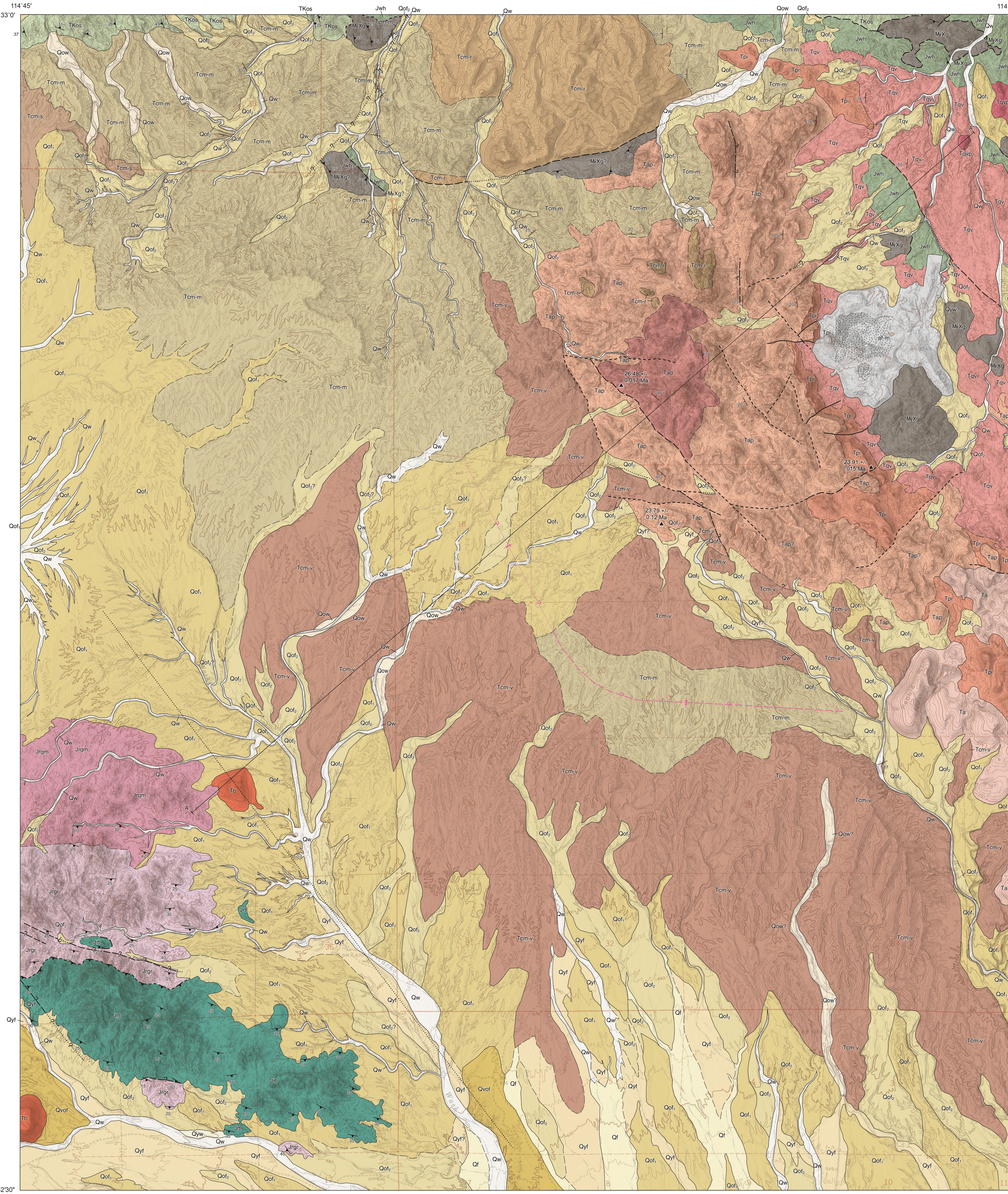
California geologic maps are available at https://www.conservation.ca.gov/cgs



Scale 1:24,000

Coordinate System:
Universal Transverse Mercator, Zone 11N,
North American Datum 1927

Topographic base from U.S. Geological Survey
Picacho Peak 7.5-minute Quadrangle, 1965
Shaded relief image derived from USGS lidar DEM, 2021

Contour Interval: 20 Feet
National Geodetic Vertical Datum of 1929

Approximate Mean
Declination, 2024

Professional Licenses and Certifications:

Key, E.L. – PG No. 9620
Cantwell, C.A. – GIT No. 1552
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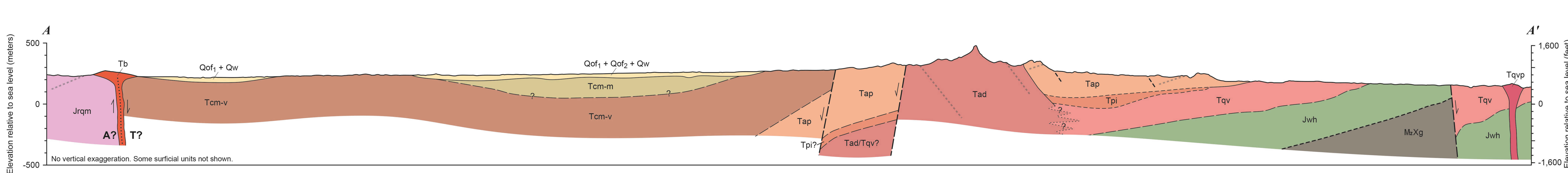

PRELIMINARY GEOLOGIC MAP OF THE PICACHO PEAK 7.5′ QUADRANGLE, CHOCOLATE MOUNTAINS, IMPERIAL COUNTY, CALIFORNIA

VERSION 1.0

By
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GIS and Digital Preparation by
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2024

California Department of Conservation
California Geological Survey

DESCRIPTION OF MAP UNITS

SURFICIAL UNITS

af-m — **Artificial fill, mining related (historic)**—Deposits of fill resulting from mining or quarrying activities, including tailings, waste rock, and fills for associated access roads. Includes local areas of mine-disturbed bedrock of unknown affinity. Includes areas of undifferentiated, mineralized rock which may include Tqv and MzXg exposed at the Picacho mine (Drobeck and others, 1986).

Qw — **Wash deposits (late Holocene)**—Unconsolidated, very pale-brown sand, gravel, cobbles, and local boulders deposited in recently active stream channels. Occur as narrow deposits in canyons upstream of the mountain front and as anastomosing to elongate deposits where active flow paths continue beyond the mountain front and traverse older fan deposits but do not form fan-shaped landforms. Sediments are derived from local bedrock or reworked from adjacent older Quaternary materials subject to mobilization and redeposition during storm events; lack soil development and oxidation on clasts, and only support local, sparse vegetation.

Qf — **Alluvial fan deposits (late Holocene)**—Unconsolidated to weakly consolidated, pink (5YR 8/3), poorly sorted deposits of sand, gravel, cobbles, and local boulders with intermixed silt forming active, undissected, alluvial fans. Fan apices form outboard and downgradient of incised older fans. Fans are a mix of sediment-rich stream deposits and poorly bedded, poorly sorted debris flow deposits containing angular to sub-angular pebble- to boulder-size clasts closer to incised older fans. Clasts are typically unweathered with little to no oxidation or desert varnish and are derived from upslope sources and reworked from adjacent, older fan deposits. Local-scale braiding on distributary fan surfaces.

Qyw — **Young wash deposits (middle Holocene to late Pleistocene)**—Unconsolidated to slightly consolidated and undissected to slightly dissected, pink, sandy and gravelly stream bed sediments locally preserved adjacent to active wash deposits. Sediments are derived from local bedrock or reworked from adjacent older Quaternary deposits and may be subject to remobilization during large storm events.

Qyf — **Young alluvial fan deposits (middle Holocene to late Pleistocene)**—Unconsolidated to weakly consolidated, pink (5YR 7/3), poorly sorted deposits of sand, gravel, cobbles, and local boulders with intermixed silt. Surfaces are undissected to slightly dissected. Clasts are generally weakly weathered with little oxidation and desert varnish. Clasts are derived from upslope sources or reworked from older, adjacent fan deposits. Fans are composed of sediment-laden stream deposits and poorly bedded, poorly sorted debris flow deposits containing pebble- to boulder-size clasts closer to the mountain front.

Qow — **Old wash deposits (late to middle Pleistocene)**—Slightly to moderately consolidated, moderately dissected, light-gray sand and gravel; typically elevated above modern washes.

Old alluvial fan deposits (late to middle Pleistocene)—Slightly to moderately consolidated, poorly sorted deposits of silty, pebbly sand to coarse gravel and boulders. Deposits form broad, isolated fan surfaces that are typically smooth to moderately dissected and isolated by intervening younger fan and wash deposits. Surfaces exhibit desert varnish patinas and desert pavement development. Surfaces are generally elevated at least several meters above active channel grade and not subject to historic flood inundation. Locally differentiated into two subunits.

Qof_2 — **Old alluvial fan deposits, younger facies**—Sediments of Qof_2 are brown to dark brown, less consolidated and fans are less dissected compared to Qof_1. Fan surfaces have sparse and discontinuous desert pavement development compared to Qof_1.

Qof_1 — **Old alluvial fan deposits, older facies**—Sediments of Qof_1 are more consolidated, brown to red brown, and fan surfaces are more dissected. Fan surfaces are smoother and desert pavement development is more continuous compared to Qof_2.

Qvof — **Very old alluvial fan deposits (middle to early Pleistocene)**—Moderately to well-consolidated, light-gray (10YR 7/2) deposits of silt, sand, gravel, cobbles, and boulders. Clasts are derived from local, upslope sources. Fan surfaces are covered in basalt boulders with significant desert varnish. Fans are composed of graded beds that contain imbricated clasts. Finer-grained intervals contain centimeter-scale cross-bedding. Fan surfaces are smooth with well-developed desert pavement and are deeply dissected by active channels. Fan surfaces may extend up to tens of meters above adjacent channel grade.

SOUTHERN CHOCOLATE MOUNTAINS UNITS

TERTIARY SEDIMENTARY UNITS

Bear Canyon conglomerate (Miocene)—The Miocene Bear Canyon conglomerate is the only Tertiary sedimentary unit that crops out in the southern Chocolate Mountains. Bear Canyon conglomerate is an informally named unit first mapped by Crowe (1978) and described in detail by Hughes (1990). This formation contains conglomerates and fluvial gravels composed dominantly of metamorphic and volcanic rock clasts likely sourced from the southern Chocolate Mountains. Ricketts and others (2011) mapped the Bear Canyon conglomerate throughout the southern Chocolate Mountains and divided the formation into three sequences based on clast composition and internal angular unconformities. In Bear Canyon, north of the map area, the uppermost sequence (sequence III) is interbedded with 9.45 Ma basalt flows, and the lowermost sequence (sequence I) rests unconformably on ~23 Ma volcanic rocks (Ricketts and others, 2011).

Complete sequences of the Bear Canyon conglomerate as documented by Ricketts and others (2011) were not observed in the Picacho Peak Quadrangle. Subunits in the study area are described and mapped based on clast and matrix composition and relative stratigraphic position observed in the field. Tcm-v is tentatively correlated to sequence I of Ricketts and others (2011) based on clast composition. Northwest of the map area in the Indian Pass Wilderness, Tcm-s is overlain by the 9.45 Ma Black Mountain Basalt. West of the map area, approximately 2 km east-southeast of the prospects around Indian Wash, deposits of Tcm-m and Tcm-s interfinger. Tcm-m and Tcm-s in the map area are tentatively correlated with lower and upper subunits within sequence II of Ricketts and others (2011). At the mouth of Bear Canyon, Tcm-r overlies Tcm-m. Tcm-r in the map area is tentatively correlated with sequence III of Ricketts and others (2011). More work is needed to determine the internal stratigraphic relationships between the subunits mapped to definitively correlate them with sequences defined by Ricketts and others (2011).

Tcm-r — **Bear Canyon conglomerate, red matrix**—Well-cemented and indurated conglomerate composed of 40–70% rounded to subangular coarse sand to boulder-size clasts in a fine-grained, red matrix. Surface exposures are conspicuously red in NAIP imagery. Some volcanic clasts are green and appear to have undergone minor alteration. Graded bedding observed in float blocks but is obscured by desert varnish in outcrop. Weathering produces arcuate caves in outcrop. Subunit locally crops out at the mouth of Bear Canyon.

Tcm-s — **Bear Canyon conglomerate, muscovite schist**—Moderately to well-consolidated, light-gray gravels deposited by fluvial processes and debris flows. Surface exposure is a conspicuously light gray to white color in NAIP imagery. Clast-supported fluvial deposits are dominantly comprised of subrounded coarse sand and cobbles and local boulders in a buff-colored, silty-clay matrix. Clasts in fluvial gravel and debris flow intervals are 70% volcanics and 30% muscovite schist, gneiss, and quartz fragments. This unit contains rounded cobble- to boulder-size clasts of kyanite schist and dumortierite. Fluvial gravel intervals contain graded beds approximately 30 cm thick.

Tcm-m — **Bear Canyon conglomerate, mixed**—Moderately consolidated, well-indurated conglomerates deposited by debris flows, and as fluvial gravels; clasts composed dominantly of metamorphic and volcanic rock. Conglomerate intervals are matrix-supported and contain angular to subangular, pebble- to boulder-size clasts with a tan, silty-clay matrix. Fluvial gravels contain interbedded sandy intervals with graded beds approximately 0.5 m thick, with centimeter-scale cross-bedding in silty intervals.

Tcm-v — **Bear Canyon conglomerate, volcaniclastic**—Alternating beds of volcaniclastic sandstone and siltstone with conglomerate intervals. Intervals of sandstone and siltstone locally contain centimeter-scale cross-bedding. Conglomerate intervals are approximately 0.5 m thick and matrix-supported with subrounded to rounded volcanic cobbles likely sourced from the Oligocene volcanic units in the Picacho Peak area.

TERTIARY VOLCANIC UNITS

The volcanic stratigraphy in the northeastern portion of the Picacho Peak Quadrangle is comprised of a complexly interfingered package of late Oligocene to early Miocene domes, tuffs, and lava flows. Original mapping by Crowe (1978) and subsequent regional mapping efforts (see Jacobson and others, 2022) has correlated the volcanic stratigraphy from the Picacho Peak Quadrangle to southwestern Arizona. The Quechan volcanics (Tqv and Tqvp) are interpreted as the oldest volcanic sequence in the map area based on relative stratigraphic position and ages reported by Crowe (1978) and Jacobson and others (2022). The dacitic plug Tad may have erupted contemporaneously with Tqv based on new age dates obtained on Tad during this study. Tpi and Tap directly overly Tqv in the area around the Picacho mine, however the relationship between Tpi, Tap, and Tad requires further field investigation. Ta overlies Tap along the Picacho Road in the northeast corner of the study area. Tb is not in contact with the other Tertiary volcanic rocks and is interpreted to be the youngest unit based on the tentative age correlation made by Muela (2011) and geomorphic expression.

Tqv displays pervasive hydrothermal alteration. Tpi and Tap host minor hydrothermal alteration localized along fault zones and fractures. No hydrothermal alteration was observed in Ta or Tb (Crowe, 1978; Girty and others, 2012). The nomenclature for volcanic rocks is mostly consistent with Crowe (1978) and Jacobson and others (2022), and differences suggested by geochemistry are stated. Further sampling, dating, and petrography are needed to determine the correlations between volcanic units, the absolute timing of eruption events, and identify possible vent sources.

Tb — **Basalt (Miocene)**—Vesicular, dark-gray, aphanitic basalt with phenocrysts of plagioclase (15%), olivine (<1%), and pyroxene (<1%). Vesicle abundance is 20% of the rock and vesicles range in size from 1 mm to 1 cm. Olivine crystals are 1 mm or smaller with iddingsite rims. Plagioclase phenocrysts are translucent and acicular to prismatic. Tb outcrops form mesas ranging from ~0.5 to 1 square km in area and consist of blocky, broken-up flows west of the central and southern Cargo Muchacho Mountains, and as a monogenetic cone to the east of the central Cargo Muchacho Mountains. Tentatively correlated with the Black Mountain basalt in the Chocolate Mountains (Muela (2011) reported an age of 9.45 +/- 0.27 Ma using $^{40}Ar/^{39}Ar$) based on petrographic similarities (Olmstead and others, 1973; Dillon, 1975).

Ta — **Pyroxene andesite (early Miocene to late Oligocene)**—Massive gray lava flows and flow breccia. Caps units Tap and Tpi. Occurs along a zone of northwest-southeast-trending faults to the southwest of the Picacho Mine and southeast of Picacho Road. Outcrops are heavily mantled by 0.3- to 1-m-diameter blocky rubble. Outcrops include 1- to 3-m-thick flow lobes with interstitial flow breccia. Phenocryst abundance is ~40%, with 20% plagioclase and ~20% pyroxene in an aphanitic groundmass of plagioclase, pyroxene, and oxide microlites. This unit yielded a whole rock K-Ar age of 25.1 +/- 1.6 Ma (Olmstead and others, 1973); however, this age is suspect based on stratigraphic position of adjacent units observed in the field and $^{40}Ar/^{39}Ar$ dates obtained for these units during this study.

Tap — **Andesite of Picacho Peak (late Oligocene)**—Lava flows, flow breccias, and laharic breccias that crop out around Picacho Peak. Originally referred to as dacite of Picacho Peak ("Tpd") by Crowe (1978); however, trace element geochemistry indicates this unit is andesite in composition. Tap is porphyritic (2–5% total phenocrysts) and includes phenocrysts of euhedral plagioclase (1–3 mm), minor olivine, and altered pyroxene phenocrysts which are sieved, embayed, and partially altered to secondary minerals. Trachytic groundmass contains up to 30% fine-grained euhedral plagioclase crystals, ~5% oxides, and scattered amygdules. $^{40}Ar/^{39}Ar$ dating of groundmass yielded an age of 23.79 +/- 0.12 Ma (written commun. Matt Heizler, New Mexico Geochronology Research Laboratory, 2023). Likely erupted contemporaneously with the ignimbrite of Ferguson Wash (Tpi) based on previous mapping by Crowe (1978) and $^{40}Ar/^{39}Ar$ dates from this study.

Tpi — **Ignimbrite of Ferguson Wash (late Oligocene)**—Variably welded, trachytic ash flow tuff, laharic breccia, and airfall deposits with large areal extent. Ash flow tuff contains 5- to 10-mm-diameter pumice fragments (1–3%), 0.1- to 2-cm-diameter lithic fragments (3–5%), and 1–2% phenocrysts in an ash matrix. Phenocrysts are plagioclase (1–3%), sanidine-anorthoclase (1–2%), iron-titanium oxides, and trace amounts of hornblende, quartz, hypersthene, zircon, and monazite (Crowe, 1978; Jacobson and others, 2022). At many localities, primary vitrophyric and pyroclastic groundmass textures are overprinted by devitrification. Near the Picacho Mine, Tpi outcrops are light gray, ledge-forming, and contain abundant euhedral phenocrysts. Where Tap overlies Tpi, Tpi weathers recessively and the matrix is composed of white ash, with smaller lithic fragments and subangular to subrounded phenocrysts. $^{40}Ar/^{39}Ar$ dating of sanidine yielded an age of 23.91 +/- 0.02 Ma (written commun. Matt Heizler, New Mexico Geochronology Research Laboratory, 2023). This age falls within error of the age of Tap, suggesting the deposition of Tap and Tpi is contemporaneous.

Tad — **Andesite dome of Picacho Peak (late Oligocene)**—Massive lava forming the southern part of Picacho Peak. Aphanitic and contains rare 1- to 2-mm-diameter euhedral phenocrysts of biotite (<1 %) in a light-gray, aphanitic groundmass. $^{40}Ar/^{39}Ar$ dating of groundmass yielded a new age of 26.4 +/- 0.12 Ma (written commun. Matt Heizler, New Mexico Geochronology Research Laboratory, 2023). This new date suggests that andesite dome of Picacho Peak may represent a much older volcanic neck that pre-dates the eruption forming the surrounding Tap. Tad may be correlative to the andesitic dome subunits of Tqv.

Tqv — **Quechan volcanics (late Oligocene)**—Rhyodacite flows and flow breccias with minor lahar deposits and trachybasaltic flows. Weathered surface of all subunits is dominantly purple or green. Tqv forms the basal unit of the Picacho volcanic sequence and is over 300 m thick (Crowe, 1978). Occurs throughout the southeastern Chocolate Mountains and the northeastern Picacho Peak Quadrangle. Previous authors (Crowe, 1978; Girty and others, 2012) have informally divided the Quechan volcanics into three subunits:1) a basal subunit of interbedded amygdaloidal olivine basalt flows and flow breccias; 2) a middle subunit of pyroxene rhyodacite flows and flow breccias; and 3) an upper unit of dacitic lava flows, flow breccias, and laharic breccias. Alteration of all subunits within the Quechan volcanics is widespread (Crowe, 1978). Low-grade recrystallization overprints the entire sequence, and there are distinct zones of more pervasive alteration along faults and fractures. Lobate flows often display fissile weathering and green argillic alteration of the matrix. Breccias are often purple to maroon, with pseudomorphed crystals, and display variable weathering ranging from crumbly to strongly welded. East of Picacho Mine in Burro Wash, amygdules are filled with secondary clays and calcite, and outcrops are cut by calcite veins. Crowe (1978) dated the dacite in the upper subunit and reported a K-Ar age of 31.8 +/- 3.2 Ma. U-Pb zircon analyses from samples of Tqv collected east of the Picacho Mine outside of the map area by Colby and Girty (2013) yielded an age of 25.2 +/- 0.4 Ma. U-Pb zircon analyses from samples of Tqv also collected outside of the study area by Needy (2009) yielded dates of 23.4 +/- 0.4 Ma and 26.0 +/- 0.6 Ma.

Tqvp — **Quechan volcanics plug (late Oligocene)**—Volcanic plug of similar composition to the uppermost subunit of the Quechan volcanics described by Crowe (1978); intrudes lower Tqv lava flows and flow breccias (Crowe, 1978).

INTRUSIVE AND METAMORPHIC ROCKS – EARLY TERTIARY AND OLDER

TKos — **Orocopia Schist (Paleocene to Late Cretaceous)**—Muscovite-biotite-quartz schist. Well-developed schistosity defined by 1- to 2-mm-diameter crystals of muscovite and biotite with scattered amphibole. Weathers into platy fragments that are 2–5 cm thick by 12–30 cm wide. Unit is cut by veins of massive milky white quartz and iron oxide-cemented breccia, which are often parallel to and within foliation. Correlative with the "Pelona-Orocopia Schist" of Haxel and Dillon (1978). U-Pb analyses of detrital zircons from samples of Orocopia schist collected in Marcus Wash north of the map area indicate a maximum depositional age of approximately 71 Ma (Grove and others, 2003).

Jwh — **Winterhaven Formation (Jurassic)**—Augen gneiss and phyllite. Phyllite is correlative with the metamorphosed dacite and argillic siltstone members of the Winterhaven Formation (Haxel and others,1985). The most prevalent unit is a purple, fine-grained phyllite with lenses of chlorite that are roughly 2–5 cm long and parallel to foliation. The augen gneiss member is strongly foliated and partially mylonitized with potassium feldspar augens that are 1–2 cm by 4 cm long. Millimeter-scale gneissic banding is defined by anhedral quartz, feldspar, biotite, and chlorite. U-Pb analyses of zircons collected from meta-dacite exposed in Marcus Wash north of the map area indicate a minimum age of 162 +/- 1 Ma (Jacobson and others, 2022).

MzXg — **Mafic orthogneiss (Mesozoic to Proterozoic(?))**—Gneiss and muscovite schist. Gneiss contains dark bands of mafic minerals roughly one centimeter apart, which define foliation. Schist contains millimeter-size intergrown grains of quartz and feldspar with roughly 15% 1- to 2-mm-diameter platy muscovite and/or biotite growing along foliation. In the modern exploration workings at Indian Pass, the contact between gneiss and schist is not exposed but both are intensely brecciated and cut by pegmatite dikes. Pegmatite dikes may be correlative to the granite phase of the Paleocene or Eocene "Marcus Wash Granite" described by Haxel (1977).

CARGO MUCHACHO MOUNTAINS UNITS

INTRUSIVE AND METAMORPHIC ROCKS – MESOZOIC AND OLDER

Jrgr — **Gold Rock Ranch granite (Late to Middle Jurassic)**—Foliated biotite granite exposed in the northern Cargo Muchacho Mountains (Tosdal and Wooden, 2015; Cawood and others, 2022). Foliation defined in part by discontinuous, millimeter-thick by 2-cm-long bands of biotite crystals (20%). Individual biotite grains are ~1 mm in diameter. 2- to 5-mm crystals of feldspar (40%) and quartz (40%), with coarser feldspar grains occurring in deuterically altered zones in the vicinity of the American Girl fault. Weathers into rectangular blocks with joints cutting foliation. This unit was mapped in detail by Dillon (1975) as coarse- to medium-grained, leucocratic biotite granite orthogneiss ("Jrbg", "Jrbf") observed cross-cutting the Araz Wash granodiorite, Araz Wash diorite, and Tumco Formation (Jrt) (Dillon, 1975). Emplacement age of 163.8 +/-1.2 Ma based on U-Pb dating of zircons (Tosdal and Wooden, 2015).

Jrqm — **Biotite-hornblende quartz monzonite orthogneiss (Jurassic)**—Foliated coarse-grained orthogneiss. Coarse-grained (up to 3 cm) microcline and plagioclase and 10% hornblende, biotite, and accessory minerals including epidote, chlorite, sphene, apatite, zircon, calcite, and opaques (Dillon, 1975). Dillon notes that Jrqm intrudes Jrt and is cut by Jrgr.

Jrt — **Tumco Formation (Jurassic)**—Laminated, grayish-orange, quartzofeldspathic gneiss (Dillon, 1975). Laminations defined by parallel alignment of fine- to medium-grained (up to 1 mm) biotite (30%). Quartz and feldspar grains are slightly coarser than biotite (1–2 mm), with scattered quartz and feldspar augens 0.2 cm by 5 cm wide. Millimeter- to centimeter-scale gneissic banding present. In thin section, partial sericitization of feldspar and chloritization of biotite are visible, as well as the presence of very fine-grained accessory garnet and scattered fine-grained amphibole. Relict depositional layering combined with preserved magmatic phenocryst textures suggest a volcanic or volcaniclastic protolith (Dillon, 1975; Tosdal and Wooden, 2015). Weathers into large meter-scale blocks. Unit is pervasively cut by felsic dikes that range from centimeter-scale ptygmatic veinlets to large features tens of meters wide, extending over one km in length (including Late Cretaceous pegmatites of Cawood and others (2022)). Based on work by previous authors (Dillon, 1975; Cawood and others, 2022) it appears that there are at least three distinct compositions of these dikes, which include Late Cretaceous pegmatites; more work is needed to resolve the spatial and chemical distribution of dikes within the Tumco Formation. Dillon (1975) observed local zones of interbedded quartzite, marble, and amphibolite throughout the unit, as well as a series of amphibolite dikes cutting the Tumco Formation (Jrt) in the southeastern Cargo Muchacho Mountains. Tosdal and Wooden (2015) obtained a rock age of 185 +/- 2.9 Ma from U-Pb dating of seven zircons in a quartzofeldspathic gneiss from the Tumco mine, southwest of the map area, that they interpreted as meta-dacite.

MAP SYMBOLS

Contact between map units – Solid where accurately located; long dash where approximately located; dotted where concealed.

Fault – Solid where accurately located; long dash where approximately located; short dash where inferred; dotted where concealed; queried where uncertain.

Thrust Fault – Sawteeth on upper (tectonically higher) plate; short dash where inferred.

Syncline – Long dash where approximately located; dotted where concealed; queried where uncertain.

Area disturbed by mining

Ar-Ar geochronology point (three samples)

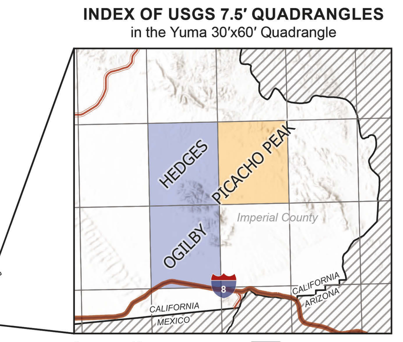
Strike and dip of geologic structure; number indicates strike or dip angle in degrees.

Metamorphic foliation; may locally represent mylonitic foliation. Trend and plunge of metamorphic lineation. Foliation and lineation orientations digitized from Dillon (1975)

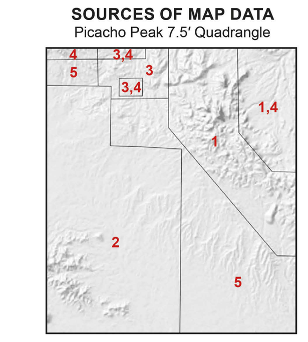
Bedding

Project Location

INDEX OF USGS 7.5′ QUADRANGLES
in the Yuma 30′x60′ Quadrangle



SOURCES OF MAP DATA
Picacho Peak 7.5′ Quadrangle

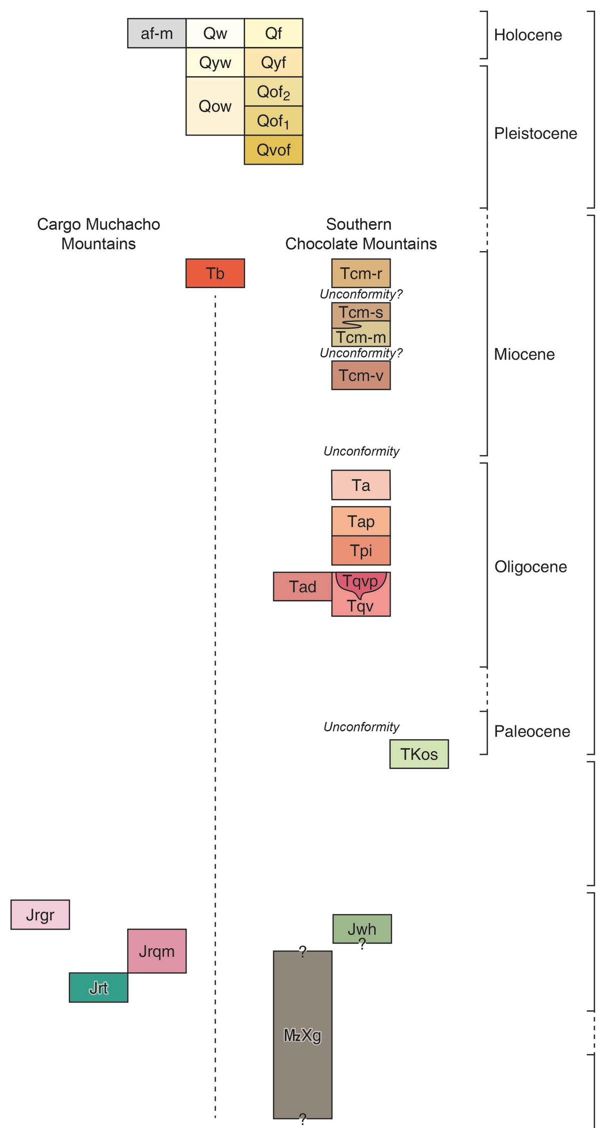


1. Crowe, 1978
2. Dillon, 1975
3. Ricketts and others, 2011
4. Haxel, 1977
5. Morton, 1977

Data source that covers the entire quadrangle:

Key and Cantwell, 2024

CORRELATION OF MAP UNITS



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