Resolution Copper Project and Land Exchange
Environmental Impact Statement

USDA Forest Service
Tonto National Forest
Arizona

August 6, 2018

Process Memorandum to File

Geology, Minerals, and Subsidence Resource Analysis: Assumptions; Methodology Used; Relevant Regulations, Laws, and Guidance; and Key Documents

This document is deliberative and is prepared by the third-party contractor in compliance with the National Environmental Policy Act and other laws, regulations, and policies to document ongoing process and analysis steps. This document does not take the place of any Line Officer's decision space related to this project.

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Revision History

Date	Personnel	Revisions Made
08/06/18	Emily Newell	Process memorandum created
10/29/18	Emily Newell	Revisions to memorandum title, revision history table added, edits to purpose of process memorandum section, references and key documents section added
10/31/18	Chris Garrett	Revisions to process memorandum to incorporate information removed from draft environmental impact statement (DEIS) section
11/15/18	Emily Newell	Added list of references, edits to applicability table for laws/regulations
12/26/18	Chris Garrett	Revisions to process memorandum to incorporate information removed from DEIS section
01/15/19	Emily Newell	Process memorandum clean up and adding from DEIS section, verifying all data included in memo
7/12/19	Donna Morey	Update process memorandum to DEIS section
8/4/19	Chris Garrett	Final update for consistency prior to DEIS release
12/23/20	Chris Garrett	Final update for consistency prior to final environmental impact statement release

Purpose of Process Memorandum

In order to provide a concise and accessible summary of resource impacts, certain detailed information has not been included directly in the environmental impact statement (EIS). The purpose of this process memorandum is to describe additional supporting resource information in detail. The geology, minerals, and subsidence section of chapter 3 of the EIS includes brief summaries of the information contained in this process memorandum. This process memorandum covers the following topics:

- Resource analysis area
- Analysis methodology
- Regulations, laws, and guidance
- Key documents and references cited

Detailed Information Supporting Environmental Impact Statement Analysis

Resource Analysis Area

As noted in the EIS, the analysis area for geology, minerals, and subsidence considers the potential direct effects of panel cave mining, the associated recovery of economic minerals, the footprint disturbance of all proposed facilities, and the exchange of Federal lands for private lands.

The potential direct effects of panel caving are associated with the proposed network of shafts and tunnels below the ore body, vertical shafts at the East Plant Site near the Oak Flat Plateau, and the entire zone of anticipated subsidence, from the base of panel caving to the area of modeled surface subsidence. The potential direct effects of proposed facilities and alternative facilities include the direct disturbance footprint of those facilities, including the East Plant Site, West Plant Site, tunnel conveying ore between the plant sites, Magma Arizona Railroad Company (MARRCO) corridor, filter plant and loadout facility, various pipeline and power line corridors, and the proposed and alternative tailings storage facility locations. In addition, the analysis area included the proposed exchange of Federal land for private offered lands currently held by Resolution Copper Mining, LLC (Resolution Copper).

As noted in the EIS, the analysis area also encompasses the potential indirect effects on geology, minerals, and subsidence. Indirect effects are those caused by the action and are later in time or farther removed in distance but are still reasonably foreseeable. Potential indirect effects on geology and minerals could be related to

- the area of groundwater dewatering, which could impact hydrogeological and geotechnical properties, as well as result in additional subsidence;
- the reactivation of geological structures, such as joints and faults directly adjacent to the area of panel caving and subsidence;
- subsidence-related impacts to caves, karst resources, and mine shafts and adits in the project area;
- project-induced local or regional seismic activity; and
- changes to mineral availability as a result of the proposed land exchange, which in some cases may remove land parcels from mineral entry. The analysis area for geology, minerals, and subsidence is generally depicted in section 3.2 of the final EIS (FEIS) in figure 3.2.2-1; note that the analysis of effects may consider regional geology and seismicity beyond the boundaries of the depicted areas.

Analysis Methodology

Approach – Baseline Data

Geological Framework

To identify geological units that occur within the project area, we consulted published U.S. Geological Survey maps and geological mapping data provided by Resolution Copper. The general plan of operations (GPO) (Resolution Copper 2016) and its associated appendices informed our analysis of the underground mining and related subsidence predictions. Several Resolution Copper response packages provided additional key data. SWCA Environmental Consultants requested these data on behalf of the Geology and Subsidence Workgroup (Workgroup), formed by the Tonto National Forest, and detailed in a report by BGC Engineering (BGC Engineering USA Inc. 2018).

With respect to the detailed interpretation of geological units, faults, and structure, the members of the Workgroup had available the complete geological framework model prepared by Resolution Copper; this model was reviewed in person during face-to-face meetings, and Resolution Copper produced specific requested data output from the geological framework model. In addition, the Workgroup had access to the core shed and reviewed select cores upon request (primarily those crossing faults).

Paleontological and Cave Resources

Occurrences of paleontological and cave resources are closely tied to the geological units in which they are contained. The probability of finding paleontological and cave resources can be broadly predicted from the geological units present in the analysis area.

Mining Claims

Resolution Copper prepared detailed inventories of unpatented mining claims upon request from the U.S. Forest Service (Forest Service); these inventories were provided in electronic form (shapefiles) for use in the analysis.

Approach – Subsidence Modeling

As part of the evaluation of potential subsidence impacts, Resolution Copper carried out a numerical assessment of the proposed caving operations, estimated the extent and depth of ground surface subsidence and fracture limits, and evaluated the potential impact to Apache Leap, Devil's Canyon, and the serviceability of U.S. Route 60 (U.S. 60) (Garza-Cruz and Pierce 2017, 2018). Subsidence predictions were based on a 3-D numerical model of the proposed panel caving operation using an industry-standard approach. The numerical model simulated caving and predicted ground surface subsidence, fracture limits, and cave angle. The fracture limit is the outer limit of any potential large-scale surface cracking (or fracturing). The fracture limit consists of an area around the cave crater in which the ground surface could be broken with open tension cracks and rotational blocks. Cave angle was also calculated from the numerical results. Also called the angle of break, cave angle is a key factor in estimating the extent of the surface crater. The model estimates a subsidence cave angle on the order of 70 to 78 degrees, with the cave fractures breaking through to the surface by year 6 of operations. This calculated cave angle compares reasonably well with empirically derived cave angle of 72 to 84 degrees, discussed in BGC Engineering (2018).

Although the fundamental analysis of subsidence was based on the modeling, additional approaches were also considered. In response to the Workgroup review of the modeling, a series of sensitivity model runs was also conducted, as well as various empirical comparisons of the results to real-world examples and conditions.

Approach – Vetting of Geological and Subsidence Modeling

To complete a thorough review of the geological data and subsidence model results, the Tonto National Forest and its contractors formed a Workgroup. The purpose of the Workgroup was to review Resolution Copper's procedures, data, and geological and geotechnical baseline documents to

- determine whether the methods employed by Resolution Copper in collecting and documenting geological data were appropriate, adequate, and according to industry standards;
- determine whether Resolution Copper's interpretations of geological structures, faults, rock properties, geotechnical data, and assumptions are reasonable;
- identify any significant data gaps;
- identify uncertainty with the interpretations with consideration of data gaps; and
- determine whether there are cases in which Resolution Copper's interpretations are not considered reasonable and, if so, provide alternative interpretations and supporting rationale.

During 2017 and 2018, the Workgroup and Tonto National Forest submitted five formal data requests to Resolution Copper and participated in two site visits and seven technical meetings as part of the review. This review is fully documented in "Resolution Copper Project and Land Exchange Environmental Impact Statement: Geologic Data and Subsidence Modeling Evaluation Report" (BGC Engineering USA Inc. 2018).

Based on the results of the model, at the end of the mine life, the fracture limit is predicted to extend to within approximately 1,115 feet (340 meters [m]) from Apache Leap, and to approximately 3,445 feet (1,050 m) from Devil's Canyon (see figure 3.2.4-1 in the FEIS). No damage to Apache Leap, Devil's Canyon, or to the serviceability of U.S. 60 was predicted from caving operations. However, sensitivity analyses completed during modeling indicated that the fracture limit could be directly impacted by reductions in rock mass and fault strength properties, as described in detail in BGC Engineering (2018). Based on the results of the sensitivity analyses, under certain conditions, the extent of the damage zone represented by the fracture limit can approach Apache Leap and U.S. 60. Under these scenarios, localized block failure at Apache Leap, as well as localized damage to U.S. 60, could occur within the influence zone of the block cave. However, no large-scale failures at Apache Leap or damage to U.S. 60 is expected.

After reviewing Resolution Copper's geological data and subsidence modeling, the Workgroup concluded the following:

- All aspects of geological data collection, including drilling, sample recovery, core logging, data management, and laboratory testing, met or exceeded industry standards.
- Resolution Copper's interpretations of geological structures, faults, rock properties, geotechnical data, and assumptions are reasonable.
- Geological data outside of the mineralized zone, as well as for the Camp and Gant Faults, are not as well represented statistically as in the mineralized zone. However, Resolution Copper used conservative modeling assumptions and sensitivity analyses to account for sparse data in these areas.
- There is a great deal of interpretation required throughout the entire process, from data collection to testing and analysis, to model input and interpretations, and sensitivity runs. There are two approaches to consider the certainty of the geological and subsidence models. One approach is empirical, meaning to compare the model results with a conceptual model of cave geometry based on what has been observed at other similar mines with similar geological settings. The other approach is to vary the input parameters to reasonable upper and lower limits to see the resulting cave geometric response (i.e., sensitivity analyses). These two approaches were included in the Workgroup review and are discussed below.
    - For an empirical comparison with other panel cave mines, the Woo et al. (2013) database of cave operations was consulted. Although very few cave operations have been included in that database with depths approaching those at the proposed Resolution Copper Mine site, the model results are generally in agreement with those cases in that database. However, it is important to note that there are uncertainties associated with the use of empirical methods to estimate surface subsidence and cave angle. These include variability in rock mass strength and fault strength properties, and local in-situ stress distribution. A proper assessment of surface subsidence resulting from a caving operation requires detailed geological, structural, geotechnical, and numerical assessments to adequately address these uncertainties.
    - The results of the numerical simulations of the Resolution Copper proposed panel cave were also evaluated. The numerical simulations conducted considered a set of geological, geotechnical, and structural conditions representative of the Resolution deposit and associated geological framework, and used a widely accepted, industry standard numerical tool to predict ground surface subsidence for the Resolution Copper proposed panel cave. Sensitivity analyses were performed to assess uncertainty and variability in several input parameters to the subsidence model. The uncertainties addressed using sensitivity studies included: rock mass global strength and residual strength properties, faults strength properties, in-situ stress orientation and magnitude, and caved rock maximum porosity. The key sources of uncertainties in the predicted surface subsidence relate to geotechnical data and the methodology used in the numerical assessment and are discussed below.

- Rock mass quality and intact rock strength properties: There are uncertainties associated with spatial variability of the rock mass properties, particularly in the Whitetail Conglomerate (Tw) geological unit, which is a relatively weak rock mass and situated immediately below the Apache Leap Tuff (Tal) unit. The uniaxial compressive strength values were derived from point load test data that were completed on core samples obtained from diamond drill cores, where available. Because a limited number of holes have been drilled in the Whitetail Conglomerate unit, the spatial variability of uniaxial compressive strength data could result in uncertainty in estimated global rock mass strength. There is also uncertainty in global rock mass strength in the Whitetail Conglomerate unit due to uncertainty in applying geological strength index (GSI) to this unit. Application of GSI to the Whitetail Conglomerate unit implies that there are three joint sets in the rock mass. The rock mass structure assessment, however, only indicated one joint set in the Whitetail Conglomerate unit; hence, GSI is underestimated and results in low global strength for this rock unit.
- Fault strength properties: Fault strength properties have been estimated based on infill characteristics, and as such, have been classified as strong, medium, or weak. Fault infill characteristics have been provided by Resolution Copper geologists and are mainly based on detailed logging of core and mapping of fault exposures on the surface. Considering the limited amount of core and mapping data available, compared with the extent and depth of the faults that have been identified within the Resolution project area, there is uncertainty associated with the fault characterization and the associated material properties assigned to each fault category. This is even more critical in the case of faults that are positioned near the perimeter of the subsidence crater and fracture limit.
- Fracture limit criterion (total strain limit at 0.5 percent): Determination of fracture limits numerically in Flac3D is directly dependent on the fracture limit criterion used. This criterion is empirical and has been validated by its successful application to other cave operations. Numerical results also have shown that total predicted strain may vary locally but significantly. The empirical nature and total strain sensitivity create a level of uncertainty in the predicted total strain and the resulting fracture limit. At this time, there is no explicit way to calibrate the model and to refine the fracture limit criterion to address this uncertainty.
- Critical plastic strain threshold as a criterion to reduce peak rock mass strength to residual: An empirically calculated critical plastic strain has been used in Flac3D to determine at what stage peak rock mass properties are reduced to residual strength within the fracture limit. Resolution Copper has developed an empirical relationship between critical plastic strain and GSI and estimated the critical plastic strain based on the calculated GSI for each rock mass domain. Considering that the GSI assigned to the Whitetail Conglomerate unit is conservative, as discussed earlier, this introduces a level of uncertainty into the calculated critical plastic strain used in the model, which could impact the extent of fracture limits predicted by the subsidence model.
- Resolution Copper's interpretations of subsidence are reasonable; therefore, the Workgroup did not propose any alternative interpretations. But there are numerous input variables and several layers of interpretation involved in the modeling of surface subsidence. Therefore, as

described above, there are several areas of uncertainty and some areas of sparse or low-confidence data; actual surface subsidence could vary from the modeled results.

The Workgroup considered several assumptions and damage criteria in the numerical assessment. These assumptions and damage criteria impact numerical results and predicted subsidence either directly or indirectly and could result in further extending the subsidence zone (conservative material properties) or reducing the extent of subsidence zone (cave limit and fracture limit criteria). There are also limitations in the geological and geotechnical data that affect the reliability of the interpreted material properties for rock domains and structures (faults/fault zones). The Workgroup reviewed these assumptions, damage criteria, and limitations in detail (BGC Engineering USA Inc. 2018). The conservativeness of the key rock mass domains (Whitetail Conglomerate and Apache Leap Tuff units) was also assessed by back analysis and comparison of the ground deformations as predicted from the numerical model with those measured by underground instruments collected during the construction of Shaft No. 10.

Status of Geology and Subsidence Workgroup

The Workgroup report referenced in the draft EIS (DEIS) was a draft document (BGC Engineering USA Inc. 2018a). The Forest Service reconvened the Workgroup after receipt of public comments on the DEIS in order to help evaluate and review comments and develop necessary analysis in response to the comments. The results of the reconvened workgroup are described in the FEIS and contained in the final workgroup memo (BGC Engineering USA Inc. 2020).

Detailed Information on Geological Framework and Geological Units

The description of the regional geological framework and geological units contained in the EIS is abbreviated and intended to provide a basic overview with limited technical jargon in order to inform the analyses contained in the EIS, particularly the subsidence and groundwater modeling analyses. A more complete and technical-oriented discussion is contained here.

Regional Geology

The Resolution Copper Project and Land Exchange is in south-central Arizona at the northeastern edge of the Basin and Range physiographic and seismotectonic province, close to the boundary with the Transition Zone of the Colorado Plateau. The region is dominated by northwest-southeast and north-south normal faults, creating a structural grain with these orientations (Wong et al. 2013). The Basin and Range physiographic province is generally characterized by a series of fault-block mountain ranges separated by broad valleys filled with geologically young alluvium. The northeastern edge of the Basin and Range province is a mountainous region of the Transition Zone called the Central Highlands that borders the Colorado Plateau province. This mountainous region consists of belts of generally linear ridges and valleys in which the rugged ranges predominate over the valleys. This is different from the Basin and Range province (including the western portion of the project area), where there are broad valleys separated by relatively narrow mountain ranges. As a result, the project area includes a combination of the gentler terrain of the Superior Basin to the west and the rugged mountainous terrain (the Superstition, Dripping Spring, and Pinal Mountains) to the north and east. Elevations within the project area range from 1,520 feet above mean sea level (amsl) at the west end of the MARRCO corridor to 4,648 feet amsl at Apache Leap.

- The eastern part of the project area, including the East Plant Site and the Resolution copper-molybdenum deposit, encompasses the rugged Oak Flat Plateau (at an elevation of approximately 4,000–4,600 feet amsl), which is part of one of the easternmost Basin and Range mountain ranges, located just east of the town of Superior. The Oak Flat Plateau's eastern edge is delineated by Devil's Canyon, and its western edge is the prominent Apache Leap escarpment. Its high peak is approximately 4,760 feet in elevation (amsl) and overlooks the town of Superior. The western portion of the project area, including the West Plant Site and the Near West tailings storage facility, lie in the Superior Basin. The topographic relief is generally low, but local mountain ridges of eroded fault blocks protrude from beneath younger, gently dipping basins of Quaternary alluvium. Queen Creek (the main drainage in the project area) originates in the Oak Flat Plateau, cuts a deep canyon through the Apache Leap escarpment, and flows west to southwest through the town of Superior and into the Superior Basin. Elevations in the Superior Basin, near the proposed Near West tailings storage facility, range from approximately 2,240 feet amsl in the southwestern portion to 2,920 feet amsl in the northeast. A distinctive landform immediately south of the project area in the Superior Basin is Picketpost Mountain, a Tertiary-aged volcanic vent complex that forms an isolated erosional butte with a peak elevation of 4,378 feet amsl.

Regional Geological Units

Previous researchers and Resolution Copper have mapped the geology of the project area in several Arizona Geological Survey quadrangles and the surrounding mining district. The most recent detailed geological map is adapted from Hart (2016) (figure 1; a full-size version of this map is also included as attachment 1 to this process memorandum). Hart (2016) incorporates years of Resolution Copper's mapping of lithology and structures to refine J. Spencer's original geological map (see figure 2.2-5b in the GPO) (Resolution Copper 2016; Spencer et al. 1996). Table 2.2-1 in the GPO (table 1 below) (Resolution Copper 2016) provides a key to the geological mapping units that have been generalized and the identifiers for those units used in the GPO (Peterson 1969; Spencer and Richard 1995; Spencer et al. 1996). A summary of the main geological units from oldest to youngest is presented below; these are intended to be used in conjunction with table 1 and figure 1/attachment 1. The abbreviations of the most common mapping units are included below.

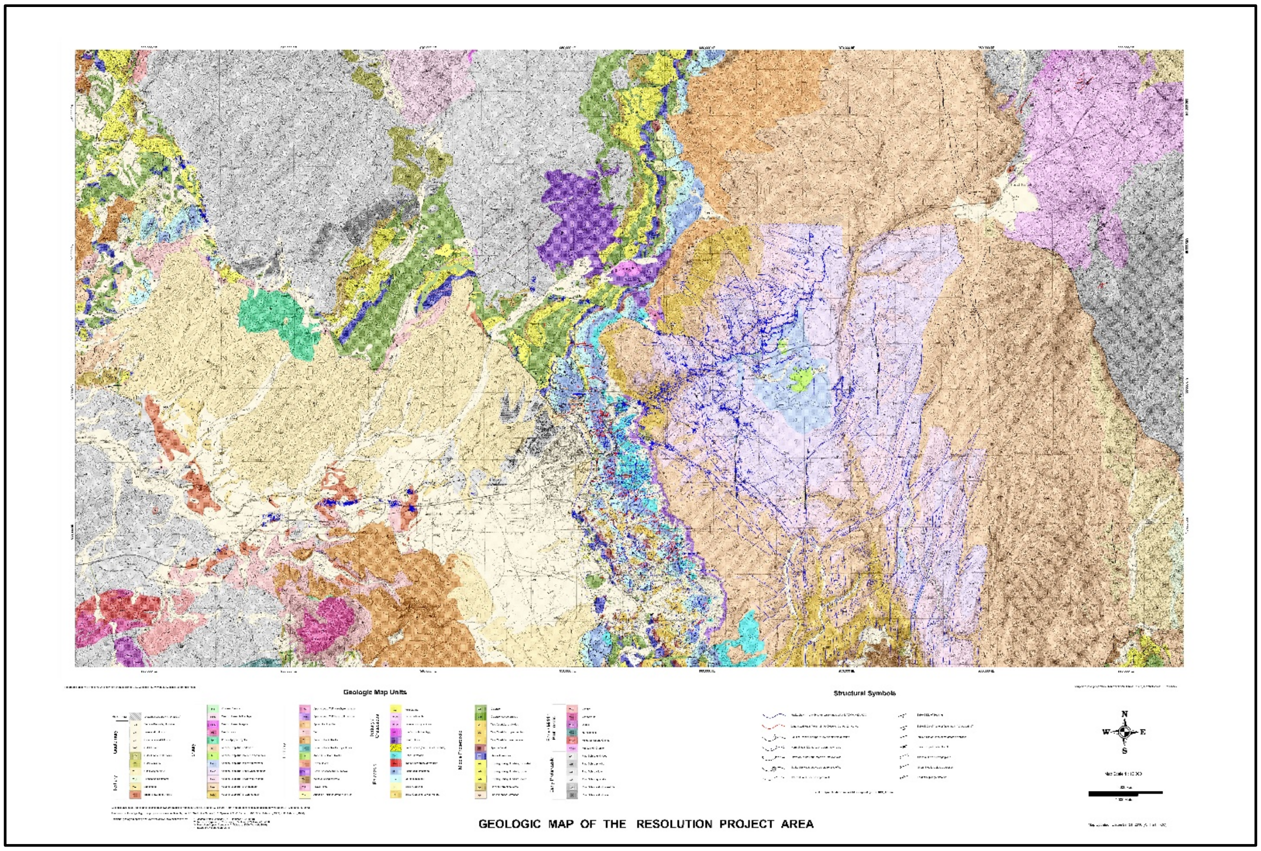

Figure 1: Geological map of the project area.

Table 1: Generalized Geological Units

Unit used for EIS Analysis	Map Unit from Spencer et al. (1998)	Map Unit from Spencer and Richard (1995)	Map Unit from Ferguson and Skotnicki (1996)	Map Unit from Peterson (1969)	Description
d	d	d	d	Qf	Disturbed surficial deposits
Qal	Qy, Qyc	Qal	Qa	Qal	Active stream channel alluvium
Qal	Ql, Qm, Qml, Qo, Qtc, Qly	Qs, Qtc, Qoa	Qao	QTg	Older alluvial fan and terrace deposits
QTg	QTl	Qls, QTls, QTs	–	Qt	Landslide deposits
QTg	Tch	Tx	–	–	Chaos: mixed units
QTg	Tcu, Tsu	Tcg, Tss	Tq	QTg	Conglomerate and sandstone (Gila)

Unit used for EIS Analysis	Map Unit from Spencer et al. (1998)	Map Unit from Spencer and Richard (1995)	Map Unit from Ferguson and Skotnicki (1996)	Map Unit from Peterson (1969)	Description
QTg	Tsm	–	–	QTg	Sandstone and conglomerate interbedded with volcanics
Tal	Tal	Tal	Ts, Tbb, Tsf, Tsl, Tsp, Tsm, Tsh, Tsx, Tsxg,Trx, Tcp, Tcpu	Tal	Apache Leap Tuff
Tvu (includes Tvy and Tvo)	Tb, Tt, Tfp, Tfpt, Tfpi	Tb, Tvx, Tql, Tp, Tr, Tt, Tf, Tdb	Tqb, Teb, Tbb, Tfu, Tful, Tdx, Tru, Trut, Tfi, Tfl, Tdl	QTb	Gila Group volcanic and intrusive rocks and equivalent units (younger than Apache Leap Tuff)
Tvu	Trdu, Trdt, Trw, Tdm	Tf, Tt, Tfp, Tfa, Tbl, Tdf, Tda, Tdb	Trd, Tdx, Tr, Tdl, Tau, Tal, Trdl, Ttq, Tt, Ta, Tbcg, Tb, Tdu, Tdub, Tduv	–	Superstition Group volcanic rocks and equivalent units (older than Apache Leap Tuff)
Tvu	Tev	–	–	Tr	Older volcanic rocks, eastern area
Tw	Tsl	Tw	Tc, Tx	Tw	Whitetail Conglomerate
TKg	Tg2	Tg	–	qmp, qma	Granitoid stock of Wood Camp Canyon
TKg	TKpg	–	–	qmp, qma	Quartz monzonite porphyry of Government Hill
TKg	Th	–	–	—	Hypabyssal intrusive rocks
TKg	TKdd	–	–	—	Dacite dikes
TKg	Kqd	Kd	–	qd, dp	Diorite porphyry and quartz diorite

Unit used for EIS Analysis	Map Unit from Spencer et al. (1998)	Map Unit from Spencer and Richard (1995)	Map Unit from Ferguson and Skotnicki (1996)	Map Unit from Peterson (1969)	Description
Pz	PPn, MCs, Cb	Me, Dm, Cb	–	Pn, Me, Dm, Cb	Naco Limestone, Escabrosa Limestone, Martin Formation, and Bolsa Quartzite
pCy	Ytd, Yta, Yt	–	–	pCt	Troy Quartzite, diabase, and Apache Group sedimentary rocks
pCy	Yd, Yad, Ya	Yd, Ym, Yds, Ydsu, Ydsl, Yp, Ypt	Ya, Yd, Yb, Ym, Yp-q, Yq, Yc, Yr, Yp, Ys	db, pCb, pCm, pCds, pCp	Diabase and Apache Group sedimentary rocks
pCgu	Yg2	–	–	–	Biotite granite porphyry
pCgu	Xgd, Xd, Xh	YXg, YXd, YXgd, YXgm	YXq, YXg, YXge, YXd, Yxv	–	Madera Diorite
pCpi	Xp, Xpp, Xpc	Xp, Xps, Xpm, Xpc, Xpcs, Xpq, Xpp	Xp, Xpa, Xpc, Xpq	pCpi	Pinal Schist

The oldest rock unit in the project area is the Precambrian Pinal Schist (Xp), which is approximately 1.7 billion years old (Ga). Early to middle Proterozoic intrusions include granite, granodiorite, diorite, horblendite, and mixed schist/granite. Lying unconformably on the Pinal Schist are middle Proterozoic (1.6 Ga) Apache Group units, from oldest to youngest: the Pioneer (Shale) Formation, Dripping Springs Quartzite, Mescal Limestone, and localized unnamed basalt flows. The younger (1.1 Ga) Troy Quartzite unconformably overlies the Apache Group, and similar-aged diabase sills and dikes intrude all the older sedimentary units. The presence of Late Cenozoic basin-fill sediments and volcaniclastics on top of the Precambrian rocks throughout the project area indicates widespread Tertiary volcanism in the region. These rocks underlie the entire project area but are exposed only in the western portion of the Superior Basin.

Unconformably overlying the Precambrian units are sequences of conformable Paleozoic sedimentary formations that include, from oldest to youngest: Bolsa Quartzite (Cb), the Martin Formation (Dm), Escabrosa Limestone (Me), and Naco Limestone (Pn). These are Cambrian (541 million years old [Ma]) to Pennsylvanian (299 Ma) in age and they are well exposed in the range front of the Apache Leap escarpment east of the town of Superior.

Laramide (Cretaceous-Tertiary) volcanic and plutonic activity is expressed in the project area with felsic intrusions (like the Silver King quartz diorite north of the town of Superior: Kqd); diorite to dacite sills, dikes and stocks (Kdp); and granite dikes and stocks (TKsg). Thick sequences of Cretaceous andesitic to felsic volcanoclastic rocks (Kvs) and quartzose sandstone (Kqs) have been observed in drill cores within the graben that hosts the Resolution deposit, but these units do not outcrop at the surface. The volcanoclastic sediments date to 74 to 64 Ma and are up to 1 kilometer (km) thick (Kloppenburg 2017).

Dating from the middle Tertiary (Oligo-Miocene, 24–22 Ma), the Whitetail Conglomerate consists of non-volcaniclastic conglomerate and sandstone, with lesser amounts of sedimentary breccia, mudstone, and minor volcanic flows that were deposited after copper mineralization. These units comprise an eastward-thickening wedge of coarse basin fill within the graben, up to 1.5 km thick, bounded on the east by the Devil's Canyon Fault. Overlying the Whitetail Conglomerate is the Miocene (18.6 Ma) Apache Leap Tuff that is a dacitic welded ashflow tuff that caps the Apache Leap escarpment and much of the Oak Flat Plateau (McIntosh and Ferguson 1998). The Apache Leap Tuff is volumetrically the most significant Tertiary formation and is mapped as eight separate units. The slightly younger middle Tertiary (18.4 Ma) Gila Conglomerate (Tcg) consists of coarse gravel, cobbles and boulders, many of which are derived from the Tertiary volcanics; the formation outcrops predominantly on the west side of the Concentrator Fault in the Superior Basin.

Quaternary deposits generally lie unconformably on top of near-surface rock formations. They consist of recent and near-recent stream deposits in basins, fans, terraces, floodplains, and channel deposits, as well as landslide and colluvial deposits. Particles range in size from clay, silt and sand to gravels, cobbles and boulders. These deposits are unconsolidated and may be weakly to strongly cemented by calcite (i.e., caliche deposits). An extensive, relatively young formation in the project area within the Superior Basin, such as at the West Plant Site and the tailings storage facility, are the Quaternary and Tertiary Basin-Fill Deposits, mapped as QTg on the GPO geological map (Resolution Copper 2016) (figure 2.2-2 of the GPO). These are mapped by Hart (2016) as Gila Conglomerate, so it appears that this mapping unit consists of both the Gila Conglomerate and valley fill deposits derived from this formation.

Structural Geology and Faults

The present-day geomorphology of the project area and immediate surrounding area can be attributed to north- to northwest-trending, down-to-the-west, Basin and Range–style normal faults with Tertiary to Quaternary movement (Hehnke et al. 2012). These include the Concentrator, Main, and Conley Springs Faults. The Concentrator Fault, which strikes generally north-northwest and dips to the west, displaces the Magma vein to an unknown depth and defined the west limit of production in the Magma Mine. The Superior Basin is formed by a large east-tilting block bounded by the Elephant Butte Fault to the west and the Concentrator Fault to the east. The Elephant Butte Fault is a major west-side-down normal fault that is located along the west side of Gonzales Pass and crosses Queen Creek east of Queen Valley near Whitlow Ranch Dam (Ferguson and Skotnicki 1996). The Resolution copper-molybdenum deposit is located in a graben structurally bounded by normal faults (known as the Resolution Graben). Regional extension, normal faulting, and tilting ended after Tertiary volcanism and during the deposition of Gila Conglomerate and Sandstone (Spencer and Richard 1995).

The project area has undergone multiple episodes of folding and faulting dating to the Precambrian. Two orogenic events that influenced the structural development of the project area are the Late Sevier/Early Laramide Orogeny (starting 64 Ma), which caused northeast-southwest crustal shortening and the Basin and Range extension (starting 22 Ma) resulting in east-west extension (Kloppenburg 2017). The northeast- to east-northeast-trending structural fabric in east-central Arizona is indicated by the dominant foliation in Pinal Schist, the northeastern trend of the 1.4 Ga Ruin Granite, and regional-scale magnetic anomalies (Hehnke et al. 2012). This trend is also reflected in the orientation of most veins in the area, the distribution and elongation of Laramide intrusions, and the orientation of thrust faults, folding, and reverse faults typical of Laramide-aged deformation. At least 5,900 feet of down-to-the-west movement along Devil's Canyon and related faults generated a basin filled with Whitetail Conglomerate and rotated a large graben block encompassing the Resolution deposit (as defined by the 1 percent copper shell).

Local Geology of Mine Area and Associated Infrastructure

The local geology of the project area, including the proposed mine area and mineral deposit, is described in detail in Hehnke et al. (2012), Resolution Copper (2016), and Kloppenburg (2017). Some descriptions of units described above are described in more detail in this section for their importance to the near-deposit geology, including subsidence and groundwater modeling. A simplified geological cross section is shown in figure 3.2.3-2 of the FEIS, as well as in figures 2 and 3 below.

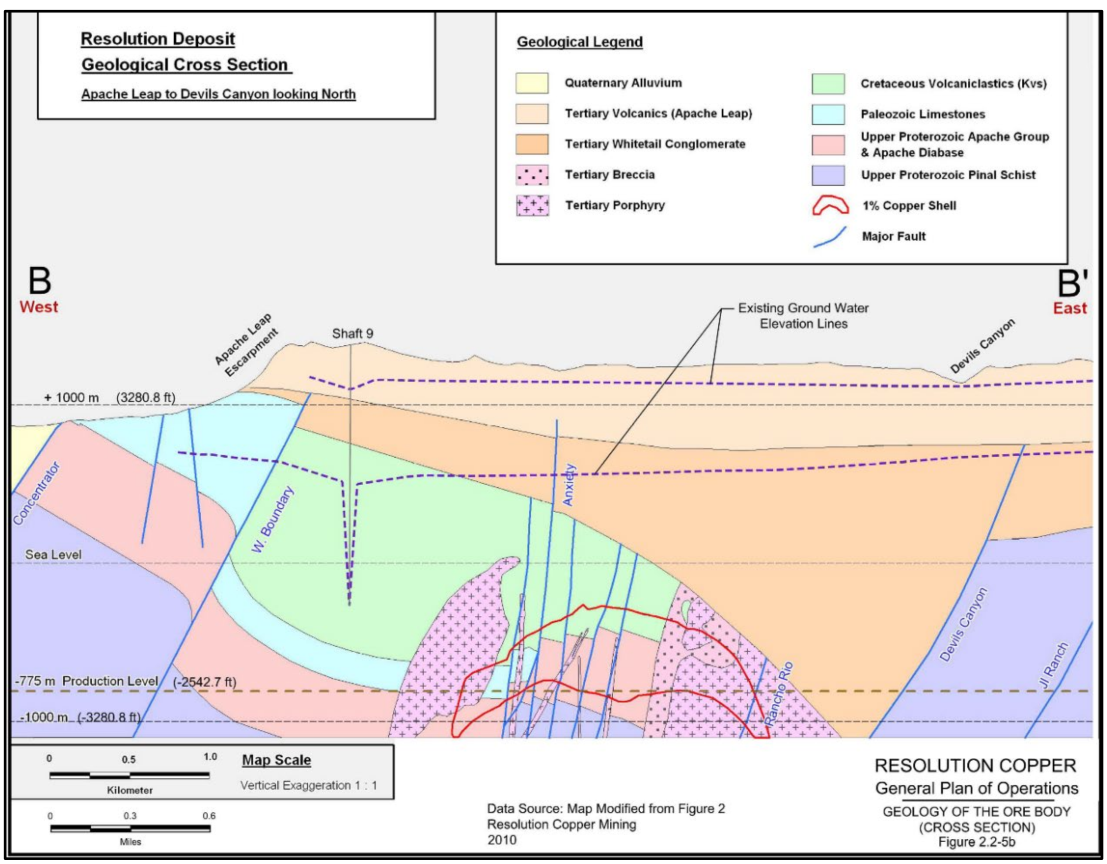

Figure 2: A simplified geological cross section of the project area, including the proposed mine area and mineral deposit (taken from GPO, figure 2.2-5b).

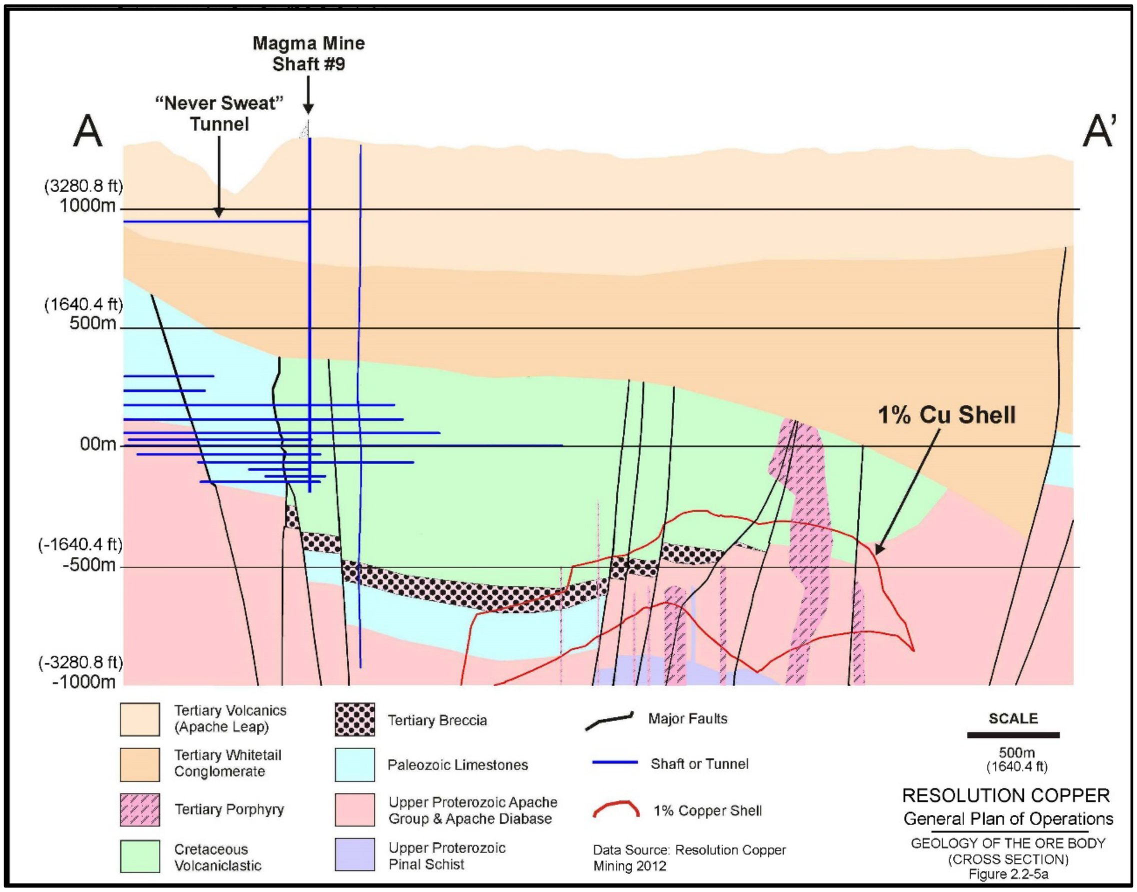

Figure 3: A simplified geological cross section of the project area, including the existing Magma Mine underground workings and depth below surface (taken from GPO, figure 2.2-5a).

As depicted in figures 2 and 3, the oldest rock unit in the area of the proposed mine is the Precambrian-age Pinal Schist, which at Resolution occurs at depths below the base of known copper mineralization. Unconformably overlying the Pinal Schist is the Proterozoic-age Apache Group, which includes a sequence of meta-sedimentary units and volcanic flows. The Apache Group sequence is intruded throughout by extensive diabase sills, which is an important host rock for copper mineralization at Resolution (Hehnke et al. 2012).

Overlying the Apache Group are a series of Paleozoic-age sedimentary rock units, including the Bolsa Quartzite, and carbonate rocks of the Martin Formation, Escabrosa Limestone, and Naco Limestone. Although these Paleozoic units are extensively present in the range front west of Resolution, they are partly eroded within the Resolution deposit graben itself and missing entirely in some sections of the deposit (Hehnke et al. 2012).

Cretaceous quartz-rich sandstone and an overlying volcaniclastic sequence are found within the graben that hosts the Resolution deposit (see figures 2 and 3) but are not found elsewhere in the project area. The thickness of both of these units increases toward the adjacent faults and provides evidence that deposition occurred during active tectonics within a fault-bounded graben

(Kloppenburg 2017). These Cretaceous sediments and volcaniclastic and volcanic rocks host the uppermost portion of copper mineralization.

Late Cretaceous–early Tertiary intrusive rocks, attributed to the Laramide Orogeny, are hosted in a 3,000-foot-wide east-northeast-trending corridor that runs through the center of the deposit. These felsic rocks host a portion (approximately 15 percent) of the copper mineralization and are predominantly pre- to early-mineralization in age. The largest volumetric unit is a rhyodacite porphyry that forms two stocks. The largest stock occurs in the eastern part of the deposit and a smaller stock is recognized in the western part of the deposit (Resolution Copper 2017). In the same corridor as, and related to, these felsic intrusive rocks are hydrothermal and intrusion breccia units, which host approximately 10 percent of the mineralization.

Overlying the Resolution deposit, and post-dating mineralization, are the two notable middle-Tertiary–age rock units, the Whitetail Conglomerate and the Apache Leap Tuff. The Whitetail Conglomerate forms a northeast-thickening succession of predominantly poorly sorted conglomerates that may be up to 4,300 feet thick. It is relatively thin and locally absent in the range front, but over the Resolution deposit it has deeply filled an early Basin and Range graben (Kloppenburg 2017). Overlying the Whitetail Conglomerate, and volumetrically the most significant Tertiary unit, is the Miocene-age Apache Leap dacitic welded tuff. It is largely formed by volcanic ash flows and forms the prominent Apache Leap escarpment. The area of projected surface subsidence is characterized entirely by the Apache Leap Tuff, which forms a prominent volcanic plateau that covers the Resolution project area (see figures 2 and 3). The geotechnical properties and characterization of the rock mass used to predict caveability, cave fragmentation, cave flow, the extent of subsidence and the impact on mine infrastructure (shafts), are detailed in a Geotechnical Rock Mass Characterization Report (Resolution Copper 2017).

The primary faults in the Resolution deposit area are the faults that bound the Resolution block or graben (Resolution Graben). These are the North, South, and West Boundary Faults, the Rancho Rio Fault, and the eastern part of the Conley Springs Fault. Most faults within the Resolution block itself strike north to north-northeast, dip steeply west, and show west-side-down displacement. None of the northerly trending faults defined within the Resolution Graben appear to extend beyond the graben-bounding faults (Resolution Copper 2017). These faults are not presently contributing to the seismic hazard in the project area (Wong et al. 2018).

Mineral Deposit

The mineralization in the Resolution deposit is characterized by an approximately 64 Ma porphyry copper-molybdenum deposit, located at depths of approximately 4,500 feet to 7,000 feet below the ground surface, and is generally defined by a 1-percent copper shell, which extends over an area of at least 1.2 miles in an east-northeast direction and 0.9 mile in a north-northwest direction (see figures 2 and 3). A detailed description of the deposit and associated mineralization is included in Hehnke et al. (2012).

Rock types with diabase, limestone, and local breccia host and control the strongest copper mineralization. Quartz-rich sedimentary rocks and Laramide intrusive rocks demonstrate the strongest molybdenum mineralization. The highest copper grades (greater than 3 percent) are located in the upper central portion of the deposit associated with a large breccia body and hosted primarily in breccia and the upper diabase sill. Locally, copper grades of 1 to 3 percent are present in all rock types, with the exception of the Pinal Schist. The location and geometry of the mineralization are structurally controlled by several generations of pre-mineralization, syn-mineralization, and post-mineralization faulting. The mineral deposit is tilted approximately 25 degrees to the east-northeast, but not significantly faulted by Tertiary Basin and Range extension (Kloppenburg 2017).

Chalcopyrite is the dominant copper mineral in the deposit, with lesser chalcocite and bornite. Molybdenum occurs primarily as molybdenite. The deposit is associated with hydrothermal alteration and includes a strong pyrite "halo" in the upper areas of the deposit, containing 7 to more than 14 percent pyrite.

Tailings Storage Facility Area – Alternatives 2 and 3

The proposed tailings storage facility site for Alternatives 2 and 3, known as the Lower West or Near West site, is located approximately 3 miles west of the town of Superior and 3 miles east of the community of Queen Valley, between Roblas Canyon on the west and Potts Canyon on the east, and includes parts of the Bear Tank Canyon and Benson Spring Canyon watersheds.

The majority of the bedrock in the central tailings storage facility area is Tertiary Gila Conglomerate. Older Precambrian Pinal Schist (pCpi) underlies the southwestern and northeastern portions of the tailings storage facility. In the northwestern part of the tailings storage facility, surface geology includes younger Precambrian sedimentary rocks, basalt, and diabase (pCy); Paleozoic sedimentary rocks (Pz); and Tertiary Apache Leap Tuff. Tertiary volcanic rocks (Tvy), including an area of perlitic rhyolite and tuff, form a small section of the surface geology in the eastern part of the tailings storage facility. Quaternary alluvial deposits are present along the washes (Resolution Copper 2016), separated by a series of parallel ridges that formed from the differential erosion of a tilted fault block dipping to the southeast (Spencer and Richard 1995).

Structural geology at the Near West site is mainly characterized by extensional faulting that occurred during the Oligocene-Miocene epochs, from northeast to southwest; the greatest movement (approximately 5 km of horizontal extension) is concentrated on the west-dipping Concentrator Fault and southwest-dipping Roblas Canyon Fault. Most extensional faulting was completed prior to deposition of the Gila Conglomerate and Gila Sandstone, though these units exhibit some tilting to the southeast of the Roblas Canyon Fault (Spencer and Richard 1995).

Two faults that may have been active during the Quaternary have been identified (Menges and Pearthree 1989). The first is approximately 5 miles long and is approximately 30 miles northwest of the proposed Near West site, trending northwest-southeast; this fault may have experienced displacement within the past 20,000 years. The second is approximately 4 miles long, located approximately 15 miles southeast of the proposed Near West site, and trends north-south. Displacements may have occurred on this second fault within the last 150,000 years; however, seismic hazard at this site is low. Short period ground motions are controlled by background seismicity not associated with a specific known fault, and longer period ground motions (similar to most large earthfill structures) are controlled by the distant San Andres Fault, which is located approximately 250 miles from the site (Wong et al. 2017).

Resolution Copper has completed geotechnical investigations at the Near West site (Golder Associates Inc. 2017; Klohn Crippen Berger Ltd. 2017). Observed surficial soils include Recent Alluvium, composed of uncemented sand and gravel; Old Alluvium, composed of partially cemented gravel with sand, silt, and clay; Old Lacustrine soils, composed of intermediate plasticity clay and silt with some sand; and Undifferentiated Quaternary Deposits, characterized by poorly sorted clay, silt, sand, and gravel.

Findings from site investigations (Klohn Crippen Berger Ltd. 2017) and other studies (Klohn Crippen Berger Ltd. 2018a, 2018b) at the Near West site include the following:

- Units with zones exhibit weak foundation conditions. These include zones with weak clay layers (Old Alluvium, Gila Sandstone, tuff), zones of potentially collapsible soils (Old Alluvium, Gila Sandstone, Gila Conglomerate, diabase), and weakness parallel to foliation (Pinal Schist).
- Dissolution features such as voids and open joints are present in the Proterozoic Mescal Limestone, particularly near the contact between the limestone and the intruded diabase. Resolution Copper has noted open joints in the Gila Sandstone, Gila Conglomerate, Tertiary Tuff, Tertiary Rhyolite, and Proterozoic Dripping Springs Quartzite. A single high-angle fault with approximately 6 feet of normal displacement was observed in the Gila Conglomerate. Heavy fracturing was observed in the Pinal Schist.
- Hawks Claw Cave is located northwest of the site.
- An abandoned mine, Bomboy Mine, is within the southwest corner of the tailings storage facility.
- Perlite Spring, located in perlitic rhyolite in the northeastern part of the site, is not a natural spring, and is formed by an impoundment located at the base of a former perlite quarry.

Tailings Storage Facility Area – Alternative 4

The Silver King Alternative tailings storage facility site is approximately 1.9 miles from the West Plant site (straight line distance, mill to center basin) and would occupy the lower end of Silver King Canyon in the Silver King Wash, the lower portion of Whitford Canyon (downstream of Reavis Trail Canyon and upstream of Potts Canyon) and Peachville Tank (which drains into Whitford Canyon). The regional groundwater at the Silver King site flows from northeast to southwest, draining to Potts Canyon or Queen Creek.

Historical mining and exploration have taken place within or near the Silver King tailings storage facility site, though the tailings storage facility footprint has been designed to avoid existing mining operations at the Silver King Mine itself (Klohn Crippen Berger Ltd. 2018c), which is 0.7 mile east of the site; the Silver King Mine workings are not expected to extend within the footprint of the tailings storage facility. Silverona Mine, Fortuna Mine, Black Eagle Mine, and “Unnamed Mine” are located near or in Peachville Wash. Also, the McGinnel Claim is at the intersection of the Main and Concentrator Faults, approximately 0.5 mile north of the Silver King Wash, and within the footprint of the scavenger tailings.

Abandoned mine workings within the tailings storage facility footprint could collapse beneath the tailings piles (Klohn Crippen Berger Ltd. 2018c), but their extent is not currently known.

The Silver King tailings storage facility site is approximately 5 miles northeast and upstream of the Near West site and therefore shares similar foundation geology. The majority of the bedrock in the central Silver King tailings storage facility area is Precambrian Pinal Schist. The scavenger tailings footprint is also underlain by Apache Group units (e.g., Dripping Spring Quartzite, Mescal Limestone), Bolsa Quartzite, and Tertiary volcanic rocks. An expanse of quartz diorite is located in the northeast corner of the tailings storage facility. Unconsolidated Quaternary alluvial deposits are confined to ephemeral drainages.

Tertiary Gila Conglomerate and Tertiary tuff underlie the external water collection ponds located south of the scavenger tailings, and the pond located to the west is founded on Apache Group quartzite. The slurry ponds south of the scavenger tailings are mostly founded on Gila Conglomerate. The pond to the west of the pyrite tailings is founded on landslide deposits (correlated to weak foliation in the Pinal Schist by Klohn Crippen Berger Ltd. (2018c)) and Pinal Schist.

The upstream diversion dam located west of the pyrite tailings is founded on Tertiary Granite, Pinal Schist, and Quaternary alluvial deposits. The diversion dam located east of the scavenger tailings is founded on Pinal Schist, diabase, and quartz diorite.

The Concentrator, Main, and Conley Springs Faults cross the Silver King site, but these faults have been observed to be healed, and are considered low-permeability boundaries (Cross and Blainer-Fleming 2012). Additionally, these faults are not believed to be active within the Quaternary (2.6 Ma to present) (Wong et al. 2017) and therefore do not present a concern for the Silver King tailings storage facility. In the absence of a site-specific hazard analysis for the Silver King site, Near West seismicity is considered to apply to the Silver King site as well.

No site-specific geotechnical investigations have been performed at the Silver King tailings storage facility site. In general, many of the site characteristics at Silver King are anticipated to be similar to the Near West site, where geological units are the same. One major difference noted by Klohn Crippen Berger Ltd. (2018c) is the presence of potentially liquefiable (e.g., loose granular deposits that are saturated or will become saturated) soils in the Quaternary alluvium and landslide deposits.

Tailings Storage Facility Area – Alternative 5

The Peg Leg Alternative tailings storage facility site is located approximately 15 miles south of the West Plant Site (straight line distance, mill to center basin) and south of the Gila River on the gently sloping western flanks of the Tortilla Mountains and bounded by the Gila River to the east and north and by Donnelly Wash to the southwest and west (Golder Associates Inc. 2018a). The site is located at lower elevation relative to the plant location (elevation difference between 590 feet and 624 feet).

Regional geology data show the site to be on unconsolidated to weakly consolidated alluvial fan, terrace, and basin floor deposits. Locally, the site is divided into two major regions: (1) an eastern area, where the pyrite tailings facility will be located, founded on granitic bedrock; and (2) a western area, where the scavenger tailings facility will be located, founded on alluvial deposits, including some travertine near the western boundary of the project site (Golder Associates Inc. 2018a). The presence of travertine may indicate that shallow perched groundwater zones exist. Granitic rocks at the site include Precambrian Ruin Granite and Tertiary Tea Cup Granodiorite.

Current foundation characterization for the Peg Leg site is based on surficial geology mapping, site reconnaissance, geophysical surveys (electrical resistivity, refraction seismic surveys, and gravity surveys), local well logs, and regional literature (Golder Associates Inc. 2018a).

Fracture zones have been mapped on the bedrock surface near the Peg Leg tailings storage facility site, but there are no known active seismic features in the vicinity. Seismicity is substantially different from the Near West site, 20 miles to the northwest of Peg Leg. Previous research suggests that the main difference is related to the deep alluvial deposits at Peg Leg. Therefore, in the absence of a site-specific hazard study, Golder Associates Inc. (2018) estimated ground motion parameters for both deep alluvium and rock foundation conditions at Peg Leg.

We anticipate that groundwater at the Peg Leg site is present in shallow fracture zones in bedrock and at greater depths in alluvial aquifers. We also expect that it ranges from less than 50 feet below ground surface in fractured bedrock to several hundred feet near the center of the Donnelly Wash Basin. Groundwater likely follows the ground surface topography and flows to the northwest (Golder Associates Inc. 2018).

Further, we expect that the Precambrian Ruin Granite and Tertiary Tea Cup Granodiorite have low permeability and high strength. However, well logs in the tailings storage facility area reviewed by Golder Associates Inc. (2018) indicate that the granitic bedrock may be highly decomposed and weathered in areas, even to significant depths, which could indicate higher permeability and lower strength in these areas.

Tailings Storage Facility Area – Alternative 6

The Skunk Camp Alternative tailings storage facility site is in the Dripping Springs Wash Basin, approximately 13 miles upstream of its confluence with the Gila River (Klohn Crippen Berger Ltd. 2018e). The facility is bounded on the west by the Dripping Springs Mountains and to the east by the Mescal Mountains and Pinal Mountains. There are no known historic-era mines within the Skunk Camp tailings storage facility footprint, but the Ray Mine, Troy Mine, Dripping Springs Mine, and Christmas Mine are within 5 to 15 miles of the site (Klohn Crippen Berger Ltd. 2018e).

Basement rock in the Skunk Camp area is Precambrian Pinal Schist overlain by Precambrian Apache Group units (e.g., Dripping Spring Quartzite, Mescal Limestone), Troy Quartzite, and diabase (Klohn Crippen Berger Ltd. 2018d). Pre-Tertiary rocks in the area are deformed due to tilting and faulting along steep normal faults, which has produced graben features with as much as 2,000 feet of displacement. The Dripping Springs Wash runs through such a graben, which is infilled with Tertiary Gila Conglomerate. The Gila Conglomerate is estimated to be over 1,500 feet thick in some locations and is the most prevalent rock unit at the site. Quaternary pediment and alluvium partially cover the conglomerate and form erosion surfaces, ridges, and valley infill deposits. Occasional travertine deposits have been observed in valley walls.

The Skunk Camp site is located approximately 19 miles from the Near West site and much of the work (i.e., geotechnical, hydrogeological, seismic) performed for the Near West site was used to inform the Skunk Camp tailings storage facility design in the absence of other geotechnical data. Similar to the Near West site, Skunk Camp is expected to have a low to moderate seismic hazard. The Skunk Camp site includes two mapped faults, the Dripping Springs and Ransome Faults, which are not believed to have been active during the Quaternary (Wong et al. 2017). However, the Skunk Camp site is closer in proximity to mapped Quaternary faults than the Near West site and may therefore experience somewhat higher ground motions for short-period seismic loads (Klohn Crippen Berger Ltd. 2018e).

According to Klohn Crippen Berger (2018e) design documents, the foundation characterization is based on recent site reconnaissance visits, limited well logs, regional geological maps, and assumptions based on similar sites (i.e., Near West). Existing foundation conditions observed at the Skunk Camp tailings storage facility site (Klohn Crippen Berger Ltd. 2018e) include the following:

- Existing Quaternary deposits within embankment footprints.
- Potential strength reduction in areas due to saturation of the Gila Conglomerate.
- Gila Conglomerate varies across the site and has been noted to be less cemented and coarser grained than at the Near West site, especially on the north end of the site; this unit may, therefore, exhibit higher permeability at the Skunk Camp site compared with the Near West site, which could impact seepage within the basin.

Additional field investigations at the Skunk Camp tailings storage facility location were conducted between the DEIS and FEIS. These are described in section 3.2 of the FEIS.

East Plant Site

The East Plant Site is on the east side of the Apache Leap escarpment in the Transition Zone on the northeastern edge of the Basin and Range physiographic province that borders the Central Highlands. The western edge of this area is generally very steep, with the cliffs of the Apache Leap escarpment rising abruptly above Superior. East of Apache Leap, an area of parallel ridges and valleys trends to the northeast. The northeastern portion of East Plant Site is relatively flat, and most of the drainages flow toward Queen Creek; however, in the southern portion of the site, Rio Rancho Creek drains toward Devil's Canyon to the east.

The Apache Leap Tuff, the youngest consolidated formation in the area, underlies the East Plant Site and forms the Apache Leap escarpment. Underlying Paleozoic sedimentary rocks are exposed along the west face of the escarpment. Tertiary Whitetail Conglomerate is present, with limited exposure below the Apache Leap Tuff west of East Plant Site and also at the toe of the slope on the west side of Apache Leap. A Quaternary alluvial deposit (Qal) overlies the Apache Leap Tuff in a small area northeast of the project area on the Oak Flat Plateau.

West Plant Site

The West Plant Site is located at the transition from the Superior Basin to the mountains north and east of Superior that border the Central Highlands. The southwestern part of the site, adjacent to the town of Superior, is moderately sloped, with a base elevation of approximately 2,680 feet amsl. The site ascends into deeply incised canyons in the rocky slopes along the northern portion of West Plant Site up to an elevation of approximately 3,400 feet amsl (figure 4) (Resolution Copper 2016).

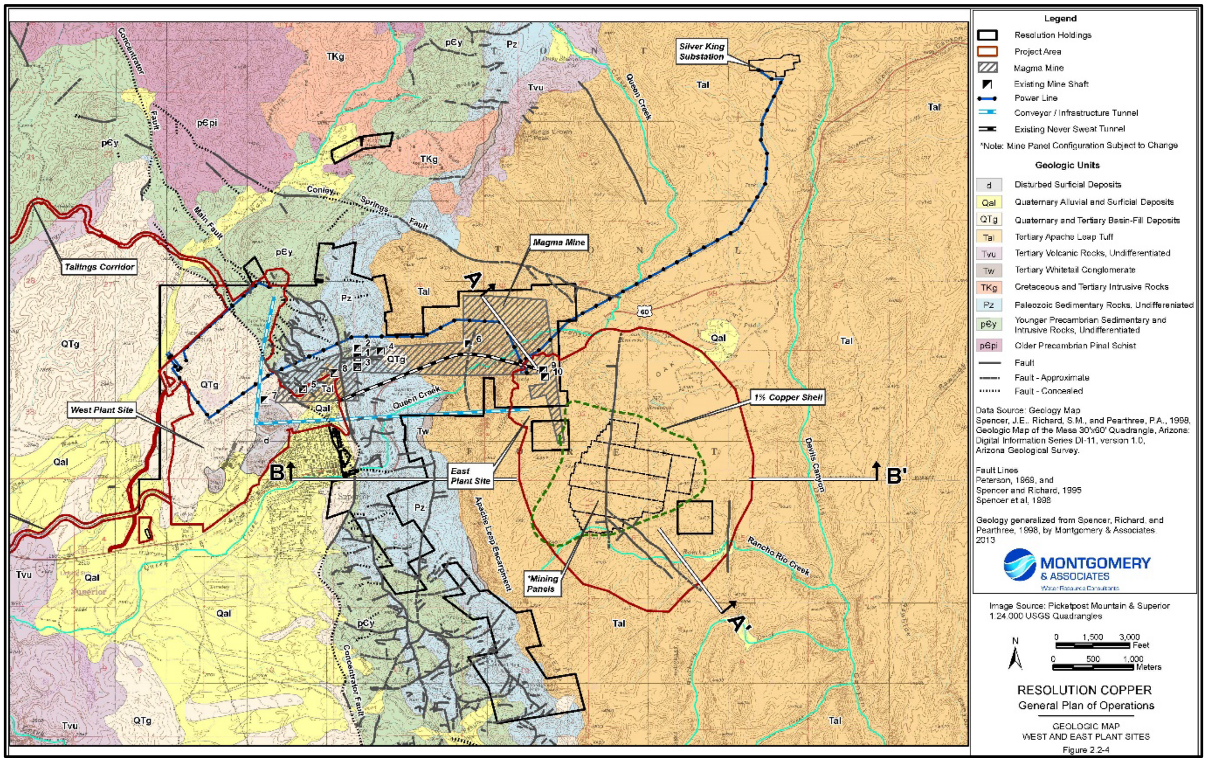

Figure 4: Geological map for the East Plant Site and West Plant Site project area (taken from GPO, figure 2.2-4).

An extensive area of undifferentiated Quaternary and Tertiary Gila Conglomerate underlies the majority of West Plant Site, which is on the west side of the Concentrator Fault. Near the eastern boundary of the West Plant Site, the Concentrator Fault crosses northwest-southeast through the West Plant Site. Northeast of this fault, the surface geology changes abruptly to include older Precambrian sedimentary rocks, basalt, and diabase, Paleozoic sedimentary rocks, and Tertiary Apache Leap Tuff. The southern edge of West Plant Site and the town of Superior lie on Quaternary alluvial deposits, and the remainder of the West Plant Site (the legacy tailings ponds and slag dump) are mapped as disturbed surficial deposits. Extensive studies of the geology of the West Plant Site have been completed as part of the Aquifer Protection Permit Program and by Golder Associates Inc. (2011).

Tunnels between East and West Plant Sites

There is an existing Never Sweat Tunnel from Shaft 9 to the West Plant Site and a proposed conveyor/infrastructure tunnel to the south of the Never Sweat Tunnel that would connect the East Plant Site and the West Plant Site. These routes start near the proposed mine site at the West Plant Site on Tertiary Apache Leap Tuff and drop down the Apache Leap escarpment through a thick sequence of Paleozoic sedimentary rocks (mostly limestone, dolostone, and quartzite). At the toe of the slope, the conveyance tunnels reach the West Plant Site, for which the geology has already been described.

Magma Arizona Railroad Company Corridor

The existing MARRCO corridor extends west from the West Plant Site then southwest past Florence Junction to the community of Magma, Arizona, a distance of approximately 27 miles. Elevations in this corridor range from approximately 3,000 feet amsl at the West Plant Site to approximately 1,520 feet amsl at Magma.

The MARRCO corridor crosses a variety of geological formations between Magma and the West Plant Site. From Magma to the crossing at U.S. 60, the geology is mapped as Quaternary alluvial deposits. From the crossing at U.S. 60 to the West Plant Site, the corridor crosses areas of Quaternary alluvial deposits, Quaternary and Tertiary basin-fill deposits (QTg), Tertiary Apache Leap Tuff, undifferentiated Precambrian intrusive rocks (pCgu), older Precambrian Pinal Schist, and undifferentiated Tertiary volcanic rocks (Tvu). Many of these units are present in small areas in multiple locations along the corridor.

Filter/Loadout Facility

The location of the filter plant and loadout facility is approximately 6 miles southwest of Florence Junction and adjacent to the MARRCO corridor. The site is in a relatively flat area southeast of a small ephemeral channel that is ultimately a tributary to the Gila River. The elevation of the site is approximately 1,670 feet amsl. The geology at the filter plant and loadout facility has been mapped by Spencer et al. (1996) on the U.S. Geological Survey Mesa quadrangle. The site is on Quaternary alluvial deposits in the nearly flat part of the basin. The Quaternary alluvial deposits of this area are characterized by Spencer et al. (1996) as moderately dissected alluvial fan and terrace deposits typically consisting of sand to cobbles.

Pipeline Corridors

The tailings corridor between the Near West tailings storage facility and the West Plant Site will cross multiple ephemeral washes: Potts Canyon, Rice Water Canyon, Happy Camp Canyon, and Silver King Wash, all of which drain southwest toward Queen Creek. The tailings corridor also crosses a variety of geological formations between the proposed Near West tailings storage facility site and the West Plant Site. The western terminus of the corridor at the tailings storage facility is underlain by Precambrian Pinal Schist. Proceeding eastward, the bedrock changes to younger Precambrian sedimentary rocks, basalt, and diabase until the corridor crosses Happy Camp Canyon, where Tertiary volcanic rocks are exposed. Tertiary Gila Conglomerate forms the ridge between Happy Camp Canyon and Silver King

Wash. Quaternary alluvial deposits are present along the channel in Silver King Wash. Precambrian sedimentary rocks, basalt, and diabase underlie the eastern terminus of the Pipeline Corridor at the West Plant Site.

Regulations, Laws, and Guidance

Mine operations are subject to a wide range of Federal, State, and local requirements. Table 2 provides a summary of geology, minerals, and subsidence laws, regulations, policies, and plans at the Federal, State, and local level.

Table 2. Regulations, Laws, Policies, and Plans

Laws, Ordinances, Regulations and Standards	Description	Applicability
Mining and Minerals Policy Act of 1970	States that the Federal government should "foster and encourage private enterprise in the development of economically sound and stable industries, and in the orderly and economic development of domestic resources to help assure satisfaction of industrial, security, and environmental needs."	Administration of *locatable* mineral resources on Forest Service lands follows direction in Federal regulations (36 Code of Federal Regulations 228 Subpart A). Locatable minerals are those subject to claim and development under the Mining Law of 1872, as amended. These regulations describe what information is required for a proposal to explore, develop, and recover locatable minerals; how impacts to resources from a proposed operation will be scoped, assessed, and mitigated; and how reclamation will be completed and bonded at the end of operations.
Multiple-Use Mining Act of 1955	Removed common varieties of minerals, such as sand and gravel, clay, building stone, and cinders, from the category of locatable materials and provided for multiple uses of the lands and surface resources on mining claims.	Land uses, including recreation, camping, and livestock grazing, currently occur on lands where Resolution Copper has mining claims.

Laws, Ordinances, Regulations and Standards	Description	Applicability
General Mining Law of 1872	Authorizes citizens to stake or "locate" mining claims on Federal lands to acquire exclusive mineral rights. The mining law consists of five basic elements: discovery of a valuable mineral, location of mining claims, recordation of claims, maintenance (performance of annual requirements on claims), and patenting of a claim, with possible transfer of the surface estate to the claimant. Conditions and requirements for these elements are detailed in Federal land management regulations (43 Code of Federal Regulations Chapter 2).	Copper is listed as a locatable mineral and available for acquisition through the General Mining Law of 1872. Resolution Copper is the owner of the mining claims associated with the mineral deposit; some non-Resolution claims are located within the footprint of the Near West and Silver King tailings storage facility, as well as the Peg Leg and Skunk Camp pipeline corridors.
Tonto National Forest Land and Resource Management Plan	Sets desired conditions, standards, and guidelines for management, protection, and use of National Forest System lands.	The Tonto National Forest is governed by a Forest Land and Resource Management Plan in accordance with the National Forest Management Act. The current plan and associated FEIS (Forest Service 1985a, 1985b) note that except for areas that are withdrawn from mineral entry, Tonto National Forest lands are subject to locatable mineral exploration and development. Environmental impacts are addressed through the approval of a plan of operations by the Forest Service (Forest Service 1985a, 1985b).
Paleontological Resources Preservation Act	Stipulates that fossils from Federal lands are Federal property that must be preserved and protected using scientific principles and expertise.	The sequence of Paleozoic sedimentary strata that outcrop in the Apache Leap escarpment below the Apache Leap Tuff, namely the Pennsylvania Naco Limestone , the Mississippian Escabrosa Limestone, and the Devonian Martin Formation, have the potential for paleontological resources.

Laws, Ordinances, Regulations and Standards	Description	Applicability
American Antiquities Act of 1906	Establishes a penalty for disturbing or excavating any historic or prehistoric ruin or monument or object of antiquity (including fossils) on Federal lands.	Shallow shelf marine fossils are common and locally abundant in the Naco Limestone (Milne 1940). The Escabrosa Limestone Formation potentially contains mostly crinoids and rugose corals with some brachiopods and trilobites. The Martin Formation potentially contains brachiopods, crinoids, and corals.
National Historic Preservation Act of 1966	Provides for the survey, recovery, and preservation of significant paleontological data when such data may be destroyed or lost as a result of a Federal, federally licensed, or federally funded project.	Fossils (as discussed above) have the potential to occur within the analysis area. Should the collection of fossils occur, a permit is required. In addition, the use of fossils found on Federal lands (in the case of Apache Leap) for commercial purposes is prohibited.
Federal Cave Resources Protection Act of 1988	Prohibits knowingly destroying, disturbing, defacing, marring, altering, removing, or harming any significant cave or altering the free movement of any animal or plant life into or out of any significant cave on Federal lands.	Caves located within the analysis area include Hawks Claw Cave, located northwest of the Near West site. In addition, cave formation has the potential to occur in the Naco and Escabrosa Limestone Formations. Caves in the analysis area also have the potential to be impacted by subsidence.
Organic Administration Act of 1897	Authorizes protection of cave resources from theft and destruction.	As mentioned above, caves within the analysis area include the Hawks Claw Cave.
Forest Service Manual 2356, “Cave Management”	Directs the Forest Service to provide cave-related recreational, cultural, educational, and scientific study opportunities that serve public needs and to balance surface resource management.	Caves such as Hawks Claw Cave are considered nonrenewable scientific resources.
Forest Service Manual 2882, “Geologic Resources Program Management”	Directs the Forest Service to secure, protect, and preserve significant caves for the perpetual use, use, enjoyment, and benefit of all people and to foster increased cooperation and exchange of information with those who use caves for scientific, educational, or recreational purposes.	Caves such as Hawks Claw Cave are considered nonrenewable scientific resources.

Key Documents and References Cited for Geology, Minerals, and Subsidence

The following list is meant to highlight key process or analysis documents available in the project record. It should not be considered a full list of all available documentation considered within this process memorandum or the EIS analysis.

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ATTACHMENT 1: FULL-SIZE VERSION OF HART 2016 GEOLOGIC MAP

Topographic base map and contours shown are from published U.S. Geological Survey 1:24,000 scale quadrangle maps.

Map and grid projection: Arizona State Plane, 1983, Central Zone [EPSG:2223]

Geologic Map Units

Age	Code	Unit
Holocene	d	Disturbed Ground / Fill (< 200 yr)
Quaternary	Qs	Surficial Deposits, Undivided
Quaternary	Qtc	Talus and colluvium
Quaternary	Qal	Unconsolidated Alluvium
Quaternary	Qoa	Old Alluvium
Quaternary	QTls	Older Landslide Deposits
Quaternary	QTs	Older Alluvium
Tertiary	Tcg	Gila Conglomerate
Tertiary	Tcgt	Tuffaceous Sediments
Tertiary	Tss	Sandstone
Tertiary	Tb	Basalt Flows and Breccia
Tertiary	Tvx	Volcanic Breccia
Tertiary	Tqmp	Quartz Monzonite Porphyry
Tertiary	Tqma	Quartz Monzonite Aplite
Tertiary	Tql	Quartz Latite
Tertiary	Tp	Perlitic Aphyric Rhyolite
Tertiary	Tal	Apache Leap Tuff, undivided
Tertiary	Ts	Apache Leap Tuff, lacustrine sediments
Tertiary	Talt	Apache Leap Tuff, top of tuff member
Tertiary	Talw2	Apache Leap Tuff, upper white member
Tertiary	Talw1	Apache Leap Tuff, lower white member
Tertiary	Talg	Apache Leap Tuff, gray member
Tertiary	Talb	Apache Leap Tuff, brown member
Tertiary	Talv	Apache Leap Tuff, vitrophyre member
Tertiary	Talbt	Apache Leap Tuff, basal tuff member
Tertiary	Tr	Spherulitic Rhyolite
Tertiary	Tt	Tuff
Tertiary	Tf	Felsic Volcanic Rocks
Tertiary	Tfp	Felsic Volcanic Rocks, crystal poor
Tertiary	Tfa	Andesitic Volcanic Rocks
Tertiary	Tbl	Lower Basalt
Tertiary	Tx	Rock Avalanche/Talus Breccia
Tertiary	Tw	Whitetail Conglomerate
Tertiary	Tdf	Felsic Dikes
Tertiary	Tda	Aphanitic Felsic-Intermediate dikes
Tertiary / Cretaceous	vq	Vein Quartz
Tertiary / Cretaceous	TKsg	Schultze Granite
Tertiary / Cretaceous	TKgp	Granite Porphyry Dikes
Tertiary / Cretaceous	Kdp	Diorite/Dacite Porphyry
Tertiary / Cretaceous	Kqd	Quartz Diorite
Tertiary / Cretaceous	Bxu	Fault Breccia (1 mi ESE of Superior)
Paleozoic	Pn	Naco Limestone
Paleozoic	Mem	Top of Escabrosa Manto Bed
Paleozoic	Me	Escabrosa Limestone
Paleozoic	Dm	Martin Limestone
Paleozoic	Cb	Bolsa Quartzite
Paleozoic	Cbl	Bolsa Quartzite, Lower Member
Middle Proterozoic	Yd	Diabase
Middle Proterozoic	Ydc	Diabase, coarse grained
Middle Proterozoic	Yt	Troy Quartzite, undivided
Middle Proterozoic	Ytu	Troy Quartzite, upper member
Middle Proterozoic	Ytl	Troy Quartzite, lower member
Middle Proterozoic	Yb	Apache Basalt
Middle Proterozoic	Ym	Mescal Limestone
Middle Proterozoic	Yds	Dripping Spring Quartzite, undivided
Middle Proterozoic	Ydsu	Dripping Spring Quartzite, upper
Middle Proterozoic	Ydsl	Dripping Spring Quartzite, lower
Middle Proterozoic	Yp	Pioneer Formation, siltite
Middle Proterozoic	Ypt	Tuff in Pioneer Formation
Early \ Middle Proterozoic	YXg	Granite
Early \ Middle Proterozoic	YXgd	Granodiorite
Early \ Middle Proterozoic	YXd	Diorite
Early \ Middle Proterozoic	YXmp	Hornblendite
Early \ Middle Proterozoic	YXgm	Mixed Schist and Granite
Early \ Middle Proterozoic	YXmg	Manitou Hill Granite
Early Proterozoic	Xp	Pinal Schist, undivided
Early Proterozoic	Xpp	Pinal Schist, phyllite
Early Proterozoic	Xps	Pinal Schist, siltite
Early Proterozoic	Xpq	Pinal Schist, quartzite
Early Proterozoic	Xpcs	Pinal Schist, calcsilicate-siltite
Early Proterozoic	Xpc	Pinal Schist, calcsilicate

Geologic units, ages, codes and descriptors shown are modified from those used by Spencer & Richard, 1995, and are described in the accompanying report (A. Kloppenburg, 2016).

Previously published geologic mapping shown was completed by the U.S. Geological Survey (J. E. Spencer & S. M. Richard, 1995; D. W. Peterson, 1969; N. P. Peterson, 1960).

Additional geologic mapping and revisions shown (this publication) by:
1. Magma Mining Company (D.F. Hammer, 1958-1998)
2. Kennecott Exploration Company (J. Gant and J. Wilkins, 2003-2005)
3. Resolution Copper Company (A. Schwarz, 2009, W. Hart, 2016)
4. 4DGeo (A. Kloppenburg, 2016)

Structural Symbols

- Faults shown in dark blue (all types) mapped by MAGMA, KEX, RCC
- Mineralized Fault / Vein (Mn-Fe Oxide +/- Cu, Pb, Zn, Ag, Au)
- Fault of unspecified type, arrow denotes dip direction
- Normal fault, tick marks on down-thrown side
- Reverse/Thrust Fault, teeth on upthrown side
- Strike-Slip Fault, arrows denote relative offset
- Inferred Fault, location approximate
- Strike & Dip of Bedding
- Strike & Dip of Plane of flattening in Tal welded tuff
- Strike & Dip of Plane of metamorphic foliation
- Strike & Dip of Plane of joint
- Strike & Dip of cleavage plane
- Shear lineation, plunge direction
- Fold axis, plunge direction

NOTE: Symbols shown in dark blue mapped by KEX, RCC, 4DGeo

N
W E
S

Map Scale 1 : 15,000

5,000 Feet

1,000 Meters

GEOLOGIC MAP OF THE RESOLUTION PROJECT AREA

Map Updated: December 31, 2016 (W. Hart, RCC)