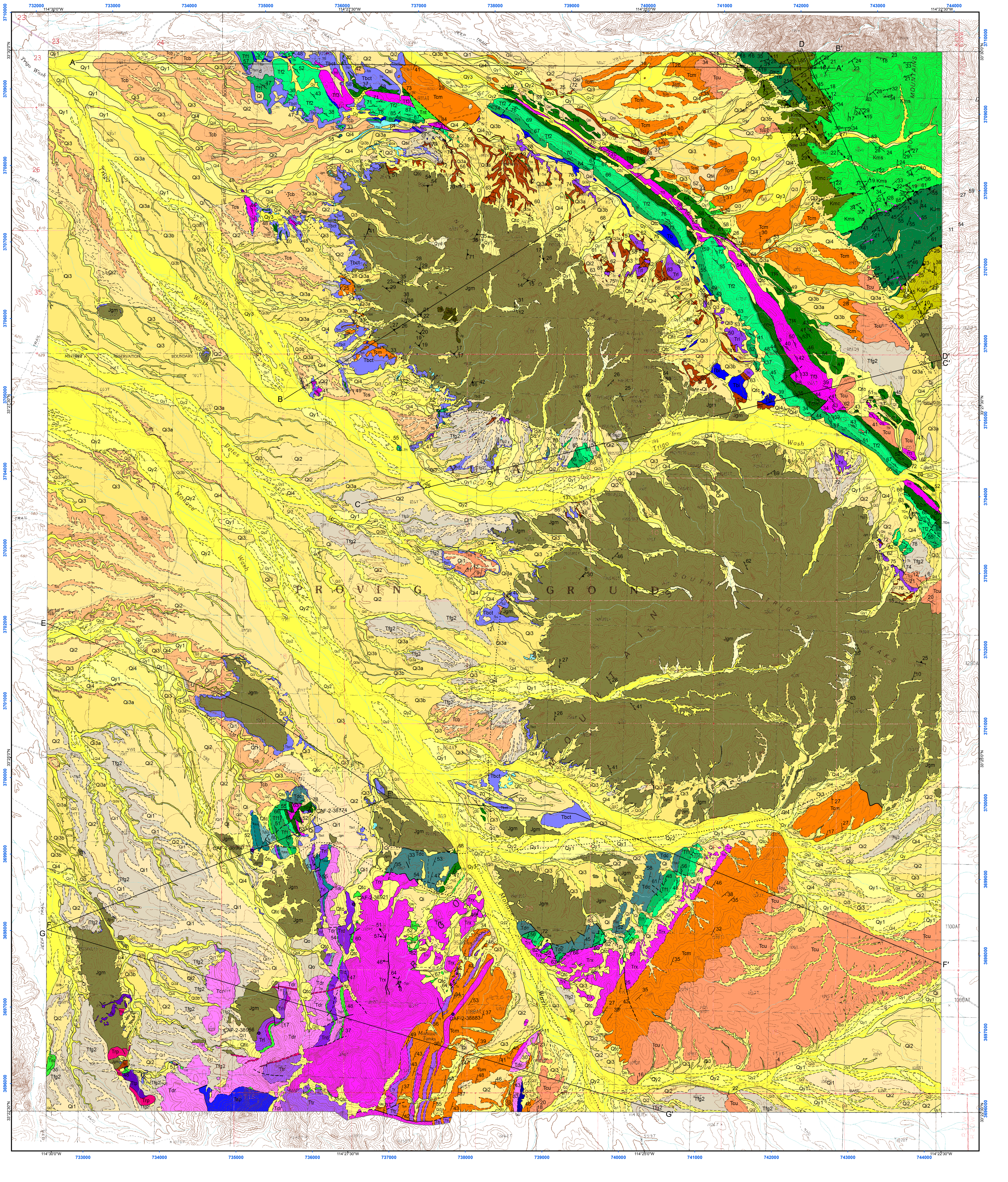

Geologic Map of the North Trigo Peaks 7 ½' Quadrangle, La Paz County, Arizona

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Arizona Geological Survey

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sheet 1 of 2

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Introduction

The North Trigo Peaks 7 ½' Quadrangle is located east of the Colorado River, southeast of Blythe, California. The map encompasses most of the northern Trigo Mountains, the upper piedmont of the lower Colorado River Valley, and several large tributary valleys and passes within the mountains. Most of the quadrangle is within the Yuma Proving Grounds (YPG), a military reservation operated by the U.S. Army. Permission was granted for us to map freely on the less-restricted parts of the YPG (hunting ranges), and escorts were provided for several days of field mapping in the restricted southeastern ¼ of the quadrangle. Due to this limited field access, much of the mapping in that part of the quadrangle was done through aerial photointerpretation.

Geologic mapping was done under the STATEMAP program, as specified in the National Geologic Mapping Act of 1992. Work was jointly funded by the Arizona Geological Survey and the U.S. Geological Survey under STATEMAP assistance award # G16AC00294. Mapping was compiled digitally using ESRI ArcGIS software. We are grateful to the U.S. Army for allowing access to the YPG.

Surficial and Basin Deposits

Surficial geologic units in the map area include tributary deposits ranging from late Miocene to Holocene, and early Pliocene river deposits the record the first arrival and early evolution of the lower Colorado River. These deposits were mapped using numerous field observations, georeferenced digital orthophotographs and satellite imagery, and analog and digital topographic information. Most of the piedmont is covered by a veneer of Quaternary alluvial fan, terrace, and channel deposits transported by tributary fluvial systems with watersheds that head in the Trigo Mountains. These deposits are predominantly locally-derived gravel dominated by crystalline and volcanic lithologies, with minor amounts of gravel and sand reworked from older Colorado River deposits. Quaternary deposits are generally thin, and only partially cover underlying late Miocene to Pliocene tributary fan deposits in upper piedmont areas, and Pliocene Colorado River sand and minor gravel in middle piedmont areas. Most of the tributary deposits covering the piedmont are middle Pleistocene or younger in age, although deeply dissected alluvial fan deposits common in upper piedmont areas are likely of Pliocene age. Coarse Holocene to latest Pleistocene deposition is predominant in mountain valleys, and young deposits cover broad valleys incised 1-20 m below older relict alluvial fan and terrace surfaces along all sizable washes. The greater part of piedmont areas are covered with dissected middle to late Pleistocene tributary deposits with moderate to fairly strong soil development.

Deposits probably or definitely associated with the Colorado River include the early Pliocene basal carbonate deposits of the Bouse Formation (Metzger, 1968), the early to middle Pliocene quartz-rich sand and exotic rounded gravel of the Bullhead Formation (Howard et al., 2015). Quartz-rich fine to medium sand deposits with minor silt and clay beds that are found high on the piedmont (unit Tcs) are likely associated with the Bullhead Alluvium, but alternatively could be part of the Bouse Formation.

Bouse deposits in the map area primarily consist of extensive, locally spectacular mantles of one to several meter-thick travertine or tufa (dubbed "travertufa" here), primarily draped over or encrusting bedrock paleotopography. Carbonate-impregnated, angular to subangular, locally-derived colluvium is common beneath and interbedded with the travertufa; limestone and calcareous sandstone interbeds are less common. Along the western margin of Trigo Peaks, travertufa can be 4-8m thick where it covered much or all of isolated bedrock piedmont, ridges and inselbergs. See "Frosted Chocolate Hills" and "Island Range" in sections AA' and EE', respectively. In these areas travertufa consist of a variety of textures: charophytes, reeds, hemispherical thrombolites, mammilaries, algal stromatolite columns, branching-dendritic forms, and complex travertine banding. Occasionally clam-coquina is interbedded with limestone micrite and travertufa beds. In paleovalleys, which are also modern valleys, travertufa, limestone with varying amounts of bioclastic material, and coarse, locally-derived, angular to subrounded gravel and sand deposits are common In these valleys, tributary gravel deposits commonly are beneath or interbedded with the basal carbonate deposits. Some of these gravel deposits are primarily fluvial, but others have mountainward-dipping bedding and bedformsindicative of reworking by nearshore processes. In addition, there are many small deposits of well-rounded, locally-derived gravel up to 1m long, including travertufa gravel, that were clearly shaped by nearshore/beach processes. Bouse basal carbonate is exposed in a variably broad band along the boundary between late Cenozoic basin deposits and bedrock and older conglomerate, and around and draped over outlying small bedrock hills and ridges, between 190 and 310 m above sea level (masl) in the mapping area. The basal carbonate certainly exists in the subsurface southern Blythe basin, and the upper limit carbonate outcrops are always erosional. Thus, the current distribution of Bouse outcrops is very much a function of what has been uncovered by subsequent erosion but has not been completely removed by erosion and denudation. The basal carbonate deposits were draped over a complex erosional paleo-landscape of hillslopes and valleys formed on crystalline and volcanic bedrock and eroded Miocene conglomerate, and less commonly, latest Miocene-early Pliocene tributary deposits (Tfg1). Travertufa, bioclastic limestone, and the well-rounded locally-derived gravel were certainly deposited in shallow water; they record a water body gradually encroaching on the complex pre-existing landscape.

Exposures beneath Quaternary deposits in some upper piedmont areas are primarily quartz-rich sand, with less common beds of rounded exotic pebbles and cobbles, and some tan to brown silt and clay beds. We tentatively interpret these beds are basin-margin deposits of the Bullhead Alluvium (Howard et al., 2015). These deposits are exposed from ~170m asl in the NW corner of the map area to as high as ~265m asl near the mountain front in the southwestern part of the quadrangle. They are interbedded with and likely grade laterally into Pliocene tributary fan gravel deposits (Tfg2). Thus, Bullhead Alluvium records massive aggradation by the early Colorado River in the early to middle Pliocene, with lesser contributions of sediment from tributary drainages. Based on age constraints farther north along the river, this aggradation culminated 3.5-4.0 Ma (House et al., 2008).

Mid-Cenozoic bedrock geology

Miocene Tertiary strata of the North Trigo Mountains are, from the top down, unified by a pair of upward-fanning, easterly tilt sequences dominated by conglomeratic rocks with sparse volcanic interbeds. The conglomerates (Tcu and Tcm) are separated by a regional, gently east-dipping angular unconformity throughout the map area. The upper conglomerate (Tcu) is gently tilted (<25°) and fans upward imperceptibly into untilted Miocene siliciclastic rocks (Tfg1, Tfg2, Tcb, Tcs) that envelope the Latest Miocene Bouse Formation (Tbc, Tbct, Tbg). The middle conglomerate (Tcm) is moderately tilted (25° -55°) and contains an ~22 Ma rhyolitic lava near its base. Strata below the middle conglomerate are steeply (55° -90°) tilted and are dominantly volcanic except in the northeast corner of the map where the strata consist of red, pebbly, arkosic sandstone and conglomerate (Tcl) interbedded with a series of felsic pyroclastic rocks that includes a single basaltic lava (Tb) with an associated sill complex (Tbi) in the middle of the sequence. The felsic pyroclastic rocks of the lower tilt-sequence are dominated by a prominent welded ignimbrite known as the tuff of Felipe Pass (Sherrod and Tosdal, 1991). The tuff of Felipe Pass is present throughout most of the map area, but is notably absent in the main part of a range of rugged peaks between Mohave Wash and Gould Wash in the southwestern part of the map area herein referred to as the "Island Range".

The tuff of Felipe Pass is best exposed in a hogback ridge parallel to Weaver Wash in the northeast corner of the map area. Four distinct ignimbrite cooling units are present (Tf1, Tf2-Tf2m, Tf3, Tf4). At least two additional, datable, pyroclastic map units, a massive, up to 70 m-thick, poorly to nonwelded, quartz-phyric rhyolite ignimbrite (Trl), and a 1-5 m thick, bedded nonwelded felsic ash (Tnt) occur within the red conglomerate below the tuff of Felipe Pass, and these constitute the regional older silicic tuff(s) of Sherrod and Tosdal (1991).

The tuff of Felipe Pass at Weaver Wash, along with a section of the lower conglomerate (Tcl) that overlies it, are overlain, with fairly pronounced angular unconformity, by the middle conglomerate (Tcm) which contains several undifferentiated lenses of probable dry-rock avalanche breccia. The only confirmed volcanic flow within the middle or upper conglomerates (Tcu, Tcm) of the Weaver Wash area is a thin basalt (Tby) within gently tilted conglomerate (Tcu) that appears to overlap the main, down-to-the west normal fault that separates the Dome Rock Mountains from the Trigo Mountains. Although never exposed in this map area, the main fault is interpreted to dip about 30 degrees to the southwest based on a 25 degree dip measured on it in the northerly adjacent Dome Rock Mountains SW map area (Spencer et al., 2016), and a dip of 34 degrees measured on the main, down-to-the west normal fault that bounds the southwest flank of the North Trigo Peaks massif (see the western part of Cross-section B-B').

The middle conglomerate (Tcm) of the southern Island Range and adjacent areas east of Mohave Wash is similar to the middle cnglomerate of the Weaver Wash area in that it contains numerous avalanche breccia lenses with clasts of welded ignimbrite, lava, and granitic basement, but is different in that it contains several discrete, thin lava flows: andesite (Tau), dacite-trachyte (Tdr), phenocryst-poor trachyte (Ttp), and several high-silica, phenocryst-rich rhyolite lava flows (Trx). One of the phenocryst-rich rhyolites (Trx) was dated (Ar/Ar sanidine) at ~22.2 Ma.

The middle conglomerate (Tcm) in the Island Range overlies two very different volcanic sequences. In the north, and in areas east of Mohave Wash, the underlying section contains at least two of the tuff of Felipe Pass ignimbrites (Tf1, Tf2, Tf3), and a basal, dacitic-andesitic lava, breccia, and volcaniclastic sequence that includes, locally, a poorly welded quartz-phyric rhyolite ignimbrite dated (Ar/Ar sanidine) at ~24.5. In the southern Island Range, none of the tuff of Felipe Pass ignimbrites are present. Instead, a thin, basal, mostly volcaniclastic conglomerate (Tcl) is overlain by a thick pile of felsic-intermediate lavas with a discontinuous welded ignimbrite at its base that yielded a sanidine Ar/Ar age of ~23.3 Ma.
The stratigraphic disconnect between the lower volcanic sections in the Island Range is compounded by differences in tilt history between the same two areas (discussed below). The differences suggest that the two sections evolved separately, and were juxtaposed by faulting before ~22 Ma, the age of the Trx rhyolite lava that apparently overlaps both sections. If the stratigraphic differences between the two sections were defined only by lava flows, whose areal extents are typically limited to only a few kilometers, any significant displacement would be hard to prove, but since important regional ignimbrites suddenly "disappear" across the fault suggests that the fault(s) accommodating the juxtaposition may have had significant strike-slip displacement. A significant southeast-striking, strike-slip fault with the potential of displacing the disconnected stratigraphic sections we observe has in fact been suggested by Richard (1993c), as the dextral (~10-16 km displacement) Cibola fault. The Cibola fault represents an important structural (the eastern boundary of Dokka and Travis' [1990] eastern California shear zone), and stratigraphic (see Figure 5 of Richard, 1993c) boundary, and its presence might account for the differences we observe. Since those differences are most clearly expressed across the next major wash to the east, Mohave Wash, we tentatively suggest that the Cibola fault is itself displaced several km in a left-lateral sense by the east-west striking fault that cuts off the north end of the Island Range, and which continues robustly to the east, northeast along the southern flank of the South Trigo Peaks massif (see also Figure 8 of Sherrod and Tosdal, 1991).

The volcanic section below the Tcm unconformity in the southern Island Range either records a complex tilt history or is disrupted by unrecognized faults. Strata directly below the Tcm unconformity, which is dated at ~23.2 Ma and dips ~45° to the east, are very steeply tilted (up to 80°), yet these strata, in turn, overlie a volcanic sequence with only moderate easterly dips (20° -50°) including a basal nonconformity with underlying Jurassic plutonic rocks that dips less than 20° at one locality. Contact relationships between all the volcanic units in the southern Island Range are well exposed and show no evidence of obvious fault juxtapositions that might explain the decrease in dip with increasing depth. Another interpretation is that the contact between overlying steeply dipping and underlying moderately to gently dipping strata is that the contact is is an inverted angular unconformity which is the interpretation shown on cross-section G-G'. The implication is that the older section may have been initially tilted to the west, beveled and then overlain by strata that were tilted to the east, and then as the younger strata were tilted continuously to the east, apparent tilting of the older, orginally west-dipping strata decreased. Whichever intrepretaion is invoked, and assuming that the geochronology is correct, rapid (~100,000 year) changes in volcanism and/or tectonic/structural configurations in the early Miocene in this area are required.

Mesozoic Geology

Pre-Cenozoic igneous and metamorphic rocks nonconformably underlie Cenozoic strata throughout the North Trigo Mountains 7.5' quadrangle. In the Trigo Mountains, these rocks are predominantly Jurassic plutonic rocks (Jgm), represented mainly by biotite granite with subordinate hornblende-biotite granodiorite and diorite. Leucogranite (Jgl) was mapped separately in the North Trigo Mountains massif (mostly via air photo interpretation), but no attempt was made elsewhere to distinguish these from other plutonic rocks. The plutonic rocks locally intrude quartzofeldspathic biotite-rich schist and paragneiss, but these metamorphic rocks were not mapped separately. Granitic rocks (Jgm) like those in the South and North Trigo Peaks massif are also present in the southernmost Dome Rock Mountains, along the eastern edge of the map area (Cross-section D-D') where they are in contact to the north with the Jgz map unit across an east-west-striking, high-angle, strike-slip and/or normal fault. The Jgz unit is a quartzofeldspathic mylonitic schist that has been interpreted as a meta-ignimbrite (Tosdal, 1988; Tosdal and Stone, 1994), but is herein reinterpreted as a strongly sheared granite in the hangingwall of the north-vergent Mule Mountains thrust system. The Jgz unit contains isolated, up to 100 m-wide, foliation-parallel lenses of weakly to non-foliated granitic rocks that are very similar to the Jgm plutonic rocks directly to the south, and in the massifs of the North and South Trigo Peaks.

The Mule Mountains thrust system is represented in this quadrangle by two thrusts, the southernmost carrying the intensely foliated granite schist (Jgz) in its hangingwall, and another to the north that carries dominantly sedimentary protolith schists of the lower member of the McCoy Mountains Formation (KJm) over younger schist members of the same formation (Kcm, Ksm). The younger members retain abundant evidence of sedimentary structures, including stratigraphic up to the east facing indicators near the base of the older of the two units (Kcm). The conglomerate schist (Kcm) contains granitic clasts that Tosdal (1988; 1990) show were derived from a granitic basement similar to or the same as those carried in the hangingwall of the thrust system, and provide an important link between rocks on either side of the fault system. The main schistosity in the younger two members of the McCoy Mountains Formation is axial planar to mesoscopic folds in the southern Dome Rock Mountains (Tosdal, 1988; Tosdal and Stone, 1994). A younger, moderately south-dipping crenulation cleavage, overprinting the main schistosity is weakly developed in the north, but towards the south, approaching the similarly oriented Mule Mountains thrust system, it becomes increasingly intense and eventually becomes the main schistosity. Schistosity in the hangingwall of the main, southern, Mule Mountains thrust is considered to be dominantly or entirely of this generation.

Preliminary geochronology

5 volcanic rocks from the Island Range were sent to the Ar/Ar geochronology lab at UNLV for mineral separation and analysis in the spring of 2017. Sanidine crystals were separated from all samples. Probability plot ages, and isochron ages with the preferred age in bold for each sample are:

38956	Sanidine Ar/Ar probability plot: 23.25 +/- 0.04	isochron: **23.30 +/- 0.05**
38883	Sanidine Ar/Ar probability plot: 23.25 +/- 0.04	isochron: **23.16 +/- 0.07**
38774	Sanidine Ar/Ar probability plot: **23.74 +/- 0.04**	isochron: 22.96 +/- 0.10
38960	Sanidine Ar/Ar probability plot: 24.48 +/- 0.05	isochron: **24.68 +/- 0.06**
38921	Sanidine Ar/Ar probability plot: 25.63 +/- 0.09	isochron: **22.90 +/- 0.23**

The feldspars in all our samples displayed relatively low (<90%) radiogenic yields, and because of this the UNLV lab recommends using the isochron age for all samples. The worst (38921) had only a few crystals that yielded >50% radiogenic Ar, and posted the widest range between isochron and probability age (22.90 and 25.63). The isochron age for 38921 is statistically a better date, and since this accords with the probability age not matching the stratigraphy, the isochron is easily assigned the best age. Having a 25.6 Ma lava in the midst of this section would make very little sense.

For samples 38956, 38960, and 38883 both ages are essentially the same, but for 38774, the only sample from the tuff of Felipe Pass, there is a significant difference. Sample 38774's probability plot is more compatible with stratigraphic relations, and for this reason plus the fact that its probability plot (in preparation) has only one sharp peak we prefer the probability age of 23.74. Continued dating of the tuff of Felipe Pass' continuent ignimbrites is planned.

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Map Unit Descriptions

d — **Disturbed ground** - Areas modified by human activity so that original geologic characteristics are obscure; rock products or other mining activity.

Qtc — **Colluvium and talus** - Unconsolidated, very poorly sorted, angular to subangular cobble, pebble, sand, silt and clay deposits derived from adjacent bedrock. Slopes are generally moderate to steep, but include some areas of gentle slopes that might be considered regolith. Generally very thin, but may be several meters thick in local areas. Mapped only where underlying bedrock is obscured.

Quaternary Piedmont Deposits

Qy_3 — **Deposits in active channels, low terraces and bars** - Gravel, sand and silt deposits located along active tributary drainages, including channels, 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, and large islands and peripheral terraces along large active washes. Some Qy2 deposits comprise extensive low relief alluvial fans in broad valley reaches. Deposits are unconsolidated to very weakly consolidated sediments, poorly sorted with sub-rounded to angular pebble to cobble bars on the surface and beds and lenses in cross section. Terrace surfaces may be partly covered by thin mantles of silt and clay - recent flood deposits. Soil development is minimal. Vegetation includes desert riparian trees and shrubs.

Qy_1 — **Deposits forming low terraces and young relict alluvial fans** - Gravel, sand, silt and clay deposits forming young but generally inactive alluvial fans and terraces. Qy1 deposits are composed of silt to pebbles in swales, and lightly to moderately varnished pebbles to small boulders in bars. Deposits form slightly elevated surfaces as islands or marginal terraces more active parts of the drainage systems. Locally, Qy1 deposits partially mantle adjacent Pleistocene deposits. Vegetation includes sparse, relatively small desert riparian trees, shrubs including creosote, and cacti.

Qyd — **Young debris flow deposits** - Bouldery very poorly sorted, angular to subangular deposits associated with small, relatively steep watersheds. Deposits typically form lateral, curvilinear levees along active drainages, or more amorphous snouts and boulder piles. Rock varnish on gravel is weak to moderate, indicative of relatively recent deposition.

Qy — **Young alluvial deposits, undifferentiated** - Poorly sorted deposits including pebbles, cobbles, sand, minor silt and clay, and locally boulders. Deposits are ssociated with active washes, but also include slightly higher terraces with modest rock varnish, minimal soil development. This unit is used primarily for smaller washes.

Qsi — **Eolian and fluvial sand deposits** - Laterally extensive sand deposits, with minor gravel, silt and clay. Includes small, low dunes. Percent coverage of sand is variable, but typically is >50 percent, Open gravel lags are common.

Qi_4 — **Youngest intermediate alluvial fan and terrace deposits** - Gravelly deposits in low terraces and relict alluvial fans. Deposits consist of pebbles, cobbles, small boulders, sand, silt and clay. Surfaces are undulating, with moderately subdued gravel bars and swales. Rock varnish is moderately dark, but typically is less strong on topographic lows. Soil development includes very slight reddening, visible carbonate accumulations. Vegetation is sparse and concentrated along slightly incised small drainageways.

Qi_3 — **Intermediate alluvial fan and terrace deposits** - Very poorly sorted deposits including pebbles, cobbles, boulders, sand, and minor silt and clay, forming laterally extensive relict alluvial fans and terraces. Surfaces are typically 1-5m above adjacent Holocene deposits and vary from gently undulating to very smooth. Desert pavements are typically strongly developed and rock varnish is quite dark. Locally, multiple levels of surfaces are grouped together, and some latest Pleistocene (Qi4) deposits are included in this unit. Soil development is weak to moderate, with slight reddening, minor clay accumulation, calcic horizon development typically stage II. Qi3 surfaces are graded to the highest level of late Pleistocene Chemehuevi Formation deposits or younger inset river terraces.

Qi_3b — **Intermediate alluvial fan and terrace deposits, younger subdivision** - Lower, younger subset of relatively smooth, darkly varnished terrace and alluvial fan deposits. In adjacent areas, these surfaces are graded to lower levels of the Colorado River that post-date maximum Chemehuevi aggradation.

Qi_3a — **Intermediate alluvial fan and terrace deposits, older subdivision** - Higher, older subset of darkly varnished, smooth alluvial fan and terrace deposits. In adjacent areas, these deposits are approximately graded to the highest level of aggradation of the Chemehuevi Formation.

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

Qi_2 — **Older intermediate alluvial fan and terrace deposits** - Poorly sorted pebbles, cobbles, sand, some boulders, and minor silt and clay associated with moderately deeply dissected remnant alluvial fans and 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.Vegetation is sparse; bushes and small trees are concentrated along small drainages.

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 to 25 m 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.

Qo — **Old, very high alluvial fan deposits** - Coarse, very poorly sorted gravel deposits preserved as broad remnants high in the landscape. Surfaces are fairly planar, but surface margins are broadly rounded. Deposits are distinguished from Qi1 deposits by strong petrocalcic soil development. Underlying deposits are poorly exposed but are likely Pliocene Tfg2 fan deposits.

Pliocene and Quaternary Colorado River-Sourced Deposits

Tcb — **Bullhead Alluvium** - Unconsolidated to moderately consolidated quartz-rich sand with lesser amounts of silt and clay, and some beds of well-rounded exotic gravel and subangular locally-derived gravel deposits. These deposits are commonly mantled by locally-derived gravel from overlying tributary deposits. Rounded pebbles and cobbles are primarily quartzite, chert, and other resistant exotic rock types. Deposits are interbedded with locally-derived fanglomerate unit Tfg2 in some areas. Correlated with the early Pliocene Bullhead Formation.

Tcs — **Older sand, silt, and clay deposits** - Predominantly medium to fine sand, with lesser amounts of silt and clay up to about 10m thick. Interbedded with locally-sourced tributary fan deposits near mountains, but also abuts or is very close to basal carbonate deposits of the Bouse Formation. This unit may be a siliciclastic phase of Bouse deposition (younger than carbonate deposition), but more likely represents fine-grained components of Bullhead alluvium on the basin margins or eolian deposits prior to and during Bullhead aggradation.

Tbc — **Bouse Formation carbonate deposits** - Carbonate-rich deposits including calcareous sandstone, bioclastic limestone coquina and hash, thin-bedded bioclastic-rich marl, and carbonate-cemented locally-derived gravel. Found primarily in paleovalleys, and is stratigraphically above and below travertine/tufa deposits. Also includes minor greenish siliciclastic deposits in a few localities.

Tbct — **Bouse Formation, travertine/tufa** - Massive travertine/tufa (travertufa) deposits or encrustations, commonly fossiliferous, with algal and microbial forms, in hemispherical and laminar shapes.Travertufa is commonly draped over substantial paleotopography. Bedrock-cored paleoslopes of bedrock and coarse, angular colluvium are commonly impregnated with carbonate and typically underlies the travertufa. Paleoslopes range from gentle to moderately steep, and rarely near-vertical. Substrate in paleovalleys is commonly locally derived gravel deposits. In many areas, the underlying gravel has been reworked by shoreline processes. Color of tufa ranges from light to dark gray weathered. This unit ranges from a few cm thick up to 5m thick. Thin travertufa beds are intercalated with calcareous sandstone, limestone, and local gravel beds.

Tbg — **Bouse Formation, basal gravel** - Gray to greenish-gray, locally derived, subangular to well-rounded, well-sorted pebbles, cobbles, and boulders, with calcareous sand lenses at the base of the Bouse Formation. These sediments are reworked from underlying colluvium and fan deposits, which 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, basal carbonate layers.

Late Miocene and Pliocene Tributary Deposits

Tfg_2 — **Younger Conglomerate** - Poorly sorted, weakly to moderately lithified conglomerate and sandstone. Clasts consist largely of subangular to angular locally derived Tertiary volcanic rocks, granite and diorite. Deposition post-dates Bouse deposition and is generally coeval with Bullhead Alluvium, although deposition may post-date Bullhead aggradation in some proximal areas. This unit thus represents mostly locally derived fan material interfingered with minor amounts of Colorado River derived sediments.

Tfg_1 — **Older Conglomerate** - Poorly to very poorly sorted, moderately lithified, generally nondeformed, locally-derived conglomerate and sandstone. Clasts consist largely of subangular to angular volcanic rocks and granite. Deposition pre-dates Bouse deposition, and in some areas Bouse inundation may have resulted in reworking of these deposits into the basal Bouse gravel.

Tilted volcanic and sedimentary rocks

Tcu — **Upper Conglomerate** - Medium- to thick-bedded conglomerate, pebbly sandstone, and sparse breccia composed chiefly of granitic and metamorphic clasts. The strata are generally weakly indurated and gently inclined, typically less than 25 degrees. Strata are truncated by only the youngest faults, and overlap older rocks, including the Middle conglomerate (Tcm).

Tby — **upper basalt** - Basalt lava associated with the upper conglomerate (Tcu).

Tbyi — **upper intrusive basalt** - Intrusive basalt, mostly in the form of dikes that intrude the ignimbrite sequence.

Tcm — **Middle Conglomerate** - Massive to thick- bedded conglomerate, and breccia with sparse to moderately abundant medium- to thick beddd pebbly sandstone. Clasts are angular to subangular in the breccia, angular to sub-rounded in the conglomerate, and sub-angular to rounded in the sandstone. Clasts are composed of varying proportions of granitic and metamorphic rocks typical of the Dome Rock Mountains, and basement cored parts of the Trigo Mountains, and the dominatly felsic volcanic rocks that directly underlie the map unit along a profound angular unconformity just northeast of Weaver Ridgei . Strata typically dip less than 45°, and as low as 20°.

Tap — **Andesite porphyry** - Crystalline matrix andesite porphyry with 10-40% <5mm plagioclase, and 2-10% pyroxene.

Tau — **upper andesite (Island Range)** - Upper andesite lava interbedded with the middle conglomerate.

Trx — **Phenocryst-rich rhyolite lava** - Rhyolite lava containing 15-30% <1cm feldspar, generally with K-feldspar larger than and > plagioclase, and 1-3% >4mm biotite and/or hornblende. The lava occurs as a massive unit forming the crest of the Island Range, and as a series of relatively thin flows interbedded with the middle conglomerate (Tcm) along the eastern flank of the Island Range and adjacent areas east of Mohave Wash. Ar/Ar sanidine ages of 23.25 +/- 0.04 (probablity plot) and 23.16 +/- 0.07 (isochron) were obtained from a sample near the base of the middle Conglomerate (Tcm).

Trp — **Phenocryst-rich rhyolite porphyry** - Intrusive rhyolite porphyry containing 15-30% <1cm feldspar, generally with K-feldspar larger than and > plagioclase, and 1-3% >4mm biotite and/or hornblende.

Trd — **Rhyodacite lava** - Red to gray lava containing 12-25% <5mm felspar phenocrysts with plagioclase generally more abundant than sanidine, and 0.5-3% biotite and/or hornblende phenocrysts <3mm. An Ar/Ar sanidine age of 25.63 +/- 0.09 Ma (probablity), and 22.90 +/- 0.23 Ma (isochron) was obtained from a sample from the southern Island Range. The younger (isochron) age is preferred.

Ttp — **Phenocryst-poor trachyitic porphyry** - Trachytic porphyry stocks and dikes containing <5%, <3mm plagioclase, and <<1% <1mm mafics.

Ttr — **Phenocryst-poor trachyitic lava** - Trachytic lava containing <5%, <3mm plagioclase, and <<1% <1mm mafics.

Tdr — **Dacitic-trachytic lava** - Moderately phenocryst-rich dacitic - trachytic lava containing 7-15% <8mm feldspar (mostly or entirely plagioclase), and 1-3% <4mm biotite and/or hornblende.

tuff of Felipe Pass (Tf4, Tf3, Tf2m, Tf2, Tf1) - A welded felsic ignimbrite in the northeastern corner of this map area known previously as the Tuff of Felipe Pass (Sherrod and Tosdal, 1991) was divided into four distinct cooling units. The third oldest is easily distinguished in the field since it is the only one that contains quartz phenocrysts. The other three have similar, crystal-rich phenocryst assemblages of feldspar with abundant (1-3%) biotite, but there are important diagnostic differences that are easily discernible in thin-section. The lower two (Tf1, Tf2m-Tf2) are both normally zoned with respect to plagioclase versus sanidine phenocryst ratios (1:1 or 1:2 upwards to 2:1 or >5:1), and they both contain ubiquitous small grains (<0.5mm) of pyroxene, and virtually no hornblende. The upper ignimbrite (Tf4) contains consistent plagioclase versus sanidine phenocryst ratios of ~3:1 throughout, but instead of pyroxene, it contains hornblende as its main subsidiary mafic phenocryst phase.

The quartz-phyric ignimbrite of the tuff of Felipe Pass (Tf3) is almost certainly the 22.3 +/- 0.4 Ma (Bagby et al., 1987 Ar/Ar sanidine) tuff of Hoodoo Well. The Tf3 ignimbrite, like the tuff of Hoodoo Well, contains plagioclase and sanidine phenocrysts, whereas the only other quartz-phyric ignimbrite in the region, the tuff of Yaqui Tanks, which directly overlies the Tuff of Hoodoo Well in the Kofa Mountains, and which is slightly younger (dated at 21.9 +/- 1.5 Ma, K-Ar biotite by Dahm and Hankins, 1982), is reported to contain only plagioclase feldspar (Grubensky and Bagby, 1990; Sherrod et al., 1993). Stratigraphic sequencing and phenocryst content correlation argue that the uppermost ignimbrite of the tuff of Felipe Pass (Tf4), as suggested by Grubensky and Bagby in 1990, is the tuff of Ten Ewe Mountain which has been dated at 22.3 +/- 0.3 Ma in the Kofa Mountains (K-Ar biotite from Bagby et al., 1987). Another significantly older K-Ar biotite age reported by Bagby et al. (1987) for an ignimbrite identified as the tuff of Ten Ewe Mountain of 24.1 +/- 0.9 Ma in the Castle Dome Mountains is suspect, and we suggest that it probably more likely correlates with the older Ferguson Wash Tuff. Additionally, and compatible with the interpretation that the top of the tuff of Felipe Pass is the tuff of Ten Ewe Mountain is the tentative assignment by Sherrod et al., (1990) of a 22.2 +/- 0.6 Ma plagioclase K-Ar age date (Bagby et al., 1987) to the tuff of Felipe Pass in the Livingston Hills at least 30km northeast of this map area.

The lower two ignimbrites of the tuff of Felipe Pass (Tf1, Tf2m-Tf2), based on their phenocryst assemblages, and new Ar/Ar geochronology of the lower one (Tf1) in the southwestern part of this map area, most likely correlate with Crowe's (1978) plagioclase-sanidine-biotite-pyroxene phenocryst-bearing multiple flow and cooling unit Ferguson Wash Tuff. We report an Ar/Ar sanidine probability age of 23.74 +/- 0.04 Ma on the Tf1 ignimbrite in the southwestern part of the map sheet (sample CAF-2-38774) which is compatible with K/Ar biotite ages reported by Olmstead et al. (1973) and Weaver (1982), respectively, of 26.9 +/- 2.1 Ma and 24.9 +/- 1.6 Ma for the Ferguson Wash Tuff at its type area in the Chocolate Mountains of southeastern California. The 22.96 +/- 0.10 Ma isochron age for sample CAF-2-38774 is not favored because the sample stratigraphically underlies a rhyolite lava (Trx) that yielded Ar/Ar sanidine dates of 23.25 +/- 0.04 (probability) and 23.16 +/- 0.07 (isochron) which are both statistically older. To complicate matters, Spencer et al. (1995) reported Ar/Ar plagioclase, sanidine, and hornblende ages of between 22.2 and 22.7 +/- 0.1 Ma for what they identified as the Ferguson Wash Tuff in the Chocolate Mountains of Arizona some 30km north of its type area. However, since the Ferguson Wash Tuff is not known to contain significant amounts of hornblende, we suggest that the hornblende-phyric ignimbrite Spencer et al. (1995) dated is probably actually the ~22 Ma tuff of Ten Ewe Mountain. Thin-sections of the Tf1 and Tf2 units throughout this map area (samples CAF-2-38774, 38909, 38910, 39103, 39105, 39132, 39175b, 39555, 39556, 39557, 39561, 39562, and 39564) contain virtually no hornblende phenocrysts.

Tf_4 — **Tuff of Ten Ewe Mountain** - Moderately to densely welded ignimbrite containing 10-25%, <5mm feldspar (~2:1 to 3:1 plagioclase:sanidine), up to 1% biotite (<1.5 mm), and 0.5-1.0% hornblende (<0.5mm). Most of the ignimbrite is moderately to densely welded, but fairly thick, poorly to nonwelded intervals that are not always clearly associated with uppermost or lowermost non-welded zones are also present. Lithic lapilli content is generally <5%, and pumice, commonly fairly small (<20cm), and orange, range up to 30% by volume. The ignimbrite is correlated with Grubensky and Bagby's (1990)
22.3 +/- 0.3 Ma K-Ar biotite, and 22.2 +/- 0.6 Ma K-Ar plagioclase (Bagby et al., 1987)
tuff of Ten Ewe Mountain based on its phenocryst assemblage, and its stratigraphic position above a prominent quartz-phyric rhyolite ignimbrite (Tf3) correlated with the tuff of Hoodoo Well.

Tf_3 — **Tuff of Hoodoo Well** - Moderately phenocryst-poor, generally moderately welded ignimbrite containing 5-12% ~2:1 <4mm feldspar (plagioclase: sanidine), <6mm embayed quartz, and sparse altered, <<0.5mm mafic/opaque phenocrysts. The ignimbrite contains <5% lithic lapilli, and 5-20% pumice, is generally light-colored, and displays abundant lithophysal-spherulitic texture. The upper half to two thirds of the unit is commonly intensely vapor-phase altered. The ignimbrite is correlated with the 22.3 +/- 0.4 Ma (Bagby et al., 1987 Ar/Ar sanidine) tuff of Hoodoo Well based on the presence of conspicuous, large, embayed quartz phenocrysts, and because it contains plagioclase and sanidine phenocrysts.

Tf_2m — **Upper zone of the Upper Ferguson Wash Tuff** - The upper, relatively more mafic zone of the main Tf2 ignimbrite is in gradational contact with the main ignimbrite across a short (<10m) interval that is differentiated based on phenocryst content in excess of 25%. The zone, which is discontinuous, typically contains at least 25% pumice fiamme, many of which are dark red in color and up to 1 meter long, abundant (3% biotite), and a relatively greater proportion of plagioclase versus sanidine phenocrysts than in the main part of the ignimbrite (Tf2).

Tf_2 — **Upper Ferguson Wash Tuff** - Densely welded, normally zoned ignimbrite containing 10-25% feldspar (<5mm), up to 3% biotite (<2mm), and up to 1% pyroxene (<0.5mm) phenocrysts. The ignimbrite is a distinct cooling and flow-unit that contains <5% lithic lapilli, and 5-35% pumice. Normal zonation is expressed by a gradual, yet rapid upward increase in mafic phenocrysts, the ratio of plagioclase to K-feldspar (sanidine), and overall phenocryst and pumice content. The upper, relatively more mafic zone overlies the main ignimbrite with gradational contact. The mafic zone, which is discontinuous, typically contains at least 25% pumice fiamme, many of which are dark red in color and up to 1 meter long. The ignimbrite is correlated with the Ferguson Wash Tuff (Crowe, 1978) based on phenocryst assemblage (although not necessarily on overall phenocryst abundance as discussed by Richard [1993a,b]), and its stratigraphic position below a prominent quartz-phyric rhyolite ignimbrite (Tf3) that is identified as Grubensky et al.'s (1993) tuff of Hoodoo Well. Sanidine phenocrysts from sample CAF-2-38774 in the southwestern part of the map area yielded Ar/Ar probability and isochron ages, respectively, of 23.74 +/- 0.04 and 22.96 +/- 0.10 Ma. The older probability age, is considered more accurate for reasons discussed in the tuff of Felipe Pass (Tf1, Tf2-Tf2m, Tf3, Tf4) heading/description.

Tf_1 — **Lower Ferguson Wash Tuff** - Densely welded, zoned ignimbrite containing 10-30% feldspar (<4mm), up to 3% biotite (<2mm), and up to 1% pyroxene (<0.5mm) phenocrysts. The ignimbrite is a distinct cooling and flow-unit that contains <5% lithic lapilli, and 5-35% pumice. Zonation is expressed by changes to more mafic compostion expressed by increase in total phenocrysts, pumice content, and the ratio of plagioclase to K-feldspar The more mafic zone(s) ones occur mostly at the top of, but also sporadically, and unpredictably within the main ignimbrite, and were not differentiated. The more mafic zones contain >25% phenocrysts, and typically at least 25% pumice fiamme, many of which are dark red in color and up to 1 meter long. The ignimbrite is correlated with the ignimbrite of Ferguson Wash (Crowe, 1978) based on phenocryst assemblage (although not necessarily its overall phenocryst abundance as discussed by Richard [1993a,b]), and its stratigraphic position below the prominent, quartz-phyric rhyolite ignimbrite (Tf3) that is identified as Grubensky et al.'s (1993) tuff of Hoodoo Well. Ar/Ar sanidine ages of 23.74 +/- 0.04 Ma (probability plot), and 22.96 +/- 0.10 Ma (isochron) were obtained for a locality in the southwestern part of the map area,

Tir — **Island Range lower rhyolite lava** - Rhyolite lava containing 10-15% feldspar, quartz and minor biotite phenocrysts associated with the Lower Island Range rhyolite tuff (Tit).

Tdc — **Intermediate volcaniclastic rocks and lavas** - Dacitiic and andesitic lavas interbedded with volcaniclastic sedimentary rocks:(Tdcs) sandstone, conglomerte, and breccia. All rocks typically propylitically altered, and the lavas are dominated by dacites (Tdcd) with phenocryst of <8mm plagioclase (10-30%), and <4mm biotite and/or hornblende and pyroxene (1-5%). Andesitic rocks (Tdca) contain <3mm pyroxene and/or iddingsite subordinate (1-5%) to <5mm plagioclase (1-20%).

Tdca — **Andesitic lava** - **Andesitic lava** flows mapped separately within the Tdc unit.

Tdcs — **Volcaniclastic rocks** - **Volcaniclastic rocks** in the Tdc unit.

Tdcd — **Dacitic lava** - **Dacitic lava**s within the Tdc map unit.

Tb — **Basalt lava** - Mafic lava with 3-10% iddingsite phenocrysts.

Tbi — **Intrusive basalt** - Crystalline matrix basalt with 3-10% iddingsite phenocrysts.

Tnt — **Non-welded felsic tuff** - Island Range: Non-welded felsic tuff, typically massive or very thick bedded, but also thin-to medium-bedded. Tuffs are generally lithic poor (<5%) and rhyolitic, containing very sparse, <1mm hydrous mafic, and 0-10% <3mm feldspar>quartz phenocrysts. Pumice are virtually indistinguishable from the matrix and their content is hard to determine.

Tl — **Limestone** - Finely crystalline, laminated limestone in beds less than 2 m thick, interbedded with sandstone and conglomerate of the Tcl unit.

Trl — **Lower rhyolite tuff** - 5-15% felspar and quartz phenocryst weakly welded to non-welded rhyolite tuff, with sparse lithics and <15% pumice. Sanidine from a rhyolite tuff at the base of the Tertiary section in the southern Island Range was dated at 23.25 +/- 0.04 Ma (probability plot), and 23.30 +/- 0.05 Ma (isochron). A rhyolite tuff at the base of the Tertiary section in the northern Island Range on the north side of a major fault, yielded a sanidine Ar/Ar age of 24.48 +/- 0.05 Ma (probability plot), and 24.68 +/- 0.06 Ma (isochron). Although mapped as the same unit lithologically, the two tuffs are considered to be different units.

Tcl — **Lower conglomerate** - Red, arkosic pebble-cobble conglomerate containing a mixture of granitic and metamorphic (quartzite, and schist) clasts which are more prevelant towards the base, and with increasing volcanic clasts up-section. Vein quartz clasts are ubiquitous, but generally <5% of the total. Several white, non-welded, medium-to thick-bedded tuff sequences <10m thick are present, most of which are mapped separately. Clasts are dominantly subrounded, and rounded, less commonly subangular. Numerous small prospect pits are associated with this unit. Although field examination identified numerous historic placer prospects within Quaternary alluvium resting on red sandstone and conglomerate, two recreational prospectors using metal detectors informed Spencer that gold nuggets were located in the red sandstone and conglomerate, not in the overlying Quaternary deposits.

McCoy Mountains Formation (Jurassic to Cretaceous)

Kms — **Sandstone Member, McCoy Mountains Formation** - Interlayered brown-weathering psammite schist and purple to grey weathering phyllite and schist. Member becomes finer grained up section.

Kmc — **Conglomerate Member, McCoy Mountains Formation** - Brown-weathering pebble to cobble metaconglomerate, psammitic schist, and grey phyllite. Rocks near the base of the member are rich in metamorphic muscovite. Clasts are dominantly quartz-phyric volcanic rocks derived from underlying Jurassic igneous units, and lesser amounts of granitic rocks, quartzite, and limestone.

KJm — **Basal Member, McCoy Mountains Formation** - Interlayered greenish gray muscovitic quartzite, muscovitic quartzose schist, phyllite, quartzose marble, and calcsilicate hornfels. Cut by milky quartz ± carbonate ± Fe oxide after pyrite veins. Includes what has been mapped as Jurassic felsic metavolcanics by Tosdal (1988; 1990) and described: Pale-grey weathering, metamorphosed, felsic volcanic rocks that are probably derived from rhyolitic tuff. Unit is now composed of muscovite schist and gneiss with local garnet. Horizons are locally characterized by quartz blastophenocrysts up to 8 mm in diameter and conspicuous oblate muscovite-rich clots up to 3 cm across that represent relict pumice lapilli reflecting the primary pyroclastic protolith. Other blastophenocryst-poor quartz-muscovite schist likely represents minor reworked tuff and volcaniclastic rocks. Includes a unit mapped as the basal member 2 of the McCoy Mountains Formation by Tosdal (1990), that is not differentiated in this version of this map described as: Interlayered green-grey weathering chlorite-rich phyllite, calcsilicate schist, and quartz-muscovite phyllite. The basal member 2 underlies the basal member 1 which constitutes most of this map unit.

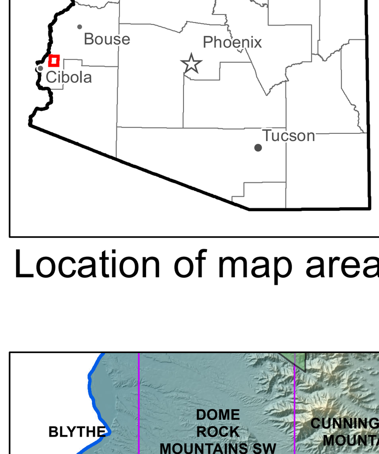
Igneous and metamorphic rocks (Jurassic)

KJgz — **Granite mylonite and granite** - Dominantly fine-to medium-grained quartzofeldspathic, biotite schist, typically strongly foliated with a schistosity strongly resembling mylonitic fabric. The schist grades into lesser (<10% by volume) lenses of weakly to non-foliated, mostly medium-grained, ~10% biotite granite and granodiorite identical to the Jgm map unit.

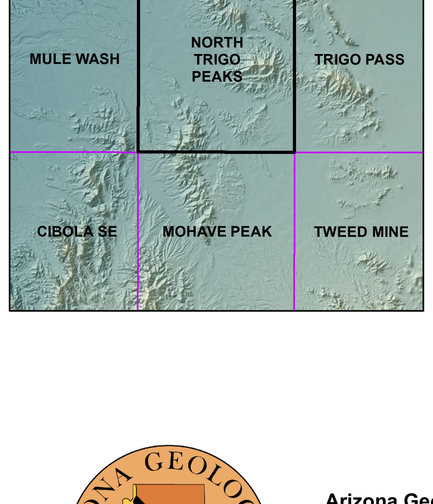
Jm — **Mafic dikes** - Dioritic dikes

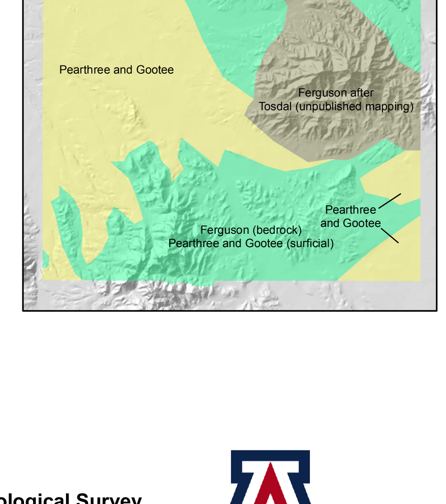
Jlg — **leucogranite** - Leucogranite wth <<5% biotite, differentiated only in the North Trigo Peaks massif.

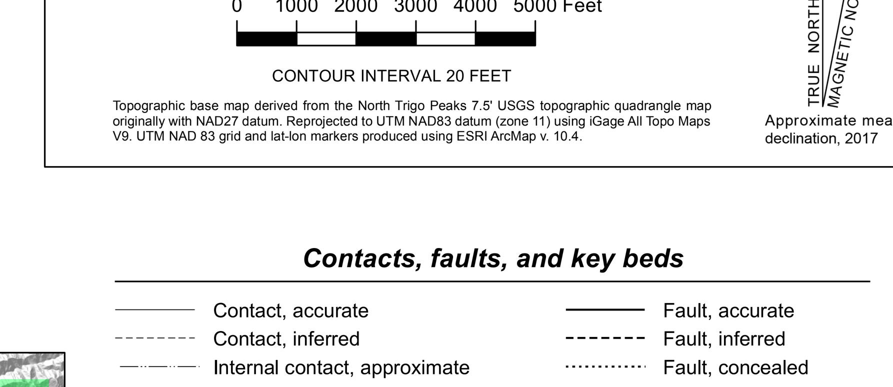
Jgm — **Granite, granodiorite, and diorite with lesser schist and paragneiss** - Granite, mostly medium-grained and equigranular, but also locally porphyritic with K-feldspar up to 2 cm. Includes zones of hornblende diorite to biotite-hornblende granodiorite, and undifferentiated quartzofeldspathic, biotite-rich schist and paragneiss, and in areas outside the North Trigo Peaks massif, leucogranite. Commonly propylitically altered with chloritic mafic minerals.



Location of map area

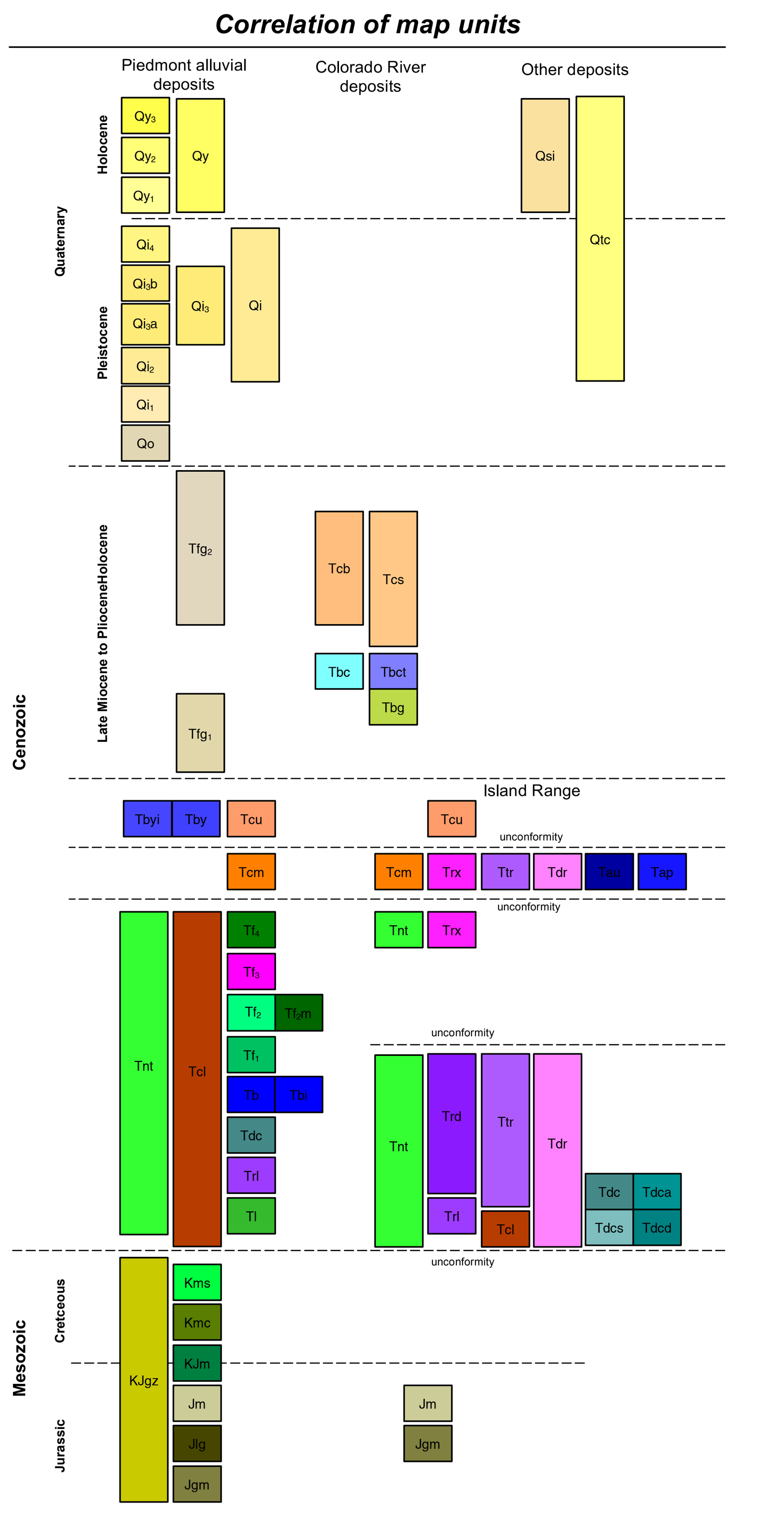






Topographic base map derived from the North Trigo Peaks 7.5' USGS topographic quadrangle map originally with NAD27 datum. Reprojected to UTM NAD83 datum (zone 11) using iGage All Topo Maps V9. UTM NAD 83 grid and lat-lon markers produced using ESRI ArcMap v. 10.4.

Correlation of map units



Contacts, faults, and key beds

- Contact, accurate
- Contact, inferred
- Internal contact, approximate
- Gradational contact, accurate
- Gradational contact, approximate
- Key bed, concealed
- Fault, accurate
- Fault, inferred
- Fault, concealed
- Thrust fault, accurate
- Thrust fault, approximate
- Cross-section lines

Structure Symbols

- bedding
- dip of mapped contact
- generic lineation
- eutaxitic foliation
- schistosity
- intersection lineation of bedding and schistosity (locally also a first generation crenulation lineation)
- second generation crenulation lineation
- elongation lineation of pebbles in metaconglomerate
- upright bedding
- crenulation cleavage
- slickenline lineation
- mylonitic foliation
- hinge line of folded schistosity (F2)

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