Geologic map of the Cunningham Mountain 7 ½' Quadrangle, La Paz County, Arizona

by

Bradford J. Johnson, Charles A. Ferguson,
Philip A. Pearthree, and Carson A. Richardson,

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Arizona Geological Survey
University of Arizona
1955 East Sixth Street, Suite 205, Tucson, Arizona 85721

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Introduction

This map depicts the bedrock and surficial geology of the Cunningham Mountain 7 ½’ quadrangle in the lower Colorado River Valley, La Paz County, southwestern Arizona. The map area encompasses part of the southern Dome Rock Mountains and eastern piedmont. The southern half of the quadrangle is on the Yuma Proving Ground, administered by the U.S. Army, which granted us access to the area. Our mapping is part of a multi-year AZGS effort to map the bedrock and basin geology in the lower Colorado River Valley (e.g., Gootee et al., 2016; Spencer et al., 2016; Johnson et al., 2017; Ferguson et al., 2018). This geologic map complements 7 previous Arizona Geological Survey 7 ½’ quadrangle mapping projects in this general area, and the geologic map of the Trigo Pass 7 ½’ quadrangle immediately to the south (Ferguson and Pearthree, 2021).

Surficial Geology

Surficial deposits of the map record the late Miocene and younger geologic history of this region. Limited deposits in the bedrock valleys in the western part the map area, which drain west to the Colorado River, consist of late Miocene to Pliocene alluvial fan deposits and Quaternary surficial deposits. The older alluvial fan deposits record a period of gradual basin filling, culminating in maximum basin filling around ~5 Ma when Colorado River water and sediment abruptly arrived in this region (House et al., 2008; Crow et al., 2018). None of the old fan deposits in this quadrangle have direct relationships with Colorado River deposits – they are all inboard (east) of the highest preserved Colorado River deposits. Based on their general characteristics they are correlative with fan deposits mapped in adjacent quadrangles that pre-date and immediately post-date the arrival of the river. Inset Quaternary alluvial fans and terraces record subsequent periods of piedmont aggradation and incision through the late Pliocene and Quaternary. Processes driving these variations are changes in base level due to Colorado River aggradation and incision, and climate changes that altered the quantity of sediment supplied from the mountains and the ability of tributary fluvial systems to transport that sediment.

The geomorphology of the broad eastern piedmont in the map area is dramatically different. These fluvial systems are part of the upper watershed of Tyson Wash, a large, north-draining tributary of the Colorado River. There is no clear evidence that Quaternary base-level variations of the Colorado

River have substantially impacted this area. The valley floor in this region is broad and minimally dissected, covered with Holocene or late Pleistocene deposits. Older Pleistocene deposits are only found in limited upper piedmont areas adjacent to the mountains, and even in those areas all of the exposed deposits are probably middle Pleistocene and younger. The extent of young deposits in these upper piedmont areas is variable, but Holocene deposition is widespread in middle and lower piedmont areas. Coarse to very coarse, relatively young debris flow deposits are abundant in steep mountain valleys and at their mouths, a testament to the occurrence of rare extreme precipitation events in this arid region.

None of the Quaternary units are directly dated, but in the lower Colorado River Valley Qi3 deposits were graded to the maximum Colorado River aggradation recorded by the Chemehuevi Formation, 50-100 ka (Malmon et al., 2011). Ages of older and younger Quaternary deposits and associated alluvial surfaces are estimated based on topographic position in the landscape and surface and soil characteristics.

Bedrock Geology

All rocks exposed in the Cunningham Mountain quadrangle are Mesozoic in age, belonging to two major sequences that crop out in several mountain ranges in western Arizona and southeastern California (Figure 1): a Jurassic magmatic complex (Dome Rock volcanic assemblage) and an overlying Upper Jurassic(?) to Upper Cretaceous clastic sedimentary succession (McCoy Mountains Formation). The Dome Rock sequence (Tosdal et al., 1989) includes thick rhyodacitic ignimbrites and lavas overlain by volcaniclastic units. The McCoy Mountains Formation is a succession of sandstone, siltstone, mudstone and conglomerate up to at least 7 km thick (Harding and Coney, 1985; Stone and Pelka, 1989; Tosdal and Stone, 1994). The Mesozoic rocks have all been deformed and metamorphosed in greenschist facies. In this map area they generally form a southeast-dipping homocline.

Stratigraphic Relationships

Tosdal and Stone (1994) outlined evidence for a disconformity between the Jurassic volcanic assemblage and the McCoy Mountains Formation in the Dome Rock Mountains, and their observations are corroborated by our mapping. Northeast of Copper Bottom Pass the Dome Rock assemblage comprises a thick rhyodacitic volcanic succession (unit Jv), an overlying rhyolite unit (Jvr), and an upper

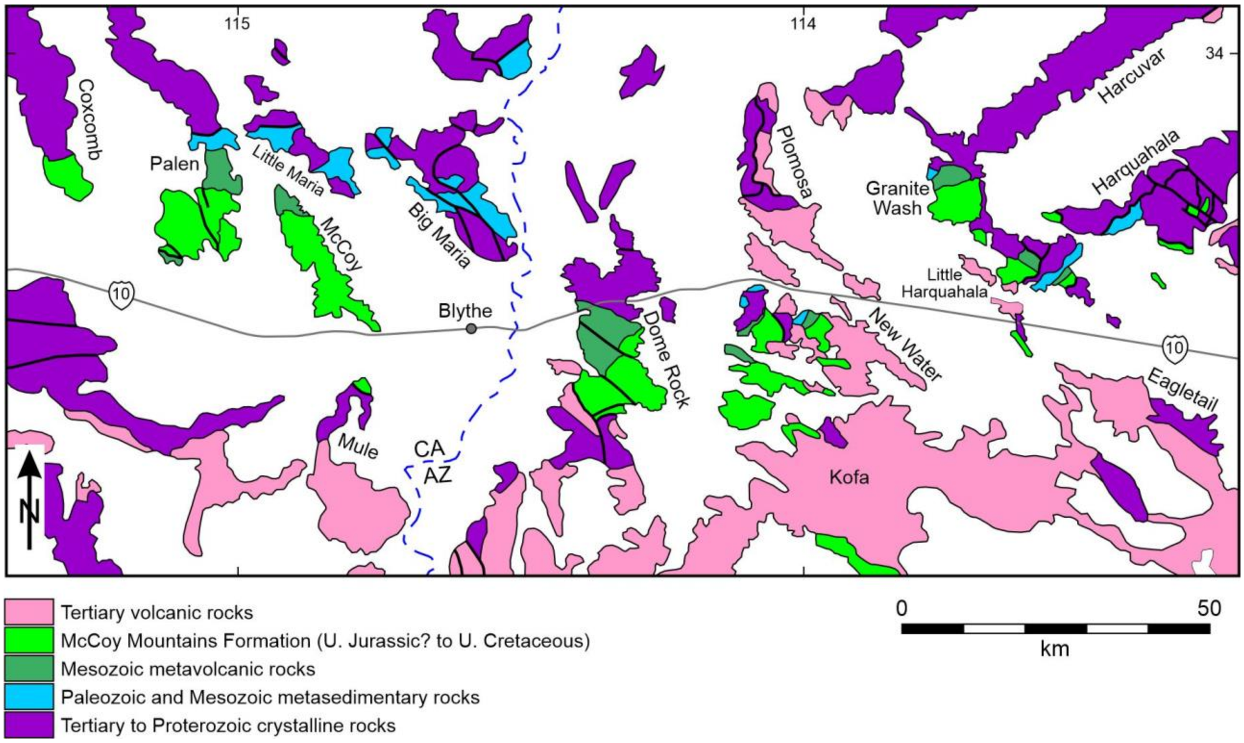

Figure 1. Geologic map showing the distribution of the McCoy Mountains Formation and correlative rocks. The Colorado River (Blue dashed line) is the boundary between western Arizona (AZ) and southeastern California (CA). Names of mountain ranges and the town of Blythe, CA, are shown. Map is simplified from Spencer et al. (2011).

volcaniclastic unit (Jvc) of variable thickness. The contact between the volcaniclastic unit and the McCoy Mountains Formation is sharp and apparently concordant. Southwest of a major fault at Copper Bottom Pass the basal sandstone of the McCoy Mountains Formation overlies the rhyodacite unit and a much thinner, discontinuous succession of volcaniclastic rocks. The contact has up to 3 m of local relief. McCoy sandstone units are the same thickness on both sides of the Copper Bottom fault (Harding, 1982), yet the upper part of the Jurassic volcanic section is missing on the southwest side. These observations led Tosdal and Stone (1994) to recognize that the Copper Bottom fault must have a complex history that includes displacement prior to deposition of the McCoy Mountains Formation and later reactivation.

Zircons from a subvolcanic intrusion, ignimbrite, and rhyolite within the Dome Rock assemblage (representing progressively shallower levels in units Jv and Jvr) have been dated using U-Pb sensitive high-resolution ion microprobe–reverse geometry (SHRIMP-RG) methods (Tosdal and Wooden, 2015), all yielding Middle Jurassic ages: 170.8 ± 1.0 Ma, 170.7 ± 1.1 Ma, and 170.4 ± 1.2 Ma, respectively. As part of the current study, new U-Pb zircon data were obtained by laser ablation–inductively coupled plasma mass spectrometry (LA-ICPMS) from a tuff in the upper part of the Dome Rock succession (unit Jrt; Johnson et al., in prep). The weighted mean from 32 dates is 160 ± 2 Ma. The interpreted maximum depositional age, based on the youngest zircon analysis, is 152 ± 3 Ma. The upper part of the Dome Rock assemblage is therefore considered to be of Late Jurassic age.

The age of initial deposition of the McCoy Mountains Formation is problematic. Detrital zircons from quartzose sandstone of Basal Sandstone member 1 in the McCoy Mountains (equivalent to unit KJm1 here) are mostly Proterozoic, with smaller components of Paleozoic and Early Jurassic zircons indicating maximum depositional ages of about 179 to 183 Ma (SHRIMP-RG analyses; Barth et al., 2004). In contrast, the youngest detrital zircons from the lower part of Sandstone member 2 (unit KJm2) indicate a maximum depositional age of 116.5 ± 0.9 Ma for that part of the succession, and the youngest detrital zircons decrease in age up-section to 84.1 ± 3.0 Ma. Spencer et al. (2011) obtained a maximum depositional age of 80.2 ± 1.8 Ma from detrital zircons in the upper part of the succession in the Dome Rock Mountains (LA-ICPMS analyses). And a tuff (unit Kt) within the Conglomerate member has yielded a U-Pb zircon (TIMS) lower-intercept date of 79 ± 2 Ma (Tosdal and Stone, 1994; thermal ionization mass spectrometry analyses).

Barth et al. (2004) interpreted the detrital zircon ages to mean that 90 percent of the McCoy Mountains Formation was deposited between the middle Early Cretaceous and middle Late Cretaceous. They also noted a correlation between zircon populations and sandstone composition: Quartz-rich sandstones contain abundant Proterozoic and Paleozoic zircons and lack Cretaceous zircons, whereas relatively quartz-poor feldspathic sandstones contain abundant Mesozoic (including Cretaceous) zircons. They interpreted this to reflect a cratonic and miogeclinal provenance to the north for the quartz-rich sandstones, while the feldspathic sandstones contain sediment derived from the Cordilleran magmatic arc to the west. The Jurassic maximum depositional ages from Basal Sandstone member 1 leave open the possibility that the lower part of the formation is latest Upper Jurassic. This would require a slow rate of deposition of the quartz sandstone of KJm1, and suggests the possibility of a cryptic unconformity between KJm1 and KJm2.

In the Dome Rock Mountains, observations made in this study suggest that there is a gradual transition from the basal succession dominated by quartz-rich sandstone interbedded with subordinate siltstone and pelite (KJm1a) to quartz-rich sandstone interbedded with abundant calcareous siltstone and pelite (KJm1b) to rocks of these same lithofacies interbedded with fine-grained lithic-feldspathic sandstone (KJm2). In the upper part of KJm2, quartz-rich sandstone becomes rare and medium-grained lithic-feldspathic sandstone becomes more common, but no unconformity has been identified anywhere in this part of the section.

Harding and Coney (1985) observed that the Conglomerate member is the lowest unit of the McCoy Mountains Formation in which detrital K-feldspar occurs, marking a dramatic change in sedimentary provenance. Tosdal and Stone (1994) presented evidence for a significant unconformity at the base of the Conglomerate member in the Livingston Hills. In the Dome Rock Mountains, they observed that this unconformity is marked by the lateral pinching out and truncation of the underlying Mudstone member, with the Conglomerate member directly overlying Sandstone member 2 southwest of the truncation. The area of this truncation was mapped carefully during the present investigation. A previously unrecognized northwest-striking fault cuts across Sandstone member 2 (KJm2), the Mudstone member (Kmm), and the lower part of the Conglomerate member (Kmcl), displacing contacts so that they now exhibit over 400 m of left-lateral separation. The fault dips steeply northeast and is interpreted as a NE-side-down normal fault, requiring 150 to 300 m of throw to account for the strike separation. All of these units continue toward Ehrenberg Wash southwest of the fault. From northeastern exposures toward this area there is a notable increase in the abundance and thickness of sandstone units in the upper part of the Mudstone member Kmm, so that southwest of the fault its appearance is much like that of KJm2. Northeast of Cinnabar Mine, the contact between Kmm and Kmcl is characterized by local intertonguing (or possibly infaulting) of pelite and pebbly sandstone, and K-feldspar was identified in a thin section from sandstone of the upper part of Kmm. From these relationships it is concluded that, while the contact between the Mudstone and Conglomerate members may represent an abrupt change in sediment provenance, it appears to be conformable here.

The lower part of the Conglomerate member (submember Kmcl) consists mainly of sandstone. The lowest thick and laterally continuous conglomerate layer marks the base of the middle submember (Kmcm), and the appearance of conglomerates containing abundant granitic clasts characterizes the upper submember (Kmcu). These subdivisions within the Conglomerate member are easily recognized in northeastern exposures (Tosdal and Stone, 1994), but they are less distinct farther southwest near Ehrenberg Wash where granitic clasts become more abundant generally in conglomerate throughout the member, and conglomerate units form a greater proportion of the section. This probably reflects proximity of the part of the depositional basin represented by strata near Ehrenberg Wash to an uplifted source of granitic detritus, and a corresponding increase in intercalated proximal alluvial facies in that area. Overall upward coarsening within the Conglomerate member is inferred to represent progradation of the alluvial system in response to continued uplift of the source. As such, it remains possible that an unconformity exists at the base of the Conglomerate member in other parts of the basin, or that one or more unconformities exist within the upper part of the member here.

Structural Relationships

The Mesozoic rocks generally form a southeast-dipping homocline, internally deformed by asymmetric south-verging folds. The fold vergence and style are consistent with their being an external, upper-level expression of the Maria fold and thrust belt, an east-west belt along the northern fringes of the McCoy Mountains Formation in which rocks of Proterozoic to Mesozoic age have been deformed (Reynold et al., 1986; Spencer and Reynolds, 1990). Folds in the McCoy Mountains Formation are characterized by cascades of steeply south-dipping to locally overturned limbs, tens of meters to about 100 m long, that disrupt the southeast-dipping homoclinal panel. The folds plunge southeast and have interlimb angles of 90 degrees or more. A well-developed fine schistosity in metapelitic rocks of the McCoy Mountains Formation dips gently northeast in the northern and central parts of the map area and dips gently south in the southern part. In sandstone this fabric is strongly refracted, expressed as cleavage that generally dips moderately northeast. Lineations formed by the intersection of calcareous lenses and transposed bedding with schistosity in pelitic rocks plunge gently northwest or southeast. The Jurassic volcanic rocks display a north- to northeast-dipping tectonic foliation and commonly also an oblique, north- to northeast-dipping, second-generation spaced cleavage. Analysis of structural measurements of fabric elements is pending.

All Jurassic and Cretaceous rocks have been displaced by northwest-striking high-angle faults, including two large fault zones and several smaller faults. The large fault system along Ehrenberg Wash exhibits about 3 km of right-lateral separation, while a parallel fault through Copper Bottom Pass has 1.5 to 2 km of left-lateral separation. As noted by Tosdal and Stone (1994), the Copper Bottom fault must have had periods of activity both before and after deposition of the McCoy Mountains Formation. First, NE-side-down displacement would have allowed accumulation of units Jvr and Jvc to the northeast while accounting for the removal, or nondeposition, of these upper parts of the volcanic section to the southwest. Northeast of Copper Bottom Pass the upper volcaniclastic unit Jvc thins dramatically, but is still present, across a fault near La Cholla Mountain. This fault therefore must have accommodated SW-side-down displacement during the Late Jurassic, creating a graben between La Cholla Mountain and Copper Bottom Pass within which the thickest section of Jvc was deposited.

The Ehrenberg Wash fault zone is parallel to the Copper Bottom fault, yet the two major faults exhibit opposite senses of strike separation of Cretaceous strata. This is best explained as a result of major components of Cenozoic dip slip rather than strike slip. While both faults may have had a complex history, the Ehrenberg Wash and Copper Bottom faults are inferred as having had large components (several hundred meters to 1 or 2 km) of, respectively, SW- and NE-side-down Cenozoic displacement, with the central part of the southern Dome Rock Mountains between the two faults forming a horst.

Another set of high-angle faults, striking west-southwest, cuts the McCoy Mountains Formation locally. At least some of these appear to have south-side-down components of slip, but many are in a part of the section (unit KJm2) where reliable stratigraphic markers are lacking.

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Description of Map Units

SURFICIAL UNITS

d - Disturbed areas (Modern)

Areas modified by human activity so that original geologic characteristics are completely altered or obscured. Includes rock products or other mining activity and a high-density residential/mobile home area in the northeastern corner of the map area.

Qtc - Hillslope colluvium and talus (Quaternary)

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.

Piedmont Alluvium

Qy3 - Deposits in active channels, low terraces and bars (Modern)

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.

Qy2 - Deposits forming low terraces and active fans (Late Holocene)

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 form 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.

Qy1 - Deposits forming low terraces and young relict alluvial fans (Holocene)

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 (Holocene to late Pleistocene)

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 moderately dark, indicative of relatively recent deposition.

Qy - Young alluvial deposits, undivided (Holocene)

Poorly sorted deposits including pebbles, cobbles, sand, minor silt and clay, and locally boulders. Deposits are associated with active washes, but also include slightly higher terraces with modest rock varnish, minimal soil development.

Qi4 - Youngest intermediate alluvial fan and terrace deposits (Latest Pleistocene)

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.

Qi3 - Intermediate alluvial fan and terrace deposits (Late Pleistocene)

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.

Qi2 - Older intermediate alluvial fan and terrace deposits (Middle to late Pleistocene)

Poorly sorted pebbles, cobbles, sand, some boulders, and minor silt and clay associated with moderately deeply dissected remnant alluvial fans and terraces ~2-5 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.

Qi1 - Oldest Intermediate terrace deposits (Middle Pleistocene)

Very poorly sorted boulder, cobble, pebble, and sand deposits, with minor silt and clay. Deposits are found only along Ehrenburg Wash, where they form an extensive terrace ~15 m above the active channel. Surface is planar and margins are substantially rounded. Soil development is strong with a reddened clay argillic horizon, and quartz fragments are common to abundant on the surface.

Qi - Intermediate alluvial fan and terrace deposits, undivided (Middle or late Pleistocene)

Undivided deposits with moderately to darkly varnished surface clasts and variable desert pavement development; includes deposits equivalent to Qi3, Qi4, and some Qi2 deposits.

Tfg - Very old alluvial fan deposits (Late Miocene to Pliocene)

Poorly exposed, poorly sorted, weakly to moderately lithified gravel and sand. Gravel consists primarily of cobbles and pebbles, but boulders are common in some outcrops. Clasts consist largely of subangular to angular locally derived Cenozoic volcanic rocks, Mesozoic crystalline rocks, and diverse rocks of the McCoy Mountains Formation. Exposed only in the western part of the map area.

Axial Wash Deposits

Qycr - Channel sand and gravel deposits (Modern)

Sand, pebbles, cobbles, silt and minor clay in active channels, low bars, and immediately adjacent floodplain areas of Tyson Wash. Lithologies are mixed, but primarily volcanic rocks.

Qy2r - Floodplain sand, gravel, silt, clay (Late Holocene)

Sand with lesser amounts of silt and clay, and minor lenses or concentrations of pebble-cobble gravel. Deposits form low terraces and more extensive floodplain areas flanking active channels. Terrace and floodplain surfaces typically 1-2 m higher than adjacent active channels.

Qy1r - Deposits in low terraces (Holocene)

Sand, silt, gravel, and clay deposits associated with stream terraces. Surfaces commonly have fine gravel lag, with weak rock varnish development, and have a gray color. They are slightly higher than adjacent Qy2r surfaces. and commonly are 1-2 m above adjacent channels.

BEDROCK UNITS

All rocks in the map area have been metamorphosed in greenschist facies. For simplicity, rocks are generally described in terms of their protoliths, and the prefix *meta*- has been omitted.

Kd - Metabasite (Late Cretaceous)

Fine-grained, light-green, mafic rock that forms tabular units generally concordant with bedding in the Conglomerate member of the McCoy Mountains Formation. These may be sills and/or lava flows, but the presence of these rocks in different map units on opposite sides of a fault in Ehrenberg Wash suggests that they are sills.

Kt - Rhyolitic metaignimbrite (Late Cretaceous)

Pink to dark orange-weathered metavolcanic rock containing 15% feldspar phenocrysts (3mm), <10% flattened pumice fragments (<10cm), and sparse (<5%) lithic lapilli. Interbedded with conglomerate, pelite, and sandstone of the McCoy Mountains Formation. Tosdal and Stone (1994) obtained a U-Pb zircon (TIMS) lower-intercept age of 79 ± 2 Ma from this unit.

McCoy Mountains Formation (Late Jurassic? to Late Cretaceous)

The McCoy Mountains Formation is a clastic sedimentary succession of sandstone, siltstone, mudstone and conglomerate that overlies volcaniclastic rocks of the Dome Rock assemblage. The contact is a disconformity. Southwest of Copper Bottom Pass the basal sandstone of the McCoy Mountains Formation overlies volcaniclastic rocks with up to 3 m of local relief, and stratigraphic units that are present in the upper part of the Dome Rock assemblage northeast of Copper Bottom Pass are absent. The base of the McCoy Mountains Formation was mapped at the base of the lowest laterally continuous quartz sandstone bed.

Sedimentary rock names are generally used in the following descriptions, although the rocks have been metamorphosed in greenschist facies. Thus, "sandstone" refers to metasandstone and "pelite" refers to fine-grained pelitic schist.

Kms - McCoy Mountains Fm, Upper Sandstone member (Late Cretaceous)

Interlayered brown-weathered sandstone and varicolored semipelitic to pelitic schist and phyllite. Sandstone units are feldspathic to lithic, medium- to thick-bedded, medium- to coarse-grained, and locally gritty to pebbly. Pelitic units range from thin-bedded to massive and from light gray to black, light green, red, and purple, locally with brown calcareous laminae and thin-beds.

Kmc - McCoy Mountains Fm, Conglomerate member (Cretaceous)

Feldspathic sandstone is the predominant rock type in this member. The basal parts of sandstone units tend to be pebbly to conglomeratic in some parts of the section and there are conglomerate intervals that range from several meters to several tens of meters thick, but conglomerate forms less than 20% of the member. Sandstone is thick- to medium-bedded, light tan to light gray, and weathered light to medium brown with dark-brown desert varnish on joint surfaces. Festoon crossbedding and planar laminae are commonly displayed. On average the sandstone is medium-grained and moderately to poorly sorted, ranging to very coarse-grained with granule and pebbly intervals. Sandstone and conglomerate are interbedded with siltstone and fine-grained semipelitic to pelitic schist in fining-upward cycles. Bases of conglomerate beds fill scoured surfaces on the tops of underlying units. Conglomerate units contain well-rounded pebbles and small cobbles in a sandy matrix and are typically framework-supported. In lower parts of the section the clasts are mostly of quartzite and metapelite, with some vein quartz. Higher in the section, clasts of quartz-feldspar porphyry are common along with leucogranite, biotite granitoid, and relatively weakly metamorphosed sedimentary rocks including carbonate, quartz sandstone, feldspathic sandstone, and siltstone. Granitic clasts become more common high in the section, and quartzite clasts remain abundant throughout.

The Conglomerate member is subdivided into 3 submembers northeast of Ehrenberg Wash.

Kmcu - McCoy Mountains Fm, Conglomerate member, upper submember (Cretaceous)

The upper submember is characterized by abundant conglomerate and abundant granitic clasts in many of the conglomerate units. Near the eastern edge of the Dome Rock Mountains the basal contact is marked at the first appearance of obvious plutonic pebbles and cobbles in the section. This criterion does not apply farther west, especially near Ehrenberg Wash where granitoid pebbles are common lower in the section as well.

Approximately 40% of the succession is conglomerate and pebbly sandstone, forming thick beds and massive, resistant outcrops. The remainder of the unit is composed of medium- to coarse-grained feldspathic sandstone and sparse fine-grained semipelitic to pelitic schist, which are intercalated with conglomerate throughout the section. Sandstone is medium- to thick-bedded and locally displays planar lamination and scour-and-fill structures.

Clasts in the conglomerate include quartzite, quartz porphyry, metapelite, medium- to fine-grained leucogranite, porphyritc andesite, and relatively weakly metamorphosed sedimentary rocks including quartz sandstone, feldspathic sandstone, and siltstone. Pebbles and cobbles are framework-supported, and the sandy matrix is medium- to coarse-grained and poorly sorted. Clasts of plutonic and metamorphic rocks increase in abundance up-section, as does the maximum clast size. Thick-bedded pebble-boulder conglomerate near the top of the unit contains clasts of fine- to medium-grained granite and granodiorite, gneiss, and schist as well as metapelite and quartzite.

Kmcm - McCoy Mountains Fm, Conglomerate member, middle submember (Cretaceous)

The basal contact of the middle submember is marked at the base of the first extensive conglomerate unit several meters thick within the Conglomerate member that is laterally continuous for hundreds of meters. This conglomerate is framework-supported, containing well-rounded pebbles and small cobbles of quartzite, metapelite, quartz-feldspar porphyry, and minor fine-grained plutonic rocks in a sandy matrix. Similar conglomerate layers are present higher in the section, with clast populations also including carbonate (mainly in northeastern exposures) and granitoid rocks (abundant to dominant in southwestern exposures).

Feldspathic sandstone and pebbly sandstone are the most abundant rock types in the unit, however. These are medium- to thick-bedded, light brown, and predominantly medium-grained, with coarse- to very coarse-grained intervals and intervals with granules and/or pebbles. Much of the medium-grained mode is moderately sorted and fine- to medium-grained with scattered coarse sand grains. Fining-upward cycles consist of sandstone with a sharp, pebbly base, grading upward to siltstone and pelite. Some intervals of sandstone, conglomerate, and pelite in northeastern exposures of this submember are calcareous. Much of the carbonate is detrital, including carbonate pebbles in conglomerate.

Kmcl - McCoy Mountains Fm, Conglomerate member, lower submember (Cretaceous)

Feldspathic sandstone (arkose and lithic arkose) is the predominant rock type in this submember. The sandstone is medium- to thick-bedded, light tan to light gray, and weathered light to medium brown. Festoon crossbedding and planar laminae are commonly displayed. On average the sandstone is medium-grained and moderately to poorly sorted, ranging to very coarse-grained with granule and pebbly intervals. Many beds have basal conglomerate and the tops of sandstone intervals fine upward to siltstone, fine-grained semipelitic to pelitic schist, and pelitic phyllite. Conglomerate beds are rarely thicker than 30 cm and the bases of conglomerate intervals fill scoured channels on the tops of underlying beds. Pebbles are mostly well-rounded quartzite and flat chips of pelite, with rare leucogranite and quartz porphyry pebbles.

Kmm - McCoy Mountains Fm, Mudstone member (Cretaceous)

Lithic-feldspathic sandstone interbedded with siltstone and fine-grained semipelitic to pelitic schist that form intervals up to several tens of meters thick. The siltstone and pelite commonly contain brown calcareous lenses and thin transposed layers. Sandstone is fine- to medium-grained to locally coarse-grained, light tan to light gray, and weathered surfaces are coated with dark-brown desert varnish. Sandstone intervals consist of groups of 2 to 5 ledges with slope-forming pelitic units between the ledges. Sandstone ledges typically are less than 5 m thick, but in the upper part of the member they are up to 10 m thick in southwestern exposures between Cinnabar Mine and Ehrenburg Wash. Both the thickness and the abundance of sandstone units apparently increase in the upper part of the Mudstone member toward the southwest, although sections were not measured to confirm the latter. Conglomerate near the bases of sandstone units contain well-rounded pebbles of quartzite, other metasedimentary rocks, and some quartz porphyry.

KJm2 - McCoy Mountains Fm, Sandstone member 2 (Late Jurassic? to Cretaceous)

The characteristic rock type of this member is lithic-feldspathic sandstone, which is interbedded with quartz sandstone, siltstone, and pelite like those in Basal Sandstone member 1. Most of the lithic-feldspathic sandstone is gray to light-green, very fine- to fine-grained, and micaceous, forming resistant cliffs and ledges that grade laterally and vertically into schistose and less-resistant outcrops with indistinct bedding. Medium- to coarse-grained lithic arkose is relatively rare, forming a few thick ledges in the middle and upper parts of the member. These sandstones are light green-gray and weathered brown, have conglomeratic bases and are locally gritty, with scattered very coarse sand grains, granules, and small pebbles. They display planar laminae and rare trough crossbedding, accentuated by heavy minerals. Conglomerate units contain well-rounded pebbles of quartzite, light-colored metapelite, subordinate dark-colored chert, and a few fine-grained granitoid and quartz-porphyritic volcanic clasts. Throughout the member, sandstone is interbedded with slope-forming siltstone and fine-grained pelitic to semipelitic schist that generally contain brown calcareous lenses, some of which are rimmed with green chlorite. Calcareous lenses are also common in fine-grained sandstones, especially in the lower part of the member.

Near Ehrenberg Wash, quartz arenite becomes more common in the lower part of this unit than farther northeast, making distinction between KJm2 and KJm1b problematic.

KJm1 - McCoy Mountains Fm, Basal Sandstone member 1 (Late Jurassic? to Cretaceous)

This unit is characterized by intervals of quartz sandstone 2-10 m thick, with interbedded siltstone and pelite. Most of the sandstone is quartz arenite, commonly cemented by calcite. The sandstone is thick- to medium-bedded, medium- to fine-grained, well-sorted, white to light tan, and typically dark brown on weathered surfaces from desert varnish. Crossbedding is locally present but rarely visible. The bases of some beds are pebbly to conglomeratic. Most of the pebbles are well-rounded quartzite, and metapelite pebbles are also common in some layers.

Basal Sandstone member 1 is subdivided into 2 submembers southwest of Copper Bottom Pass.

KJm1b - McCoy Mountains Fm, Basal Sandstone member 1, upper submember (Late Jurassic? to Cretaceous)

The base of the upper submember of KJm1 is marked by an interval of calcareous pelite and semipelite, with layers of brown carbonate or calcareous siltstone up to several cm thick and platy, fine-grained, calcareous sandstone. This interval is overlain by a thick ledge (>10 m) of quartz arenite with quartzite-pebble conglomerate at its base. Above that, ledges of medium- to thick-bedded quartz sandstone are thinner, the sandstone is mostly fine-grained, and intervals of calcareous pelite, semipelite, and siltstone become predominant. Unit KJm1b is gradational to KJm2, with a decrease in quartz arenite up-section concomitant with the appearance of gray to light-green, very fine-grained, micaceous metasandstone. The contact between them is mapped at the top of the uppermost interval 10 m thick in which quartz arenite is predominant; it is mapped with less certainty closer to Ehrenberg Wash.

KJm1a - McCoy Mountains Fm, Basal Sandstone member 1, lower submember (Late Jurassic? to Cretaceous)

This unit is characterized by intervals of quartz sandstone 2-10 m thick composing well over 50 percent of the section, with subordinate interbedded siltstone and pelite.

Dome Rock volcanic assemblage (Middle to Late Jurassic)

Named the *Dome Rock sequence* by Tosdal et al. (1989), this assemblage includes rhyodacitic to rhyolitic volcanic and volcaniclastic rocks and related shallow-level intrusions.

Jrt - Quartz-sericite metatuff (Late Jurassic)

White, thin-bedded to laminated, fine-grained quartz-sericite schist layer 2-4 m thick between two mafic lava flows of unit Jvm. Interpreted as a rhyolitic tuff. A sample from this unit was dated by U-Pb LA-ICPMS methods, yielding dates ranging from 216 ± 7 to 152 ± 3 Ma from 48 zircon grains (Johnson et al. in prep). The weighted mean from 32 dates is 160 ± 2 Ma (MSWD = 0.9, probability of fit = 0.64). The interpreted maximum deposition age based on the youngest date is 152 ± 3 Ma.

Jvm - Metabasalt (Late Jurassic)

Vesicular and amygdaloidal mafic lava flows containing very sparse, <1mm plagioclase, and rare <<1mm mafic minerals. The unit ranges from weakly or non-foliated metabasite to moderately foliated amphibole schist, with the massive parts corresponding to coherent flow facies and the more schistose varieties representing incoherent, autobreccia, and scoriaceous flow facies.

Jvc - Volcaniclastic rocks (Middle to Late Jurassic)

Variably schistose rocks derived from volcaniclastic sandstone, ash-fall tuff, and pelite. These include medium- to thick-bedded, medium- to coarse-grained feldspathic sandstone and conglomerate. The sandstone is commonly gritty to pebbly, containing granules and pebbles of feldspar, quartz, felsic volcanic rocks (including quartz-feldspar porphyry), vein quartz, quartzite, argillite, and medium- to coarse-grained granite. The sandstone and conglomerate are interbedded with gray to light-green pelite and semipelite that range from thin- to thick-bedded and are laminated in some intervals. Ash-fall tuff and pumiceous sandstone are white to light gray, composed mostly of sericite and quartz with locally visible feldspar grains, and contain sparse to abundant sericitic lapilli (probably former pumice) as well as a few silicic lithic clasts (some of which contain <1% feldspar phenocrysts). Bedding in the ash-fall units is accentuated by heavy-mineral laminae.

Jvr - Feldspar-quartz porphyritic metarhyolite (Middle Jurassic)

White to light-gray blastoporphyritc schist derived from rhyolite lava flows with 5-15% quartz (<6 mm) and up to 20% feldspar (<5 mm) phenocrysts. Autobreccia texture is locally displayed, characterized by elliptical inclusions up to 20 cm with the same phenocryst assemblage as the host. Locally these rocks contain up to 10% clasts of red rhyodacite or dark-brown porphyritc andesite. Interbeds of fine-grained finely laminated sandstone are also locally present.

Rhyolite from this unit has yielded an age of 170.4 ± 1.2 Ma (Tosdal and Wooden, 2015; U-Pb zircon SHRIMP-RG method).

Jv - Quartz-feldspar porphyritic metarhyodacite (Middle Jurassic)

This unit comprises metamorphosed ignimbrite, lava, and related shallow-level intrusions. The ignimbrite contains 5-25% relict phenocrysts of quartz (2-4 mm, round, commonly embayed) and feldspar (1-3 mm) and up to 50% lithic lapilli in a light-gray to green matrix of microcrystalline quartz, sericite, biotite, and epidote. The lithic clasts contain variable abundances of quartz and feldspar phenocrysts and are in part devitrified and metamorphosed pumice fragments, flattened parallel to the foliation. Rhyodacite lava flows are generally more massive and feldspar-rich than the ignimbrite, typically containing >20% feldspar phenocrysts. The feldspar is commonly euhedral, up to 5 mm long, and is more abundant than quartz phenocrysts in these units. Monomict breccias, consisting of clasts of rhyodacite lava forming resistant lenses up to 20 cm across in schistose matrix, are interpreted as carapace breccias.

Much of the schist at deeper levels in this unit is interpreted as intrusive porphyry. Like the ignimbrite, these rocks contain 10-15% combined phenocrysts of quartz (2-5 mm, typically round) and feldspar (1-4 mm). But they also contain scattered (<1%) K-feldspar phenocrysts 5-10 mm long, 20-30% fine-grained biotite that occurs both as dispersed grains and as clots up to 2 cm across, and sparsely scattered dark inclusions that are concentrations (60-85%) of fine-grained biotite. The groundmass of the intrusive porphyry is white to light gray, microcrystalline, and quartzofeldspathic with variable amounts of sericite. Deformation and metamorphism have rendered contacts between these and other rocks of the unit indistinct.

Ignimbrite and a subvolcanic intrusion from this unit have been dated by U-Pb zircon SHRIMP-RG methods at 170.7 ± 1.1 Ma and 170.8 ± 1.0 Ma, respectively (Tosdal and Wooden, 2015).

Ju - Undivided Jurassic rocks (Jurassic)

Includes a variety of metasedimentary and metaigneous rocks that generally exhibit cryptic contact relationships, both between various components of this unit and with adjacent units (Johnson et al., 2017).