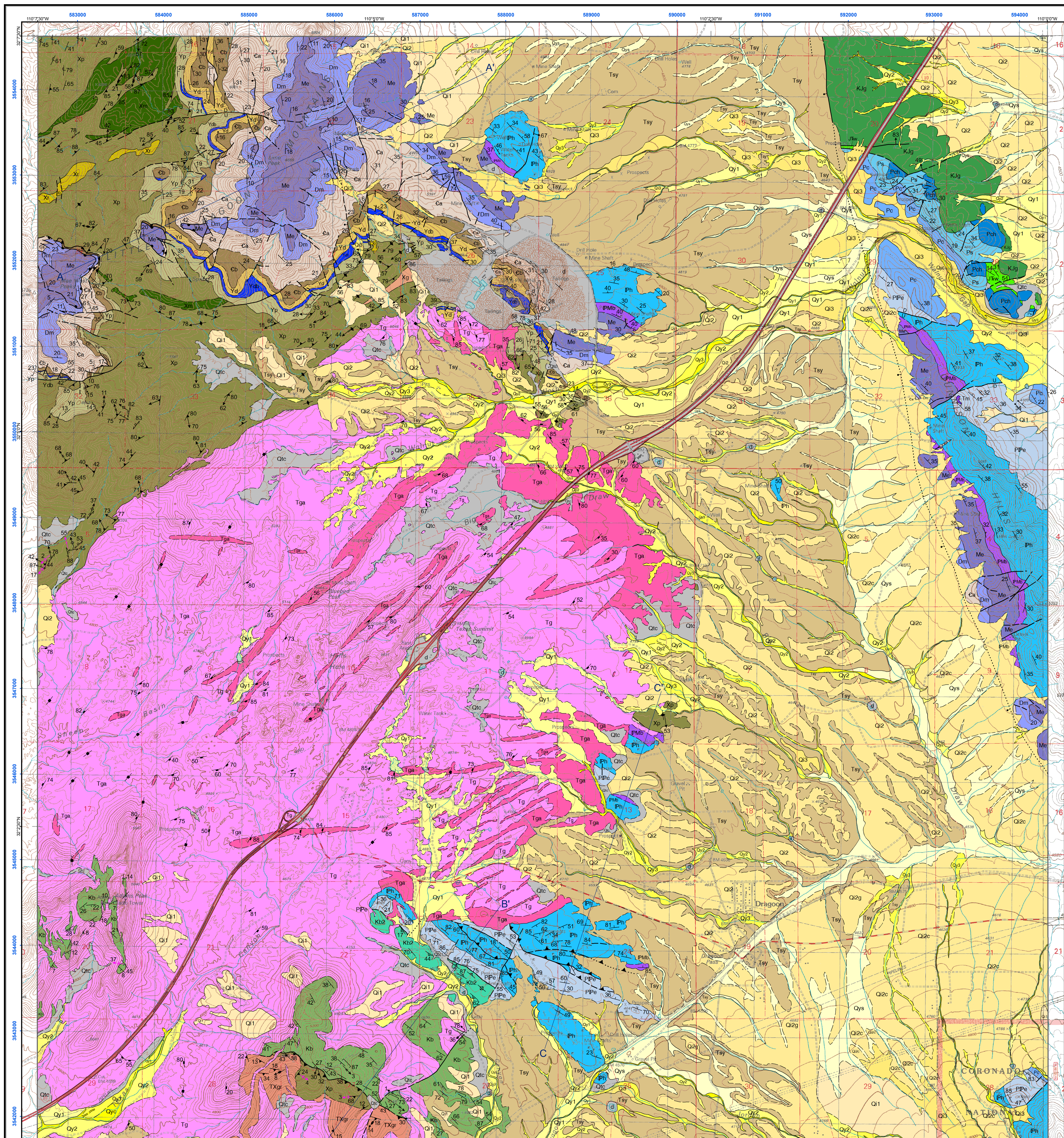
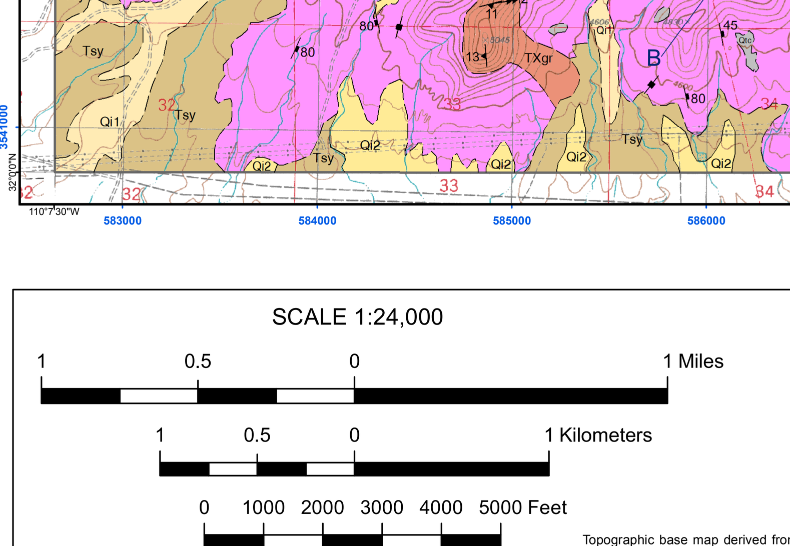
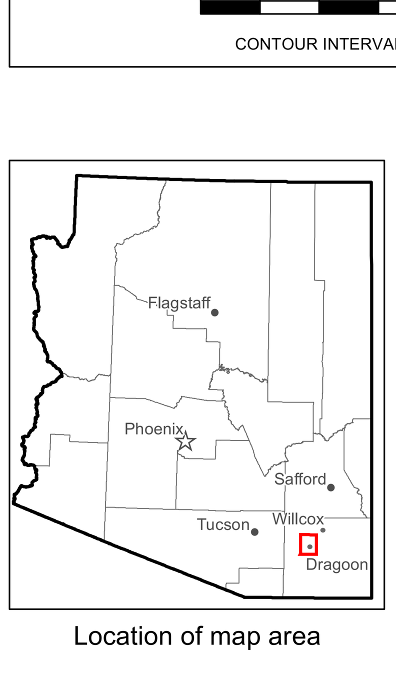
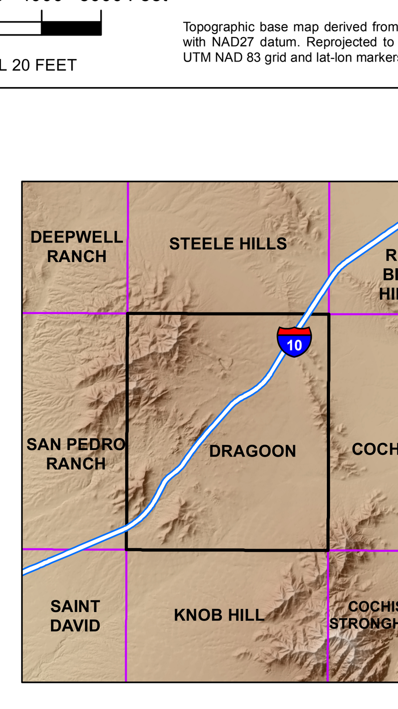


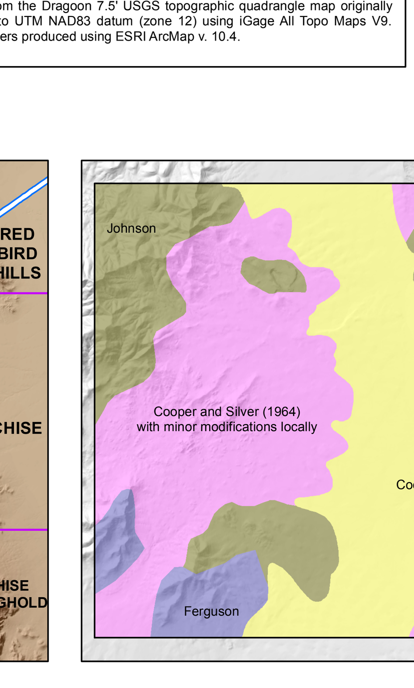


Topographic base map derived from the Dragoon 7.5' USGS topographic quadrangle map originally with NAD27 datum. Reprojected to UTM NAD83 datum (zone 12) using iGage All Topo Maps V8. UTM NAD 83 grid and lat-lon markers produced using ESRI ArcMap v. 10.4.



Location of map area

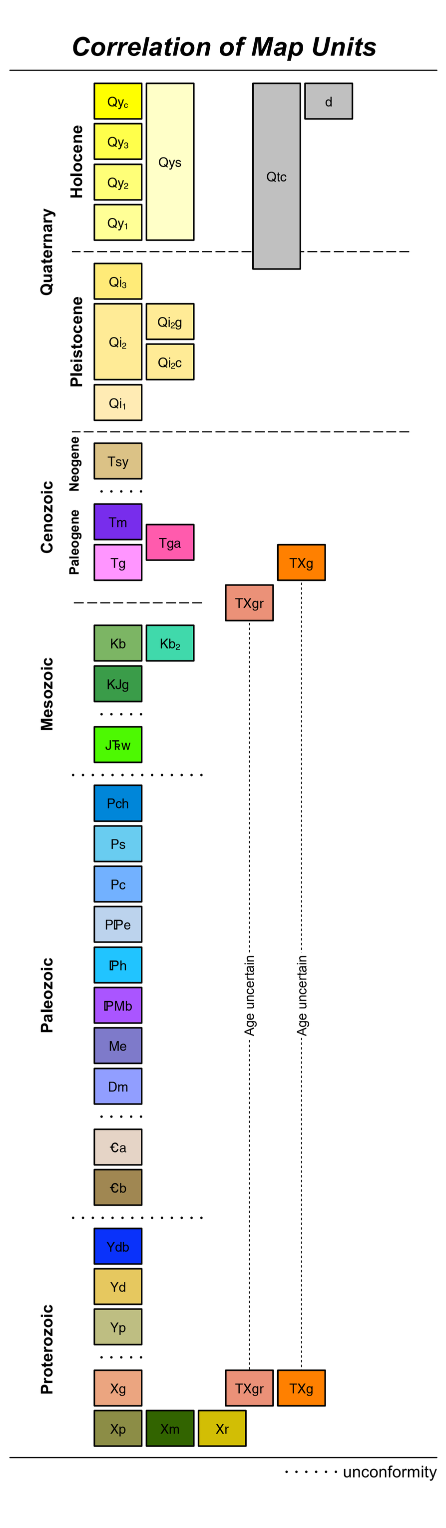


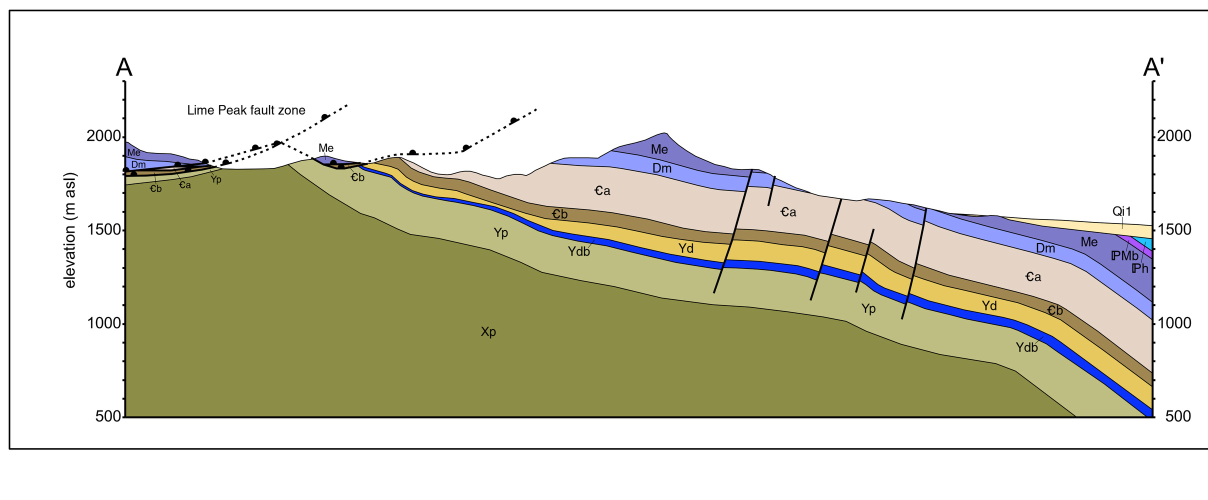


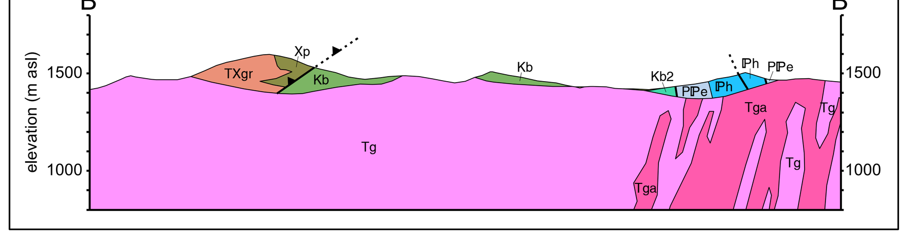
Symbols and Lines

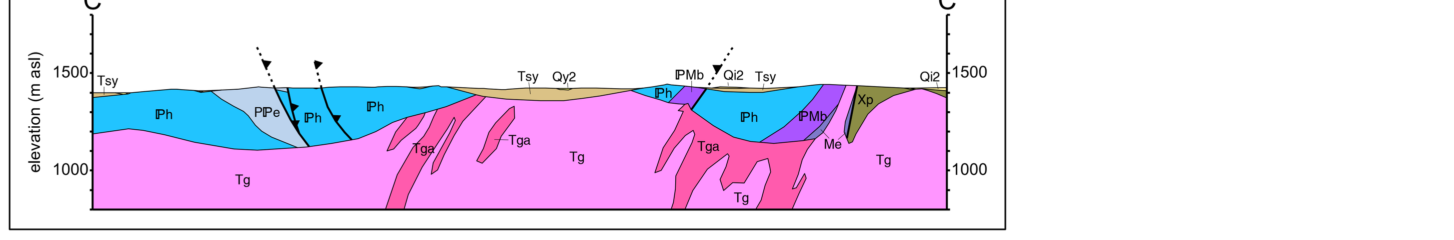
- Contact, accurate
- Contact, approximate
- Contact, concealed
- Fault, accurate
- Fault, approximate
- Fault, concealed
- High-angle normal fault, ornament on hanging wall
- Low-angle normal fault, ornament on hanging wall
- Thrust fault, ornament on hanging wall
- Fault showing local offset: U upthrown block, D downthrown block
- Dip of fault
- Strike and dip of inclined bedding
- Strike and dip of inclined bedding, tops known from local features
- Strike and dip of overturned bedding
- Strike and dip of cleavage
- Strike and dip of inclined bedding and parallel schistosity
- Strike and dip of inclined schistosity
- Strike of vertical schistosity
- Strike and dip of inclined second-generation schistosity
- Strike and dip of inclined compositional layering and parallel shape fabric
- Strike of vertical compositional layering and parallel shape fabric
- Strike and dip of inclined fracture or joint
- Trend and plunge of mineral-aggregate lineation
- Trend and plunge of elongation lineation
- Trend and plunge of elongation lineation, top-down-plunge shear sense indicated
- Trend and plunge of lineation at intersection of bedding and schistosity
- Trend and plunge of intersection of first- and second-generation foliations
- Trend and plunge of axis of second-generation minor fold
- Trend and plunge of axes of crenulations

Correlation of Map Units









Geologic map of the Dragoon 7 ½' Quadrangle, Cochise County, Arizona

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Arizona Geological Survey

Digital Geologic Map 125 (DGM-125)

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This geologic map was funded in part by the USGS National Cooperative Geologic Mapping Program under StateMap award number G16AC00294, 2016. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Introduction

The Dragoon 7 ½' Quadrangle is located midway between the towns of Benson and Willcox in Cochise County, southeastern Arizona, and is traversed by Interstate Highway 10. The quadrangle encompasses the eastern and southern parts of the Little Dragoon Mountains and the flanking piedmont, as well as the northern Gunnison Hills and a small portion of the northwestern Dragoon Mountains. A drainage divide extends northwestward from the Dragoon Mountains and Dragoon Pass, near the southern edge of the map, through the crest of the eastern Little Dragoon Mountains and thence northeastward off the map area to the Winchester Mountains. The watershed that includes Walnut Wash and Big Draw drains eastward to Willcox Playa in Sulphur Springs Valley, whereas Dragoon Wash, Texas Canyon, Sheep Basin, and small canyons in the northwest corner of the map area drain westward toward the San Pedro River. Geologic mapping was done under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992, and was jointly funded by the Arizona Geological Survey and the U.S. Geological Survey under STATEMAP assistance award #G16AC00294. Mapping was compiled digitally using ESRI ArcGIS software.

Surficial Geology

The surficial geologic units in the Dragoon 7 ½' Quadrangle consist of very high-standing relict alluvial fan deposits, broadly dissected and well-rounded basin fill alluvium grasslands, inset alluvial terraces, and riparian canyons near the mountain front. In the middle and distal piedmont deposits include widespread successions of high-standing and well-armored Pleistocene alluvium, unconsolidated distal Holocene terrace and channel deposits, and wide low-energy valley bottoms dominated by sheetflow and aggradational processes. Surficial geologic units were mapped using field observations, interpretation of digital aerial imagery, and digital elevation models (DEMs). Relative ages of alluvial deposits were estimated using characteristics of clast weathering, soil development, carbonate accumulation, and position in the landscape (Gile et al., 1981; Machette, 1985; Bull, 1991; Birkland, 1999). Soil development and carbonate accumulation begin once a deposit is isolated from active alluvial processes. As a result, the degree of soil development and carbonate accumulation are one of the criteria used to identify the approximate ages of surficial units.

Younger alluvial deposits have little to no soil development, retain the original grey or brown color of the alluvial sediment, and no carbonate accumulation. Clasts in these deposits have no weathering rinds or surface patinas and thus appear brighter and fresher than older clasts. Young alluvial surfaces often retain original depositional characteristics such as bars and swales. Conversely, older alluvial deposits have better developed soils that appear orange or red in color, with soil horizons reflecting clay and carbonate accumulations. Clasts on older alluvial deposits often exhibit darkened weathering rinds or rock varnish, and thus appear darker on the ground and in aerial photographs. Preserved alluvial surfaces may be smooth and flat (Qi3), becoming more rounded and coarser with age (Qi2). The oldest alluvial surfaces (Qi1) are often eroded, well-rounded ridges with degraded soil preservation and carbonate horizon exposed. These surfaces appear white on aerial photos due to widespread exposure of the carbonate horizon. Alluvial deposits sourced from limestone and carbonate-rich parent material exhibit very strong carbonate accumulation and are very resistant to erosion. Alluvial deposits sourced from granitic parent material exhibit very red, clay-rich surfaces with mature B horizons and clay-coated clasts. Exposures of well-cemented older alluvium are present along active channels and within younger, unconsolidated alluvium in the middle and distal piedmont. Basin fill alluvium is present and intermittently exposed beneath all younger alluvial deposits throughout the mapping area indicating burial of older alluvium is relatively shallow. Holocene alluvium along modern washes and arroyos is often inset below older deposits by several meters and confined to relatively narrow expanses within older alluvium. Within the modern incised channel bottom, young terraces are prone to flooding.

Bedrock Geology

The Dragoon quadrangle is underlain by rocks ranging in age from Paleoproterozoic to Paleogene. There are excellent exposures of a major nonconformity between the Paleoproterozoic Pinal schist and Mesoproterozoic sedimentary strata of the Apache Group. These are overlain by a thick and generally well-exposed Paleozoic sedimentary section dominated by carbonate rocks, with significant disconformities below the basal Middle Cambrian sandstone of the Bolsa Quartzite and below the Devonian Martin Formation. In the Gunnison Hills, a nearly complete section of pristine fossiliferous carbonate and subordinate siliciclastic rocks of Mississippian through Permian age is well-exposed. They are overlain unconformably by a small remnant of Upper Triassic or Jurassic volcaniclastic rocks, and the latest Jurassic to Lower Cretaceous Glance Conglomerate lies unconformably on a surface carved into these and upper Permian units.

The Texas Canyon Quartz Monzonite is an Eocene pluton that intrudes Mesozoic and older rocks and forms distinctive outcrops that display dramatic spheroidal weathering. Carbonate and siliciclastic rocks near the pluton have been contact-metamorphosed to marble, hornfels, schist, and skarn. Skarn in the Abrigo Formation hosts copper-zinc mineralization that was mined at several underground workings beginning in the 1880s, and that beginning in the 1970s was exploited in pits and open cuts at the currently inactive Johnson Camp mine. Alteration zones in the Texas Canyon pluton (unit Tga) are associated with tungsten-bearing quartz veins that have been mined in several small workings. Lead-silver veins in the Gunnison Hills also have been the focus of small mining operations.

The structural geology exhibits manifestations of Paleoproterozoic, Laramide (Late Cretaceous to Paleogene), and younger Cenozoic deformation. The Pinal schist displays tectonic fabrics that are variably developed and that predate deposition of Mesoproterozoic rocks. In the northernmost exposures, bedding is well-preserved in Pinal metasandstone, with a nearly parallel schistosity developed in intercalated pelitic units that commonly form the upper parts of graded beds. A southward increase in the development of schistosity to some extent coincides with a general increase in the pelitic component of the rocks. South of the ridge between Mae West Peaks and Lime Peak, schistosity is ubiquitous. In some places the dominant schistosity is a second-generation fabric (S2); bedding and a parallel first-generation foliation (composite S0-S1 fabric) locally lie oblique to the S2 schistosity and locally form rootless, tight to isoclinal folds, but otherwise S0-S1 has been transposed into parallelism with S2 schistosity. The transition from metasandstone units with well-preserved bedding to more strongly deformed schist was interpreted by Swift (1987) as a thrust fault, and the generally more-deformed rocks to the south as representing remnants of a subduction complex with mélange and lenses of broken formation thrust northward over coherent strata. These lithotectonic units were mapped by Swift (1987) and further described by Swift and Force (2001). The present mapping effort did not find conclusive evidence to either confirm or refute this interpretation, and the Pinal schist has not been subdivided here.

Mesoproterozoic through Cretaceous rocks have been deformed by Laramide-age open folds. The foliation in the Pinal schist, which generally dips steeply, is broadly folded possibly as a result of this same deformation. In the Dragoon Mountains and the southern foothills of the Little Dragoon Mountains, the rocks have been imbricated by NE-verging thrust faults and high-angle faults involving rocks as old as Paleoproterozoic and as young as Cretaceous. Among these structures are a major thrust west of Walker Canyon that placed Pinal schist over Lower Cretaceous Bisbee Group, and thrusts in the northern Dragoons that have duplicated parts of the Paleozoic section. In contrast, rocks of the higher elevations of the Little Dragoons generally form a gently E-dipping homocline deformed by broad folds that plunge gently to moderately NE and have nearly vertical axial planes. Strata in the Gunnison Hills also form a NE-dipping homocline.

The contact between the Bisbee Group and Paleozoic rocks in Walker Canyon was interpreted by Cooper and Silver (1964) as a SW-dipping, NE-verging thrust, with the Bisbee thrust over NE-facing Horquilla Limestone. For the most part, the Paleozoic rocks and the Bisbee (unit Kb2) dip steeply NE near the contact. The present mapping suggests that the Horquilla grades southwestward into the Earp Formation, implying that those strata face SW and are therefore overturned. Contact metamorphism related to emplacement of the Texas Canyon Quartz Monzonite obliterated many textures in pre-Eocene rocks in this area and rendered the contact between the Bisbee and the Earp somewhat cryptic. The contact may simply be the pre-Bisbee unconformity. However, unit Kb2 displays a relict ductile shape fabric parallel to layering, suggesting that the contact zone was modified and perhaps attenuated by ductile shear before being strongly overprinted by contact metamorphism. Shearing must have occurred in the Cretaceous or Paleocene, constrained by the age of the Bisbee and the post-tectonic Texas Canyon Quartz Monzonite; the kinematics of shear have yet to be determined. Northeast of Walker Canyon the Horquilla and Earp formations are exposed in two large NE-facing panels, and perhaps other smaller panels, disrupted by faults that are interpreted here as SW-verging Laramide backthrusts and high-angle normal faults. Paleozoic rocks near the Centurion mine again face SW and have been imbricated by NE-verging thrusts.

At Mae West Peaks on the crest of the Little Dragoons the Mesoproterozoic and Paleozoic section is disrupted by low-angle faults, or a combination of low- and moderate-angle faults. They have cut out section, resulting in imbricated Paleozoic units and juxtaposition of Mississippian carbonate plus slivers of Cambrian and Devonian rocks on Pioneer Shale and Pinal schist. This structure was interpreted as a fan of Laramide thrusts by Cooper and Silver (1964) and as a low-angle normal fault by Dickinson (1984). The latter is more consistent with the observed stratigraphic omission and thin-skinned nature of the faults, which appear to be restricted to, or at least focused in, the supracrustal rocks.

High-angle faults of at least two sets cut all of the aforementioned structures. North-striking normal faults commonly form west-side-down half grabens and some terminate against westerly striking faults. A northerly striking range-bounding fault along the west side of the Gunnison Hills is one of the youngest Cenozoic structures in the area.

Acknowledgments

Excelsior Mining Corp kindly allowed access to the Johnson Camp mine. Geologist Jeff Bickel and site manager Matt Williams are thanked for facilitating site visits and sharing geological information. Derek Thorkelson shared observations on outcrops of the Pinal schist and greenstone. The geology of this area was previously mapped by Cooper and Silver (1964), including old underground mine workings. Their maps and report are of exceptionally good quality, especially the detailed map of the Johnson Camp mine area, parts of which were compiled into this map with only slight modification. They provided excellent detailed descriptions of the lithology and stratigraphy, especially of the Abrigo and Martin formations which host the copper mineralization at Johnson Camp.

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Map Unit Descriptions

Piedmont alluvium

Qyc — **Active stream channel deposits** - Qyc deposits are composed of unconsolidated, very poorly sorted sand to cobbles in lightly vegetated piedmont channels. Channels may be flat-bottomed or exhibit bar and swale microtopography with bars composed of coarser sediments. Qyc deposits are generally devoid of vegetation and exhibit no soil development although small shrubs and grasses may be found on slightly elevated in-channel bars. Qyc deposits are lined by cottonwood and oak in near mountain reaches and mesquite, acacia, creosote, and desert broom farther from the mountain front. Qyc deposits commonly become submerged during moderate to extreme flow conditions and can be subject to deep, high velocity flow and lateral bank erosion. Channels are generally incised .25 - 1.5 m (1 - 5 ft) below adjacent Holocene alluvium and may be incised into adjacent Pleistocene alluvium by 2 m (6.5 ft) or more.

Qy3 — **Low swales, tributary drainages, and weakly incised channels** - Piedmont alluvium located along active drainages including small channels, adjacent low terraces, or floodplain areas. Qy3 deposits are composed of unconsolidated, unvarnished sand, gravel, and silt deposits. Qy3 deposits may also exhibit significant cobble and boulder accumulations reworked from adjacent Qy2 and Qy1 terraces and splay deposits. Qy3 drainages are often wider, lower energy, and more heavily vegetated than the Qyc channels they drain into. In upper piedmont areas Qy3 includes active stream channels where Qyc cannot be broken out at the map scale. Soil development is generally absent or incipient on Qy3 deposits which exhibit pale buff to light brown (10 YR) surface coloration.

Qys — **Sheetflood deposits and swales, reworked basin fill deposits** - Laterally extensive, unconsolidated fine-grained alluvium in valley bottoms and mantling the lower parts of adjacent slopes on eroded basin fill (Tsy) deposits. These sediments are light brown to light tan to white in color and consist of sand, silt, clay, and gravel. Occasionally weakly channelized flow occurs but minor gradient changes or vegetation cause aggradation that leads again to sheetflow or infiltration. In valley bottoms, these deposits are primarily silt and sand beds with a small component of thin and discontinuous gravel beds. Weakly developed buried soils are common. On the toes of slopes, sandy to pebbly calcium carbonate aggregate nodules are common. Surface soil development is weak.

Qy2 — **Broad drainages and piedmont terrace deposits** - Qy2 deposits consist of terrace deposits located primarily along the flanks of incised drainages and low-relief terraces inset into Pleistocene age fan deposits. Some Qy2 deposits comprise extensive low relief alluvial fans where unconfined by older piedmont alluvium. These deposits consist of predominantly fine grained unconsolidated to weakly consolidated sediments with sub-rounded to sub-angular pebble to cobble bars on the surface and beds and lenses in cross section. Where inset into older alluvium, Qy2 deposits are planar with remnant bar and swale microtopography. Planar Qy2 terraces are typically elevated from 30 cm - 1.5 m (1 - 5 ft) above active channels. Soil development on Qy2 deposits is minor, characterized by no to incipient stage I-II calcium carbonate accumulation in the form of small filaments and medium brown (10 YR) surface coloration. Vegetation on Qy2 surfaces consists of small shrubs, weeds, bunch grass, yucca, Mormon tea, prickly pear, desert broom, and the occasional cholla. These surfaces are subject to inundation during moderate to extreme flow conditions when channel flow exceeds capacity or due to channel migration on low-relief portions of broad distal fan deposits.

Qy1 — **High standing broad piedmont terraces** - Qy1 deposits consist of planar terraces along larger piedmont drainages that are 1 - 2 m (3 - 6 ft) higher in the landscape than adjacent Qy2 terraces and eroded, remnant alluvial fan deposits on lower piedmont areas. Qy1 deposits are composed of sandy to pebbly swales with coarser unvarnished to very lightly varnished pebble to cobble bars, and partially overlie Pleistocene deposits in some areas. Near the mountain front, Bar and swale microtopography is somewhat muted by generations of vegetation mounding. Pebbles and cobbles exposed in cross section exhibit stage I-II calcium carbonate accumulation within a medium brown matrix of fine sand to silt. Some reddened clay rich aggregate and calcium carbonate coated clast inclusions have been reworked from older deposits. Qy1 surfaces are generally isolated from flooding associated with the modern drainage system although inundation may be possible during extreme precipitation and runoff events. Vegetation on Qy1 deposits is similar to that found on Qy2 deposits with the addition of creosote, whitethorn and catclaw acacia.

Qi3 — **Low-intermediate terraces and alluvial fan deposits** - Broadly planar terrace and fan deposits elevated up to 3 m (10 ft) above adjacent Holocene (Qyc, Qy3, Qy2, and Qy1) deposits. Surface soil on Qi3 deposits is mildly reddened (7.5 YR 5/4). Cobbles and boulders dominate Qi3 deposits in cross section where exposed by incised channels or roadcuts. Qi3 deposits consist mostly of locally derived clasts but may also include reworked Gila River clasts, especially towards the valley center. On broad planar Qi3 surfaces farther from the mountain front surface soil is composed of sand, silt, and small pebbles with partially buried cobbles to boulders creating remnant bar and swale microtopography. Some Qi3 deposits appear to overlie highly eroded basin fill deposits (units Tsy, Tsc, Tsf and Tsp) and are likely less than a few meters thick. Vegetation on Qi3 deposits is dominated by creosote but includes prickly pear, barrel, and cholla cactus; bunch grasses, small shrubs, whitethorn and catclaw acacia, mesquite, agave, yucca, and mormon tea.

Qi2 — **Intermediate-high terrace and remnant alluvial fan deposits, undivided** - Broadly planar to moderately rounded cobble to boulder-dominated terrace and fan deposits capping underlying basin fill (Tsy) deposits. Qi2 deposits are elevated up to 10 m (33 ft) above Holocene piedmont deposits near the mountain front and 4 m (13 ft) farther out in the valley. In the southeast portion of the map area Qi2 deposits may be sourced from either granitic or sedimentary and carbonate parent material. Deposits originating from Jordan Canyon in the Dragoon Mountains are composed of primarily granitic clasts. Deposits sourced from Wood Canyon are composed of sedimentary and carbonate clasts. The result is deposits of similar age with very different characteristics. Dominantly granitic Qi2 deposits exhibit distinct, well-reddened soils while nearby Qi2 deposits with abundant carbonate parent material exhibit a white to buff color and very strong impermeable soil carbonate layer (stage IV+) just below the surface. In some areas where the contact between Qi2 and underlying Tsy deposits is exposed, an erosional unconformity is evident. Vegetation on Qi2 deposits is similar to that found on Qi3 deposits although creosote is less abundant and more widely spaced. Most Qi2 surfaces are grass-covered with punctuated mesquite, prickly pear, yucca, agave, whitethorn and catclaw acacia, mormon tea, and ocotillo near carbonate-rich eroded edges.

Qi2g — **Intermediate-high terrace and remnant alluvial fan deposits, granitic parent material** - Grusy, very well-reddened clay rich Qi2 deposit sourced from granitic parent material. Qi2g deposits appear very red on air photos and exhibit thick 20-30 cm clay rich B horizons with blocky structure and clay-coated clasts and faces. Qi2g deposits often overlie basin fill alluvium (Tsy deposits) and form extensive planar to broadly crowned fan lobes throughout the southern and central portion of the map area. These deposits are generally covered by thick grasses with widely spaced creosote, mesquite, acacia, and ocotillo.

Qi2c — **Intermediate-high terrace and remnant alluvial fan deposits, carbonate parent material** - Carbonate-rich Qi2 deposits sourced from limestone parent material. Qi2c deposits appear white to gray on air photos and exhibit extensive, 20-50 cm thick, impermeable laminar soil carbonate horizons in the proximal and mid-fan environment. Qi2c deposits are extensive in the southern and central portion of the map area near Wood Canyon in the Dragoon Mountains and along the flank of the Gunnison HIlls. These deposits are covered by thick grasses with widely spaced agave, yucca, ocotillo, creosote, and mesquite. Channel incision in the upper fan is minor due to the well-cemented alluvium and channels often exhibit steps and plunge pools around embedded boulders. Channel walls in the lower fan are very well-cemented and exhibit overhanging walls and benches along outside meanders.

Qi1 — **High standing relict alluvial fan remnants** - Qi1 deposits are relict alluvial fan remnants overlying Tsy basin filling sediments or bedrock that stand higher in the landscape than Qi2 and younger deposits. Qi1 surfaces are planar to well-rounded near eroded edges. Where extensively preserved, Qi1 deposits exhibit deeply incised mature tributary drainage networks and clay rich, reddened (2.5 - 5YR 3/6) soils. Qi1 deposits commonly cap and preserve underlying finer grained Tsy deposits. Coarse cobble to boulder lag derived from erosion of the Qi1 cap also covers the flanks of underlying Tsy deposits, shielding them from erosion. Vegetation on Qi1 deposits consists of mesquite, grasses, small shrubs, prickly pear, barrel, creosote, agave, ocotillo, and oak near incised drainages.

Basin fill alluvium

Tsy — **Basin fill deposits, undivided** - Weakly to moderately consolidated silt, clay, sand, and gravel deposited in basins during and after late Cenozoic faulting. Tsy deposits are generally light to medium brown to tan (7.5 Y R 6/4) in color. They commonly form high rounded hills and ridges in modern basins, and locally form prominent bluffs when overlain by more consolidated, erosion resistant Quaternary deposits. Where uncapped, these deposits form gently rolling, low-relief hills throughout the map area, broadly dissected by tributary drainage networks. Where exposed, a clear erosional contact is evident between the basin fill deposits and overlying, coarser Quaternary units (Qi1, Qi2, Qi3) suggesting that these basin fill deposits are Pliocene in age. Vegetation on basin fill deposits ranges from bunch grass ground cover, creosote, small shrubs, acacia, desert broom, and mesquite in lowlands to yucca, prickly pear, barrel, larger mesquite, oak, and agave on high-standing Tsy deposits.

Bedrock Units

Tm — **Mafic intrusion** - A small sill-like intrusion in limestone of the Earp Formation, appears to be locally discordant although all contacts are covered. The rock is fine-grained to aphanitic, with some plagioclase up to 1 mm, and appears to be composed of nearly equal amounts of plagioclase and altered green mafic minerals with minor brown iron oxide and possibly carbonate. It locally displays variolitic texture, with 0.5-1 cm spheroidal aggregates of fine-grained plagioclase and pyroxene(?) occurring singly and as coalesced masses in dark-green aphanitic groundmass.

Tg — **Texas Canyon Quartz Monzonite** - Monzogranite to quartz monzonite, typically containing 30-35% quartz, 30-40% plagioclase, 25-30% K-feldspar, and about 5% biotite (or locally biotite and muscovite). The rock is medium- to coarse-grained and, except near contacts with country rocks, is generally porphyritic to megacrystic, with 2-5% megacrysts of K-feldspar that typically are 1-5 cm long (and range up to 10 cm). In the groundmass, plagioclase forms euhedral to subhedral crystals 1-4 mm long zoned from oligoclase to albite, with interstitial anhedral quartz and K-feldspar (Cooper and Silver, 1964). The K-feldspar is in part perthitic microcline and may be in part orthoclase. Quartz also forms subhedral crystals and polycrystalline aggregates up to 10 mm. Biotite forms small plates and books. The rock is light gray to light orange-pink and weathers light yellowish brown, forming distinctive spheroidally weathered outcrops and deeply weathered grus.

The monzogranite is crossed by dikes and segregations of aplite and fine- to (locally) medium-grained muscovite leucogranite, some of which contain pegmatite segregations within them. These are nearly ubiquitous but are especially abundant near contacts with country rocks. Locally gradational contacts with the monzogranite indicate that the leucogranite was almost certainly derived from residual liquid differentiated from the same parent magma and emplaced during final crystallization of the monzogranite.

The Texas Canyon Quartz Monzonite has yielded a U-Pb zircon age of 55.5 +/- 1.9 Ma (Chapman et al., 2018).

Tga — **Altered Texas Canyon Quartz Monzonite** - Zones of alteration within the Texas Canyon Quartz Monzonite (Tg) form haloes around tungsten-bearing quartz veins. Each halo consists of an inner zone of quartz-muscovite alteration, grading abruptly to an outer zone in which feldspar (especially plagioclase) has been replaced by clay minerals, in turn grading outward into unaltered monzogranite. In the inner zones, plagioclase has largely been replaced by fine- to coarse-grained muscovite, the K-feldspar has been silicified, and biotite has been replaced by muscovite with intergrown pyrite. Contacts between unit Tg and the altered unit Tga, which represent generalized boundaries around some of the larger areas of variably altered rock associated with arrays of multiple veins, are from the map of Cooper and Silver (1964), and the description here is briefly summarized from theirs.

TXg — **Leucogranite** - Leucocratic monzogranite, fine- to medium-grained, light green-gray, weathered light tan. Composed of 40-50% K-feldspar (microcline), including sparse phenocrysts up to 15 mm. The rest of the rock is mostly plagioclase and quartz in subequal amounts, with <3% combined biotite and secondary muscovite. The rock is fractured and recrystallized but not foliated. South of the Dragoon quadrangle, Cooper and Silver (1964) reported that this granite intrudes the Pinal schist, but its age relative to other rocks is uncertain; it bears some resemblance to granite that intrudes the Bisbee Group in the Dragoon Mountains and also to the 1.4 Ga Tungsten King granite, and could therefore be either Paleogene - Late Cretaceous or Proterozoic.

TXgr — **Foliated megacrystic granite** - Medium- to coarse-grained granite containing K-feldspar megacrysts 2-5 cm long and 10-25% biotite. Xenoliths of schist are common. The granite is foliated and is locally protomylonite.

Bisbee Group

Kb — **Morita and Cintura formations undivided** - Medium- to fine-grained sandstone interbedded with siltstone, generally somewhat contact-metamorphosed since all exposures of this unit are pendants intruded by the Texas Canyon Quartz Monzonite. The sandstone is mostly arkosic arenite but some units are quartz arenite or subarkose. Medium-grained sandstone is pink to light green or light gray, is weathered pink to light gray, and is medium- to thick-bedded. Some sandstone higher in the section is brown to pinkish gray and is weathered brown to olive brown. Siltier units are light green to green-gray on fresh surfaces and are weathered gray to gray-green. Some layers contain epidote lenses up to a few cm long.

Kb2 — **Contact-metamorphosed tectonite derived from Bisbeee Group** - Granular quartzofeldspathic rock containing lenticular clasts, thin seams, and layers of laminated hornfels and schist. Most of this unit is strongly silicified, with patchy zones in which quartz and feldspar grains are visible. Feldspar is 1-5 mm, with rare domains in which K-feldspar crystals 1-3 cm long occur. In some places feldspars have been flattened and broken. Quartz forms polycrystalline grains up to 5 mm that range from equant and spherical to variably flattened, in some cases forming ribbons. Matrix between the grains is mostly microcrystalline quartz, with epidote, tremolite, muscovite, and iron oxides dispersed in variable proportions. The rock contains lenticular granule- to pebble-sized clasts of schist and laminated hornfels that tend to weather recessively, and a few clasts of fine-grained quartzite. Thin layers of laminated hornfels, marble, and fine-grained quartzite are present, mostly in decimeter-thick intervals. The granular quartzofeldspathic rocks display a variably developed foliation parallel to that layering, defined by grain-size variation and preferred orientation of lithic clasts, tabular feldspar, and flattened quartz.

Cooper and Silver (1964) interpreted the rocks of this unit as sheared and contact-metamorphosed Bisbee Group, and this appears reasonable. The rocks display evidence of ductile deformation (flattened quartz grains), strongly overprinted by contact metamorphism (silicification and growth of calcsilicate minerals). In some places the rock looks like altered granite, especially where large feldspar (phenocrysts?) are present, so perhaps the unit contains cryptic granitic sills. But quartz and feldspar generally form discrete grains rather than intergrown crystals, and for the most part the rocks appear to have been derived from pebbly sandstone. The laminated hornfels and marble layers resemble rocks of the Earp Formation, which flanks this unit to the northeast, and some layers along the southwest side of the unit resemble Pinal schist, but suitable protoliths for these rocks also occur in the Morita and Cintura formations of the Bisbee Group. Contacts of this unit with adjacent units are covered or, in the case of the Earp, cryptic. The unit is clearly older than the Texas Canyon Quartz Monzonite, which shows no evidence of alteration or foliation in nearby exposures.

KJg — **Glance Conglomerate** - Framework-supported conglomerate composed of rounded to subangular pebbles and cobbles of varicolored limestone and dolostone with interstitial matrix of rounded to subrounded quartz sand, granules of fine-grained quartz sandstone, and carbonate sand, cemented by calcite. Near the base of the unit there are some pebbles of quartz sandstone. The Glance Conglomerate overlies older units unconformably, and the vast majority (or all) of its clasts were derived from the Naco Group.

JTrw — **Walnut Gap Formation** - Volcaniclastic sandstone and ash-fall tuff. These rocks are red-brown to purple, thin- to medium-bedded, very fine- to very coarse-grained, and generally poorly sorted with pebbles and granules in many layers. Some beds of lithic-feldspathic sandstone are medium-grained and moderately or well- sorted. The sand-sized fraction includes 25-50% subangular feldspar (plagioclase), <10-15% subrounded quartz, a few percent biotite flakes, and lithics. Chert pebbles are common in the lower part of the section, but the most common pebbles and granules are red-brown dacitic volcanics with phenocrysts of feldspar, biotite, and trace quartz (up to 10% combined). Others include light-gray andesite with 15% altered hornblende phenocrysts. Tuff beds are compositionally similar to the sandstone but the feldspar grains are angular and broken and the grains are supported in red-brown matrix. White pumice lapilli containing biotite and feldspar phenocrysts are present in some layers.

Naco Group

Pch — **Concha Limestone** - Dark- to light-gray, thick- to medium-bedded limestone containing abundant chert nodules. The unit is locally dolomitic in the basal few meters and is pink to light gray. Limestone above that generally becomes darker gray up-section, with orange-weathered chert nodules standing out in high relief. The chert nodules are mostly 10-20 cm across although some have coalesced to form masses >1 m across. Some beds contain prominent large brachiopods.

Ps — **Sherrer Formation** - Quartz sandstone and subordinate carbonate. The lower part consists of medium- to thin-bedded sandstone (quartz arenite), with some shaly intervals and a few beds of dolostone. The sandstone is white to pink, weathered light orange-pink, and is composed of fine-grained, well-sorted, rounded to well-rounded quartz grains cemented by quartz. Dolostone is pinkish-gray, weathered light gray to light tan-gray, and forms ledges up to 2 m thick. The upper part of the formation is marked by an interval of medium-bedded, light- to medium-gray-weathered, micritic dolostone and dolomitic limestone up to 50 m thick, overlain by more medium-bedded, planar-laminated quartz arenite. Echinoid spines are common in the dolostone and limestone.

Pc — **Colina Limestone** - Medium- to thick-bedded, dark-gray, micritic limestone, weathered dark to medium gray and characterized by tabular beds and scarcity of siliciclastic layers. In the lower and upper parts there are a few beds of fine-grained quartz sandstone, gray on fresh surfaces and weathered dark orange-brown. In the upper part there are also beds of light-tan to light-orange dolostone and, in some sections, dark- to medium-gray limestone near the top displays light-brown-weathered dolostone layers 2 cm thick and patchy discordant dolomitization. The upper interval of mixed lithology likely correlates with the "Epitaph dolomite" of Gilluly et al. (1954). Limestone of the Colina contains prominent fossil gastropods, and echinoid spines up to 2 cm long are common in the upper interval of mixed lithology.

PPe — **Earp Formation** - A mixed unit comprising approximately equal proportions of carbonate and siliciclastic rocks. Ledges of gray limestone in the lower part alternate with intervals of poorly exposed sandstone and shale littered with abundant sandstone float. The sandstone is fine- to very-fine-grained, weathered light orange-brown to light brown, and is light gray on fresh surfaces. The middle part of the formation is characterized by notably multicolored limestone and dolostone ledges and recessive intervals of poorly exposed sandstone and shale. Limestone and dolomitic limestone are generally weathered light gray to light tan, while dolostone beds are commonly weathered yellow or orange. The carbonate rocks are typically light pink to light pinkish-gray on fresh surfaces. They are medium- to thick-bedded, and some beds exhibit internal lamination in their upper parts.

A distinctive conglomerate interval marks the base of the upper member of the Earp Formation. On the eastern slope of the Gunnison Hills the conglomerate is 2-3 m thick, framework-supported, composed of flat pebbles and cobbles of limestone and very-fine- to fine-grained sandstone along with rounded pebbles of chert, and is overlain by light-brown, medium-grained, calcareous sandstone 1 m thick with small-ripple crossbedding. In another fault block on the northwest side of the hills, the conglomerate is a few m thick and consists of a lower layer containing rounded to well-rounded small chert pebbles and an upper layer containing flat carbonate pebbles and small cobbles; both layers are framework-supported. The conglomerate is overlain by a succession of medium- to thick-bedded, ledge-forming, dark-gray limestone weathered medium to dark gray to brown-gray, interbedded with medium- to thin-bedded, planar-laminated, fine-grained, pink to grayish-pink quartz sandstone weathered light orange to light orange-brown, and a few tan-weathered dolostone beds that are locally sandy and locally display faint small-ripple crossbedding.

In the Walker Canyon area west of Dragoon, the siliciclastic components of the Earp Formation have generally been metamorphosed to light-green or orange-pink hornfels and the limestone has been metamorphosed to fine-grained marble.

Ph — **Horquilla Limestone** - Ledges of thick- to medium-bedded limestone alternating with recessive intervals of light-tan to light orange-brown shale, very-fine-grained shaly sandstone, and thinly interbedded shale and limestone. In the basal part of the section in the Gunnison Hills, limestone is medium to dark gray and the shale is light green, in contrast to the pink limestone and red-brown shale of the underlying Black Prince Limestone. Above that, limestone forms ledges 1-3 m thick with intervening slopes that are mostly covered except for local outcrops of shale and sandstone. The limestone is light to medium gray, commonly cherty, and is mostly lime mudstone with packstone and wackestone intervals containing crinoid, fusilinid, brachiopod, and rugose coral remains. There are a few beds of calcarenite and intraclast packstone, and an interval in the upper part of the formation contains horizons of well-preserved tabulate coral (*Syringopora*) colonies. Thick beds of limestone in the upper part of the unit contain nodules and lenses of chert. Near the top, carbonate-dominated intervals several meters thick alternate with siliciclastic-dominated intervals; the contact with the overlying Earp Formation is gradational.

West of Dragoon near Walker Canyon, the Horquilla has been metamorphosed to marble ribbed with resistant siliceous laminations, interlayered with intervals up to 1 m thick of siliceous hornfels with recessive thin carbonate layers. The marble is mostly weathered white to light gray, locally light tan or pink.

PMb — **Black Prince Limestone** - Limestone and subordinate shale. A [distinctive] basal unit 7-8 m thick consists of shaly red-brown mudstone containing chert lenses up to 15 cm thick, capped by thin-bedded limestone with shale partings. This is overlain by light-gray to pink thick-bedded limestone, crinoidal and cherty in the lower part, becoming pink up-section with layers up to 25 cm thick of green to brown shale and intervals up to 3 m thick of solution-brecciated limestone in red-brown mudstone matrix.

Me — **Escabrosa Limestone** - Light-gray, thick-bedded limestone and subordinate dolostone, forming resistant ledges and cliffs and the highest peaks in the Little Dragoon Mountains, and also forming the lower western slopes of the Gunnison Hills. The basal part consists of medium- to thick-bedded ledges of medium-gray dolostone, weathered tan to light brown to gray. This gives way up-section to mainly light gray, thick-bedded limestone, with lesser dolostone and a few medium-bedded intervals. Beds locally exhibit internal lamination defined by grain-size variation, including intervals of crinoid packstone or wackestone interlayered with carbonate mudstone. The upper part of the unit is thick-bedded to massive, light gray to white limestone containing abundant chert nodules, including lenses 10-20 cm thick and several meters in lateral extent. Much of the upper part is sparry crinoid packstone, and a few intervals contain horn corals.

Dm — **Martin Formation** - Dolostone and sandy dolostone with subordinate sandstone and shale. The lower part of the formation consists of light-tan, medium-bedded dolostone at the base, overlain successively by gray dolostone and orange-brown sandstone with poorly defined bedding. The middle part is medium- to thin-bedded sandy dolostone and dolomitic sandstone, weathered tan to dark brown, interbedded locally with pink shale. The upper part of the formation consists of medium- to thick-bedded dolostone ledges. The dolostone is medium to dark gray to grayish-pink, is weathered tan to light brown to gray, and locally contains small siliceous geodes. Some beds are laminated internally. The top of the formation is marked by an interval several meters thick of light brown, fine-grained, shaly sandstone and pink shale.

Near the Johnson Camp mine, dolostone of the Martin has been metamorphosed to a hard, white, calcsilicate rock (tactite), and the upper shale has been converted to hard brown hornfels.

Ca — **Abrigo Formation** - Thin-bedded limestone, calcareous and dolomitic sandstone, sandy dolostone, and shale. The lower part of the formation consists mostly of thinly interbedded light-green to yellow-green shale and fine- to medium-grained, pink, brown-weathered sandstone. There are a few interbeds of light-brown sandy dolostone, gray to tan limestone (some with silty laminations), and intraformational conglomerate. The middle part is dominated by thin-bedded gray limestone with distinctive, wavy, brown-weathered silty laminations. This limestone interval is overlain by light-gray to light-tan, sandy, crossbedded limestone thinly interbedded with red-brown-weathered calcareous sandstone, with intraformational flat-pebble conglomerate and thin shale intervals becoming abundant up-section. The upper part of the Abrigo is marked by a unit of thin- to medium-bedded dolomitic sandstone and sandy dolostone with a few thin shale partings. A quartz sandstone unit up to 2 m thick is overlain by another interval of dolomitic sandstone and sandy dolostone. Near the top there is a distinctive unit of light-gray to tan laminated dolostone, in part crossbedded, with sandy laminations that contain coarse quartz sand grains and granules. The top of the formation is marked by a ledge of quartz sandstone 3-4 m thick.

The Abrigo Formation exhibits strong contact metamorphism near the Texas Canyon Quartz Monzonite and is host to Cu-Zn mineralization at the Johnson Camp mine. The metamorphic rocks include fine-grained marble with thin calcsilicate layers, thin-bedded calcsilicate hornfels, and skarn containing locally abundant sulfides. Cooper and Silver (1964) noted that the metamorphic effects include: conversion of the lower shale to biotite hornfels; not much change of the middle limestone except at high grade of metamorphism, where it has become garnetite; replacement of intervals of sandy limestone and calcareous sandstone by garnetite even at lower grade; conversion of the upper sandy dolostone to diopside- or tremolite-bearing calcsilicate rock ("white tactite"); and conversion of the laminated dolostone near the top to marble with serpentine pseudomorphs after olivine.

Cb — **Bolsa Quartzite** - Medium- to thick-bedded, mostly planar-laminated, white to light gray quartz arenite weathered white to locally light brown. Hematitic layers locally accentuate planar lamination and trough crossbedding, especially near the base of the unit. Trace fossils of worm burrows are common on upper bed surfaces. The sandstone is medium-grained, well-sorted, and subrounded. The base of the unit locally exhibits a thin breccia layer containing subangular pebbles of arkose derived from the underlying Dripping Spring Quartzite. The Bolsa Quartzite grades into the overlying Abrigo Formation through an interval in which white quartz arenite is interbedded with calcareous brown-weathered sandstone, shaly sandstone, and light-brown shale.

Ydb — **Diabase** - Fine- to medium-grained altered diabase, forms a widespread sill, and in some places a pair of sills, intruding the contact between the Pioneer Shale (unit Yp) and Barnes Conglomerate (base of unit Yd). Zircons from the sill have yielded a minimum age of 1100 +/- 15 Ma based on the $^{207}Pb/^{206}Pb$ isotopic ratio (Silver, 1978).

Apache Group

Yd — **Dripping Spring Quartzite** - Arkosic arenite, medium- to fine-grained, moderately to well-sorted, subrounded to subangular, bright orange-pink to grayish orange-pink, weathered light orange to light orange-brown. The sandstone forms thick beds with internal layering (planar lamination) marked by color variations reflecting variations in feldspar content and grain size. Layers of conglomerate up to 2 m thick occur at the base of the unit (the Barnes Conglomerate). The conglomerate is framework-supported, composed of well-rounded pebbles and cobbles up to 10 cm of vein quartz, chert, and a few of jasper, in a medium- to coarse-grained sandy matrix. Where metamorphosed near the Johnson Camp mine, the feldspar in the sandstone is white and the rock lacks its distinctive orange-pink color.

Yp — **Pioneer Shale** - Sandstone interbedded with purple siltstone and purple to light-olive-green mudstone. The lower part of the formation has thick- to medium-bedded intervals of white to light-gray, medium-grained, quartz-rich sandstone with trough and small-ripple crossbedding. Sandstones higher in the section are thin- to medium-bedded and medium-grained to very fine-grained. They range from dark purple to light purple-gray to maroon on fresh surfaces and are weathered various shades of purple, light purple-gray, olive-brown, and light brown. They commonly display planar lamination defined by alternate purple, gray, and white laminae, and are interbedded with siltstone and shaly mudstone. The base of the unit is marked by conglomerate 10-35 cm thick (the Scanlan Conglomerate), which unconformably overlies the Pinal schist. The conglomerate is framework-supported, composed of subrounded to subangular pebbles and cobbles of white vein quartz and pink to purple quartzite and a few red chert pebbles in a medium-grained sandy matrix.

Xg — **Granodiorite** - Medium-grained gray granodiorite composed of 40% plagioclase (albite), 30% quartz, 15% K-feldspar, and 15% combined fine-grained biotite, muscovite, magnetite, apatite, epidote, and chlorite (Cooper and Silver, 1964). The rock has a recrystallized texture and is weakly foliated parallel to schistosity in the host Pinal schist.

Pinal Assemblage

Xr — **Metarhyolite** - Gray metarhyolite porphyry containing approximately 10% phenocrysts 1-4 mm of quartz and albite plagioclase in an aphanitic groundmass composed of feldspar, quartz, and sericite with minor biotite and chlorite. Forms lenses within Pinal schist (unit Xp). Near contacts with the schist this rock is foliated and recrystallized. The distribution and description of this unit is adapted from Cooper and Silver (1964).

Xm — **Greenstone** - **Greenstone** and chlorite schist, fine-grained, massive to variably foliated. Cooper and Silver (1964) described the massive variety as composed mainly of amphibole (45-70%) with subordinate chlorite, epidote, and plagioclase. Aggregates 1 mm across of fine-grained amphibole appear to be pseudomorphs after another mineral (probably pyroxene). Massive greenstone commonly grades to chlorite schist, especially near contacts with sericitic schist of unit Xp. In some places, however, greenstone containing amphibole aggregates appears to have intruded schist that lacks those aggregates. Swift and Force (2001) interpreted this unit as comprising metamorphosed diabase dikes and sills and basalt pillow lavas, based on comparison with sections of Pinal schist in the Dragoon Mountains.

Xp — **Pinal schist and metawacke** - Quartz-sericite schist interlayered with feldspathic to micaceous metasandstone (metawacke). The metasandstone is medium- to fine-grained and poorly to moderately sorted, is schistose where it contains abundant sericite and is flaggy to massive where there is less sericite. Fine- to coarse-grained subrounded quartz grains are prominent, whereas white feldspar and sericite have less-distinct grain boundaries when viewed with a hand lens. In the northwest corner of the map area, intervals dominated by thin- to medium-bedded metasandstone commonly exhibit graded bedding, with scattered coarse to very coarse sand grains near the bases of beds contrasting sharply with pelitic tops. South of Mae West Peaks, pelitic to semipelitic schist is predominant and metasandstone beds are mostly 15 cm thick or less, locally forming lenses or boudins. Some intervals of schist have layers 1-5 cm thick of fine-grained quartzite, and thin quartz veins are common.

In the transition from north to south into more pervasively schistose rocks, quartz-sericite schist envelops lenses of undeformed metawacke that define a steeply plunging elongation lineation. Although these appear to be boudins of resistant metawacke in relatively highly strained pelite-dominated intervals, similar structures were interpreted by Swift (1987) as pre-metamorphic phacoids in mélange.

Other units

d — **Disturbed** - Heavily disturbed or altered ground associated with mine dumps and leach pads, highways, excavation, and municipal development. Original geologic features are concealed or obscured.

Qtc — **Colluvium and talus** - Poorly sorted, angular to subangular, weakly to massively bedded, locally derived hillslope deposits. In some areas may include grus derived from deeply weathered granite.

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