Geology and Geomorphology of 12 Small Watersheds in the Peloncillo Mountains, Central Portion of the Malpai Borderlands Project Area, Hidalgo County, New Mexico

by
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Introduction

This report summarizes the geology and geomorphology of 12 small watersheds in the Peloncillo Mountains, southwestern New Mexico. The study site is located in the central portion of the Malpai Borderlands project area, on the eastern piedmont of the southern Peloncillo Mountains (Figure 1). It consists of an eastward trending ridge with small dissected basins on either side, and is bordered on the north and south by Walnut and Whitmire creeks, respectively. These creeks flow eastward into southern Animas Valley. The U. S. Forest Service has selected 12 watersheds along the ridge (Figure 2) for a paired watershed experiment to compare effects of two burning seasons, spring and summer, on native vegetation, wildlife, surface water flow, slope stability and erosion (G. Gottfried, US Forest Service, pers. comm., October 2000). As part of this experiment, the Forest Service is installing a sediment trap and two different-sized flumes on each study watershed to record and compare sedimentation and surface flows before and after burning. One flume will be located about 50 feet downstream from the sediment trap and will record higher volume flows of up to 57 cubic feet per second (cfs). Another flume will be located 18 feet further downstream and will record lower volume flows of up to 4 cfs (G. Gottfried, US Forest Service, pers. comm., October 2000). A major concern with this study area is that local geology may provide pathways for surface water to infiltrate and flow between study watersheds, causing erroneous runoff results, or to circumnavigate the flumes altogether. Another concern is a potential increase in erosion rates, or decrease of slope stability, after burning. The purpose of this report is to describe the geologic and geomorphic framework of the study area, to delineate surficial deposits to help define potential erosion, and to provide information concerning potential for sub-surface flow between watersheds or under the flumes. Field investigations and mapping were done in November, 2000, and January, 2001. A 1:12,000-scale map showing bedrock and surficial geology is included with this report (Plate 1).

Acknowledgements

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Figure 1. Map showing the location of the study area for this report in relation to Hidalgo County and the state of New Mexico.
Figure 2. Study watersheds in the Peloncilo Mountains, Hidalgo County, New Mexico. Letters correspond to U.S. Forest Service watershed designations as referred to in the text.
Climate

The study area is located in the southern Peloncillo Mountains, New Mexico, which is part of the Chihuahuan Desert. The present climate is semi-arid. Vegetation at the site varies from desertscrub to woodlands. The nearest active official weather station is located in Animas, New Mexico, at an elevation of 4,110 feet. Recorded average daily maximum and minimum temperatures from 1923 to 2000 were 77.3°F and 43.1°F, respectively (Western Regional Climate Center). Average annual precipitation was 10.99 inches and average total snowfall was 5.9 inches. A weather station at Eicks Ranch (elevation 5,310 feet), just south of the project area, recorded weather data from 1933 to 1961. Recorded average daily maximum and minimum temperatures from Eicks Ranch were 73.0°F and 41.6°F, respectively (Western Regional Climate Center). Average annual precipitation was 14.67 inches and average total snowfall was 4.9 inches. Of the total average annual precipitation at each weather station, approximately 67 percent in Animas and 56 percent at Eicks Ranch fell during the July to October monsoon.

Access to the study site is through the Cascabel Ranch in Whitmire Canyon, elevation 5,450 feet. Reese Woodling, previous owner of the Cascabel Ranch, recorded rainfall from 1981 to 1999 at the ranch house. Total yearly precipitation ranged from 14.15 inches in 1989 to 31.95 inches in 1991, with a yearly average of 23.53 inches (J. Medina, Animas Foundation, pers. comm., February, 2001). Of the total annual precipitation, an average of approximately 54 percent fell during the July to October monsoon.

The climate of the Chihuahuan desert has not remained constant over the time period represented by the alluvial deposits and surfaces in the study area. The transition from the relatively warm and stable Pliocene climate to the dramatic glacial-interglacial cycles of the Pleistocene resulted in major aggradation and erosion events recorded as alluvial fans and fan remnants in the study area. Analysis of packrat middens, preserved for tens of thousands of years, indicates an increased annual precipitation, probably peaking in the late Pleistocene, with milder seasonal temperature extremes than modern and enhanced winter rainfall (Van Devender and Spaulding, 1979). Increased winter precipitation would have infiltrated more deeply than summer moisture due to decreased evapotranspiration rates, and thus would have been more conducive to weathering of bedrock and soil minerals than the interglacial regime of today (Bull, 1991). By the early Holocene, temperatures were probably similar to modern with an enhanced summer monsoon (Spaulding and Graumlich, 1983). Vegetation collected from packrat middens indicate that the present climatic and vegetational regimes were established about 8 ka (Van Devender and Spaulding, 1979).

Previous Work

Several geologic and geomorphic investigations have been conducted in this area. Erb (1979) mapped the volcanic geology of the Animas and southern Peloncillo Mountains. Hayes and others (1983) mapped the mineral resource potential of the southern Peloncillo

**Geomorphic and Geologic Framework**

The study site is located on the eastern piedmont of the southern Peloncillo Mountains, New Mexico (Figure 1), in the Basin and Range Physiographic Province. Southwestern New Mexico and adjacent Arizona was the site of an extensive mid-Tertiary volcanic field composed of silicic ash flow tuffs and lava flows that was active during Oligocene and possibly early Miocene (approximately 33-26 Ma) (McIntosh and Bryan, 2000). This was followed by high-angle normal faulting of the late Miocene to Pliocene Basin and Range disturbance that produced isolated bedrock mountain ranges separated by alluvial valleys (Machette et al., 1986). The Peloncillo Mountains and Animas Valley were formed by Basin and Range faulting. Decreasing tectonism after the primary phase of Basin and Range disturbance, in conjunction with Quaternary climate change, resulted in the accumulation of broad alluvial fans in tectonic basins throughout the southwestern US, including Animas Valley (Biggs et al., 1999; Bull, 1991; Menges and McFadden, 1981). Vincent and Krider (1998) estimated the age of these fans in southern Animas Valley to be middle Pleistocene. Low levels of fault activity in the Pleistocene and Holocene along with climatic fluctuations, resulted in various episodes of alluvial incision and aggradation in Animas Valley (Vincent and Krider, 1998; Machette et al., 1986).

Southern Animas Valley can be divided into three subbasins based on topographic and drainage differences. The southern-most subbasin is topographically closed and internally drained. It is separated from the rest of Animas Valley by an alluvial fan complex that emerged from Foster and Clanton draws and Whitmire Creek in the middle Pleistocene, 750 – 500 ka (Vincent and Krider, 1998; Krider, 1997). The middle subbasin drains north and contains highly dissected alluvial fan and terrace remnants of middle Pleistocene and younger alluvium. Incision in the middle basin was a result of base-level fall in the northern subbasin. Base-level decreased in the northern subbasin due to Quaternary faulting, in conjunction with climate change, resulting in subsidence relative to the southern subbasins. Variations in sediment supply to the basin as a result of climate changes may have contributed to the basin dissection.

The twelve study watersheds are located along an eastward trending ridge (Figures 2 and 3) and drain north and south into Walnut and Whitmire creeks, respectively. These creeks drain into the middle sub-basin of southern Animas Valley. In general, streams in the northern study basins have longer, lower gradient channels than those in the southern
study basins. Differences in stream geomorphology are due to size of drainage areas for Walnut and Whitmire creeks, lithologic changes, and relative location of the creeks to the ridge crest. Whitmire Creek begins at the crest of the Peloncillo Mountains and includes the drainage area of Salt Canyon (Figure 1). As a major watershed for the area, Whitmire Creek has downcut into the surrounding countryside forming Whitmire Canyon. The canyon broadens to the east of watershed B, where Whitmire Creek flows from rhyolite, which forms narrow canyons, to the more easily eroded conglomerate and sandstone units. This change in lithology results in a broader canyon floor and steeper canyon walls. Walnut Creek begins just a few miles upstream from the study area and does not include any other large drainages. It has formed a minor canyon and does broaden slightly as the stream flows from rhyolite to sedimentary rocks, but not to the extent or

![U.S. Forest Service aerial photograph of the study area. Photo number 2187-191, dated 11-9-87 (scale 1:24,000). Letters correspond U.S. Forest Service watershed designations as referred to in the text.](image)
scale of Whitmire Canyon. In addition, Walnut Creek is located farther to the north of the study ridge crest than Whitmire Creek is to the south. This results in shorter, steeper channels in southern watersheds and longer, lower gradient channels in northern watersheds.

**Quaternary Geology**

The surficial geology of the study area was mapped using two sets of aerial photographs, geomorphic surface maps (Vincent and Krider, 1998), field mapping, and observations of soils and stratigraphy. Preliminary mapping was conducted using 1:24,000 color aerial photographs from 1987 and 1995, provided by the U.S. Forest Service. Mapping of geomorphic surfaces of the southern Animas Valley by Vincent and Krider (1998) was used to augment preliminary mapping. The study area was field checked by Ann Youberg, with assistance and suggestions by Philip Pearthree.

The physical characteristics of Quaternary alluvial surfaces (channels, alluvial fans, floodplains, stream terraces) were used to differentiate their associated deposits by age. Alluvial surfaces of similar age have a distinctive appearance and soil characteristics because they have undergone similar post-depositional modifications. They are different from both younger and older surfaces. Terraces and alluvial fans that are less than a few thousand years old still retain clear evidence of the original depositional topography, such as bars of gravel deposits, swales (troughlike depressions) where low flows passed between bars, and distributary channel networks, which are characteristic of active alluvial fans. Young alluvial surfaces have little rock varnish on surface clasts, little soil development, and are minimally dissected. Very old fan surfaces, in contrast, have been isolated from substantial fluvial deposition or reworking for hundreds of thousands of years. These surfaces are characterized by strongly developed soils with clay-rich argillic horizons and cemented calcium-carbonate horizons, well-developed tributary stream networks that are entrenched 10 m or more below the fan surface, and strongly developed varnish on surface rocks. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

For this project, Quaternary surficial deposits are subdivided based on their source and estimated age of deposits. Surface and soil characteristics were used to correlate alluvial deposits and to estimate their ages. Surface pits were used to assess soil characteristics associated with deposits of different ages and from different sources. Where possible, soils and surfaces documented in the map area were generally correlated with units described by Vincent and Krider (1998).

There are two general sources of alluvium in the study area. One is alluvium derived from Whitmire Creek and deposited in Whitmire Canyon. These are modern channel deposits (Qycr) and recent (<~2 ka) floodplain and terrace deposits (Qy2r). Other alluvial deposits are derived from older piedmont alluvium and from within the study watersheds.
Alluvium within study watersheds typically are deposited in or along channels, or as alluvial fans at mouths of watersheds. Most channel deposits within the study watersheds are bars, floodplains or terraces that are too small to map at this scale. Mappable deposits are typically found at tributary junctions and contain some colluvium from adjacent hillslopes (Qy2). Modern alluvial fans (Qy2) and older fan remnants (Qy1 and Ql) are found at the mouths of watersheds in the broader eastern portion of Whitmire Canyon.

Ridges and hillslopes throughout the study area are covered with thin pockets colluvial and residual soil between outcrops, along with scattered discrete deposits of older peidmont alluvium. Older alluvial fan remnants with thin (<1.5 m), well-developed soil (Qm) are found on bench-like hillslopes above Whitmire Canyon in the eastern half of the study area. Very old, high alluvial fan remnants are found on scattered ridge tops throughout the study area. Many ridge tops are relatively flat and appear to be remnant erosional surfaces. On some eastern ridges planar to slightly rounded remnant fan surfaces with strongly developed soil are present (Qmo). These deposits probably correlate to Vincent and Krider’s (1998) middle Pleistocene fan remnants. Scattered deposits of thin, well developed soils (Qo) are found on remnant erosional ridge tops throughout the study area, and may represent degraded or reworked alluvium. Because the lithology in the Peloncillo Mountains where alluvium would have originated is the same as the lithology in the underlying conglomerates, it is not possible to tell if these deposits are degraded or reworked alluvium, or colluvium and residuum. Nevertheless, these deposits are distinct from the surrounding thinner, less developed colluvial/residual soil. Qo probably correlates to Vincent and Krider’s (1998) Am unit; reworked alluvium and/or colluvium appearing as remnant fan surfaces.

**Bedrock Geology**

As recognized by Hayes et al. (1983), bedrock map units in the study area consist of two general lithologies, a rhyolite lava flow overlain by volcaniclastic sedimentary rocks. These units dip gently to the northeast, and represent the uppermost part of an extensive Mid-Tertiary volcanic field that makes up most of the bedrock exposures in the Peloncillo Mountains (Erb, 1979; McIntyre, 1988; Hayes et al., 1983; McIntosh and Bryan, 2000). The rhyolite lava flow exposed in the study area is part of an extensive field of rhyolite lava named the rhyolite of Clanton Draw (Erb, 1979; McIntyre, 1988) which caps the volcanic field in this area. Erb (1979) reports a zircon, fission-track age of 25.8 ± 1.2 Ma for the unit, and McIntosh and Bryan (2000) report a ^{40}Ar/^{39}Ar, sanidine, single-crystal, laser-fusion age of 27.34 ± 0.14 Ma. Based on the close similarity of the age of the rhyolite of Clanton Draw with a widespread welded ash-flow tuff unit, the 27.44 ± 0.08 Ma (sanidine ^{40}Ar/^{39}Ar) Park Tuff, whose source caldera has not been identified, McIntosh and Bryan (2000) suggest that the source caldera for the Park Tuff might be buried by the rhyolite lava of Clanton Draw. Based on the small area we mapped during this study we were unable to confirm or refute this interpretation.
Although poorly exposed, the contact between the rhyolite of Clanton Draw and the sedimentary rocks in the study area is sharp, and there is little or no evidence of prolonged hiatus along the contact. There is no well-developed paleosol and there is no evidence that the rhyolite was extensively eroded or structurally deformed prior to deposition of the sedimentary rocks. The preservation of a pumiceous carapace autobrecia, generally an easily eroded lithology, at the top of the rhyolite unit throughout the map area indicates that the lava flow was probably buried quickly by the sedimentary rocks.

**Rhyolite lava**

The rhyolite lava in the study area is very crystal-poor, containing less than 2% phenocrysts. The principal phenocryst phase is biotite with crystals ranging in size from 0.5 to 3.0 mm. Feldspar phenocrysts are very sparse and generally very small (<0.5 mm). Quartz phenocrysts are rare to absent. McIntyre (1988) reports that other lava flows in the rhyolite of Clanton Draw contain more abundant phenocrysts of plagioclase and K-feldspar (sanidine), and quartz. Clasts in the overlying sedimentary rocks consist entirely of crystal-poor (<1-5% phenocrysts) and moderately crystal-rich (10-20% phenocrysts) rhyolite lava, and all of these clasts are interpreted to be derived from the rhyolite of Clanton Draw.

**Textural variations**

Textural variations preserved in the rhyolite lava reflect the normal and predictable zonations or facies that occur at the top of silicic lava flows throughout the world (Fink and Manley, 1987; Duffield and Dalrymple, 1990; McPhie et al., 1993). Four facies were mapped separately from bottom to top: 1) crystalline core coherent facies, 2) spherulitic lithophysal coherent facies, 3) vitric spherulitic coherent facies, and 4) pumiceous carapace autoclastic breccia facies. The three coherent facies represent the massive interior of the lava flow, and the variations reflect differences in cooling history. Towards the middle of the flow, the crystalline core was insulated the most and cooled slowest, allowing for the crystallization of a felted microscopic framework of feldspar and quartz in the matrix. The outer vitric coherent facies cooled rapidly and its matrix froze or quenched quickly as volcanic glass or obsidian. Spherulites are spherical growths of devitrified glass that are common in silicic volcanic rocks. Spherulites are high-temperature phenomenon that range in size from millimeters to several centimeters. Spherulites are present in the outer coherent facies of this study ranging in abundance from <5% to >50% of the rock. The spherulites in the vitric zone of this study area are brownish red in color and are concentrated along flow-bands. A zone of coherent facies lava with exceptionally large gray spherulites (up to 30 cm), some of which are cored by lithophysal cavities occurs along the contact between the vitric coherent facies and crystalline core coherent facies. Lithophysal cavities are gas cavities rimmed by
crystalline material. Lithophysal cavities in this study area are typically rimmed with agate. The spherulitic, lithophysal zone, although not recognized as a map unit in most areas, was differentiated in this area because it represents a particularly resistant unit whose physical properties are significantly different from adjacent map units.

The vitric spherulitic coherent facies of this study area grades upwards into an autoclastic carapace breccia. Autoclastic breccias form along the periphery of silicic lava flows where changes in shape and relief of the flow causes the rapidly quenched rind of the flow to break apart and crumble into local depocenters. In an idealized flow, autoclastic breccias occur at the base and at the top. Basal autobrecia consists of blocks that break loose and accumulate in a heap in front of the flow. These accumulations are eventually buried by the fluid portion (coherent facies) of the flow as it advances. Carapace autobrecia constitutes the rigid rind of a flow that is broken apart as the fluid interior undulates below. In some cases, protrusions of the fluid interior ramp upward as the flow advances forming spines that crumble into piles of carapace autobrecia on top of the flow. There are many examples of ridges and spines of vitric spherulitic coherent facies lava in the study area. These ridges or spines account for the locally highly irregular and non planar contact between the coherent facies and the autoclastic facies flow units in the study area.

**Volcaniclastic sedimentary rocks**

A volcaniclastic sedimentary sequence of conglomerate and sandstone overlies the rhyolite of Clanton Draw. The sedimentary rocks are monolithic, containing only clasts of rhyolite lava, but there are at least two types of lava. The most abundant clasts (75-95%) are of crystal-poor lava and were probably derived from the flow present in the western part of the study area. Three different sedimentary units were recognized in the study area based on subtle differences in sedimentology: 1) a lower boulder-cobble conglomerate, 2) a middle pebbly sandstone, and 3) an upper cobble-pebble conglomerate. The units are defined based on the overall abundances of the different types of conglomerate and sandstone, but it is important to note that in each map unit, the other types are present in lesser amounts.

Terminology for the description of the sedimentary rocks in this report follow the Wentworth (1922) and Schmid (1981) classifications for grain size, the Ingram (1954) classification for bed thickness, and the Powers (1953) classification for rounding (Appendix A).

The sedimentary rocks become finer grained gradually up-section, but it is the change from clast-supported dominated texture in the upper and lower conglomeratic units to matrix-supported texture in the middle pebbly sandstone unit that defines the different map units. The clast-supported textures are characteristic of fluvial sedimentation. The presence of plane-bedding, cross-stratification, and channel bed forms in these rocks are also evidence that the rocks were deposited gradually in an alluvial environment. The
matrix-supported textures prevalent in the middle sedimentary unit suggest that these rocks were deposited during mass-flow and flood-flow events. The greater thickness, lack of sedimentary structures, channels, and imbrication of the clasts in the middle unit support this interpretation.

**Site Hydrologic Characteristics and Erosion Potential**

A primary purpose of this investigation was to determine if the site geology might provide pathways for surface water to infiltrate and flow between study watersheds, causing erroneous runoff results, or to circumnavigate the flumes altogether. Potential pathways could be provided by faults, lithologic contacts, or highly permeable units. Orientation of the bedrock, horizontal or dipping, may also influence subsurface flow. Based on our reviews of aerial photographs and literature, and our field investigation, no faults were identified in the study area. Lithologic contacts and permeability are controlled by the physical properties of the bedrock units.

In terms of physical properties of the different rhyolite map units that might influence infiltration of surface runoff, there are significant differences between the coherent facies and the autoclastic facies. The coherent facies of the lava are significantly more impermeable to surface runoff infiltration. This was clearly expressed during our mapping of the study area during the winter storm period of October and early November, 2000. The autoclastic carapace breccia map unit was relatively dry during this period, but a great deal of surface runoff could be seen to be seeping out along its basal contact where it overlies the uppermost coherent facies lava. In terms of permeability, there seems to be very little difference between the three different variations of the coherent facies. Due to the highly unstable nature of volcanic glass, however, the uppermost vitric coherent facies forms a recessive, easily weathered unit. The vitric unit is characterized by a fine, crumbly, black (obsidian clasts) soil that fills in low, flat lying areas between the more resistant spherulitic, lithophysal coherent and the autoclastic breccia facies. Based on flagging at the time of our field investigation, flumes in watersheds A, B, and H, where rhyolite units are found, will be installed below the breccia and vitric units. In addition, the rhyolite flow is tilted only about 5° to the northeast, therefore it is unlikely that infiltrated water would flow between watersheds.

In terms of physical characteristics of the different volcaniclastic sedimentary units that might effect infiltration of surface runoff, the clast-supported units are clearly better sorted than the matrix-supported units. Finer grained particles tend to be winnowed out of the clast-supported, fluvial units, and the result is that these rocks, ideally, will have higher degrees of porosity and possible permeability. Because they were deposited en mass, the matrix-supported units have a greater percentage of fine-grained (fine sand, silt, and clay) particles in the matrix and these rocks tend to have less porosity, and possibly they are less permeable. However, without a detailed study of the cementation in these rocks, it is impossible to say which units are more or less permeable. For example, clast-
supported sedimentary frameworks can become quite impermeable if they are tightly
cemented during diagenesis. Detailed studies of this type are beyond the scope of this
report, and probably unnecessary. Since matrix and clast-supported units are present in
all three sedimentary map units, we believe that even if any systematic variation in the
permeability of these rocks was due to these differences, it would be only very slightly
expressed in terms of resistance to infiltration of surface runoff in areas that are
dominated by one of the sedimentary map units.

During the winter storm period of October and early November, 2000, surface flow
was observed in all study watershed channels. During the January, 2001, field visit,
which occurred several days after a winter storm, surface water was observed puddled in
some northern watershed channels, but southern watersheds were dry. The volcaniclastic
sedimentary units dip five to ten degrees northeast so it is possible that surface water is
infiltrating, flowing downdip and resurfacing in northern watersheds. A more likely
explanation has to do with slope aspect, however. North-facing watersheds are cooler
and moister. Snow lingers longer, melts slowly and infiltrates. South-facing watersheds
are warmer and drier. Snow melts quickly and much of it runs off or evaporates, so a
smaller proportion infiltrates relative to northern watersheds.

Without conducting a groundwater study it is not possible to say that there is no
subsurface flow between basins. However, due to the limited area of these watersheds,
we expect that any subsurface flow between basins will be very small compared to runoff
and surface flow within each basin. Further testing is beyond the scope of this project,
and probably not necessary.

Concerns over potential increase in erosion rates after burning were also considered
during this study. Soil depths throughout the study area are quite shallow, typically less
than one meter. Alluvial deposits may be up to two meters thick. Generally these
deposits are small and located on relatively flat ridge tops (Qmo and Qo), or bench-like
hillslopes (Qm) downgradient of study watersheds. Therefore the potential for increased
erosion is probably small. Evidence of geologic hazards within the study area, such as
landslides and debris flows, were not observed during this study.

### Map Unit Descriptions

#### Quaternary

**Whitmire Creek Deposits**

**Qycr - Modern channel deposits (<~100 years).** This unit consists of modern river
channel deposits of Whitmire Creek. Channel deposits consists of cobbles, sand,
gravels and boulders near the western end of the study area, fining to mostly sands
and gravels with some cobbles at the eastern end. Whitmire Creek is entrenched less
than one meter below adjacent floodplains. The channel is extremely flood prone and
is subject to deep, high, velocity in moderate to large flow events. Channel banks are
subject to lateral erosion during floods. This unit is equivalent to Vincent and Krider’s (1998) unit Y – late Holocene or active bottomland stream terraces and floodplains.

**Qy\textsubscript{2r} – Late Holocene floodplain and terrace deposits (~2ka)**. Qy\textsubscript{2r} consists of channel deposits (Qyrc) too small to delineate at this scale, floodplains, and low terrace deposits of Whitmire Creek. Qy\textsubscript{2r} deposits are composed of sand, silt, gravel and cobbles and are coarser in the western portion of the study area where Whitmire Canyon is narrow. As Whitmire Canyon broadens, Qy\textsubscript{2r} deposits form the floodplains and terraces with small channels that flow during floods. This unit is also equivalent to Vincent and Krider’s (1998) unit Y – late Holocene or active bottomland stream terraces and floodplains.

**Piedmont Alluvium**

**Qy\textsubscript{2} – Late Holocene alluvium (~2ka)**. Qy\textsubscript{2} deposits consists of channels, low terraces and small alluvial fans composed of cobbles, sand, silt and boulders that have been recently deposited by modern drainages. Within study watersheds, Qy\textsubscript{2} deposits are discontinuous and very small; most are not mappable at this scale. Qy\textsubscript{2} deposits within the watersheds typically form where tributary channels join the main wash and often times will contain some colluvium from adjacent hillslopes. Larger Qy\textsubscript{2} fan deposits are found at the mouths of watershed streams along the broader eastern portion of Whitmire Canyon. These deposits are ½ to 1 meter above Qy\textsubscript{2r} deposits and are typically finer than those deposits within the watersheds. Soil development associated with Qy\textsubscript{2} deposits is minimal.

**Qy\textsubscript{1} – Holocene Alluvium (0 to ~10 ka)**. Qy\textsubscript{1} surfaces consists of older fan deposits from tributary watersheds into Whitmire Creek. Only two small deposits of Qy\textsubscript{1} were mapped. Qy\textsubscript{1} surfaces are typically ½ to 1 m above Qy\textsubscript{2} fan deposits. Unit Qy\textsubscript{1} is relatively planar and composed of silts, sands and gravels. Qy\textsubscript{1} soils are weakly developed with some soil structure.

**Ql – Late Pleistocene alluvium (~10 to 30 ka)**. Unit Ql is found at the mouths of study watershed streams in Whitmire Creek. Ql surfaces are composed of relict fan deposits 4 to 6 m above active channels. Unit Ql consists of open to loose gravel and cobble surface lag with dark brown soil. It is equivalent to Vincent and Krider’s (1998) unit M – latest Pleistocene stream terraces and small fans.

**Qm – Middle Pleistocene alluvium (~130 to 750 ka)**. Qm deposits are found on south-facing bench-like hillslopes above Whitmire Canyon, in the eastern half of the study area. Unit Qm probably represents remnant piedmont alluvial fan deposits, but may also contain reworked alluvium and colluvium. Deposits are open to tightly packed gravel and cobble surface lag with well developed, shallow (~1.5 m) soil that is distinct from the surrounding thinner, less developed colluvial/residual soil.
Qmo – Middle to early Pleistocene alluvium (~500 ka to 2 Ma). Qmo surfaces consist of very old, high, dissected alluvial fan remnants with planar to slightly rounded fan surfaces and strong soil development. They are found only on the ridge tops in the eastern portion of the study area. These surfaces appear dark brown to reddish on aerial photographs. The strongly developed soil is shallow, less than 1 m, is very dark brown to dark reddish brown with a strong blocky structure and high clay content. Unit Qmo at the extreme eastern edge of the study area is well preserved and planar with moderately varnished scattered cobble and boulder surface lag (Appendix B, Soil Pit 1). Smaller, planar to slightly rounded Qmo surfaces are located on ridges in the center of the study area lag (Appendix B, Soil Pit 3). Surface lags on these areas consists mostly gravels and cobbles. This unit is equivalent to Vincent and Krider’s (1998) geomorphic unit V.

Qo – Early Pleistocene alluvium (~1 to 2 Ma). Unit Qo is composed of degraded or reworked remnant alluvial fan surfaces on scattered ridges. These small units contain open to tightly packed gravel and cobble surface lags. Unit Qo forms on somewhat flat to slightly rounded ridges that are remnant erosional surfaces. Deposits are well developed soils that are shallow (<1-2 m) and discontinuous (Appendix B, Soil Pit 2). Because the lithology in the Peloncillo Mountains where alluvium would have originated is the same as the lithology in the underlying conglomerates, it is not possible to tell if the soil developed on these erosional surfaces are remnant or reworked alluvium, or residuum. Nevertheless, these deposits are distinct from the surrounding thinner, less developed colluvial/residual soil. Unit Qo may be equivalent to Vincent and Krider’s (1998) unit Am – surface mantle of alluvium (and colluvium) appearing as reworked fans with moderate gradients (2-3°) and covering pedimented bedrock. This unit was created by Vincent and Krider (1998) to categorize landforms with deposits that appeared to be both alluvial and hillslope in origin and reworked after deposition.

Colluvium and residuum. Colluvium and residuum were found throughout the study area in thin, often less than ½ meter, discontinuous pockets among bedrock outcrops. Where mappable, deposits were at the base of slopes mixed in with Qy2 alluvium, and mapped as Qy2.

Tertiary

Volcaniclastic sedimentary rocks

Tcu - Upper cobble-pebble conglomerate (Oligocene-Miocene) at least 60 meters: A sequence of monolithic, rhyolite lava clast, volcaniclastic conglomerate dominated by medium- to thick-bedded clast-supported cobble-pebble conglomerate, and pebble-granule sandstone, with lesser amounts of matrix-supported pebbly sandstone. The coarser grained clasts are sub-angular to sub-rounded, and are commonly imbricated and concentrated towards the base of beds. Some of the beds are plane-bedded and/or cross-stratified. The unit weathers into ledgy, cliff and cornice outcrops with the
coarser grained, clast-supported intervals forming the resistant ledges. Between outcrops this unit is typically covered by thin colluvium.

**Tcm - Middle pebbly sandstone (Oligocene-Miocene)** 20-30 meters: A sequence of monolithic, rhyolite lava clast pebbly sandstone and sandy, pebble conglomerate dominated by massive thick- to very thick-bedded, matrix-supported sandstone with floating pebble and rarely cobble clasts. Lesser amounts of cobble-pebble, clast-supported conglomerate are also present. The massive, matrix supported beds are interpreted as dilute debris flows and/or hyperconcentrated flood flow deposits. The unit is best exposed in the south where relatively sharp contacts bound its upper and lower boundaries, but to the north, the unit includes an increasingly higher proportion of clast-supported conglomerate, and its contacts are more difficult to define. The unit weathers into rounded, slope-forming outcrops. Bedding is poorly defined, and difficult to discern. Between outcrops this unit is typically covered by thin colluvium.

**Tcl - Lower boulder-cobble conglomerate (Oligocene-Miocene)** 40-50 meters: A sequence of monolithic, rhyolite lava clast, conglomerate dominated by medium- to thick-bedded, clast-supported beds. Lesser amounts of matrix-supported, pebbly sandstone is present. The conglomerate beds are commonly arranged into channelized, cut and fill bedforms. Clasts are sub-rounded to angular, and commonly nonequant in shape. Imbricated texture, and internal cross-stratification or plane-bedding is common in the clast-supported beds. The unit weathers into ledgy, cliff and cornice outcrops with prominent overhangs and small caves developed in the sandier beds. Between outcrops this unit is typically covered by thin colluvium.

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**Rhyolite lava**

**Tr - Rhyolite of Clanton Draw, undifferentiated (Oligocene)** at least 60 meters: Crystal-poor rhyolite lava containing less than 2% phenocrysts of biotite (0.5-3 mm) and sparse, small (<0.5 mm) feldspar phenocrysts. Texture varies depending on location within flow from autoclastic carapace breccia on top to crystalline core in the middle. Various flow facies are mapped separately and described below.

**Tra - Rhyolite of Clanton Draw, pumiceous autoclastic carapace breccia facies (Oligocene)** 0-10 meters: An unsorted, clast-supported breccia of angular to very angular blocks (5-75 cm) of crystal-poor rhyolite lava set in an autoclastic, pumiceous, ashy matrix. The blocks are tan, pumiceous crystal-poor lava except near the base where some are black obsidian. The breccia has an irregular lower contact with the vitric spherulitic coherent facies. Locally along the base of this unit, the breccia consists of jig-saw fit, elongate lapilli-sized black vitric lava clasts with a reddish, ashy matrix.

**Trv - Rhyolite of Clanton Draw, vitric spherulitic coherent facies (Oligocene)** 3-10 meters: Black to dark reddish brown vitric, flow-banded crystal-poor lava with
scattered reddish brown spherulites (0-60%) concentrated along flow-bands. Gradational contacts into overlying and underlying units. Along the upper contact spines and ridges of the this unit protrude upward as much as 5 meters into the breccia. The spines are jig-saw fit brecciated along the contact and grade into the breccia. The lower contact grades into the spherulitic lithophysal facies as the vitric matrix diminishes and the spherulites increase to over 75%.

**Trs - Rhyolite of Clanton Draw, spherulitic lithophysal coherent facies (Oligocene)**
5-10 meters: Gray spherulitic, crystal-poor lava with abundant lithophysal cavities (2-40 cm) lined with agate. This facies grades downward into the massive crystalline core facies.

**Trc - Rhyolite of Clanton Draw, crystalline core coherent facies (Oligocene)** at least 30 meters: Light gray, microcrystalline matrix, crystal-poor, flow-banded lava. Spherulites are essentially nonexistent, but this facies contains a few percent small (2-10 cm) lithophysal cavities.
References


Western Regional Climate Center, 2000, Arizona climate summaries, in Western U.S. historical climate summaries, WRCC Web Page, Desert Research Institute, University of Nevada.
Appendix A – Sedimentary Terminology

<table>
<thead>
<tr>
<th>PARTICLE SIZE</th>
<th>Pyroclasts Schmid (1981)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Epiclasts</strong></td>
<td><strong>mm</strong></td>
</tr>
<tr>
<td>Wentworth (1922)</td>
<td></td>
</tr>
<tr>
<td>clay</td>
<td>0.004</td>
</tr>
<tr>
<td>silt</td>
<td>0.0625</td>
</tr>
<tr>
<td>very fine sand</td>
<td>0.125</td>
</tr>
<tr>
<td>fine sand</td>
<td>0.25</td>
</tr>
<tr>
<td>medium sand</td>
<td>0.5</td>
</tr>
<tr>
<td>coarse sand</td>
<td>1</td>
</tr>
<tr>
<td>very coarse sand</td>
<td>2</td>
</tr>
<tr>
<td>granule</td>
<td>4</td>
</tr>
<tr>
<td>pebble</td>
<td>64</td>
</tr>
<tr>
<td>cobble</td>
<td>256</td>
</tr>
<tr>
<td>boulder</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BED THICKNESS (Ingram, 1954)</th>
</tr>
</thead>
<tbody>
<tr>
<td>tlam thin-laminated</td>
</tr>
<tr>
<td>lam laminated</td>
</tr>
<tr>
<td>vtb very thin-bedded</td>
</tr>
<tr>
<td>tb thin-bedded</td>
</tr>
<tr>
<td>mb medium-bedded</td>
</tr>
<tr>
<td>kb thick-bedded</td>
</tr>
<tr>
<td>vkb very thick-bedded</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARTICLE SHAPE Zingg (1935)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very angular 1</td>
</tr>
<tr>
<td>Cylindrical (disk)</td>
</tr>
<tr>
<td>Braked</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Distribution</th>
<th>Angularity</th>
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<tbody>
<tr>
<td>O</td>
<td>A</td>
<td>Well-rounded</td>
</tr>
<tr>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
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</tbody>
</table>
**Appendix B – Soil Descriptions**

**Soil Pit 1:**  
Date: Nov 6, 2000  
Described by: AY  
Geomorphic Surface: Qmo  
Location: UTM Coordinates 12R 0692382  3490762

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td>A</td>
<td>Very dark gray (5YR 3/1, moist), weak coarse platey to fine subangular blocky sandy clay, sticky, very plastic, hard consistence (dry), abrupt boundary.</td>
</tr>
<tr>
<td>4-24</td>
<td>Bt₁</td>
<td>Black (5YR 2.5/1, moist), moderate fine to medium subangular blocky sandy clay, sticky, very plastic, very hard consistence (dry), common distinct clay films, abrupt irregular boundary, weak effervescence along root zones.</td>
</tr>
<tr>
<td>24-47</td>
<td>Bt₂</td>
<td>Dark reddish brown (5YR 3/3, moist), very strong medium subangular blocky clay, sticky, very plastic, extremely hard consistence (dry), many prominent clay films, abrupt irregular boundary, no to very slightly effervescent.</td>
</tr>
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</table>
Soil Pit 2:
Date: Nov 7, 2000
Described by: AY
Geomorphic Surface: Qo1
Location: UTM Coordinates 12R 0690550  3491471

<table>
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<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
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<tbody>
<tr>
<td>0-2</td>
<td>A</td>
<td>Brown (7.5YR 4/2, moist), weak medium platey sandy clay loam, slightly sticky, slightly plastic, soft consistence (dry), abrupt smooth boundary. ~75% rock fragments.</td>
</tr>
<tr>
<td>2-21</td>
<td>Bt₁</td>
<td>Dark brown (7.5YR 3/2, moist), weak medium subangular blocky sandy clay loam, sticky, plastic, soft consistence (dry), common distinct clay films, abrupt wavey boundary, no to very slightly effervescent. ~50% rock fragments.</td>
</tr>
<tr>
<td>21-47</td>
<td>Bt₂</td>
<td>Brown (7.5YR 4/3, moist), weak fine subangular blocky to medium coarse subangular blocky sandy clay loam, sticky, plastic, slightly hard consistence (dry), very few faint clay films, no to very slightly effervescent. ~75% rock fragments.</td>
</tr>
</tbody>
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Soil Pit 3:
Date: Nov 7, 2000
Described by: AY
Geomorphic Surface: Qmo
Location: UTM Coordinates 12R 0691577 3490981

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>A</td>
<td>Very dark gray (5YR 3/1, moist), weak fine subangular blocky sandy clay loam, slightly sticky, slightly plastic, soft to slightly hard consistence (dry), abrupt smooth boundary. ~75% rock fragments.</td>
</tr>
<tr>
<td>3-19</td>
<td>Bt₁</td>
<td>Black (5YR 2.5/1, moist), weak medium subangular blocky clay, sticky, very plastic, friable consistence (moist), common distinct clay films, abrupt wavey boundary, no to very slightly effervescent. ~25% rock fragments.</td>
</tr>
<tr>
<td>19-36</td>
<td>Bt₂</td>
<td>Dark reddish brown (5YR 3/3, moist), weak fine subangular blocky to medium coarse subangular blocky sandy clay loam, sticky, very plastic, extremely hard consistence (dry), many prominent clay films, no to very slightly effervescent. ~10% rock fragments.</td>
</tr>
<tr>
<td>36+</td>
<td>C</td>
<td>Decomposing conglomerate.</td>
</tr>
</tbody>
</table>