Geologic Map of the Mule Wash 7 ½' Quadrangle, La Paz County, Arizona, and Riverside County, California 2016

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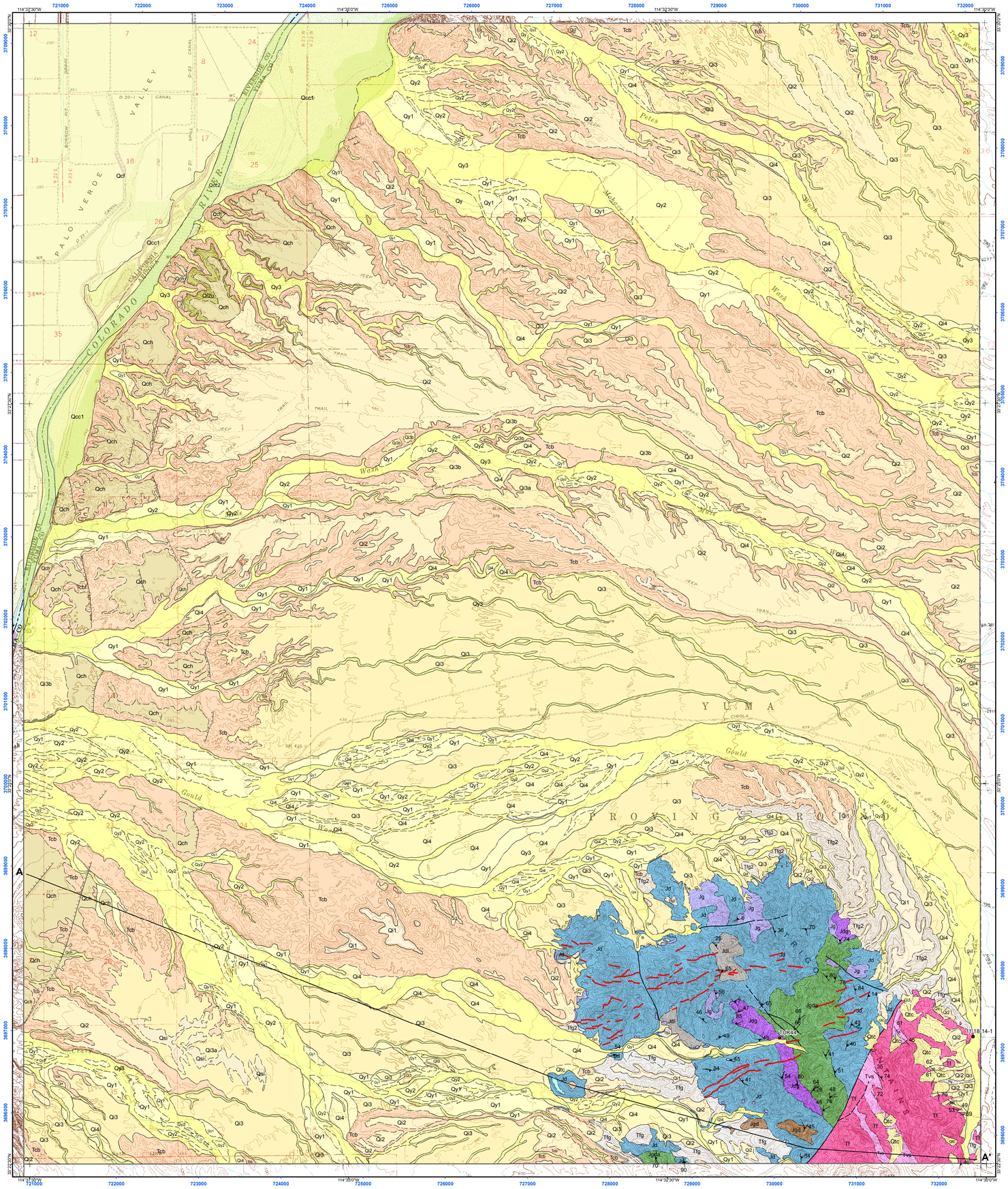
Arizona Geological Survey Digital Geologic Map DGM-117

scale 1:24,000, 1 sheet with text



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Introduction

The Mule Wash 7 ½' Quadrangle is located in western Arizona east of the Colorado River and southeast of the town of Blythe, California. The Quadrangle encompasses the west flank of the northern Trigo Mountains and most of the east-west extent of the piedmont that extends from the foot of the range toward the Colorado River. Geologic 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 assistance award #G14AC00424. Mapping was compiled digitally using ESRI ArcGIS software. Previously unpublished bedrock mapping by Richard Tosdal (former USGS employee) was incorporated into the map with minor revisions, and Kyle House (current USGS employee) assisted with field mapping.

Surficial geologic units including tributary and river deposits were mapped using field observations, stereo aerial photographs, georeferenced digital orthophotographs and satellite imagery, and digital elevation models (DEMs). Relative ages of alluvial deposits and surfaces were estimated using characteristics of clast weathering, soil development, carbonate accumulation, and position in the landscape. Most of the piedmont is covered by Quaternary alluvial fan, terrace, and channel deposits transported by alluvial systems that originate from adjacent Trigo Mountains. These deposits are predominantly locally-derived gravel with minor reworked Colorado River gravel clasts, and local and Colorado River sand. These tributary Quaternary deposits are thin, and only partially cover underlying Colorado River sand and gravel and older tributary fan deposits. Most of the tributary deposits covering the piedmont are late Pleistocene or younger in age, with uncommon to rare high deposit remnants that record middle Pleistocene and older deposition. The lateral extent of Holocene deposition is confined topographically by older deposits, but valley bottoms covered by young deposits are commonly quite wide, and distribution of deposits of different ages within the Holocene is quite complex, recording shifting patterns of deposition.

Deposits associated with the Colorado River include the early to middle Pliocene Bullhead Formation and the late Pleistocene Chemehuevi Formation Essentially all of the exposures beneath Quaternary deposits in the valley are Bullhead Formation sand and rounded exotic gravel (Tcb), with silt and clay beds (Tcbf). Bullhead deposits are commonly interbedded with tributary fan gravel deposits (Tfg2). Bullhead deposits record massive aggradation by the early Colorado River in the early to middle Pliocene following an unknown amount of erosion of Bouse deposits. Chemehuevi Formation silt, clay, sand, and gravel deposits (Qch) are found fairly close to the valley axis, where they typically are banked up against and draped over erosional topography formed on Bullhead deposits. Locally, fairly prominent fluvial scarps associated with Chemehuevi deposition are preserved as strath deposits.

The latest Miocene to early Pliocene Bouse Formation in the map area consists of one to several meters of bioclastic limestone, gray tufa or travertine, and marl; no outcrops of fine siliciclastic Bouse (Tbs) were found, but they have been interpreted in the subsurface of the basin from nearby well logs (cross-section AA'). All carbonate outcrops are at or near the bedrock mountain front draped over an erosional landscape of paleo-hillslopes and valleys. Pre- and syn-Bouse tributary fan gravels (Tfg1) are relatively uncommon or unmappable, but where they are in contact with the basal Bouse carbonated deposits, tributary gravels are often reworked and well-rounded into a basal gravel deposit (Tbg). The depositional environment of the southern Bouse Formation is disputed: they are either lacustrine deposits associated with the arriving Colorado River or evidence of a marine embayment that partially predates the development of the river.

Bedrock in the map area consists primarily of Jurassic granitoid rocks with less abundant Oligocene to early Miocene felsic volcanic rocks and shallow intrusions. Granitoids are dominated by dark hornblende diorite to hornblende-biotite quartz diorite, with less abundant granodiorite and leucodiorite. The granitoids are associated with diorite schist and gneiss and biotite augen gneiss. Foliation generally strikes northwest and dips northeast and is associated with a northeast plunging lineation. The Oligocene to early Miocene volcanic units include both shallow intrusions and bedded volcanic-lithic clastic to volcaniclastic units. At one location an intrusive contact between a felsic intrusion and bedded volcanic-lithic conglomerate is clearly exposed. The bedded rocks are tilted steeply to the northeast and, although faulted against the Jurassic granitoid rocks, suggest that all of the exposed bedrock was tilted steeply to the northeast by Miocene extensional faulting.

Description of map units

Piedmont Surficial units

Qy$_3$ — **Deposits in active channels, low terraces and bars** - Piedmont gravel, sand and silt deposits located along active drainages, including channels, adjacent gravel bars and low terraces, and broader distributary multi-channel expansion reaches. Qy3 deposits are poorly sorted and unconsolidated, gravel clasts are not varnished unless reworked from older deposits, and soil development is minimal. Vegetation includes desert riparian trees including palo verde, ironwood, and mesquite.

Qy$_2$ — **Deposits forming low terraces and active fans** - Gravel, sand, and silt deposits forming low terraces and small alluvial fans, located primarily along the flanks of active washes. These deposits are unconsolidated to very weakly consolidated sediments, poorly sorted with sub-rounded to sub-angular pebble to cobble bars on the surface and beds and lenses in cross section. Topographically low areas commonly are covered by thin mantles of silt and clay. Soil development is minimal. Vegetation includes desert riparian trees and shrubs.

Qy$_1$ — **Low terrace and low relict alluvial fan deposits** - Gravel, sand, silt and clay deposits forming relict alluvial fans and terraces along larger piedmont drainages. Qy1 deposits are composed of silt to pebbles in swales, and lightly to moderately varnished pebbles to small boulders in bars. These deposits are generally located on the margins of incised valleys away from the more active parts of the drainage systems, and typically are 1-2m above adjacent active washes. Vegetation includes sparse, relatively small desert riparian trees, shrubs including creosote, and cacti.

Qy — **Young channel, terrace and alluvial fan deposits, undivided** - Poorly sorted pebbles, cobbles, sand, minor silt and clay, locally boulders. Associated with active and recently active washes, and slightly higher terraces with modest rock varnish, minimal soil development.

Qsi — **Sand sheet deposits** - Laterally extensive sand deposits, with minor gravel, silt and clay; not spatially associated with active drainages. Percent coverage of sand is variable, but typically is >50 percent. Includes small areas of gravel lag, and eroded fine-grained deposits.

Qlc — **Colluvium and talus** - Unconsolidated, very poorly sorted, angular to subangular cobble, pebble, sand, silt and clay derived from adjacent bedrock, on moderate to steep hillslopes.

Qi$_4$ — **Youngest intermediate alluvial fan and terrace deposits** - Gravelly deposits in low terraces and alluvial fans. Deposits consist of pebbles, cobbles, small boulders, sand, silt and clay. Moderate varnish on clasts, weak to moderate undulating desert pavements, but not was well developed as Qi3. Soil development includes very slight reddening, visible carbonate accumulations. Vegetation is sparse and concentrated along slightly incised small drainageways.

Qi$_3$b — **Intermediate fan and terrace deposits, lower level** - Younger Qi3 deposits that clearly post-date maximum aggradation of the Colorado River in the late Pleistocene. Qi3b surfaces are broad and flat with strongly varnished and well-developed pavements with subtle bar and swale topography. The vesicular horizon is is up to 10 cm thick on this surface. Qi3b is 2-3 m below Qi3a.

Qi$_3$a — **Intermediate fan and terrace deposits, higher level** - Higher Qi3 surfaces graded approximately to the highest level of Chemehuevi river aggradation. Surfaces with dark, well-developed pavements are inset ~5-10m below Qi2 surfaces. Qi3a surfaces are slightly more rounded than the younger Qi3 surfaces, with more carbonate development on clasts with mm thick rinds.

Qi$_3$ — **Intermediate alluvial fan and terrace deposits** - Very poorly sorted deposits including pebbles, cobbles, sand, minor silt and clay, locally boulders forming laterally extensive relict alluvial fans and terraces. Surfaces are typically 1-5m above adjacent Holocene deposits, Surfaces vary from undulating to very smooth, desert pavements are moderately to strongly developed and rock varnish is quite dark. Soil development is moderate, with slight reddening, minor clay accumulation, calcic horizon development II-III.

Qiu — **Intermediate deposits beneath Chemehuevi deposits** - Intermediate to young fan deposits composed of locally-derived gravel and sand. This unit is younger than high-standing Qi2 deposits and pre-dates unit Qch river terrace deposits. A diagnostic cobble-gravel lag caps this unit underlying Qch deposits. Unit Qi2u generally pre-dates younger Qch deposits, but are interfingered with older Qch deposits. We interpret Qi2u to be generally coeval with the main Chemehuevi aggradation event, although it may be older than Qch in some localities.

Qi$_2$ — **Older intermediate alluvial fan and terrace deposits** - Poorly sorted pebbles, cobbles, sand, minor silt and clay, some boulders. associated with moderately dissected remnant terraces ~5-20 m above active washes. Rock varnish and pavement development is variable, quite strong on well-preserved surfaces and moderate to weak on more eroded surfaces. Soils are obviously reddened beneath pavements, and carbonate rinds are moderately thick.

Qi — **Intermediate alluvial fan and terrace deposits, undivided** - Undivided deposits with darkly varnished surfaces, variable pavements, primarily equivalent to Qi3 and Qi4, may include some Qi2 deposits.

Qi$_1$ — **Oldest intermediate alluvial fan deposits** - Poorly sorted cobble, pebble, sand deposits, with minor silt, clay, and boulders. Deposits are found capping moderately high ridges, and typically are 15-25m above active washes. Planar surfaces are generally fairly narrow and margins are substantially rounded. Deposits typically are a few meters thick over underlying fan deposits or Bullhead alluvium. Soil development ranges from strong on well-preserved surfaces to weak to moderate on eroded slopes.

Pliocene to Pleistocene map units related to the Colorado River

Qcc$_2$ — **Colorado River active channel deposits** - Deposits submerged beneath the modern channel of the Colorado River. Includes gravel, sand, silt and clay, poorly exposed. Margins of this unit are formed by man-made levees.

Qcc$_1$ — **Colorado River inactive channel and floodplain deposits** - Sand, gravel, silt, and clay deposits in recently abandoned river channels, bars, and low terraces. These deposits are very similar to Qcf and Qcc2 deposits, all are latest Holocene river deposits, but these areas have not been cultivated but are isolated from the active river channel by man-made levees.

Qcf — **Colorado River floodplain deposits** - Deposits of the Colorado River floodplain. Poorly exposed, entirely covered by agricultural fields. Prior to cultivation, these areas certainly included active and recently active channels, bars, and low terraces. Deposits consist of sand, silt, clay, and gravel.

Qch — **Chemehuevi Formation** - Sand, silt, clay and minor Colorado River gravel deposits draped over older piedmont and Colorado River deposits. These deposits record a period of major aggradation by the Colorado River in the late Pleistocene (Malmon et al., 2011, USGS PP 1786). Northeast-southwest trending scarps represent a series of recessional terraces strathed on older deposits. The earliest Qch deposits may be coeval with post-Qi2 and pre-Qi3 deposits (Unit Qi2u).

Tcbf — **Bullhead Alluvium, fine-grained deposits** - Thin to medium bedded silt, clay, and fine sand deposits, spatially associated with coarser-grained Bullhead Formation deposits and tributary fan gravel deposits. Relatively low landscape position, probably grades laterally and up-section into coarser Bullhead deposits.

Tcb — **Bullhead Alluvium** - Unconsolidated to moderately consolidated well-rounded to subangular cobbles and pebbles, quartz-rich sand, and lesser amounts of silt and clay. Surfaces of these deposits are commonly mantled by gravel, and gravel beds are common, but sandis the dominant particle size in the map area. Rounded pebbles and cobbles of primarily quartzite, chert, and other resistant rock types. Tentatively correlated with the Bullhead Alluvium (Howard et al, 2015), but locally may include Quaternary Colorado River deposits.

Tbs — **Bouse Formation, siliciclastic deposits** - Fine-grained sand, mud and clay deposits penetrated by wells immediately north, west and south of the map area (see cross-section AA'). Unit Tbs is exposed south of the map area near Cibola (Gootee et al., 2015).

Tbc — **Bouse Formation carbonate deposits** - Carbonate-rich deposits undivided including algal limestone, massive tufa drapes on paleohillslopes, and thin-bedded calcarenite and lime marl.

Tbcb — **Bouse Formation, bioclastic limestone and resistant marl** - Pale gray to tan, generally thin-bedded, moderately to well-sorted bioclastic limestone, typically containing abundant skeletal-barnacle fragments. Internal sedimentary structures are often well-preserved, and include parallel lamination, both wave ripple and unidirectional cross-lamination, and trough and tabular crossbed sets. Bioclastic limestone beds are generally interbedded within more abundant marl and calcareous siltstone. Tbg pebble beds and lenses are common within bioclastic limestone facies. This unit is generally 1-3 m thick and is typically present adjacent and down dip from massive tufa deposits draped on bedrock.

Tbct — **Bouse Formation, tufa** - Massive tufa deposits and scabrous encrustations, typically fossiliferous, algal and microbial forms, hemispherical shapes, commonly draped on moderately-sloping paleo-hillslopes formed on bedrock and older, eroded fanglomerate and colluvium. Also found as cobble and boulder aggregations within marl and bioclastic limestone deposits. Color of tufa ranges from light to dark gray. This unit ranges from a few cm thick up to 1-2 m thick.

Tbg — **Bouse Formation, basal gravels** - Gray to greenish-gray, locally derived, subangular to well-rounded, well-sorted gravels and cobbles with calcareous sand lenses at the base of the Bouse Formation. Includes coarse gravel beds with 1- 5 cm clasts. This unit is exposed primarily in the southeastern corner of the map area. These sediments are reworked from underlying colluvium and fan deposits. The deposits range from coarse fanglomerate cobbles and pebbles to sand-dominated facies and include moderate to well-sorted, well-rounded beach and nearshore gravel deposits. Beds from this unit are overlain by, and locally interbedded with, Bouse bioclastic limestone (unit Tbcb).

Miocene to Pliocene map unit

Tfg$_2$ — **Younger fanglomerate** - Poorly sorted, weakly to moderately lithified sandstone, conglomeratic sandstone, and conglomerate. Clasts consist largely of subangular to angular locally derived Tertiary volcanic rocks, granite and diorite, but includes trace to several percent clasts of tufa and bioclastic calcarenite, rounded local clasts reworked from Tfg deposits, and rounded black chert and quartzite eroded from coeval Bullhead Alluvium deposits. This unit thus represents mostly locally derived fan material interfingered with minor amounts of Colorado River derived sediments. Unit Tfg2 grades laterally into unit Tcb towards the basin, and locally is unconformably overlain by unit Tcb. Unit Tfg2 erosionally overlies bedrock and Bouse strata.

Tfg$_1$ — **Older fanglomerate** - Poorly sorted, light brown conglomerate and conglomeratic sandstone with angular to rounded clasts of local volcanic rocks, granitoids including locally derived Jurassic diorite. The uppermost part of this unit imay be coeval with Bouse deposition. The top of this unit grades conformably into the basal Bouse units (Tbg, Tbct, or Tbc), but in other areas basal Bouse deposits are draped disconformably over intact fan surfaces.

Tfg — **Fanglomerate, undivided** - Locally sourced very poorly sorted boulders, pebbles, cobbles, sand, with minor silt and clay. Relationship to Bouse deposition and later Bullhead aggradation is not clear, but we suspect that most exposed Tfg is roughly coeval with Bullhead aggradation.

Oligocene to Miocene map units

Tf — **Felsic hypabyssal igneous rocks** - Rocks of this unit consist primarily of massive felsic extrusive and/or shallow intrusive rocks that are locally brecciated or flow banded. Contacts with adjacent bedded volcanic-lithic rocks are steep and, at one location (and probably another), clearly intrusive. Unit contains <20%, <10 m sanidine (<10%, <3mm sanidine in most samples), <7%, <3mm hornblende, and <3%, <2mm biotite. Plagioclase content is difficult to determine in hand samples except where plagioclase is chalky due to alteration while sanidine is unaltered. Plagioclase made up ~20% of one sample, with chalky phenocrysts up to 10mm. Quartz was not identified in most samples, although one sample contains 4-7%, <3mm quartz. Some rocks are weakly to moderately vitric.

Tvs — **Volcanic-lithic tuffaceous sandstone and conglomerate** - Rocks of this unit are bedded to massive and consist largely of tuffaceous sandstone and volcanic-lithic conglomerate with a tuffaceous matrix. Brown volcanic-rock fragments and pale gray and tan tuffaceous clasts are up to 10 cm diameter. Bedding is defined by sorting and variable abundance of fragments. Hornblende is present in some rocks of this unit. Some massive, light colored rocks included in this rock unit may be altered lavas or pyroclastic rocks. Flattened volcanic-lithic fragments that would indicate compaction of hot pyroclastic rocks were not seen. Rocks of this unit are typically light in color on aerial imagery compared to darker-weathering intrusive felsite. This rock unit is closely associated with felsic intrusions of map unit Tf which clearly intrudes it in its northern area of exposure.

Kitt Peak - Trigo Peaks supersuite (Jurassic)

Jg — **Granite** - Leucocratic, medium grained, biotite monzogranite to granite. Locally foliated along contact margins. Pegmatite and aplite dikes related to larger bodies are common throughout older porphyritic granodiorite and derivative augen gneiss (units Jgd and Jgda) as well as phases of the diorite unit (units Jd and Jdl) and derivative metamorphic rocks. Commonly form dikes 0.5m to 10m thick too small to map. One dike has a U-Pb age of 163.0 ± 2.6 Ma (Tosdal and Wooden, GSA Special Publication 513). Locally intruded by Late Jurassic(?) hornblende-biotite diorite dikes too small to be mapped separately.

Jgd — **Porphyritic granodiorite** - Medium- to coarse-grained hornblende-biotite porphyritic granodiorite and derivative augen gneiss. Characterized by K-feldspar phenocrysts as much as 5 cm in length. Correlated to similar rocks included within the Middle Camp porphyritic unit throughout the lower Colorado River region with ages between 164 and 168 Ma (Tosdal and Wooden, GSA Special Paper 513). Xenoliths of diorite are common. Locally intruded by Late Jurassic(?) hornblende-biotite diorite dikes too small to be mapped separately. Contains mappable units of Biotite augen gneiss (map unit Jgda).

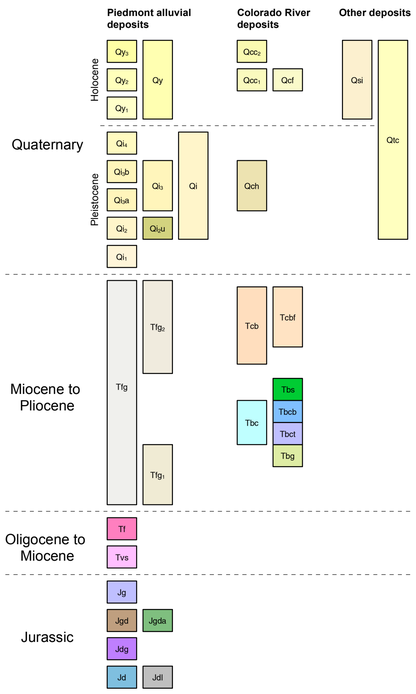
Jgda — **Biotite augen gneiss** - Unit is characterized by penetrative foliation marked by biotite, elongate grey to bluish quartz, and alignment of K-feldspar porphyroclasts. Unit is metamorphosed equivalent of the porphyritic granodiorite unit (map unit Jgd).

Jd — **Diorite** - Mesocratic to melanocratic hornblende diorite, biotite-hornblende diorite, biotite quartz diorite, hornblendite, and metamorphosed equivalents. Locally characterized by primary compositional layering of alternating plagioclase-rich and hornblende-rich layers a few centimeters thick. Correlated to diorite rocks included in the Araz Wash diorite unit throughout the lower Colorado River region with ages between 169 and 173 Ma (Tosdal and Wooden, GSA Special Paper 513). Contains mappable units of map units Jdl and Jdg.

Jdg — **Dioritic gneiss and schist** - Foliated biotite quartzofeldspathic gneiss, biotite schist, and amphibolite. Locally forms finely layered, foliated sequence presumably derived from originally compositionally layered diorite intrusive complex.

Jdl — **Leucodiorite** - Diorite that is rich in plagioclase and poor in mafic silicates. Unit forms mappable bodies within the larger diorite unit (map unit Jd).

Correlation of map units



SCALE 1:24,000

1 0.5 0 1 Miles

1 0.5 0 1 Kilometers

0 1000 2000 3000 4000 5000 Feet

CONTOUR INTERVAL 20 FEET

TRUE NORTH
MAGNETIC NORTH
11°
Approximate mean declination, 2013

Topographic base map derived from Mule Wash 7.5' USGS topographic quadrangle map originally with NAD27 datum. Reprojected to UTM NAD83 datum (zone 11) using iGage All Topo Maps V9. UTM NAD 83 grid and lat-long markers produced using ESRI ArcMap v. 10.4.

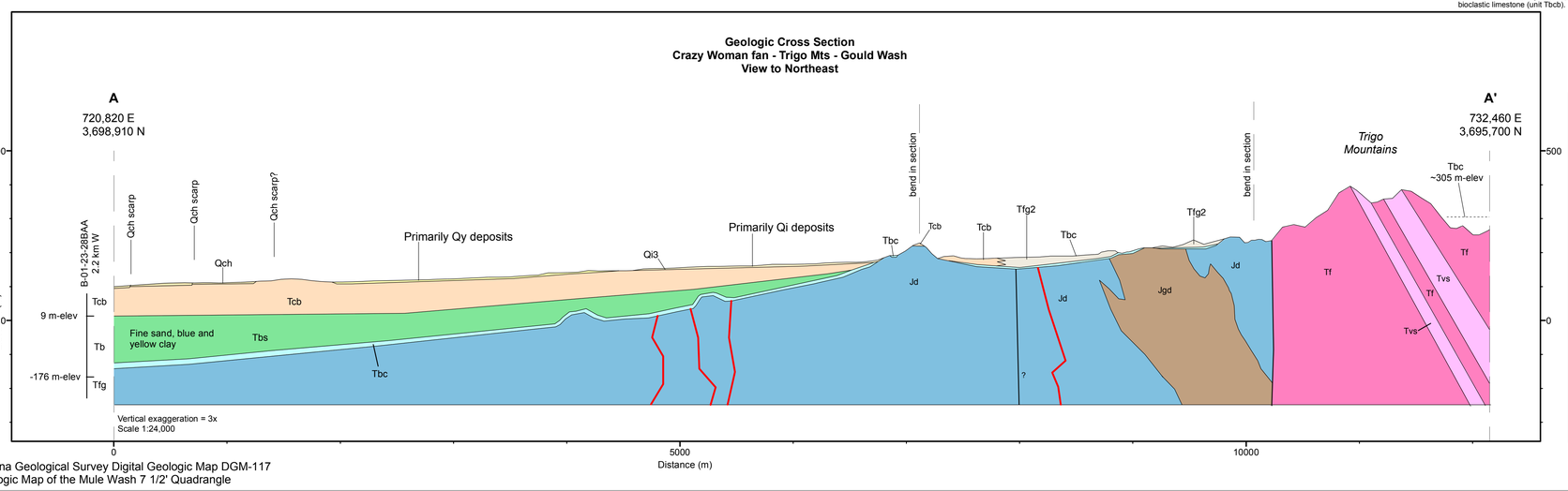
Legend

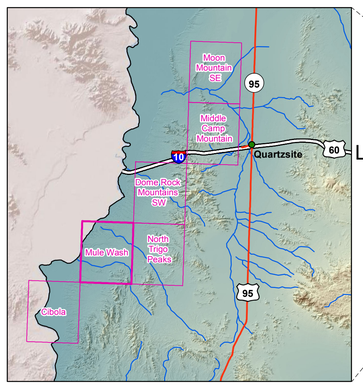
Structure symbols and sample locations

- Strike and dip of joints or planar fractures
- Strike and dip of inclined bedding
- Flow foliation in volcanic rocks
- Tectonic foliation, generic
- Tectonic foliation, vertical
- Tectonic lineation, generic
- Geochronology sample

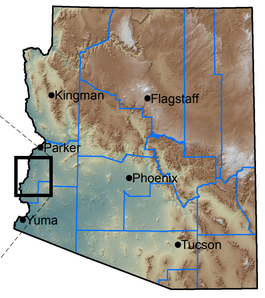
Contacts, faults, and dikes

- Contact, accurate
- Contact, approximate
- Contact, gradational
- Fluvial scarp, tics on down-slope side
- Fault, accurate
- Fault, approximate
- Granitic dike





Named quadrangles are mapped by AZGS or mapping is in progress



Location of map area

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THE UNIVERSITY OF ARIZONA