Unit Descriptions

Digital geologic map and cross sections of the Clifton-Morenci area, Greenlee County, Arizona

compiled by
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The Clifton-Morenci map area includes four 7.5' USGS quadrangles: Coronado Mountain, Copperplate Gulch, Clifton, and Mitchell Peak. Descriptions of the Precambrian, Paleozoic, and Mesozoic rocks are primarily from Lindgren (1905a,b). The early Tertiary (Laramide) intrusive rock units are also described in detail by Bennett (1975), Menzer (1980), Preece and Menzer (1992), Griffin, Ring and Lowery (1993), Walker (1995), Phelps Dodge (1996), and Wright (1997). Hydrothermal alteration of the rocks of the Morenci porphyry copper deposit is well described in Lindgren (1905a), Reber (1916), Bennett (1974), Preece, Stegen and Weiskopf (1993), and Walker (1995). Descriptions of the Tertiary volcanic and sedimentary rocks are primarily derived from recent mapping by Ferguson and Enders (this report). Many of the unit names were derived from work in adjacent areas by Richter et al. (1983), Houser et al. (1985), Ratté and Brooks (1995), and Schroeder (1996).

RECENT

R Stockpiles, mill tailings, road embankments and other facilities (Recent):
Extensive areas of the Morenci block and adjacent valley to the south are covered by mine tailings, stockpiles, ponds, and related facilities. Mining began in the district around 1882. The location of covered areas as of January 1999 are shown with the underlying bedrock geology where data was available from earlier maps.

QUATERNARY

Qt Talus (Quaternary) [0-5 meters]:
Talus and landslide deposits consisting of blocky talus and colluvium on steep hillsides along portions of the east-side of the upper San Francisco River canyon.

Qac Colluvium (Quaternary) [0-2 meters]:
Chiefly talus and other slope debris mixed with alluvium from numerous small streams. The deposits are unconsolidated or caliche-cemented and consist of poorly sorted and crudely bedded silt to angular boulders and occurs in the southwestern portion of the map area and adjacent Guthrie quadrangle (Richter et al., 1983).

Qa Alluvium (Quaternary) [0-6 meters]:
Unconsolidated alluvium in active channels of perennial streams and adjacent washes. The alluvium consists of moderately well-sorted silt to boulder sized, rounded clasts in variously imbricated, lenticular beds. Clast composition is variable, depending on source and reworking.

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Qap Pediment alluvium (Quaternary) [0-6 meters]:
Unconsolidated or caliche-cemented alluvium on pediments and in smaller washes. The size, sorting and bedding are similar to alluvium of unit Qal. Pediment alluvium occurs in the southern portion of the map area and in the adjacent Guthrie quadrangle (Richter et al., 1983).

Qao Older alluvium (Quaternary) [0-6 meters]:
Unconsolidated alluvium in lower terraces above and adjacent to present streams and washes.

QUATERNARY AND TERTIARY

QTao Older alluvial deposits (Pliocene? to Pleistocene) [0-10 meters]:
This unit represents alluvium of ancestral Eagle Creek and the Gila and San Francisco Rivers (Richter et al., 1983). It consists of unconsolidated or caliche-cemented, variably imbricated, poorly sorted sand to boulder-size deposits on high terraces and interfluves above present channels. Clasts are rounded and consist of variable amounts of locally derived older conglomerate, basaltic andesite and rhyolite (59%), red Proterozic granite (30%), felsic porphyry (7%), as well as limestone, quartzite, and shale (4%). Some deposits contain up to 20% black polished hematite and magnetite clasts along with variable amounts of skarn and hydrothermally altered and leached copper-oxide mineralized porphyritic and granitic clasts from the Morenci copper deposit.

QUATERNARY AND TERTIARY GILA GROUP

The Gila Group is a complex sequence of Pleistocene, Pliocene, and Miocene-aged variably indurated, post-volcanic conglomerate, sandstone and siltstone that fills closed basins within the present physiographic boundaries. The group consists of several informal subdivisions defined largely on clast content, and to a lesser extent, on lithification and sedimentology. The informal subdivisions follow Richter et al. (1983) and Houser et al. (1985) from the Guthrie and Safford Quadrangles to the south and southwest respectively.

QTgs Unit of Smuggler Canyon (Gila Group, Pliocene to Pleistocene?) [0-150 meters]:
Unconsolidated to weakly indurated, locally caliche-cemented, moderately well-sorted cross-stratified sandstone, conglomerate, siltstone, and bouldery gravel. Clast proportions are highly variable and consist of locally derived red Proterozoic granite (45%), volcanic rocks (30%), Laramide porphyritic plutonic rocks (17%), and Paleozoic sedimentary rocks (7%). Clasts are weakly to strongly imbricated in places and may be rounded to sub-angular in shape, depending on proximity to source area. The unit contains <1 to 15% black polished hematite and magnetite clasts, and copper-oxide mineralized, veined, altered and leached clasts of skarn, porphyry, quartzite, and granite. The unit forms rounded slopes with a typically indistinct lower contact with the underlying cliff-forming unit of Buzzard Roost Canyon or conglomerate of Midnight Canyon. A thick lens of silt and clay occurs in the town of Morenci at the site of the "clay borrow pit".

QTgg Unit of Smuggler Canyon, granite-clast facies (Gila Group, Pliocene to Pleistocene?) [0-100 meters]:
A facies recognized along the west-side of the upper San Francisco River canyon where it is composed of >95% angular to sub-rounded, red, Proterozoic granite clasts.

QTgd Unit of Smuggler Canyon, diorite-clast facies (Gila Group, Pliocene to Pleistocene?) [0-100 meters]:

A facies recognized along the southwestern margin of the Morenci block where it is composed of >85% angular to sub-angular Laramide-age buff-colored, diorite porphyry clasts (unit Tpd).

Tgbr Unit of Buzzard Roost Canyon (Gila Group, Pliocene) [0 - >800 meters]:

Tan, strongly indurated, medium- to thick-bedded conglomerate interbedded with siltstone and sandstone. The beds commonly display large-scale planar crossbedding. Clasts are typically non-imbricated, rounded to sub-rounded. Clast composition is highly variable, but on average they consist dominantly (64%) of volcanic rocks; predominantly andesite but also rhyolite. Other clasts are Laramide-age porphyritic plutonic rocks (23%), red Proterozoic granite (7%), and Paleozoic sedimentary rocks (5%). The matrix is largely altered to zeolite minerals, but calcite cement is common in places. The unit has a gradational lower contact that is marked by the first appearance of Paleozoic limestone or quartzite and typically 1-5% red granite clasts. The abundance of non-volcanic clasts increases upwards to 15-30% at the top of the unit. In places the unit contains rare clasts of skarn and oxidized copper-sulfides in veined and altered porphyry and Proterozoic granite. Conglomerates of this unit form nearly vertical cliffs 80 to 100 meters high along the lower San Francisco and Gila River canyons south and southwest of Clifton. The unit grades from poorly sorted boulder conglomerate proximal to the Eagle Creek and San Francisco faults and in the corresponding canyons, to more distal facies of alternating 1-meter thick beds of moderately well-sorted pebbly conglomerate and silty sandstone to the south and southeast in the Duncan basin. Although the unit is widespread throughout the region, it appears to be restricted to the current physiographic boundaries of the valleys.

$Tgbr_{cc}$ Unit of Buzzard Roost Canyon, Chase Creek facies (Gila Group, Pliocene) [0 - 110 meters]:

Reddish-tan conglomerate containing more abundant Paleozoic sedimentary and Proterozoic granite clasts than sub-unit $Tgbr_{sf}$

$Tgbr_{sf}$ Unit of Buzzard Roost Canyon, San Francisco facies (Gila Group, Pliocene) [0 - 250 meters]:

Light greyish-tan conglomerate, containing abundant volcanic clasts in the Chase Creek area.

Tgmc Conglomerate of Midnight Canyon (Gila Group, Miocene and Pliocene) [0-360 meters]:

Light tan, massive, strongly indurated, fluviatile, volcaniclastic, medium- to thick-bedded conglomerate containing clasts predominantly of basaltic andesite with sub-equal but highly variable amounts of rhyolite lava and tuff. The unit consists mostly of matrix-supported conglomerate with angular to subrounded clasts ranging in size from coarse sand to boulders in a matrix of zeolite-cemented silt and sand. This unit was mapped as rhyolite by Lindgren (1905a,b), as rhyolite conglomerate by Heindl (1960), and as QTg by Richter and Lawrence (1981). The lower two-thirds forms prominent, nearly vertical cliffs and hoodoos from 30 to 100 meters high along Eagle Creek and the San Francisco River and tributary canyons. The upper third is finer grained, better sorted, less indurated and grades upward into the overlying unit of Buzzard Roost Canyon (Tgbr). The basal contact is marked by thin tuff lenses (Ttt) in the southwestern portion of the map area where present, or by indistinct gradation into the basaltic conglomerate and andesite of the conglomerate of Bonita Creek (Tbck) below. Tgmc is the most widespread conglomerate in the region and crops out extensively in the Eagle Creek and San

Francisco River sub-basins as well as north of the map area in the Pigeon Creek area and to the southwest in the Safford basin (Kruger et al., 1995).

TERTIARY UNITS OLDER THAN THE GILA GROUP

Tcb Basaltic conglomerate (Miocene) [0-30 meters]:
Medium- to thick-bedded, sandy conglomerate, and conglomerate containing rounded clasts of basaltic andesite. Occurs only in the upper San Francisco River Canyon directly below nonwelded tuff of the Enebro Mountain Formation. Its genetic relationship to the conglomerate of Bonita Creek or Gila Group is unknown.

Tbck Conglomerate of Bonita Creek (Miocene) [0-150 meters]:
Tan to brown, massive, strongly indurated, volcaniclastic conglomerate locally interbedded with nonwelded tuffs of unit Ttt and basaltic andesite flows of unit Tb. The unit consists of matrix-supported to clast-supported conglomerate with angular to sub-rounded clasts ranging in size from coarse sand to boulders of andesite and basaltic andesite in a matrix of zeolite-cemented silt and sand. Rare clasts of rhyolite are present in the upper part of the unit. Some clasts exhibit weathering rinds and the rock typically breaks across clasts. Bedding is crude to poor with local large-scale crossbeds. This unit was mapped as basaltic conglomerate by Heindl (1960) and included as part of unit QTg by Richter and Lawrence (1981). Richter et al. (1983) provided a typical stratigraphic section of this unit in the Bonita Creek area that differs in detail from that observed in the Eagle Creek area. The unit forms cliffs as much as 100 meters high and box canyons in lower Eagle Creek, and in the Gila Box and Bonita Creek areas further to the southwest.

Ttt Rhyolite pyroclastic flows and ash-fall deposits (Miocene, 18.2 + 0.05 Ma, this report) [0 - 30 meters]:
White to very light grey, moderately indurated, nonwelded, thin- to medium-bedded pumice-rich ash-flow tuff and pumice, crystal and lithic-rich ash-fall tuff. The tuffs contain a few percent phenocrysts of 1 to 2 mm quartz, sanidine and sparse biotite, and several percent 0.5 to 1.0 cm lithic fragments of basaltic andesite. The unit occurs at the contact between the conglomerate of Bonita Creek (Tbck) and the Gila Group (Tgmc) in lower Eagle Creek. A similar, but slightly older (19.1 Ma) tuff also mapped as Ttt occurs in the lower part of the conglomerate of Bonita Creek to the southwest of the Gila Box (Richter et al., 1983).

Te Enebro Mountain Formation (Miocene, 20.6 and 20.9 Ma, Marvin et al., 1987; 21.7 and 20.0 Ma, Schroeder, 1996; 22.3 Ma, this report) [0-340 meters]:
Crystal-poor to aphyric, high-silica rhyolite lava interbedded with nonwelded tuff and locally intruded by hypabyssal rhyolite. The formation has been divided into three sub units based on how the rhyolite was emplaced; lava (Ter), hypabyssal or intrusive (Tei), and tuff (Tet). The lava unit (Ter) includes all varieties of flow type, from vitric or devitrified flow-banded to vitric or devitrified autobreccia, and clast-supported block and ash-flow deposits. Hypabyssal bodies (Tei) occur as dikes, plugs and sills. Nonwelded, bedded or massive ash-flow tuff (Tet), ash-fall tuff and surge deposits are interbedded and intruded by the other units. Lavas and hypabyssal rocks occur in three main areas: Enebro Mountain, Chesser Gulch, and as isolated eruptive centers east of the San Francisco River. Tuffs are present over a wider area and are interlayered with basal conglomerates of the Gila Group in the northern part of the map area. To the south, bedded, nonwelded tuffs present at the base of the Gila Group are significantly younger (~18 Ma)

and are assigned to a different unit probably derived from silicic centers in the northern Peloncillo Mountains (Richter et al., 1983; Houser et al., 1985).

Tet Enebro Mountain Formation, nonwelded tuff (Miocene) [0-200 meters]:
Thin- to thick-bedded nonwelded, crystal-poor, rhyolite ash-flow tuff, ash-fall tuff and surge deposits associated with lavas of the same formation. The tuffs are interbedded with the lavas and are also found beyond the limits of the lava flows.

Ter Enebro Mountain Formation, lava (Miocene) [0-300 meters]:
This unit includes all varieties of lava, from vitric or devitrified flow-banded to vitric or devitrified autobreccia. The unit may also locally include some clast-supported block and ash-flow deposits.

Tei Enebro Mountain Formation, intrusive (Miocene):
Dikes and plugs associated with lava flows of the same formation.

Tb Basaltic andesite undivided (Oligocene – Miocene, 24.5-30 Ma, this report and Cook, 1994) [100-1,200 meters]:
A complex sequence of mafic lavas characterized by abundant plagioclase phenocrysts and variable amounts of pyroxene, $\pm$ hornblende and biotite. Olivine phenocrysts are notably absent from most of these rocks. The lavas display typical flow textures and variations in flow morphology in massive to brecciated flows that typically range from 1 to 10 meters in thickness, but locally are up to 30 meters thick. Minor interbedded felsic pyroclastic rocks and volcaniclastic rocks are present and help divide the unit into local subdivisions. However, the lack of lateral continuity of the interbeds makes it difficult to correlate subdivisions of the mafic lavas across the study area. The oldest lava flows, mapped separately as unit Tbl, occur between the Clifton and Bloodgood Canyon tuffs are at least 28 Ma. Although dated at as young as ~22 Ma (this study) we interpret this date as reset during emplacement of the overlying ~22 Ma Enebro Mountain Formation. There is no indication of any mafic lava younger than the rhyolite lava and tuff of the approximately 21-22 Ma Enebro Mountain Formation in the Morenci area.

Tbs Mafic volcaniclastic and pyroclastic rocks (late Oligocene) [0-20 meters]:
Dark-colored, mafic clast-rich, medium- to thick-bedded sandstone, conglomerate and minor interbedded scoria and nonwelded mafic tuff. The unit occurs within the basaltic andesite (Tb) unit north and northeast of Clifton.

Tbb Basaltic andesite scoria and lava breccia (late Oligocene) [0-40 meters]:
An isolated occurrence of bedded and massive scoria and agglutinate in the lower Eagle Creek area. The presence of these rocks suggests that a vent was in this area.

Tbi Hypabyssal bodies of basaltic andesite (late Oligocene):
Hypabyssal varieties of the basaltic andesite unit (Tb).

Tbc Bloodgood Canyon Tuff (late Oligocene, 28.1 Ma, McIntosh et al, 1992; 27.94 $\pm$ 0.09 Ma, this report) [0-40 meters]:
Light grey to white, crystal-rich, high-silica rhyolite densely to moderately welded ash-flow tuff containing large (3-5 mm) embayed quartz phenocrysts, and plagioclase, sanidine, and biotite phenocrysts. Its western pinch-out is preserved in the cliffs above Clifton and near the head of Placer Gulch.

Tbl Lower basaltic andesite (late Oligocene, between ~34 Ma and 28 Ma) [0-150 meters]:
A sequence of basaltic andesite lava flows that occur between the Clifton and Bloodgood Canyon tuffs. This unit is recognized in the Limestone Gulch area northeast of Clifton, and is tentatively correlated with an isolated outcrop of basaltic andesite at TV hill (south of Coronado Mountain) based on a 28.5 Ma date (this report) and a 30.0 Ma andesite dike in the Metcalf pit (Cook, 1994).

Tdc Crystal-poor ash-flow tuff (late Oligocene, ~29.0 Ma by correlation with Davis Canyon Tuff) [0-30 meters]:
Light grey, densely welded, pumice-poor, rhyolite ash-flow tuff that contains 1-5% blocky plagioclase and quartz phenocrysts and sparse lithic fragments. The unit crops out in only one area in the footwall of the San Francisco fault north of Sardine Creek. Although similar in appearance to the Davis Canyon Tuff of Ratté and Brooks (1995) in the Big Lue Mountains just to the east, the lack of sanidine phenocrysts in this tuff suggests that it may be a different unit. The crystal-poor ash-flow tuff overlies the Clifton Tuff (Tc) and underlies the basaltic andesite (Tb). Until additional information is available, this unit is tentatively correlated with the 29.0 Ma Davis Canyon Tuff of McIntosh et al. (1992).

Tcl Lower conglomerate (late Oligocene) [0-15 meters]:
Medium- to rarely thick-bedded orange to reddish sandstone, pebbly sandstone, and conglomerate present locally in between the Clifton Tuff and overlying basaltic andesite of unit Tb. In places the unit contains large-scale cross-beds. The unit is moderately well-sorted and well-indurated with flat, platy angular to sub-angular clasts predominating. The clasts are mostly composed of Paleozoic and Proterozoic lithologies (60%), limestone, quartzite, and shale; and non-mineralized intrusive porphyry (30%). In some lenses, volcanic clasts comprise a few percent to 10% of the clasts and consist of andesite, and tuff apparently derived from the underlying Clifton Tuff. The lower conglomerate crops out in the hill northwest of the confluence of Chase Creek and the San Francisco River in Clifton. It also crops out in the footwall of the San Francisco fault near Sardine Creek in the extreme northeastern corner of the map area.

Tc Clifton Tuff (Oligocene, 33.7 Ma, Marvin et al, 1987; 33.1 Ma, Wahl, 1980; ~34 Ma, McIntosh et al., 1992) [0-110 meters]:
Crystal-rich, rhyolite to rhyodacite ash-flow tuff containing abundant phenocrysts of plagioclase and biotite. The tuff is typically light pink and crumbly weathering despite its densely welded character, as evidenced by abundant, light-colored, strongly compacted pumice fragments. The crumbly weathering may be a result of intense vapor-phase crystallization of the matrix. The Clifton Tuff unit is probably correlative with the Cooney Tuff in New Mexico (McIntosh et al, 1992). Typically, it unconformably overlies Paleozoic or older rocks. The Clifton Tuff is very well exposed in the cliffs behind the Old Jail House in Clifton.

PALEOCENE AND EOCENE INTRUSIVE ROCKS

Tertiary intrusive rocks are common throughout the Morenci block and portions of the bedrock on the eastern side of the San Francisco sub-basin. The intrusive suite ranges from Paleocene to early Eocene in age (64.7 to 52.8 Ma) and from diorite to monzonite to granite porphyry in composition and texture (Moolick and Durek, 1966; Preece and Menzer, 1992). Throughout this section, IUGS rock classifications (IUGS sub-commission, 1973) are based on normative and modal interpretations reported in Preece and Menzer (1992), Griffin, Ring and Lowery (1993), and Walker (1995), but without supporting data. In the mine area, monzonite porphyry (Tpm) and older granite porphyry (Tpgo) are the principal intrusive host rocks for porphyry copper mineralization. These rocks also crop out extensively to the north of the Morenci district in the Silver Creek area as well as along the margins of the San Francisco River and Eagle Creek sub-basins where there are largely fresh and unmineralized. Pending further petrographic, geochemical, and geochronological data, the Silver Creek granodiorite of More (1995), the dacite porphyry in the Garfield area, and the intrusive rocks in the San Francisco River and Eagle Creek areas have been mapped as undivided Laramide-age porphyry (Tp). Recent dating of a sample of dacite porphyry yielded a K-Ar age on orthoclase of 58.7 +/- 1.5 Ma (this study). Within error limits, this date corresponds to an unpublished K-Ar age on feldspar of 61.7 +/- 2.8 Ma from AMAX and indicates that one or more Laramide-age intrusions were probably emplaced in between units Tpd and Tpm. The range in ages and associated errors suggests that additional work needs to be done to better define the petrogenesis of these rocks.

Tbx Intrusive breccia, undivided (Eocene, 52.8 Ma sericite date on Candelaria breccia, Bennett, 1975):

This unit includes several breccia bodies in the district. The Morenci breccia is located in the Morenci pit and is an oblate lenticular mass approximately 76 meters wide, 488 meters long and 23-62 meters thick. The Candelaria Breccia cuts the older granite porphyry complex along its northern margin and is about 550 by 825 meters in dimension and funnel-shaped in form. Fragments of XYg, Xp, and quartz-poor Tpgo, in a matrix of quartz-sericite and specularite characterize the Candelaria breccia. The Metcalf breccia and King breccia appear to have formed contemporaneously with the younger granite porphyry (Tpgy). The Metcalf breccia forms a rind along the eastern margins of the laccolith and the King breccia forms a nearly cylindrical pipe located between the older and younger granite porphyry bodies along the southeastern edge of the Tpgy complex. These bodies are characterized by fragments of Tpgo with subordinate amounts of Tpgy, XYg, Tpm, and quartz in a matrix similar to younger granite porphyry that displays flow-banding around the fragments (Griffin, Ring and Lowery, 1993).

Tp Porphyry, undivided (Eocene):

Undifferentiated porphyry units which include units (not shown on this map) informally referred to as the Silver Creek granodiorite (More, 1995), the dacite porphyry in the northeast, and unamed bodies in the San Francisco River and Eagle Creek areas.

Tpgy Younger granite porphyry (Eocene):

Greenish-grey to light grey intrusive porphyry containing 5-8% large (5-10 mm) bipyramidal quartz phenocrysts, subordinate orthoclase, euhedral plagioclase (An 25-30), and biotite altered to chlorite in a fine-grained matrix of strongly sericitized and argillized quartz, orthoclase and albite. In places a younger rhyolite porphyry (Tpry) phase has been mapped, but not shown on this map, that consists of nearly equigranular, angular and fragmental phenocrysts of quartz and plagioclase in a very fine-grained matrix of quartz, plagioclase and sericite. Modal composition of altered Tpgy is granodiorite. The complex occurs as a 1400 meter diameter laccolithic-shaped plug, associated with several small breccia bodies, near the center of the older granite porphyry stock complex in the center of the mining district. Younger granite porphyry characteristically lacks through-going veins and stockwork mineralization and alteration is poorly developed, although the rock is pervasively sericitized and argillized.

Tpgo Older granite porphyry undivided (Eocene, 57.6 Ma, Bennett, 1975):
Grey to tan where fresh, light grey to white where altered, intrusive porphyry with 3-10% quartz phenocrysts and crowded rectangular plagioclase and less abundant orthoclase phenocrysts. Two phases of granite porphyry are recognized in the Morenci mine area, but not shown on this map. Older granite porphyry 1 ($Tpgo_1$) is characterized by 3-7% small (<4 mm) subhedral quartz phenocrysts and crowded rectangular feldspar phenocrysts (<4 to 6 mm) commonly andesine in composition. Older granite porphyry 2 ($Tpgo_2$) is characterized by 5-10% bipyramidal quartz phenocrysts up to 1-cm in diameter with matrix-supported feldspar phenocrysts. The aphanitic groundmass consists of albitic plagioclase, quartz, and orthoclase. The normative composition of altered rock is alkali granite, but the modal composition is granodiorite to quartz monzonite. Contacts between the two phases are both transitional and intrusive. The intrusive complex consists of several plugs and stocks including the two porphyry phases and three breccia bodies of unit Tbx, along with related dike swarms in the central portion of the Morenci district. Older granite porphyry displays well-developed quartz-sericite stockwork veining and pervasive quartz-sericite-pyrite alteration and supergene characteristics similar to those described for monzonite porphyry (Tpm). Rare Tpgo dikes occur in outlying portions of the map area along both sides of the San Francisco River canyon where they are generally less altered and unmineralized.

Td Diabase (Eocene):
Dark grey to black where weakly altered, mottled green to reddish-brown where strongly altered sub-ophitic diabase. The term “diabase” has been used for all older mafic rocks in the district and may include mafic dikes that are not true diabase. Compositions are highly variable but typically consist of plagioclase, augite, labradorite, and hornblende with up to 5% quartz. These rocks have been strongly altered to epidote, chlorite, carbonate, sericite, with minor apatite, and up to 10% magnetite. The texture is highly variable and ranges from finely ophitic to coarsely granular. The rock may contain abundant magnetite +/- hematite and pyrite outside of the mineralized area, and is locally mineralized with pyrite, chalcopyrite +/- chalcocite inside of the Morenci deposit. In addition, it locally contains garnet-magnetite skarn alteration in the Metcalf area. Diabase occurs chiefly along major east-west-striking faults in the central portions of the Morenci block that intrudes monzonite porphyry (Tpm). Diabase is locally crosscut by younger porphyries, and occurs as sills in Proterozoic granite (XYg) and Coronado Quartzite (Cc) in the northern portion of the district. This rock has not been dated; and in the absence of cross-cutting field relationships, it cannot be easily distinguished from diabase that occurs as sills and dikes in the Apache Group elsewhere in Arizona except on the basis of textural variations (Force, pers. commun.).

Tpmq Quartz monzonite porphyry (Eocene):
A variation of the monzonite porphyry in the Morenci pit that contains a few percent quartz phenocrysts (Wright, 1997).

Tpm Monzonite porphyry (Eocene , 56.5 Ma, McDowell, 1971):
Grey to greenish-grey or brownish-grey where fresh, light grey to white where altered porphyry. The texture is characterized by crowded phenocrysts of feldspar and subordinate and variable amounts of biotite and rare quartz in a microcyrstalline groundmass of feldspar and quartz. Feldspar phenocrysts consist of un-zoned andesine to oligoclase, but orthoclase tends to be restricted to the groundmass. Biotite appears to have been abundant (up to 10 vol.%) but is rarely preserved. Normative calculations of weakly altered porphyry indicate compositions

ranging from granodiorite through quartz monzonite, and modal analysis indicates compositions ranging from tonalite to granodiorite. The unit occurs throughout the map area but is best recognized as the elongate stock and dike-swarm complex that intrudes unit Tdp and older rocks in the Morenci mine area. In the mine area abundant quartz-sericite stockwork veining and pervasive quartz-sericite-pyrite alteration obscure the original texture and chemistry of the rock. Secondary chalcocite mineralization with supergene clay alteration is abundant in the sulfide zone that underlies an oxidized and leached zone containing limonite +/- copper-oxide mineralization in the mine area.

Tpd Diorite porphyry (Paleocene, 63.0, 64.7 Ma, McDowell, 1971):
Light grey to greenish-grey mottled hornblende diorite containing large phenocrysts of hornblende and plagioclase with subordinate quartz and biotite in a microcrystalline groundmass of chlorite, epidote, montmorillonite and plagioclase. Ocillatory-zoned plagioclase phenocrysts range from An 52 - An 58 in the cores to An 57 – An 34 in the rims. Modal and normative compositions are diorite. This intrusion is unmineralized and weak propylitic alteration is expressed as epidote and chlorite after hornblende and biotite. The diorite porphyry occurs in the southwestern portion of the Morenci district where it intrudes the Pinkard Formation (Kp) and forms a thick sheet or laccolith with associated radiating dikes.

MESOZOIC - TERTIARY

TKv Volcanic and hypabyssal rocks undivided (Late-Cretaceous and Early Tertiary) [0-300 meters]:
Shown only on cross-section D-D', this unit represents the hypothetical eastern edge of a field of intermediate volcanic and hypabyssal rocks that are exposed in the eastern Gila Mountains. These rocks have been dated at approximately 58 and 68 Ma (Houser et al., 1985).

MESOZOIC

Kp Pinkard Formation (Late-Cretaceous) [0-430 meters]: Originally defined by Lindgren (1905a,b).
This unit consists of a succession of banded, green, yellowish-brown, and black thin-bedded and laminated shale. The shale is interbedded with light grey, thin- to medium- bedded, quartzose sandstones in the upper portion of the unit. The unit unconformably overlies the Modoc Formation (Mm) and fills karst features in some outcrops. The best exposures are in Silver Basin area surrounding the hills of diorite porphyry (Tpd) in the southwestern part of the map area. The Pinkard Formation is regionally correlative with Upper Cretaceous rocks of southern New Mexico in general, but more precise correlations will require biostratigraphic information. In places, diorite porphyry sills of unit Tpd up to 56 meters thick intrude Pinkard Formation. In the Morenci mine area, the unit locally contains epidote hornfels alteration. The unit is not known to exist north of the Quartzite-Producer fault zone in the southern portion of the Morenci district. It is not known if this is due to non-deposition or early Tertiary erosion. Drill hole intercepts in holes SW-1 and SW-9 in the hanging wall of the Eagle Creek fault indicated the thickness of the Pinkard to be greater than 238 m and potentially up to 430 m thick. In this area, the Cretaceous strata included alternating sandstone, shale, and coal seams, and have been correlated to the Ft. Crittenden Formation of Campian age from the Santa Rita Mountains (Phelps Dodge, 1969).

PALEOZOIC

Pu Paleozoic, undivided (Cambrian-Pennsylvanian) [75-375 meters]:
This unit is shown only on some cross-sections combining all units of the Paleozoic.

MPt Tule Springs Formation (Mississippian-Pennsylvanian) [0-150 meters]:
Originally defined by Lindgren (1905b). Medium- to thick-bedded, bluish-grey, amalgamated limestone recognized only in the northern third of the map area, north of the Garfield fault. The lower 60 meters is equivalent to the Modoc Formation (Mm) and the upper 90 meters is considered Pennsylvanian in age. Apparently, the Mississippian-Pennsylvanian boundary as defined by the skeletal faunas is not distinct enough to be used as a rock-stratigraphic unit boundary.

Mm Modoc Formation (Mississippian) [50-100 meters]:
Originally defined as Modoc limestone by Lindgren (1905a,b) and renamed Modoc Formation because it contains subordinate beds of dolostone and calcareous quartzite. The formation consists of blue-grey, medium- to thick-bedded, fossiliferous limestone with 1 to 3-meter thick beds of crinoidal and coraliferrerous limestone. The Modoc Formation is regionally correlative with the Escabrosa Formation. In the Morenci mine area, limestone of the unit is altered to andradite garnet +/- epidote along contacts with monzonite porphyry dikes of unit Tpm and displays sharp contacts with marble outward from the deposit (Bennett, 1974).

Dm Morenci Formation (Devonian) [20-91 meters]:
Originally defined by Lindgren (1905a,b). The formation consists of shale and limestone. The upper 30 meters consists of light grey to reddish brown shale that conformably and gradationally overlie 20 to 25 meters of fine-grained, medium- to thin-bedded, argillaceous limestone. The Morenci Formation is typically a slope-former. The unit is correlative with the Martin formation to the west in Arizona and the Percha shale to the east in New Mexico. In the Morenci mine area, argillaceous limestone in the lower part of the formation is altered to epidote and the shale is altered to hornfels (Bennett, 1974).

Ol Longfellow Formation (Ordovician) [50-160 meters]:
Originally defined by Lindgren (1905a,b). Light tan to brownish grey, medium- to thin-bedded limestone, cherty limestone, and dolomite. The upper 45 meters typically forms a cliff of massive and amalgamated limestone and the lower 75 meters contains shaly intervals and forms slopes leading to unit Cc below. Limestone in the lower part typically contains up to 10% quartz granules. The upper member is regionally correlative with the El Paso Limestone of southeastern Arizona and Second Value Dolomite while the lower member is correlative with the Copper Queen Member of the Abrigo Formation in the Bisbee area. In the Morenci mine area, the unit contains mineralized veins, pervasive diopside-tremolite alteration, and local chlorite-epidote-garnet alteration (Bennett, 1974).

Cc Coronado Quartzite (Cambrian) [0-120 meters]:
Originally defined by Lindgren (1905a,b). Medium- to thick-bedded, brown, pink, and maroon quartzite, feldspathic quartzite, and minor arkose. The upper portion of the unit typically forms precipitous cliffs. The lower portion typically consists of quartz pebble to cobble conglomerate that is up to 15 meters thick. The unit is regionally correlative to the lower two-thirds of the Abrigo Formation and the Bolsa Quartzite to the west near Bisbee. In the Morenci mine area, the

unit contains stockwork mineralization, and quartz-sericite-pyrite alteration of the more arkosic varieties (Bennett, 1974).

EARLY OR MIDDLE PROTEROZOIC

XYg Granite (Early or Middle Proterozoic):
Coarse-grained, equigranular granite, typically yellowish-red to deep brownish-red in unaltered areas, and light tan to light grey where altered to a quartz-sericite-pyrite assemblage. This granite contains orthoclase, albite, quartz, minor biotite and rare hornblende with magnetite and zircon accessory minerals. Grain size ranges up to 5 mm in diameter and the feldspars show a perthitic to micro-perthitic texture. This unit locally includes dikes and irregular masses of fine-grained red aplite, and porphyritic granite. Although this unit clearly intrudes Pinal Schist, its age relationship to the granodiorite and ferrodiorite is uncertain. The granite is the principal Proterozoic basement rock throughout the southern part of the district. It occurs as two large domes and smaller masses throughout the district: Coronado Mountain on the west in the Pinal-Eagle Creek horst and Copper King ridge on the east in the Malpais-San Francisco horst of the Morenci block. The granite is prominently jointed and sheeted in a northeast to north direction. The joints stand almost vertically and separate the rock into thick ribs, benches, and angular outcrops. Granite forms the country rock into which the Laramide intrusions and related alteration and mineralization were emplaced and contains similar alteration and mineralization to units Tpm and Tpgo.

XYgd Granodiorite (Early or Middle Proterozoic):
Medium- to coarse-grained hypidiomorphic granular granodiorite with hornblende and biotite plus minor apatite and a trace of zircon. The granodiorite is exposed chiefly in the American Mountain area and along the footwall of San Francisco fault directly northeast of Morenci. In the Morenci Pit, the rock is altered and mineralized with feldspars variably altered to mixtures of sericite and minor carbonate, magnetite altered to leucoxene and hornblende altered to epidote, carbonate, and secondary biotite. The age relationship between the granodiorite (XYgd) and the granite (XYg) is not clear. Moolick and Durek (1966) interpreted the granodiorite as younger, but Preece (1984) considered it to be older.

XYd Ferrodiorite (Early or Middle Proterozoic):
Brown to dark grey, medium-grained equigranular quartz diorite or quartz monzodiorite containing clinopyroxene and hornblende (Force, 1998). Orthoclase rims plagioclase and hornblende replaces clinopyroxene in some samples. The ferrodiorite is so named because of the dark, high iron (11.3% Fe_2O_3) content of the rock. Although most outcrop relationships are ambiguous, exposures of this unit crop out on the eastern side of the San Francisco River canyon north of Clifton where they appear to have been intruded by granite of unit XYg. The ferrodiorite may be related to a hornblende-pyroxene diorite found in drill holes below the Morenci pit (Lee, 1994) that is composed of oligoclase altered to sericite, magnetite, hornblende altered to actinolite and carbonates, pyroxene altered to tremolite and carbonates, primary and secondary biotite, and apatite. These rocks may be part of the granodiorite complex in unit XYgd.

EARLY PROTEROZOIC

Xp Pinal Schist (Early Proterozoic):

A wide variety of pelitic to arenaceous metamorphic rocks consisting of sequences of medium- to thick-bedded, cross-stratified and ripple-laminated quartzite interbedded with psammitic to pelitic, varicolored quartz sericite schist. The quartzite sequences comprise less than 30% of the unit. Less than 5% of the unit consists of dark green amphibolite lenses. The unit is invaded by multiple generations of milky quartz veins, both pre- and post-kinematic with respect to the dominant schistosity. The unit is tightly to isoclinally folded with consistent south-vergent folds defined by quartzite sequences in the upper Chase Creek area. Pinal Schist is not known to occur south of the Garfield fault in the Morenci mine area.

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