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Geologic map of the Clark Ranch 7 1/2′ Quadrangle and the western half of the Rhodes Peak 7 1/2′ Quadrangle, Pinal and Graham Counties, Arizona

Brian F. Gootee, Jon E. Spencer, Charles A. Ferguson,
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2009

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version 1.0

August, 2009

Scale 1:24,000 (1 sheet, with text)

Arizona Geological Survey
416 W. Congress St., #100, Tucson, Arizona 85701

This geologic map was funded in part by the USGS National Cooperative Geologic Mapping Program, award no. 07HQAG0110. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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INTRODUCTION

The Clark Ranch 7½' Quadrangle and the western half of the Rhodes Peak 7½' Quadrangle include part of the San Pedro River, flanking valley fill, and bedrock on the east side of the valley that forms part of the Galiuro Mountains range front (Fig. 1). Production of this new geologic map continues the Arizona Geological Survey mapping program of the San Pedro River valley. This mapping was done under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992, and was jointly funded by the Arizona Geological Survey and the U.S. Geological Survey under STATEMAP Program Contract award number 07HQAG0110. Mapping was compiled digitally using ESRI ArcGIS software. Parts of the Clark Ranch and Rhodes Peak Quadrangles were mapped previously by Creasey et al. (1961), Dickinson (1987, 1991, 1998), Marsh (2001), and Skotnicki (undated)). Studies of Cenozoic sedimentary strata in the Clark Ranch 7½' Quadrangle include those by Blake (1902, 1903), Bollaert (1952, 1953, 1962), Heindl (1963), Agenbroad (1967), Krieger et al. (1974), Ladd (1975), Scarborough and Wilt (1979), Utley (1980), Lindsay (1984), Dickinson (1988), Shenk (1990), and Dickinson (2003). The regional geochronology of the Oligo-Miocene volcanic rocks is outlined by Dickinson and Shafiqullah (1989). Studies of the Copper Canyon mineral district include those by Marsh (2001), Creasey et al., (1981), Guthrie (1994), Guthrie and Moore (1978), Hausen et al. (1988), Walker (1979) and Eichenlaub and Seedorff (2008).

Geologic Setting

The map area is located within the San Pedro River valley in the Basin and Range Province of southeastern Arizona. Most of the Clark Ranch Quadrangle is underlain by late Cenozoic, valley-filling clastic and chemical sedimentary strata of the Quiburis Formation (Dickinson, 1998, 2003). These consist mostly of sandstone and conglomerate in alluvial fans that flank the valley and an axial lacustrine facies that includes a diatomite sub-facies. Well preserved ash deposits are found throughout stratigraphic intervals in the lacustrine facies and diatomite sub-facies. Each facies of the Quiburis Formation have an interfingering relationship. The uppermost lacustrine facies are overlain by distal alluvial fan (sandflat) and conglomeratic facies, respectively, thus representing progradational of alluvial fans over the lacustrine strata.

Integration of the San Pedro drainage system with the Gila River terminated basin-filling sedimentation and began a period of incision that continues to the present (Dickinson, 2003). Geomorphic modification of the valley during incision has produced a complex Quaternary landscape with many Quaternary units reflecting different periods of Quaternary aggradation and incision.

Geologic Hazards

Geologic hazards within the mapping area include flooding in the San Pedro River channel, flash flooding from tributaries to the San Pedro River and groundwater contamination from mine tailings. Flooding in the San Pedro River corridor is constricted to a valley floor delineated on both sides by a bluff approximately 10 to 15 meters above Holocene river and tributary alluvial fan deposits. Tributaries are capable of transporting coarse sand and gravel and occasionally cobbles in response to runoff from flash floods following intense thunderstorms. Contamination from mine tailings presents a possible long-term hazard to groundwater and potentially gaining portions to the San Pedro River.

Other geologic hazards include soil expansion, soil creep, small landslides and dust. Soil expansion can occur where there is substantial soil clay accumulation, commonly associated with Qi2 and Qi3 terrace deposits. Soil creep can occur on gentle to steep slopes associated with silt, mud or clay widespread in the Quiburis playa and lacustrine facies. The playa and lacustrine facies of the Quiburis Formation contain substantial amounts of gypsum, which is quite soluble. Wetting of these deposits may result in gypsum dissolution and soil compaction or collapse. Small landslides can occur in areas where cliffs of loose material are undercut by erosion. An uncommon geologic hazard unique to the mapping area may include silicosis due to prolonged exposure to silica-rich dust generated from diatomite and volcanic ash beds common in the diatomite sub-facies of Quiburis formation. For more information on the character and mitigation of many of the aforementioned geologic hazards, see AZGS Down-to-Earth series No. 13 (Harris and Pearthree, 2002).

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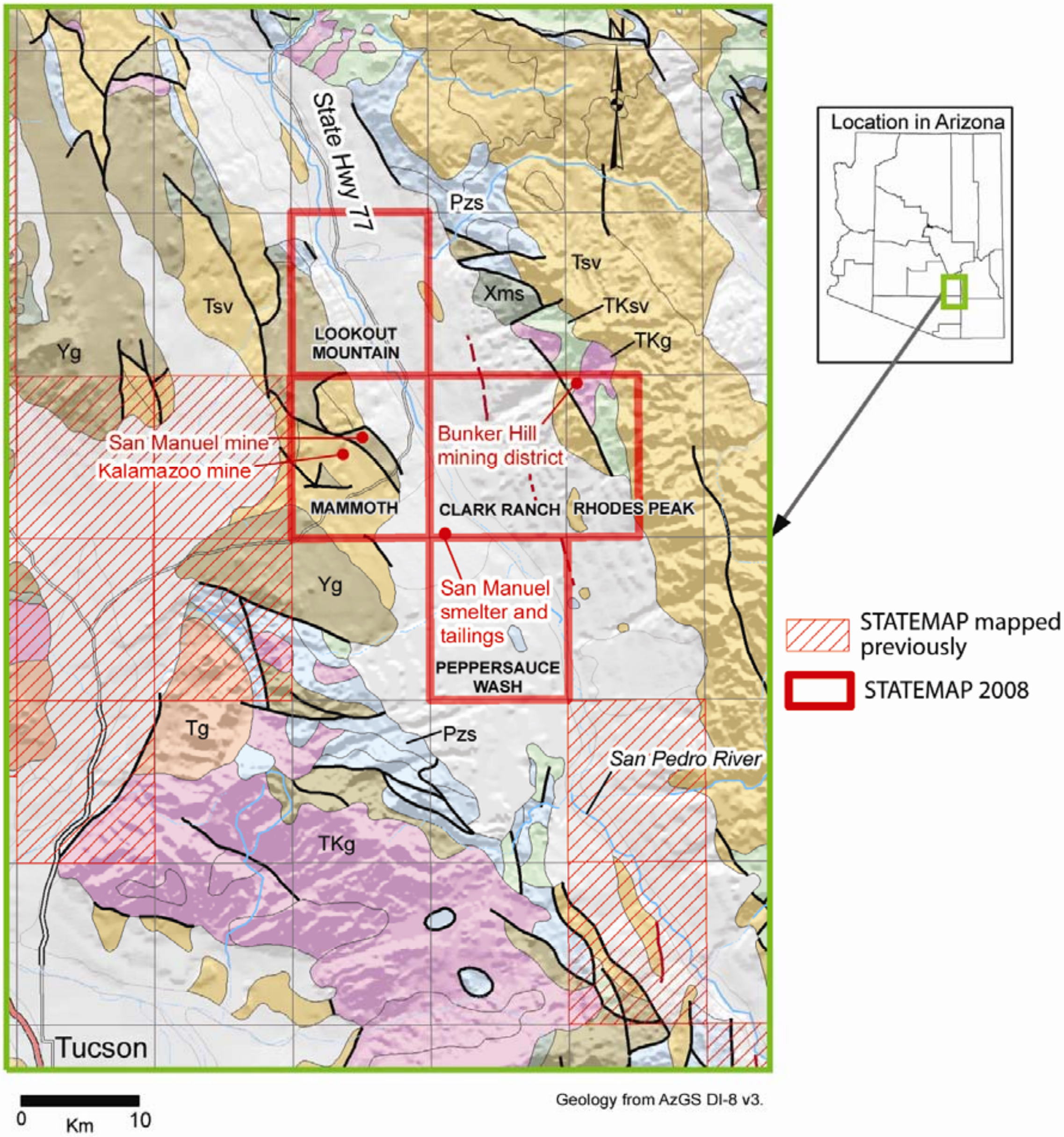

Tsv - Oligo-Miocene sedimentary and volcanic rocks
Tg - Oligo-Miocene granitic rocks
TKg - Early Tertiary and late Cretaceous (Laramide) granitic rocks
TKsv - Early Tertiary and Cretaceous sedimentary and volcanic rocks
Pzs - Paleozoic sedimentary rocks
Yg - Mesoproterozoic granitic rocks
Xms - Paleoprotoerozoic metasedimentary rocks

Figure 1. Geologic map of the lower San Pedro River valley area, southeastern Arizona, showing STATEMAP 2008 map areas.

MAP UNITS

SURFICIAL MAP UNITS

San Pedro River Alluvium

Qycr **Active River Channel Deposits -** Deposits are dominantly unconsolidated, very poorly sorted sandy to cobbly beds exhibiting bar and swale microtopography but can range from fine silty beds to coarse gravelly bars in meandering reaches based on position within the channel. Clasts are typically well-rounded but may be angular to sub angular. Qycr deposits are typically unvegetated to lightly vegetated and exhibit no soil development. Qycr deposits are entrenched from 30 cm to 10 meters or more below adjacent early historical floodplain deposits depending on location, geomorphic relationship, and local channel conditions. Although much of the San Pedro was a perennial stream historically, some sections are dry or marshy at the surface during much of the year. These deposits are the first to become submerged during moderate to extreme flow events and can be subject to deep, high velocity flow and lateral bank erosion.

Qy4r **Flood channel and low terrace deposits -** Deposits are found adjacent to active channels that form lightly vegetated in-channel bars, small planar fluvial terraces within 30 cm of river elevation, and recent erosional meanders outside the presently active channel. Terrace deposits are inset into older river alluvium and usually narrow, rarely more than 100 meters across. Qy4r deposits are composed of poorly sorted unconsolidated sediments ranging from fine silts to gravel bars depending on location in the channel at the time of deposition. Pebbles and cobbles are well-rounded to sub-rounded. These surfaces are commonly inundated under moderate to extreme flow events and can be subject to deep, high velocity flow and lateral bank erosion. These deposits do not exhibit soil development but may exhibit a light vegetation cover of small trees and bushes and grasses due to their relatively frequent inundation.

Qy3r **Historical river terrace deposits -** Terrace deposits that occupy elevations from 1 to 2 meters above Qy4r deposits and are inset below the pre-incision historical floodplain. These surfaces are generally planar but exhibit bar and swale microtopography. Although no soil development is present, dense grasses and small mesquite trees abound. Sediments composing these deposits are poorly sorted silt, sand, pebbles and cobbles. Pebbles and cobbles are well-rounded to sub-angular. Trough crossbedding, ripple marks, and stacked channel deposits viewable in cross-section indicate deposition in a low to moderate energy braided stream environment. These deposits are prone to flooding during extreme flow events, and undercutting and rapid erosion of Qy3r surfaces is possible during lower flow events.

Qy2r **Latest Holocene to historical river deposits -** Deposits associated with the floodplain that existed prior to the early historical entrenchment of the San Pedro River (Hereford, 1993; Huckleberry, 1996; Wood, 1997). Qy2r deposits are associated with broadly planar surfaces that locally retain the shape of historical river meanders. Qy2r surfaces are up to 7 meters above modern Qycr deposits and are the most extensive river terraces in the valley. Qy2r sediments were deposited when the San Pedro was a widespread, shallowly-flowing river system and are dominated by fine grained floodplain deposits. Dense mesquite bosque and tall grass is typically present on these surfaces except where historic plowing or grazing has taken place. These surfaces appear predominantly fine grained at the surface due in part to the input of organic matter and windblown dust deposition but are composed of interfingering coarse sandy to pebbly braided channel and fine sand to silty river floodplain deposits. Where Qy2r deposits are moderately to deeply incised they not subject to inundation by river floods, but they may be flood-prone in areas with less channel incision. Qy2r deposits are subject to catastrophic bank failure due to undercutting and lateral erosion during flow events. Distal piedmont fan deposits (Qy2 and Qy2f) onlap onto Qy2r deposits although an interfingering relationship likely exits in the subsurface.

Qy1r **Late to Early Holocene San Pedro terrace deposits** - Deposits associated with slightly higher terraces that represent either higher elements of the early historical floodplain or remnants of older Holocene aggradation periods. These fine-grained terrace deposits commonly have been disturbed by plowing or cattle grazing. When undisturbed, Qy1r deposits are densely vegetated by mature mesquite trees (mesquite bosque) and tall grasses. Soil development is moderate and surface color ranges from 10 to 7.5 YR 4/4. Due to the dense vegetation input of organic matter at the surface is high and often results in a thin (< 10 cm) organic soil horizon. A light dusting (incipient stage I) calcium carbonate accumulation is evident on the undersides of some buried clasts. Qy1r surfaces are up to 7 meters above the active channel in highly incised locales and typically are less than 1.5 m higher than adjacent Qy2r surfaces.

Qi3r **Late Pleistocene river terrace deposits** - Terrace deposits are up to 10 to 25 m higher than the San Pedro channel. These deposits consist of well rounded pebbles, cobbles and boulders exhibiting stage I+ calcium carbonate accumulation with cross-bedded coarse sandy interbeds. Shallow clay accumulation varies from light to moderate in color, similar to Qi3 soil development (7.5 YR 4/4). Clast composition is varied and includes rock types not found in the mountains from which modern piedmont material is derived from. Qi3r terrace surfaces are planar, often surrounded by distal piedmont alluvium, and are generally lightly vegetated except for creosote, small weeds and grasses, and occasional cacti. Commonly, Qi3r deposits are inset into adjacent piedmont alluvial deposits but can also be inset into older river gravel terraces and underlying Quiburis basin fill deposits. Soil development is weak, possibly due to the porous nature of these deposits.

Qi2r **Middle to late Pleistocene river terrace deposits -** Terrace deposits are similar to Qi3r deposits but occupying higher positions in the landscape. Terrace surfaces are slightly to moderately rounded. Clast composition is varied and includes rock types not found in the mountains from which modern piedmont material is derived from. Well-rounded pebbles, cobbles and boulders with stage I-II calcium carbonate accumulation armor Qi2r surfaces. In some places characteristic euhedral calcite crystals form interstitial cement which mold and radiate around clasts. Commonly, Qi2r deposits are inset into adjacent piedmont alluvial deposits but can also be inset into older river gravel terraces and underlying Quiburis basin fill deposits. Soil development is generally weak on Qi2r surfaces, but where well preserved soil color is light to moderate (5 YR 5/4). Vegetation is sparse, consisting of small shrubs, grasses and cacti. Qi2r surfaces are typically found as high-standing isolated mounds surrounded by distal fan alluvium or as small terraces inset into older fan or basin fill alluvium.

Qi1r **Early to middle Pleistocene river gravel terraces -** Fluvial facies includes moderately to well-cemented sandstone and conglomerate beds with river bedding structures, and lacks fine-grained deposits. River bedding structures include channel lag boulders in trough cross-beds overlain by climbing sets of tabular cross-beds (up to 1m thick). These deposits are scoured into Tqc and Tqp deposits and weather as a cliff-forming unit typically. Clast composition is varied and includes rock types not found in the mountains from which modern piedmont material is derived from. In some localities a relict stage III+ to IV calcrete is present, lacking any remnant of an argillic horizon. Characteristic euhedral calcite crystals form interstitial cement commonly molded and radiating around clasts. The type locality for this facies is at the mouth of Tar Wash in the Mammoth Quadrangle. This facies can be traced intermittently from the mouth of Tar Wash down the west flank of the San Pedro River into the southwest portion of the Clark Ranch Quadrangle. Paleo-flow directions are down-gradient to the northwest, sub-parallel to the San Pedro River. Sparse small shrubs, weeds, and cacti are present on these surfaces. This facies is interpreted to be lateral-bank fluvial deposits that mark the initial formation of the San Pedro River.

Piedmont Deposits

Qyc **Active tributary channel alluvium -** Unconsolidated, very poorly sorted sandy to cobbly piedmont channel sediments. Channels may exhibit bar and swale micro-topography with bars composed of coarser sediments. Qyc deposits are typically unvegetated and exhibit no soil development although small shrubs and grasses can be found on slightly elevated bars. Qyc deposits commonly become submerged during moderate to extreme flow conditions and can be subject to deep, high velocity flow and lateral bank erosion. Channels are generally incised 1 to 2 m below adjacent Holocene alluvium and may be incised into adjacent Pleistocene alluvium by 10 m or more.

Qy3 **Latest Holocene alluvium -** Recently active piedmont alluvium located primarily along active tributary drainages including floodplain, low-lying terrace, and overflow channels. Qy3 deposits are composed of unconsolidated to very weakly consolidated silty to cobbly deposits and exhibit greater vegetation than Qyc deposits. These deposits generally exhibit bar and swale meso-scale topography and are susceptible to inundation during moderate to extreme flow conditions when channel flow exceeds capacity. Soil development is generally absent or incipient on Qy3 deposits which exhibit pale buff to light brown (10 YR) surface coloration.

Qy2 **Late Holocene alluvium -** Piedmont terrace deposits located primarily along the flanks of incised drainages and ephemeral floodplains, broad low-relief distal fan deposits onlapping onto Holocene river alluvium, and active tributary drainage deposits. These deposits consist of predominantly fine grained unconsolidated to weakly consolidated sediments although isolated sub-rounded to sub-angular cobbles and boulders may be present at the surface in small quantities. Where inset into older alluvium, Qy2 deposits are planar with remnant bar and swale meso-scale topography. Distal fan Qy2 deposits are broad and sandy with numerous small braided channel systems. Rarely active Qy2 tributary drainages are generally of limited extent, relatively steep, and more densely vegetated than Qy3 tributary drainages. Soil development on Qy2 deposits is weak, characterized by incipient stage I calcium carbonate accumulation in the form of small filaments and medium brown (10 YR) surface coloration. Vegetation on Qy2 surfaces ranges from numerous small mesquite trees and grasses in distal fan environments to medium creosote, acacia, and cholla in tributaries and inset terraces. These surfaces are subject to inundation during moderate to extreme flow conditions when channel flow exceeds capacity or due to channel migration on low-relief portions of broad distal fan deposits. Qy2 terraces are typically elevated from 30 cm to 1.5 m above active channels.

Qyaf **Late Holocene alluvial fan deposits -** Qy2f deposits consist of active alluvial fan deposits in the San Pedro valley. These deposits have distributary drainage patterns and are prone to flooding and channel migration. Sediments are unconsolidated and consist of poorly sorted silt to cobbles. Vegetation includes small mesquite trees, shrubby acacia, prickly pear, and creosote.

Qy1 **Early to late Holocene alluvium -** Deposits consist of broad, low-relief, undulating fan deposits that sit higher in the landscape than younger Holocene alluvium. Portions of these deposits are mantled by coarse to very coarse angular quartz sand and exhibit diverse vegetation patterns dominated by cholla, prickly pear, small (1-1.5 m tall) mesquite, and numerous small shrubs and grasses. Overall relief between broad fan crests and incised drainages on gently rolling Qy1 deposits typically does not exceed 1.5 meters. Numerous shallow braided channels drain widespread portions of Qy1 surfaces. Qy1 deposits exhibit incipient calcium carbonate accumulation (stage I) and soil development characterized by medium brown (10-7.5 YR) coloration where unincised. Deposition of Qy1 sediments in a braided channel aggrading alluvial fan environment has, in places, resulted in shallow burial of adjacent piedmont deposits. This relationship is visible along incised channels where thin Qy1 deposits overly redder, grusy, clay-rich Qi3 deposits.

Qi3 **Late Pleistocene alluvium -** Qi3 deposits form widespread planar reddish fan terraces mantled by angular to sub-angular pebbles to boulders. These deposits exhibit moderate calcium carbonate accumulation (stage I to II) and soil development with reddish shallow subsurface coloration (7.5 YR 4/4). This color varies with position in the piedmont due to differences in parent material (mixed granitic, metamorphic and volcanic clasts west of San Pedro and volcanic clasts to the east). Qi3 deposits have saguaro, palo verde, mesquite, cholla, prickly pear, creosote, acacia, and numerous small grasses and shrubs. Qi3 deposits stand between 5 to 20 meters higher in the landscape than adjacent Qy1 and Qyc deposits depending on local incision and position within the piedmont.

Qi2 **Middle to late Pleistocene alluvium -** Qi2 deposits form broad planar fan and terrace surfaces that cap Quiburis basin fill deposits. These deposits generally exhibit reddish (5 YR 5/4) soils and moderate calcium carbonate accumulation (stage I to IV). Varnish and pavement development is moderate to poorly exhibited. Qi2 deposits are overall planar but can exhibit mild to moderate rounding near incised channels or inset terraces. Vegetation on Qi2 surfaces consists of saguaro, palo verde, medium mesquite, prickly pear, cholla, barrel cactus, and numerous small shrubs and short grasses. Where incised, these deposits often exhibit a cap up to 1 meter thick of moderately calcium carbonate cemented clasts. This cap preserves underlying, less-indurated portions of the Qi2 deposit as well as any older deposits it may overly. Qi2 terraces deposited onto basin fill deposits may stand as much as 30 to 40 meters above active piedmont channels.

QTa **Quaternary-Tertiary alluvium** – Coarse gravelly deposits that erosionally overlie Quiburis basin-fill conglomeratic facies and form the upper parts of high, very rounded ridges. QTa deposits are composed of carbonate-cemented fanglomerate cap which armors the underlying, basin-fill sediment. The flanks of QTa ridges are also armored against erosion due to the mantle of coarse clast cover derived from weathered sections of the cap. Exposures of QTa deposits are generally poor, but they may locally be at least 30-40 meters thick and are commonly the highest standing deposits in the proximal piedmont. Exposures of this unit are likely more widely distributed than shown on the geologic map.

Other Surficial Units

d — **Disturbed deposits (upper Holocene)** – Disturbed ground due to mining activity, agriculture, extensive excavation, or construction of earth dams.

Plowed — **Plowed areas** – Historically or actively plowed fields, irrigated pasture, and other lightly disturbed ground, including the White Cliffs Diatomite Mine.

Mine tailings — **Mine tailings** – Tailings derived from processing ore from the San Manuel mine.

Qtc — **Quaternary talus and colluvium deposits –** Unconsolidated to weakly consolidated, very poorly sorted, massive to weakly bedded, angular rock debris deposited at the base of bedrock slopes.

Qs — **Quaternary alluvial deposits, undivided –** Undivided terrace gravels and alluvial deposits within mountain valleys.

Basin Fill Deposits

Tqc — **Late Miocene to Pliocene Quiburis deposits, alluvial facies -** sandy conglomerate, conglomeratic sandstone, some sandstone, rare mudrock formed as alluvial fans and braidplain deposits. Generally very light gray and moderately to strongly indurated. Outcrops of Tqc weather moderately to well rounded. Sand is poorly sorted, angular, medium grained to granule sand, with abundant disaggregated granite particles of quartz or feldspar. Clasts in conglomerate typically include significant percentage of Oracle granite, also Cloudburst volcanics, and sparse Apache Group clasts. Percentages of granite and volcanics vary as much as 50% depending on location and proximity to source terrain. Bedding generally massive yet distinguishable by grain size variations, locally by parting between beds. Tqc overlies the playa facies in sharp contact, most noticeably near cliffs, along the west and east basin margins, interpreted to be a progradational event.

Tqs — **Late Miocene to Pliocene Quiburis deposits, fan toe and sandflat facies** – distal-fan and deltaic sandflat and lake margin facies include massive to laminated sandstone, siltstone, mudstone, and gypsum. This facies varies in grain size, relative distribution and depositional environment between laterally equivalent alluvial-fan/braidplain (Tqc) and lacustrine (Tql) facies. Interstitial gypsum in fine-grained clastic deposits is common and characteristic of these distal fan- to basin-axis deposits. Occasional beds of diatomite up to 0.75m thick and 10 to 30cm beds of green-brown mudstone are interbedded. Volcanic ash beds have been documented in this facies and are locally reworked into clastic beds. Tqs weathers commonly into slopes, although where gypsum, massive siltstone and sandstone predominate, cliff and stair-step exposures appear to be more common. Tqs gradationally overlies the lacustrine facies east of the San Pedro River, interpreted to be a progradational event.

Tql — **Late Miocene to Pliocene Quiburis deposits, lacustrine facies -** Laminated lacustrine facies includes interbedded mudstone, limestone, gypsum, and diatomite beds of varying thickness, with sparse and thin intercalations of laminated lacustrine sandstone. Diatomite beds range from 20cm to 1.5m thick. Where diatomite beds interbedded with siltstone dominate this facies exhibits a characteristic white outcrop color, although silt and mud commonly coat outcrop surfaces. Diatomite beds are resistant to weathering and commonly form cliff-slope-cliff topography. Relatively softer beds are composed of a mix of mudstone, siltstone, and limestone. Rare beds of soft, unconsolidated volcanic ash are preserved best underlying resistant beds of gypsiferous siltstone and diatomite. Insects commonly burrow in the volcanic ash layers.

Tqd **Late Miocene to Pliocene Quiburis deposits, diatomite facies -** Bedded diatomaceous facies include predominantly medium to thick beds of diatomite interbedded mudstone, limestone and sparse lacustrine sandstone. Diagnostic green chert beds are also present at lower stratigraphic intervals. Diatomite beds range from 20cm to 1.5m thick. Where diatomite beds interbedded with siltstone dominate this facies exhibits a characteristic white outcrop color, although silt and mud commonly coat outcrop surfaces. Diatomite beds are resistant to weathering and commonly form cliff-slope-cliff topography. Relatively softer beds are composed of a mix of mudstone, siltstone, and limestone. Rare beds of soft, unconsolidated volcanic ash are preserved best underlying resistant beds of gypsiferous siltstone and diatomite. Insects commonly burrow in the volcanic ash layers.

BEDROCK MAP UNITS

Oligocene to lower Miocene volcanic and sedimentary units

Tdu **Dark vitric dacitic lava (Oligocene to lower Miocene)** – Fine-grained, phenocryst-poor, dark vitric lava with feldspar xenocrysts and elongate spherulitic lenses <20 cm long and <5 cm wide. This unit caps the highest ridge crest where it overlies the tuff of Sombrero Butte. Chemical analysis of a single sample indicates that this unit is borderline between trachyte and dacite (Fig. 2; Tables 1, 2, and 3).

Ttsu **Tuff of Sombrero Butte, upper unit (Oligocene to lower Miocene)** – Upper unit capping Sombrero Butte is differentiated by its well defined eutaxitic foliation, with numerous elongate pits interpreted as relict pumice fragments, and by much less resistance to weathering so that unit forms slopes rather than cliffs. The contact between the upper and lower units is fairly sharp, with no obvious change except greater abundance of elongate pits above the contact.

Tts **Tuff of Sombrero Butte (Oligocene to lower Miocene)** – Massive ash-flow tuff containing 15% phenocrysts of quartz, feldspar, and biotite. Based on examination of two thin sections, the tuff contains 4-12% sanidine, 6-12% plagioclase, and 2-4% biotite (no quartz was seen). Basal vitrophyre ~15 m thick overlies ten-meter-thick bedded volcanic-lithic tuff and massive volcanic-lithic breccia. Breccia fragments, generally <10 cm diameter, are a mix of flattened and unflattened. The lower 30 m of tuff, above the basal vitrophyre, is affected by numerous subhorizontal fractures and weak, parallel lithologic variations that influence color and resistance to weathering, imparting a vague fabric to the tuff. Fragmental character of tuff is apparent in a small fraction of outcrops, with 5-10%, 1-10 cm fragments that are slightly more gray than host tuff but otherwise identical. Spaced parallel planar fractures with faint color and weathering variations in main, cliff-forming part of tuff are parallel to locally visible eutaxitic foliation. Chemical analysis of a sample of basal vitrophyre indicates a trachytic composition (Fig. 2; Tables 1, 2, and 3).

Tap **Andesite porphyry lava flows (Oligocene to lower Miocene)** – Dark brown to dark gray lava flows with 5-25%, <30 mm, euhedral, tabular plagioclase and <10% dark mafic minerals (mostly pyroxene?) ("Turkey-track porphyry" of Cooper, 1961). A sample of this unit, from upper Youtcy Canyon in the eastern Santa Catalina Mountains, yielded a K-Ar date of 26.9 ± 2.5 Ma from plagioclase (Shafiqullah et al., 1978).

Tapf **Andesite porphyry lava flows, fine grained (Oligocene to lower Miocene)** – Similar to map unit Tap but with generally <10 mm, tabular, plagioclase phenocrysts. Chemical analysis of two samples indicates that this unit is a basaltic trachyandesite (Fig. 2; Tables 1, 2, and 3).

Tvs **Volcanic-lithic sandstone and conglomerate (Oligocene to lower Miocene)** – Pale green, pale tan, and pale yellowish tan, volcanic-lithic sandstone and pebbly sandstone, massive to moderately well bedded. Stratigraphic top directions were not determined in steeply dipping exposure of this unit west of Sombrero Butte.

Td **Dacite lava flows (Oligocene to lower Miocene)** – Dacitic or trachydacitic lava flows with 5-35% plagioclase that is typically <3 mm diameter but locally as large as 10 mm, <2%, <2 mm biotite, and 0-3%, <1 mm hornblende or pyroxene. Four thin-sections, stained for potassium, did not reveal any K-feldspar. Unit generally consists of massive lava flows or autobreccia, either of which are vitric in some areas. Flow foliation is locally revealed by relief due to variable weathering resistance at scale of 1-20 cm, or by variable devitrification on scale of 1-10 cm, with iron-stained devitrification fronts parallel to foliation. Local vugs/lithophysae are elongate parallel to flow foliation, with aspect ratios of 2:1 to 10:1. Weathering color is generally pale tan to gray, locally darker, and black where vitric. Chemical analysis of five samples indicate that this unit is a trachyte (four samples) or rhyolite (one sample), but all analyses place this unit close to the dacite field (Fig. 2; Tables 1, 2, and 3).

Abundant fine biotite (<1 mm), forming 1-3% of rock unit, is apparent in thin section. One thin section (sample 1-30-08-3 from station JES-08-180) revealed a mineral with up to second-order blue birefringence color, high relief, moderately inclined extinction, and very little pleochroism. This mineral appears individually within dacite matrix or within clots containing dozens of crystals of this mineral plus plagioclase and opaque grains. Very weak pleochroism suggests that this mineral is pyroxene (in contrast to typical strong pleochroism in hornblende).

This unit also includes crystal-poor lava flows and autobreccia of crystal-poor biotite felsite exposed around Sombrero Butte. Crystal-poor dacite contains 1-3%, 1-3 mm plagioclase and <1%, <1 mm biotite, and <<1%, <1 mm hornblende(?) or pyroxene(?). Unit is typically highly fractured and weathers to form abundant, very platy, medium brown to slightly reddish brown rock debris.

Tdw **Crystal-poor dacite lava of Whitlock Wash (Oligocene to lower Miocene)** – Dacitic lava and autobreccia with 5-8%, 1-3 mm plagioclase and ~1%, <1 mm pyroxene(?). Unit is located in the Whitlock Wash area near the southern edge of the map area. In this area, the dacite and crystal-poor dacite are end members of a gradation with different geomorphic characteristics: crystal-rich variety forms bold outcrops and cliffs, whereas crystal-poor variety tends to form slopes.

Tdxw **Dacitic breccia and conglomerate of Whitlock Wash (Oligocene to lower Miocene)** – Autobreccia capped by 2-4 m of crudely bedded pyroclastic rocks and massive to crudely bedded volcanic-lithic conglomerate in which bedding is defined by variations in clast size.

Most clasts are 1-10 cm, locally to 20 cm (20 cm is common in coarse beds). Clasts are composed of dacite like nearby bedrock.

Taf **Fine-grained andesite lava flow (Oligocene to lower Miocene)** – Vesicular andesite lava with <10%, 1-5 mm plagioclase, 3%, 1-4 mm hornblende and/or pyroxene mafic minerals. This thin lava flow is interbedded within the silicic sequence along part of the Galiuro range front.

Tai **Intrusive andesite (Oligocene to lower Miocene)** – Massive andesite intrusion with 10%, <7 mm pyroxene.

Trx **Coarse grained rhyolitic lava (Oligocene to lower Miocene)** – Rhyolite lava flows with 10-15%, <5 mm feldspar, and several percent quartz and biotite. Chemical analysis of two samples indicate that the unit is transitional between rhyolite and trachyte (Fig. 2; Tables 1, 2, and 3).

Trp **Very phenocryst-poor rhyolitic lava (Oligocene to lower Miocene)** – Rhyolite lava and autobreccia with <2%, <2 mm feldspar and <2%, <1 mm biotite. Chemical analysis of a single sample indicates a composition on the border between the dacite and trachyte fields of Le Bas et al. (1986; Fig. 2; Tables 1, 2, and 3). This rhyolite is overlain by a <10 m thick, thin-bedded ash-fall tuff that is included with this map unit.

Tf **Aphyric felsic lava (Oligocene to lower Miocene)** – Chemical analysis of a single sample indicates that this unit is a trachyandesite (Fig. 2; Tables 1, 2, and 3).

Tvx **Bedded volcanic-lithic breccia (Oligocene to lower Miocene)** – Volcanic-lithic breccia with 4-6%, <4 mm feldspar, overlies mafic volcanic-lithic breccia west of Sombrero Butte.

Ta **Basaltic andesite lava (Oligocene to lower Miocene)** – In exposures west of Sombrero Butte, this unit consists of lava flows and autobreccia with 1-10%, generally <5 mm pyroxene and up to 10%, <6 mm, plagioclase phenocrysts. Matrix commonly contains abundant <0.1 mm plagioclase needles and equant magnetite. Oxidative alteration is typically significant to strong, and the presence of olivine was not established, although it could be present but obscured by alteration. In eastern exposures along the range front, this unit is similar to map unit Tap but with generally <10 mm, tabular, plagioclase phenocrysts. Chemical analysis of two samples, one from each area, indicates that this unit is a basaltic trachyandesite (Fig. 2; Tables 1, 2, and 3).

Andesite dike (Oligocene to lower Miocene) – Dike contains 20%, 2-3 cm plagioclase and is <5 m thick. Flow-foliation is parallel to dike.

Felsite dike (Oligocene to lower Miocene) – Discontinuous set of aligned dikes near Rhodes Ranch that intrudes Pinal Schist. Dikes are ~10 m thick and contain 10-15%, 1-6 mm feldspar and less abundant, 1-2 mm biotite and hornblende.

Tmbx **Mafic volcanic-lithic breccia of Scanlon Wash (Oligocene to lower Miocene)** - Clast-supported, volcanic-lithic breccia with mostly 3-100 mm diameter, subangular clasts of mafic volcanics. Breccia is indurated, with matrix typically as resistant to weathering as clasts. Microscope examination of two samples reveals the following crystalline constituents: (1) 6-8%, 20-100 micron opaques, (2) 3-6%, 1-2 mm plagioclase, (3) 25-40%, 50-500 micron acicular plagioclase microlites, (4) 6-8%, anhedral, 20-400 micron pyroxene(?) as indicated by at least second-order birefringance, high relief, pale to medium greenish color, and weak pleochroism. Field examination indicates variable feldspar content, from ~2 to 40%, which indicates that the unit is derived from a heterogeneous source. Vitrophyre is present very locally, as are biotite- and hornblende-bearing breccias. The breccia also contains ~4 x 20 mm voids, possibly pumice or vugs, that are parallel to anastomosing, parallel fractures. Chemical analysis of a single sample indicates that this unit is a trachyandesite (Fig. 2; Tables 1, 2, and 3).

Tr **Rhyolitic to trachyitic lavas (Oligocene to lower Miocene)** – Rhyolitic lava, autobreccia, and local block and ash flow. This unit contains 5-10% feldspar generally <3 mm but locally up to 6 mm, and minor biotite.

Tri **Intrusive rhyolite (Oligocene to lower Miocene)** – Flow-foliated rhyolite dikes and a single large intrusion near Mercer Ranch. Rhyolite contains 2-5%, <2 mm feldspar and minor biotite.

Tt **Nonwelded tuff (Oligocene to lower Miocene)** – Generic non-welded tuff present between several of the silicic lava flows. Includes volcaniclastic sandstone and conglomerate and mostly clast-supported, thick- to very thick-bedded lithic tuff with clasts mostly (>70%) of 5% feldspar-porphyritic, biotite-phyric rhyolitic lava, and less abundant, dark, fine-grained andesite.

Tro **Rhyolitic to trachyitc lava flows (Oligocene to lower Miocene)** – Lava containing 4-10%, 1-3 mm phenocrysts of plagioclase, sanidine, and ~1% biotite. A single sample, analyzed for major elements, has a composition that lies in the trachyte field of Le Bas et al. (1986), but is very near the triple point between dacite, trachyte, and rhyolite fields.

Tb **Pyroxene-porphyritic basaltic lava (Oligocene to lower Miocene) –** Basaltic lava flows, autobreccia, and scoriaceous lava containing ~5-10%, <8 mm pyroxene and 2-6%, <3 mm plagioclase, and probable olivine. In thin section, a sample of this unit contains (1) 6-8%, 0.1-1.0 mm, opaque grains and brown-stained spots that are opaque to very slightly transparent (commonly with voids in central parts of brownish opaque spots). These are interpreted as iron oxides formed by alteration of olivine. (2) 8-12%, 0.2-2 mm long, elongate, twinned plagioclase crystals, (3) 4-6%, <2 mm grains forming up to 5 mm aggregates of a mineral that is colorless, high relief, with first-order birefringence colors (orange), rounded with a lot of 135 degree angles, no cleavage apparent, and inclined extinction (most likely pyroxene, as inferred in field), in (4) matrix containing abundant (~50-60%) plagioclase microlites. Chemical analysis of a single sample indicates that this unit, at the sampled locality, is a basaltic trachyandesite (Fig. 2; Tables 1, 2, and 3).

Tu **Oligo-Miocene bedrock, undivided (Oligocene to lower Miocene)** – This unit is represented by a single, small exposure of bedrock at the far southeastern corner of the map area. This outcrop was not visited but is dark on aerial photograph imagery and is suspected to consist of Oligo-Miocene mafic volanic rocks.

Laramide volcanic and intrusive units

TKhx **Hydrothermal breccia (Upper Cretaceous to lower Tertiary)** – Massive fragmental rock unit with generally <20 cm, fine-grained granitic(?) rocks altered to silica, iron oxide, and clay, within silica and sericite matrix that in some breccias is more resistant to weathering than the clasts.

TKvt **Tourmaline vein (Upper Cretaceous to lower Tertiary)** – This black tourmaline vein is associated, in the general area, with black tourmaline replacement of Pinal Schist and sparse to abundant sprays of black tourmaline up to several cm across in Laramide granite to granodiorite.

TKa **Andesite lava and autobreccia (Upper Cretaceous to lower Tertiary)** – Locally vesicular, dark- to medium-gray volcanic rocks with 8-30%, <8 mm feldspar and locally occurring, ~2%, <2 mm pyroxene(?), in a microcrystalline to aphanitic matrix. Fragmental textures are common but not ubiquitous. Clasts are generally <20 cm and interpreted as autobreccia fragments. Alteration is common in this unit, and in some areas (northeast of Sombrero Butte), altering fluids apparently traveled along fractures and highly altered rocks adjacent to fractures. Where fractures were space sufficiently, rounded unaltered rock remains between altered zones.

TKam **Massive andesite (Upper Cretaceous to lower Tertiary)** – Dark gray, aphanitic, hypabyssal andesite with 15%, <5 mm plagioclase.

TKg **Medium to fine grained granite to granodiorite (Upper Cretaceous to lower Tertiary)** – Fine-grained, slightly porphyritic granite to granodiorite, generally with 10-20% mafic minerals and 10-20%, 2-4 mm feldspar phenocrysts in a fine-grained granitic matrix.

TKgp **Porphyry (Upper Cretaceous to lower Tertiary)** – Hypabyssal intrusion with 1-3 mm plagioclase phenocrysts and <1 mm mafic minerals in a microcrystalline matrix. Phenocrysts form 40-50% of rock.

Paleozoic and Proterozoic sedimentary and metamorphic units

Ꞓb **Bolsa Quartzite (Cambrian)** – Fine- to locally medium-grained sandstone, plane bedded to cross bedded with cross-beds forming beds less than ~15 cm thick. Sandstone varies from chocolate brown to orangish tan to, rarely, white. Cylindrical trace fossils (burrows?), <1 cm diameter, are locally abundant, both on bedding planes and on surfaces perpendicular to bedding planes. Many that are visible in cross section (perpendicular to bedding) have a hook-shaped base.

Ym **Mescal Limestone (Mesoproterozoic) –** Medium bedded recrystallized carbonate.

Ydst **Dripping Spring or Troy Quartzite, undivided (Mesoproterozoic)** – Medium to thick bedded, plane-bedded quartzite, with sparse conglomerate beds containing subangular to rounded quartzite pebbles and cobbles. In northern exposures, this unit consists of mostly massive, pale grayish white quartzite with local, faint, dark, thin bands (1-5 cm thick) and parallel fractures that define bedding. This quartzite seems a little too massive and pure to be Dripping Spring Quartzite, and the presence of pebbly beds in various parts of the section is also unlike Dripping Spring Quartzite. For this reason it seems possible that it is correlative with Troy Quartzite, also a member of the Mesoproterozoic Apache Group (Wrucke, 1989). Arguing against this interpretation is the presence of probable Mescal Limestone above the quartzite, although it is not certain that the stratigraphic sequence is right-side up or that the limestone is in fact Mescal.

YXa **Argillite (Mesoproterozoic or Paleoproterozoic)** – This unit consists of very fine grained, tan, brown, and dark gray phyllite and argillite, with very low metamorphic grade. Bedding laminations are preserved locally. A weak phyllitic fabric is present in most outcrops. A small body of fine-grained diabase consisting of 1- 2 mm crystals of plagioclase altered to white sericite or clay, enclosing black chlorite-epidote altered mafic minerals, apparently intrudes the unit. Contact at base of overlying Dripping Spring or Troy quartzite unit appears to be depositional with a thin, discontinuous conglomeratic unit along the contact which contains subangular fragments of argillite and fine-grained quartzite. The conglomerate is lithologically more similar to Scanlon that Barnes. Contact with Laramide andesitic rocks is concordant to apparent bedding orientation, but is nowhere exposed well enough to determine the nature of the contact. The contact is mapped as a fault because of the stratal discontinuity. This argillite unit could be a very low-grade Pinal Schist equivalent, or a slightly metamorphosed Pioneer Formation.

Xp **Pinal Schist (Paleoproterozoic)** – Dark gray to greenish gray siltstone and thin-bedded, fine-grained quartzose sandstone. Includes thin-bedded to laminated argillite and siltstone. Paleoproterozoic Pinal Schist is distinguished from younger units by its schistosity that obscures lithologic layering (and locally imparts weathering to pencil shaped fragments), by common quartz veinlets, and by quartz-rich hydrothermal or metamorphic segregations that partly define lithologic layering. Tight to isoclinals folds are locally present. Lithologic layering (2-20 cm scale) in very fine grained metasandstone is inferred to represent transposed bedding. Preferential fracturing and weathering parallel to lithologic layering are inferred to result from oriented microphyllosilicates that parallel lithologic layering.

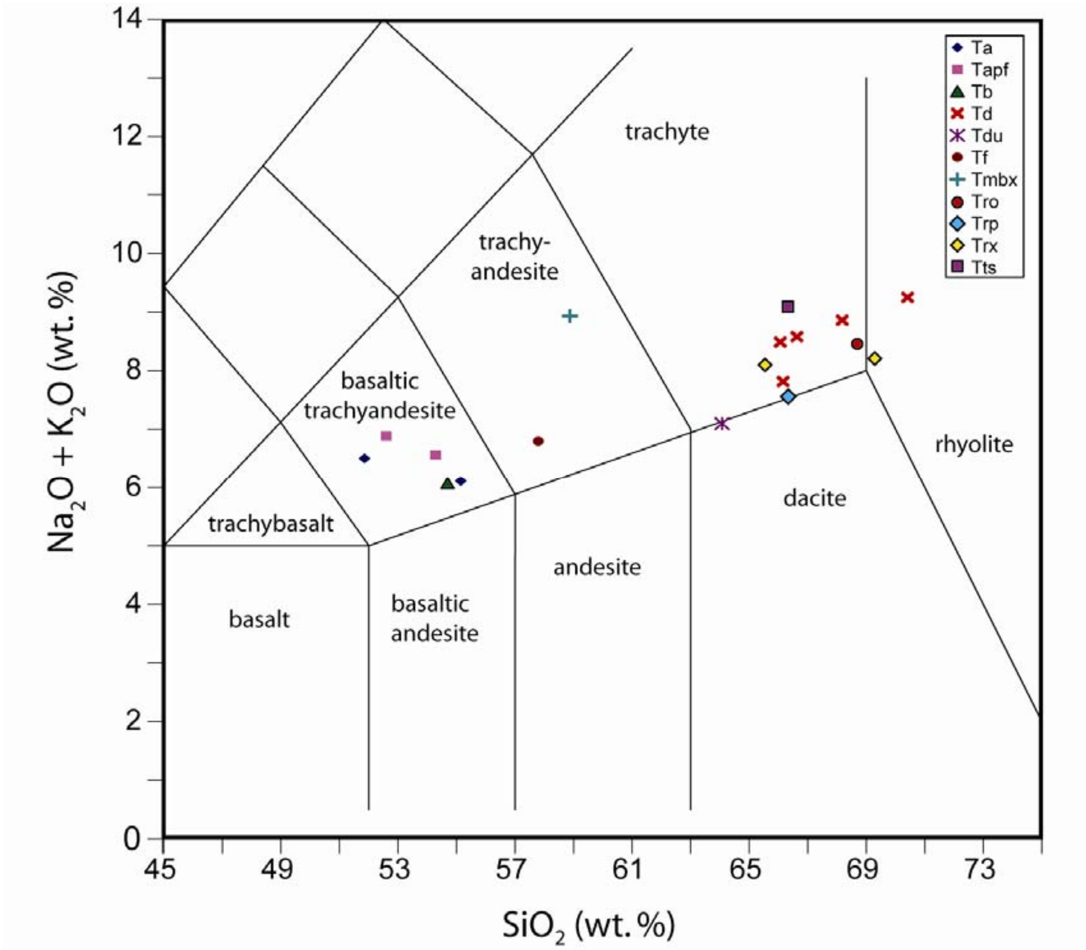

Figure 2. Alkali-silica plot of geochemical data (Le Bas, 1986) from volcanic rocks in the map area (see Tables 1, 2, and 3 for analytical data and sample locations).

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TABLE 1. MAJOR-ELEMENT CHEMISTRY

Sample number	map unit	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3(T) (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	P_2O_5 (%)	LOI (%)	Total (%)	Ba (ppm)	Sr (ppm)	Y (ppm)	Sc (ppm)	Zr (ppm)	Be (ppm)	V (ppm)
21821	Ta	55.12	15.58	6.87		4.54	5.66	3.68	2.43		0.4	3.48	98.78		732			268		122
2-7-08-3	Ta	51.84	16.4	8.41	0.092	3.79	6.26	3.61	2.89	1.396	0.68	4.11	99.49	1105	807	27	17	301	2	162
21737	Tapf	54.27	15.83	8.27		4.39	6.05	3.6	2.96		0.52	2.36	99.76		618			321		159
23549	Tapf	52.58	17.2	9.01		2.48	6.01	3.75	3.13		0.72	2.59	99.34		561			469		141
21819	Tb	54.67	15.68	6.63		5.57	7.16	3.63	2.44		0.37	2.1	99.27		767			226		148
1-16-08-4	Td	70.36	14.02	2.25	0.078	0.3	0.71	3.34	5.9	0.344	0.09	0.84	98.22	1841	114	33	6	417	2	< 5
1-30-08-3	Td	68.13	14.96	3.37	0.072	0.47	2.02	4.18	4.67	0.597	0.21	0.5	99.19	1466	316	28	6	334	3	33
2-13-08-3	Td	66.58	14.28	1.88	0.092	0.27	1.03	5.3	3.27	0.298	0.05	5.75	98.8	868	51	36	6	420	3	< 5
2-14-08-2	Td	66.11	14.3	2.37	0.082	0.47	1.46	4.68	3.13	0.382	0.1	5.95	99.05	1378	317	35	5	348	3	5
2-21-08-1	Td	66.02	14.4	2.24	0.08	0.48	1.2	4.1	4.38	0.369	0.09	4.98	98.33	1382	202	35	5	359	3	7
23552	Tdu	64.03	15.65	4.66	0.069	1.76	3.77	3.5	3.59	0.587	0.28	2.72	100.6	1040	527	18	7	246	2	76
21782	Tf	57.77	16.6	8.16	0.07	2.04	5.12	4.04	2.75	1.238	0.32	1.47	99.57	993	636	20	12	190	2	156
2-26-08-5	Tmbx	58.84	18.09	6.71	0.069	0.86	2.89	7.35	1.57	0.989	0.33	1.07	98.78	586	495	13	9	160	1	100
22375	Tro	68.58	13.83	1.77	0.079	0.24	0.94	4.6	3.83	0.263	0.07	5.37	99.56	1377	126	37	5	304	3	< 5
21677	Trp	66.31	14.5	2.35	0.074	0.52	1.64	4.15	3.41	0.343	0.11	6.16	99.56	1983	445	35	6	433	3	< 5
21801	Trx	65.49	15.21	3.34	0.071	1.07	2.08	3.77	4.32	0.729	0.2	2.37	98.66	1218	311	41	7	413	3	41
22381	Trx	69.24	13.76	1.51	0.104	0.15	0.77	4.52	3.68	0.195	0.02	5.44	99.4	128	85	46	4	256	4	< 5
2-26-08-3A	Tts	66.3	14.41	2.47	0.067	0.5	1.33	3.82	5.27	0.492	0.1	3.42	98.18	1071	178	45	5	438	4	20
Detection Limit		0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	2	2	1	1	2	1	5

All analyses by Activation Laboratories Ltd.

Sample preparation by lithium metaborate/tetraborate fusion. Analysis by inductively coupled plasma - mass spectrometry (Actlab whole-rock package code 4B (2008))

TABLE 2. TRACE-ELEMENT ANALYSES

Analyte Symbol		MnO	TiO_2	Au	Ag	As	Ba	Be	Bi	Br	Cd	Co	Cr	Cs	Cu	Hf	Hg	Ir	Mo	Ni	Pb
Unit Symbol		%	%	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppm
Detection Limit		0.01	0.005	5	0.5	2	3	1	2	1	0.5	1	1	0.5	1	0.5	1	5	2	1	5
Analysis Method*		FUS-ICP	FUS-ICP	INAA	MULT INAA / TD-ICP	INAA	MULT INAA / FUS-ICP	FUS-ICP	TD-ICP	INAA	TD-ICP	INAA	INAA	INAA	TD-ICP	INAA	INAA	INAA	TD-ICP	TD-ICP	TD-ICP
sample number	**map unit**																				
21821	Ta	0.08	0.948	< 5	< 0.5	< 2	940	2	< 2	< 1	< 0.5	27	182	< 0.5	47	5	< 1	< 5	< 2	142	8
21737	Tapf	0.11	1.412	< 5	< 0.5	< 2	875	3	< 2	< 1	0.5	32	115	3	69	7	< 1	< 5	< 2	97	15
23549	Tapf	0.12	1.764	< 5	0.6	< 2	937	3	< 2	< 1	< 0.5	25	35	3	124	9	< 1	< 5	< 2	48	13
21819	Tb	0.1	0.946	< 5	< 0.5	< 2	903	2	< 2	< 1	< 0.5	37	164	3	54	4	< 1	< 5	< 2	175	11

TABLE 2. TRACE-ELEMENT ANALYSES, CONTINUED

Analyte Symbol		Rb	S	Sb	Sc	Se	Ta	Th	U	W	Y	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Mass
Unit Symbol		ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	g
Detection Limit		20	0.001	0.2	0.1	3	1	0.5	0.5	3	1	1	0.2	3	5	0.1	0.1	0.5	0.1	0.05	
Analysis Method*		INAA	TD-ICP	INAA	INAA	INAA	INAA	INAA	INAA	INAA	FUS-ICP	TD-ICP	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA
sample number	**map unit**																				
21821	Ta	50	0.001	< 0.2	15	< 3	< 1	8.7	1.3	< 3	18	67	51.4	75	28	5.9	1.6	< 0.5	1.6	0.11	1.93
21737	Tapf	110	0.009	0.4	19	< 3	< 1	13.8	2	< 3	31	76	63.2	95	42	8.2	2.2	< 0.5	2.9	0.3	2.18
23549	Tapf	120	0.004	< 0.2	17.8	< 3	3	12	< 0.5	< 3	43	84	72.2	113	42	10.1	2.5	< 0.5	3.9	0.43	2.06
21819	Tb	90	0.001	0.2	18.2	< 3	< 1	7.2	1.9	< 3	17	63	43.2	63	27	5.2	1.5	< 0.5	1.6	0.06	1.77

All analyses by Activation Laboratories Ltd. (analysis code 4E: ICP, INAA, ICP/MS and XRF are all used for analysis)

*FUS: Sample preparation by lithium metaborate/tetraborate fusion. ICP: Analysis by inductively coupled plasma - mass spectrometry. INAA: Instrumental neutron activiation analysis.
TD: Total digestion by acid. MULT: Multicollector mass spectrometry.

TABLE 3. GEOCHEMISTRY SAMPLE LOCATIONS

Area	sample number	GPS station	NAD	Grid zone	UTM East	UTM North
Sombrero	21677	CAF-2-21677	83	12	551630	3619925
Sombrero	21737	CAF-2-21737	83	12	552682	3622248
Sombrero	21782	CAF-2-21782	83	12	551543	3619490
Sombrero	21801	CAF-2-21801	83	12	552400	3618420
Sombrero	21819	CAF-2-21819	83	12	551247	3618716
Sombrero	21821	CAF-2-21821	83	12	551331	3618824
Sombrero	22375	CAF-2-22375	83	12	552019	3615763
Sombrero	22381	CAF-2-22381	83	12	552486	3616265
Sombrero	23549	CAF-2-23549	83	12	552570	3619610
Sombrero	23552	CAF-2-23552	83	12	552859	3619282
Sombrero	1-16-08-4	JES-08-143	83	12	548898	3619457
Sombrero	1-30-08-3	JES-08-180	83	12	547496	3613360
Sombrero	2-7-08-3	JES-08-210	83	12	546491	3618293
Sombrero	2-13-08-3	JES-08-218	83	12	550288	3616479
Sombrero	2-14-08-2	JES-08-231	83	12	549282	3617534
Sombrero	2-21-08-1	JES-08-255	83	12	546471	3617556
Sombrero	2-26-08-3A	JES-08-269	83	12	547965	3619651
Sombrero	2-26-08-5	JES-08-271	83	12	546609	3619951