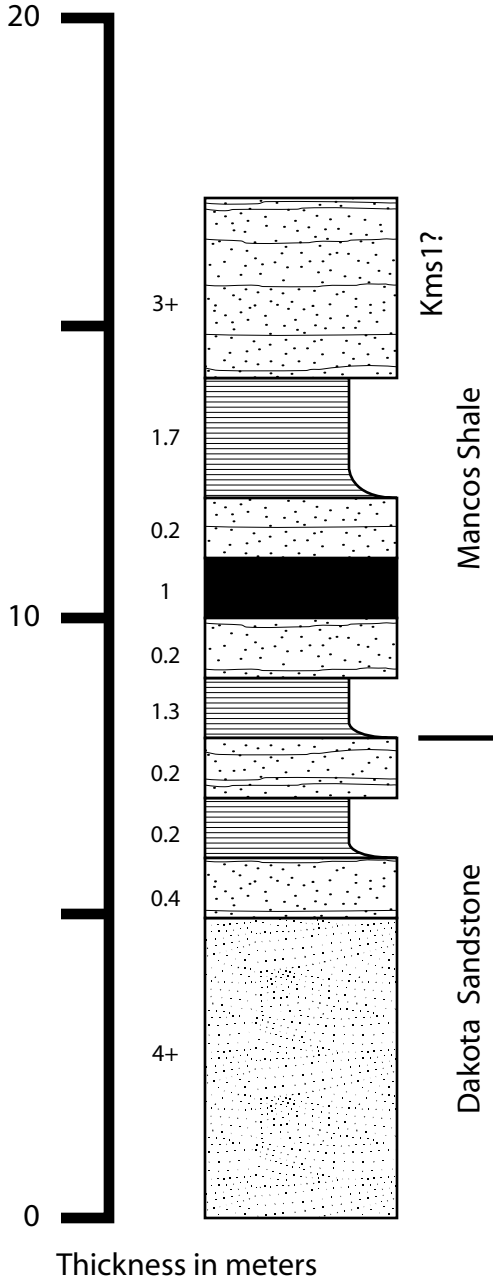
Very fine-grained quartz sandstone and siltstone. 1-2 beds pinch out laterally. Horizontal burrows on top surface.

Dark, organic-rich shale. Possible sparse fish scale impressions up to 5 mm across.

–o–o–o– = septarian concretions

Measured Section 17

Isolated road-cut exposure about along main road
about 1 mile southeast of Paguate Pueblo



Rounded basalt cobbles on top of hill.

Very frine-grained quartz sandstone. The more crumbly beds contain burrows. The more resistant ledges show planar laminae in beds up to 30 cm.

Upper 1.2 meters is interbedded siltstone and shale. Recessive cliff. Lower 0.5 meters is dark shale.

Fine-grained quartz sandstone. Thinly bedded.

Aphanitic mafic sill.

Fine- to medium-grained quartz sandstone. Thin- to medium-bedded.

Dark organic-rich shale.

Coarse-grained quartz sandstone. Abundant vertical burrows.

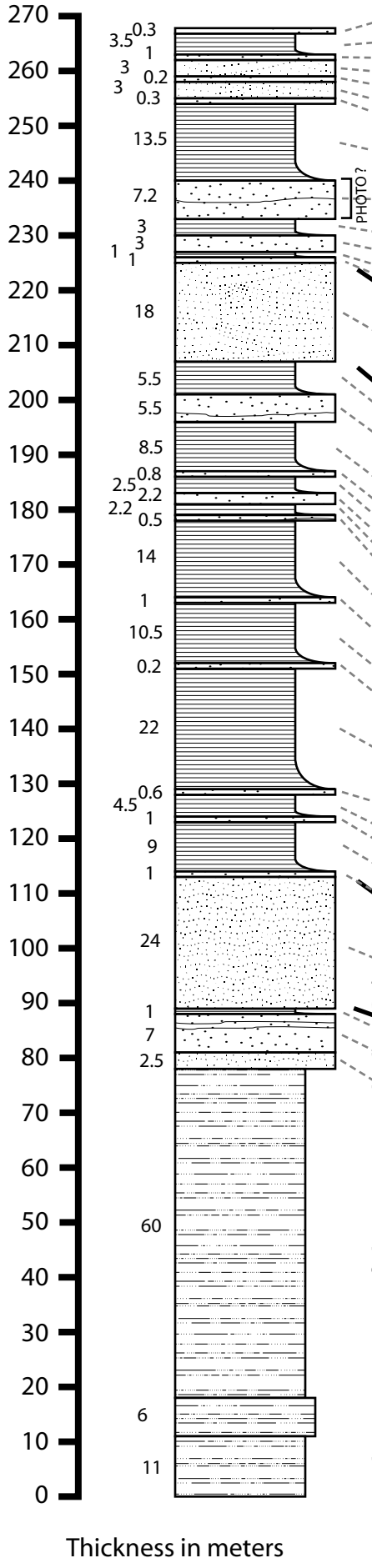
Dark organic-rich shale.

Coarse-grained quartz sandstone. Abundant vertical burrows.

Fine- to medium-grained quartz sandstone. Grains are subrounded and frosted. Medium- to thick-bedded. Planar to trough cross-bedding in sets >1 meter.

Measured Section 20

Near the northeastr corner of the map, south of Mesa Chivato.



Orange fine-grained to medium-grained quartz sandstone, with minor dark lithic grains. Contains small clay chips. Bedding is faint to massive.

Dark shale.

Fine-grained quartz sandstone. Faint planar cross-beds. Forms resistant cap.

Light gray frine-grained quartz sandstone. Planar cross-beds in sets up to 2 m.

Thinly bedded fine-grained quartz sandstone.

Fine-grained quartz sandstone. Planar cross-beds in sets up to 2 m.

Fine-grained quartz sandstone. Thin- to medium-bedded.

Black, brown, and gray shale. Abundant lignite coal.

Medium- to thick-bedded fine-grained quartz sandstone. Planar cross-beds are in sets up to 50 cm.

Dark shale.

Fine-grained quartz sandstone. Faint planar cross-beds in sets up to 80 cm.

Dark shale.

Thin- to medium-bedded fine-grained quartz sandstone. Planar cross-beds in sets up to 15 cm.

Fine-grained quartz sandstone. Rare darker lithic grains. Light gray. Uppermost 5m shows planar cross-bedding in sets up to 1 m. Below that bedding is mostly horizontal with low-angle cross-beds, especially in the lowermost 2-3 meters. Forms prominent cliff.

Dark shale.

Fine-grained quartz sandstone with minor dark lithic grains. Faint horizontal bedding in thick to thin beds. Planar cross-beds in lowermost 2 m.

Dark brown and black shale and thin organic-rich siltstone. Beds of coal up to 1 m.

Fine-grained quartz sandstone. massive.

Dark shale.

Fine-grained quartz sandstone. Horizontally bedded. Thin- to thick-bedded.

Dark shale.

Very fine-grained quartz sandstone. Massive.

Dark shale with minor siltstone. Abundant coal.

Very fine-grained quartz sandstone. Platy along planar cross-beds.

Dark shale with coal.

Very fine-grained quartz sandstone. Massive.

Dark shale. Some light gray siltstone beds and dark beds of coal.

Very fine-grained quartz sandstone. Faint horizontal bedding. RIpple marks and horizontal burrows on bedding planes. Plant stem casts.

Dark shale.

Fine-grained quartz sandstone. Massive.

Dark shale.

Fine-grained quartz sandstone. Orange, massive.

Fine-grained quartz sandstone. Upper 8 metersshows faint planar cross-bedding in sets up to 50 cm. Below is faint horizontal bedding.

Dark shale and siltstone.

Very fine-grained quartz sandstone. Thin-bedded, platy. Thin horizontal burrows on bedding planes.

Fine-grained quartz sandstone. Massive.

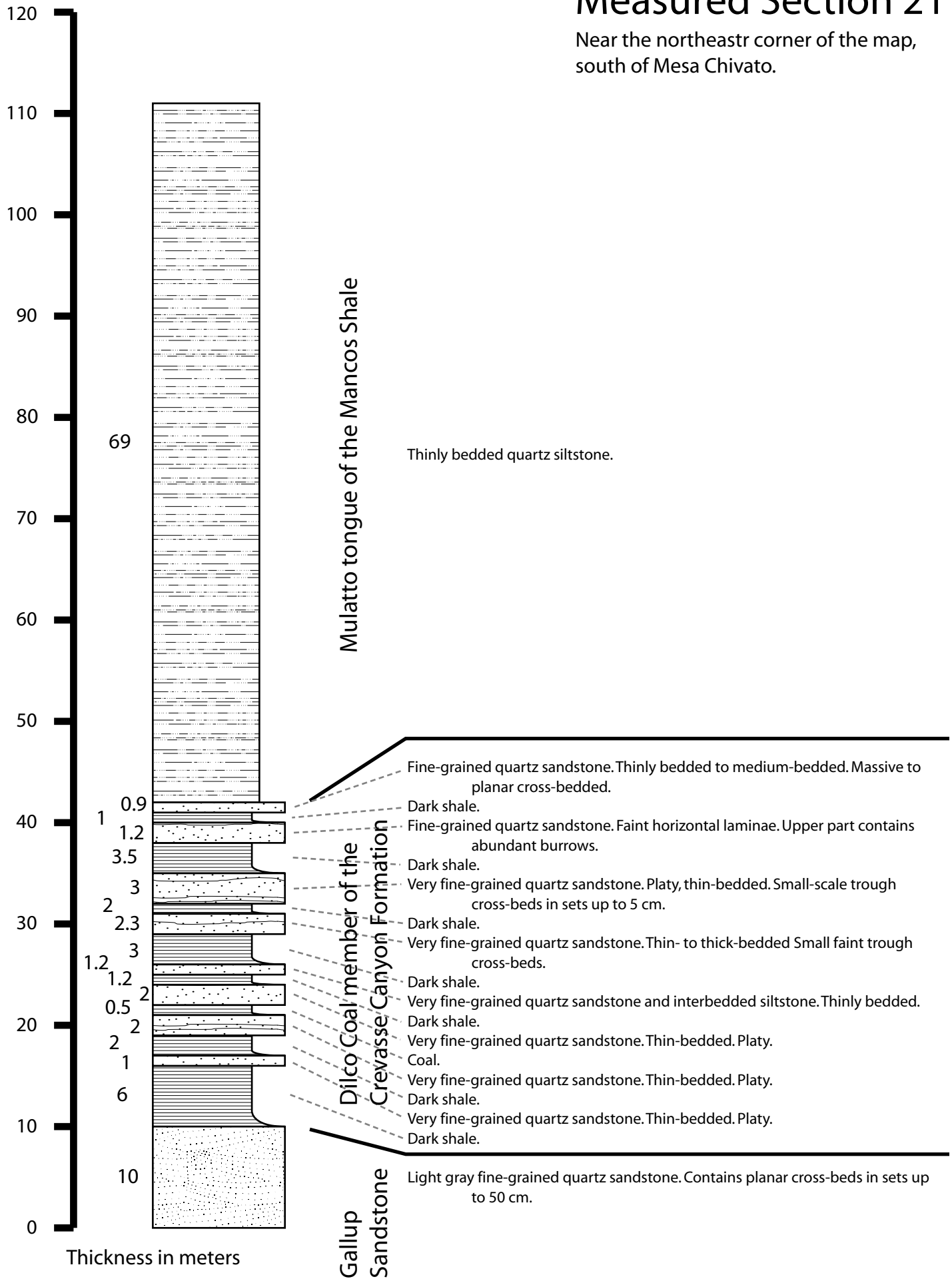
Thinly bedded siltstone.

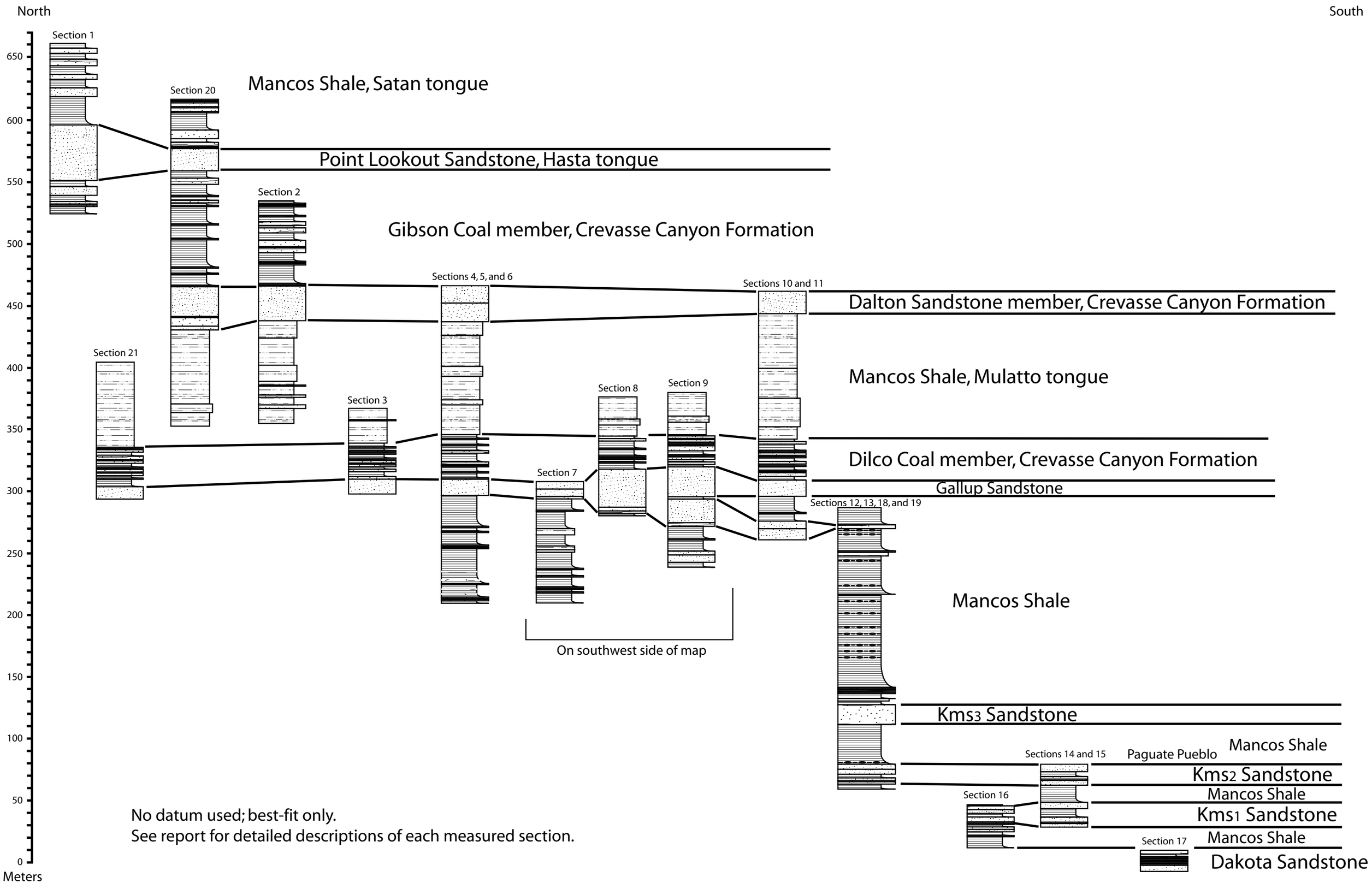
Very fine-grained quartz sandstone and siltstone. Thin- to medium-bedded. Branching burrows on bedding planes. Forms a small cliff.

Thinly bedded siltstone.

Measured Section 21

Near the northeastr corner of the map, south of Mesa Chivato.





No datum used; best-fit only.
See report for detailed descriptions of each measured section.