Overview

Perhaps the most dominant feature of the proposed Resolution Copper Mine is the great size and depth of the ore body; for this reason, Resolution Copper plans to extract the ore from below, using gravity, in a technique known as "block caving" or "panel caving." However, removal of such a large volume of rock would result in an approximately 1.8-mile-wide and between 800- and 1,115-foot-deep subsidence crater at the Oak Flat Federal Parcel. Along with a discussion of subsidence impacts, this section of the EIS describes known geological characteristics at each of the major facilities of the proposed mine, including alternative tailings storage locations, and how the development of the project may impact existing cave and karst features, paleontological resources, mining claims, and geological hazards.

3.2 Geology, Minerals, and Subsidence

3.2.1 Introduction

This section presents an overview of the geology and mineral resources within the analysis area, analyzes the estimated extent, amount, and timing of potential land subsidence resulting from underground mining activities, and the potential impacts on cave and karst resources, paleontological resources, and mining claims.

Some aspects of the analysis are briefly summarized in this section. Additional details not included are captured in the project record (Newell and Garrett 2018a).

3.2.2 Analysis Methodology, Assumptions, and Uncertain and Unknown Information

3.2.2.1 Analysis Area

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 ("offered lands"). These areas are shown in figure 3.2.2-1.

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 following:

- The area of groundwater dewatering, which could impact hydrogeological and geotechnical properties, as well as result in additional subsidence. Assessment of additional subsidence from groundwater dewatering is discussed in Section 3.7.1, Groundwater Quantity and Groundwater-Dependent Ecosystems.
- The reactivation of geological structures, such as joints and faults directly adjacent to the area of panel caving and subsidence, or in the region. These impacts are assessed in this section.
- Subsidence-related impacts on caves, karst resources, and mine shafts and adits in the analysis area. These impacts are assessed in this section.
- Changes to mineral availability as a result of the proposed land exchange, which in some cases may remove land parcels from mineral entry.

3.2.2.2 Surface Subsidence Review

Note that two different types of subsidence have been raised as concerns for the Resolution Copper Project. This section of the EIS addresses surface subsidence that occurs at the mine site due to the block-cave mining itself. Possible subsidence resulting from groundwater pumping for the mine water supply is addressed in section 3.7.1.

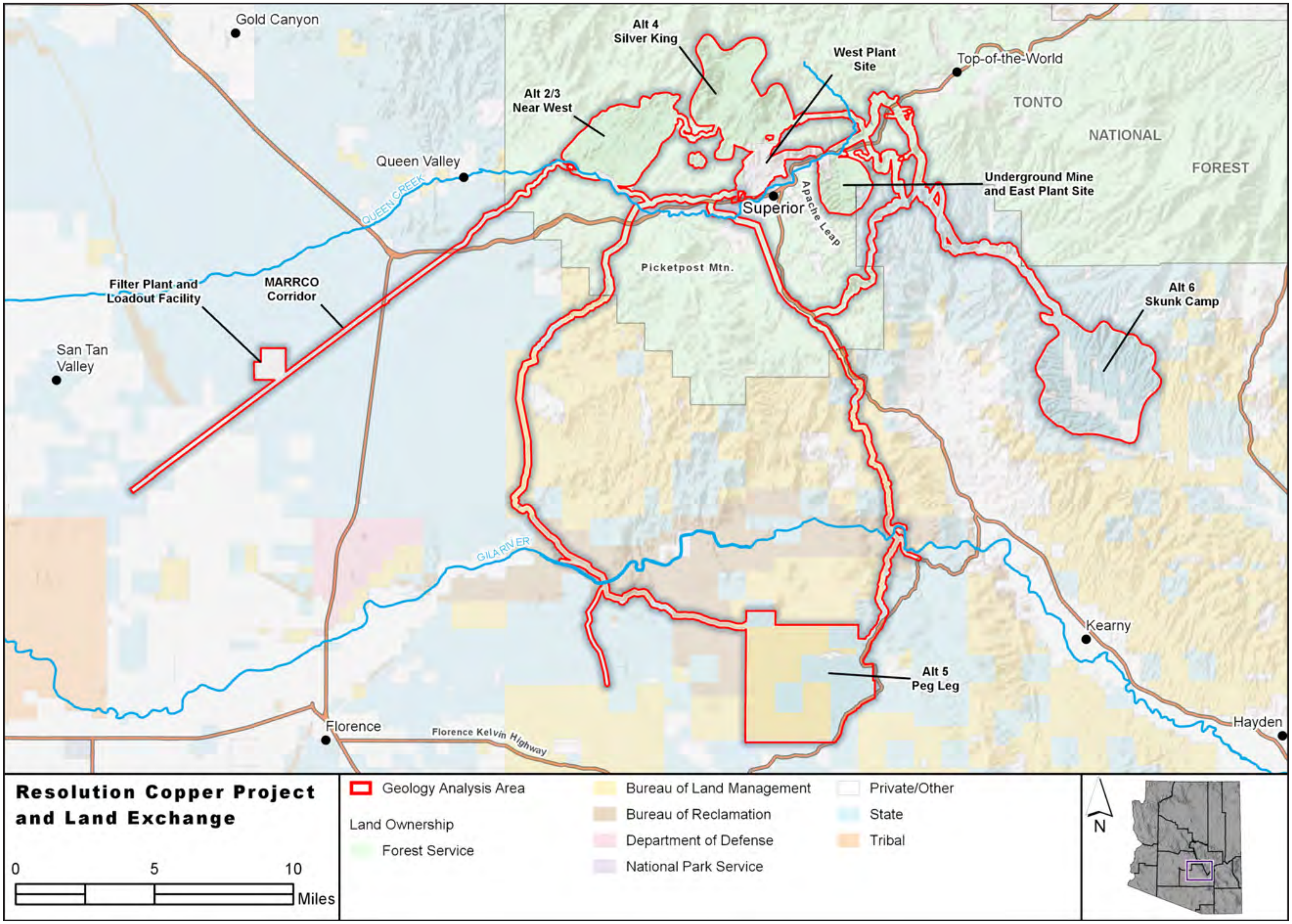

Figure 3.2.2-1. Geology, minerals, and subsidence analysis area

The understanding of regional and local geology relied on U.S. Geological Survey (USGS) maps, geological mapping data provided by Resolution Copper, and mineral resource information from Resolution Copper reports and published resource information. Subsidence effects were originally assessed in the GPO (Resolution Copper 2016d), but Resolution Copper conducted further modeling of the proposed caving operations, estimated the extent and depth of ground surface subsidence, and evaluated the potential impact on Apache Leap, Devil's Canyon, and the serviceability of U.S. 60 (Garza-Cruz and Pierce 2017, 2018).

The Tonto National Forest formed a Geology and Subsidence Workgroup to direct and evaluate this work. In 2017 and 2018, the Geology and Subsidence Workgroup 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 documented in "Resolution Copper Project and Land Exchange Environmental Impact Statement: Geologic Data and Subsidence Modeling Evaluation Report" (BGC Engineering USA Inc. 2018a).

Resolution Copper developed an estimate of surface subsidence based on a three-dimensional numerical model of the proposed panel caving operation using an industry-standard model called FLAC3D (Garza-Cruz and Pierce 2017). The numerical model simulated caving and predicted ground surface subsidence, fracture limits, and cave angle (figure 3.2.2-2). The fracture limit consists of an area around the actual caved area in which the ground surface could be broken with open tension cracks and is the outer limit of any potential large-scale surface cracking (or fracturing). Cave angle is a key factor in estimating the extent of the surface subsidence. The model estimates a subsidence cave angle on the order of 70 to 78 degrees (angle varies with depth), with the cave fractures breaking through to the surface by year 6 of operations.

After reviewing Resolution Copper's geological data and subsidence modeling, the Geology and Subsidence 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 the mineralized zone, as well as for the Camp and Gant Faults, are not as well represented statistically as in the mineralized zone. To address this, conservative modeling assumptions were used and sensitivity analyses to account for sparse data in these areas.
- Resolution Copper's interpretations of subsidence are reasonable; therefore, the Geology and Subsidence Workgroup did not propose any alternative interpretations. However, there are numerous input variables and several layers of interpretation involved in modeling surface subsidence. There are several areas of uncertainty and some areas of sparse or low confidence data; actual surface subsidence could vary from the modeled results.

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 that consider the certainty of the geological and subsidence models. Both approaches were included in the Geology and Subsidence Workgroup review and are discussed in more detail in BGC Engineering (2018a).

- One approach to address uncertainty is empirical, meaning the model results are compared with what has been observed at other similar mines with similar geological settings. The modeled cave angle was compared observed cave angles from a database of more than 100 cave mining operations throughout the world, including both historical mines that have ceased to operate and those still producing (Woo et al. 2013); the historic database suggests a range from 72 to 84 degrees, which

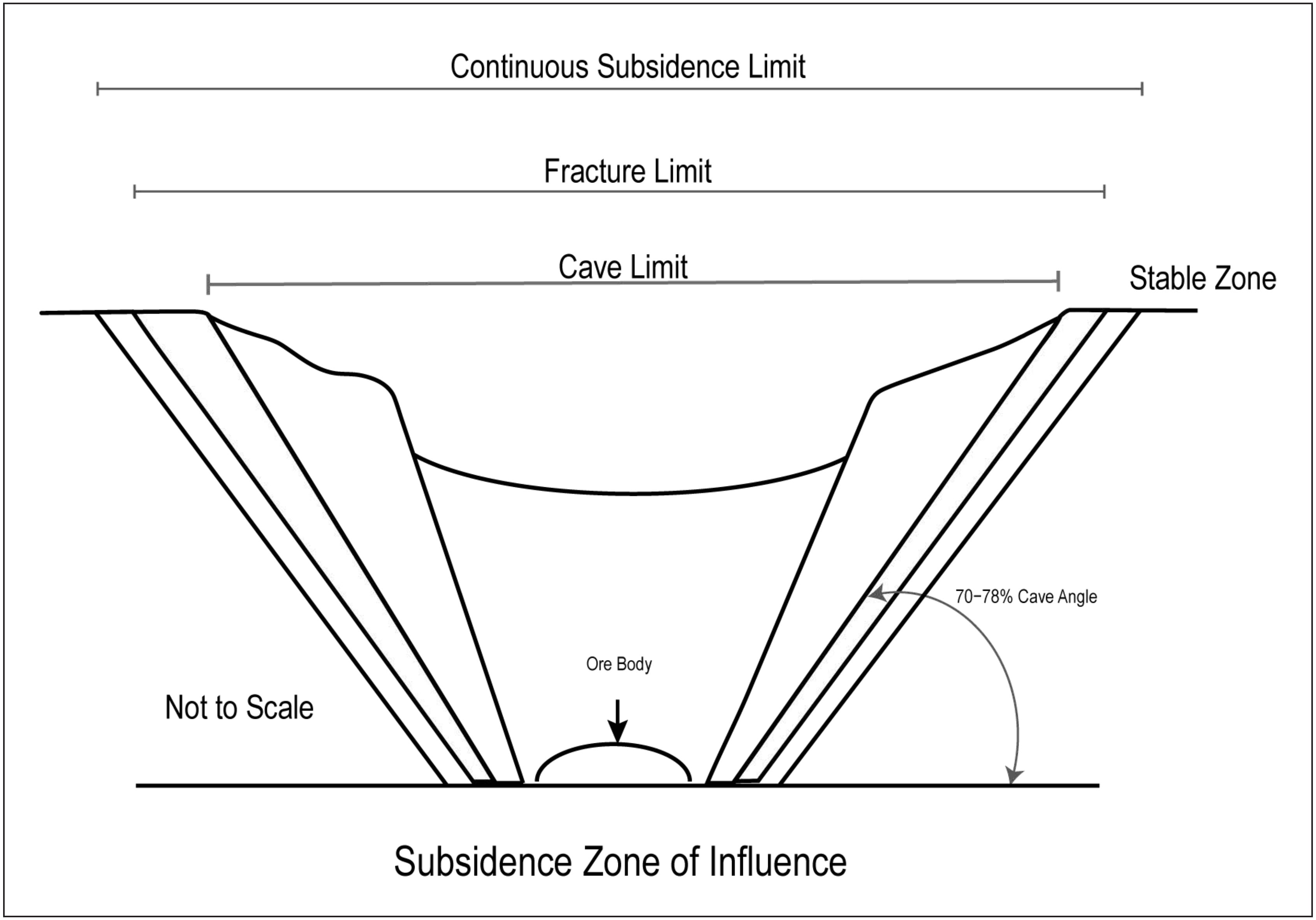

Figure 3.2.2-2. Conceptual cross section of the block-cave and subsidence zone

corresponds well with the modeled results (BGC Engineering USA Inc. 2018a). In a similar way, the conservativeness of the key rock units (Whitetail Conglomerate and Apache Leap Tuff units) was assessed by comparing results to actual measurements collected using underground instruments during the construction of Shaft #10.

- A second approach to address uncertainty is to vary the input parameters to reasonable upper and lower limits to see the resulting cave geometric response (i.e., sensitivity analyses).

3.2.2.3 Geological Hazards

Three types of geological hazards are evaluated: the potential for induced seismicity or reactivation of faults caused by the project; public access to the subsidence area; and the potential for rockfall or other changes to Apache Leap. The potential for induced seismicity is analyzed primarily using analog data observed at other mining sites. The potential for changes to Apache Leap is derived from the subsidence modeling results, and by assessing the changes in stresses and movement caused by the subsidence.

Many of the various rock units and tailings have potential to be acid generating when exposed to oxygen and moisture, resulting in the potential to create water quality problems. This issue is fully evaluated in section 3.7.2 and is not included here as a geological hazard.

3.2.2.4 Paleontological Resources

The probability of finding paleontological resources can be broadly predicted from the geological units present in the analysis area.

3.2.2.5 Caves and Karst Resources

Some cave resources are known to exist in the analysis area, derived from general knowledge of geology and recreation Forest Service specialists. Aside from these known resources, the probability of finding cave resources can be broadly predicted from the geological units present in the analysis area.

Primary Legal Authorities Relevant to the Geology, Minerals, and Subsidence Analysis

- U.S. mining laws, implemented through regulation for administration of locatable minerals (36 CFR 228 Subpart A)
- Paleontological Resources Preservation Act (16 U.S.C. 470aaa through 470aaa-11), implemented through Paleontological Resources Preservation regulations (36 CFR Chapter 2, Part 291)
- Federal Cave Resources Protection Act of 1988 and its implementing regulations at 43 CFR Part 37

3.2.2.6 Unpatented Mining Claims

The known unpatented mining claims associated with the analysis area were taken from comprehensive claims databases administered by the BLM. The focus of this analysis is on claims that are not related to the Resolution Copper Project, but that could be impacted by the project.

3.2.3 Affected Environment

3.2.3.1 Relevant Laws, Regulations, Policies, and Plans

Metals and other mineral resources on NFS lands are managed in accordance with the Mining and Minerals Policy Act of 1970, which 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 NFS lands follows direction in Federal regulations (36 CFR 228 Subpart A); locatable minerals are those subject to claim and development under the General Mining Law of 1872, as amended.

The Multiple-Use Mining Act of 1955 reaffirms the right to conduct mining activities on public lands, including mine processing facilities and the placement of mining tailings and waste rock. Although a right to conduct mining activities exists, proposals must comply with applicable Federal and State environmental protection laws, and the Forest Service can require reasonable measures, within its authority, to minimize impacts on surface resources (see 30 U.S.C. 612 and 36 CFR 228.1). Mining claim location and demonstration of mineral discovery are not required for approval of locatable minerals operations subject to Forest Service regulations at 36 CFR 228 Subpart A.

One of the alternatives would involve construction of a tailings storage facility on BLM land instead of NFS land. BLM operates under different mining regulations (43 CFR 3809), but also has limited discretion for approving mining operations, provided the mine complies with applicable Federal and State environmental protection laws. As noted in chapter 2, BLM would require the submittal of a separate mining plan of operations to determine whether unnecessary or undue degradation would occur (43 CFR 3809.11(a)) and could require reasonable mitigation measures if determined necessary.

Alternative 6 does not involve any Federal land. Activities and resource impact occurring on these lands would not be regulated under either Forest Service or BLM regulations, though Resolution Copper would potentially employ some of the same environmental protection measures and mitigation.

3.2.3.2 Existing Conditions and Ongoing Trends

Regional Geology – East Salt River Valley, Superior Basin, and Oak Flat

The project is located within a geological region known as the Basin and Range province, near the boundary with another geological region known as the Arizona Transition Zone. The Basin and Range physiographic province is generally characterized by a series of mountain ranges separated by broad valleys filled with geologically young alluvium. The mountain ranges are typically bounded by faults that run northwest-southeast and north-south (Wong et al. 2013). At the northeastern edge of the Basin and Range province is the Arizona Transition Zone, a mountainous region that rises toward the highlands of the Colorado Plateau in northeastern Arizona. The Arizona Transition Zone is geologically complex, but generally consists of belts of linear rugged ridges, separated by relatively narrow valleys.

West of Whitlow Ranch Dam and Gonzales Pass the East Salt River valley begins—a 30- to 40-mile-wide alluvial valley that is typical of the Basin and Range. The Desert Wellfield is located in the East Salt River valley, where groundwater is readily accessible in the extensive, thick, alluvial aquifers. General elevation of this area is about 1,500 feet amsl.

The area roughly east of Whitlow Ranch Dam and east of Apache Leap is called the Superior Basin. This area is where the town of Superior, the West Plant Site, and the Alternative 2 tailings storage facility are located. The Superior Basin is about 10 miles wide, and generally flat, but unlike the East Salt River valley, young alluvium is limited to areas along washes and the main drainage of Queen Creek. Between drainages, low ridges formed of older geological units dominate the Superior Basin. The most distinctive landform immediately in the Superior Basin is

Picketpost Mountain, an isolated butte of Tertiary-aged rock[22] with a peak at 4,378 feet. Queen Creek originates in the Oak Flat Plateau, cuts a deep canyon through the Apache Leap escarpment, and flows west through the town of Superior before continuing southwestward across the Superior Basin. The Superior Basin generally lies about 2,200 to 2,900 feet amsl.

East of Superior lies the rugged Oak Flat Plateau, with an elevation of roughly 4,000 to 4,600 feet amsl. Oak Flat is about 3 miles wide, with the eastern edge formed by Devil's Canyon. On the west, the prominent Apache Leap escarpment forms the division between Oak Flat and the Superior Basin. The East Plant Site is located on Oak Flat, and the Resolution ore deposit is located below Oak Flat.

Regional Geological Units

Previous researchers and Resolution Copper have mapped the geology of the analysis area. The most recent detailed geological map is a compilation of published USGS mapping and Resolution Copper geological mapping (Hart 2016). A number of other useful sources also exist, including the GPO (Resolution Copper 2016d; Spencer et al. 1996). A summary of the main geological units from oldest to youngest is presented in this section, and these are intended to be used in conjunction with the tables and figures reproduced in Newell and Garrett (2018a).

Regional geology of the Superior Basin and Oak Flat is shown in figure 3.2.3-1 and shown as a conceptual cross section in figure 3.2.3-2. The abbreviations of the most common mapping units are included in the following text, which are commonly used on geological maps.

PRECAMBRIAN UNITS

The oldest rock units in the analysis area are more than 1 billion years old and include the Pinal Schist (pCpi); the Apache Group (pCy), which includes sedimentary and metamorphic units like shale, quartzite, limestone, and basalt; and the Troy Quartzite. Intrusions of granite, granodiorite, diorite, and diabase are found throughout these sedimentary units. These rocks underlie the entire analysis area but are only exposed in the western part of the Superior Basin.

PALEOZOIC SEDIMENTARY UNITS

Overlying the Precambrian units are sequences of Paleozoic-age (Pz) sedimentary formations. From oldest to youngest these include the Bolsa Quartzite, the Martin Formation, the Escabrosa Limestone, and the Naco Limestone. These units are well-exposed in the hills rising toward the Apache Leap escarpment.

CRETACEOUS-TERTIARY VOLCANIC UNITS

Numerous types of volcanic intrusions, including sills, dikes, and stocks of granite and diorite are located throughout the area. One well-known unit is the Silver King quartz diorite north of the town of Superior. A particularly thick sequence of Cretaceous-age volcanoclastic rock (Kvs) has been observed within the Resolution Graben (the Graben is

22. The use of technical geological terms has been intentionally limited in the EIS. However, the relative age of geological units can be important to understanding impacts, as some geologic time periods are commonly used to describe units. The following ages are the most commonly used, in order from youngest to oldest. The term "consolidated" means the unit is hard rock, whereas unconsolidated units are still loose, like soil or sand:

Quaternary – Refers to geologically young, largely unconsolidated units, that are less than 2.6 million years old.

Tertiary – Refers to geological units, largely consolidated, that are between 66 and 2.6 million years old.

Cretaceous – Refers to consolidated geological units that are about 145 to 66 million years old.

Paleozoic – Refers to consolidated geological units that are about 541 to 252 million years old.

Precambrian – Refers to the oldest geological units in the analysis area, older than 541 million years.

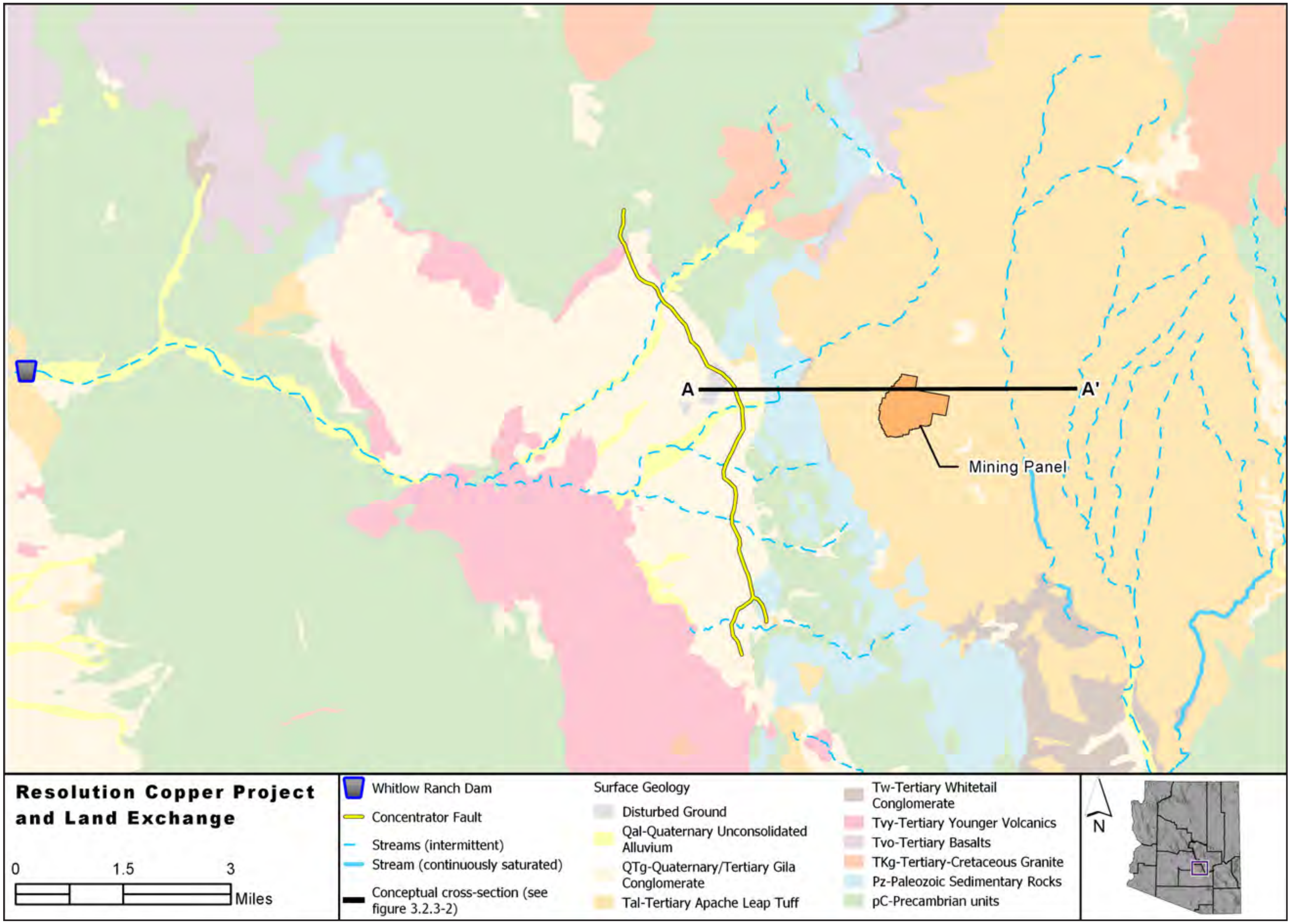

Figure 3.2.3-1. Generalized geological map of Superior Basin and Oak Flat

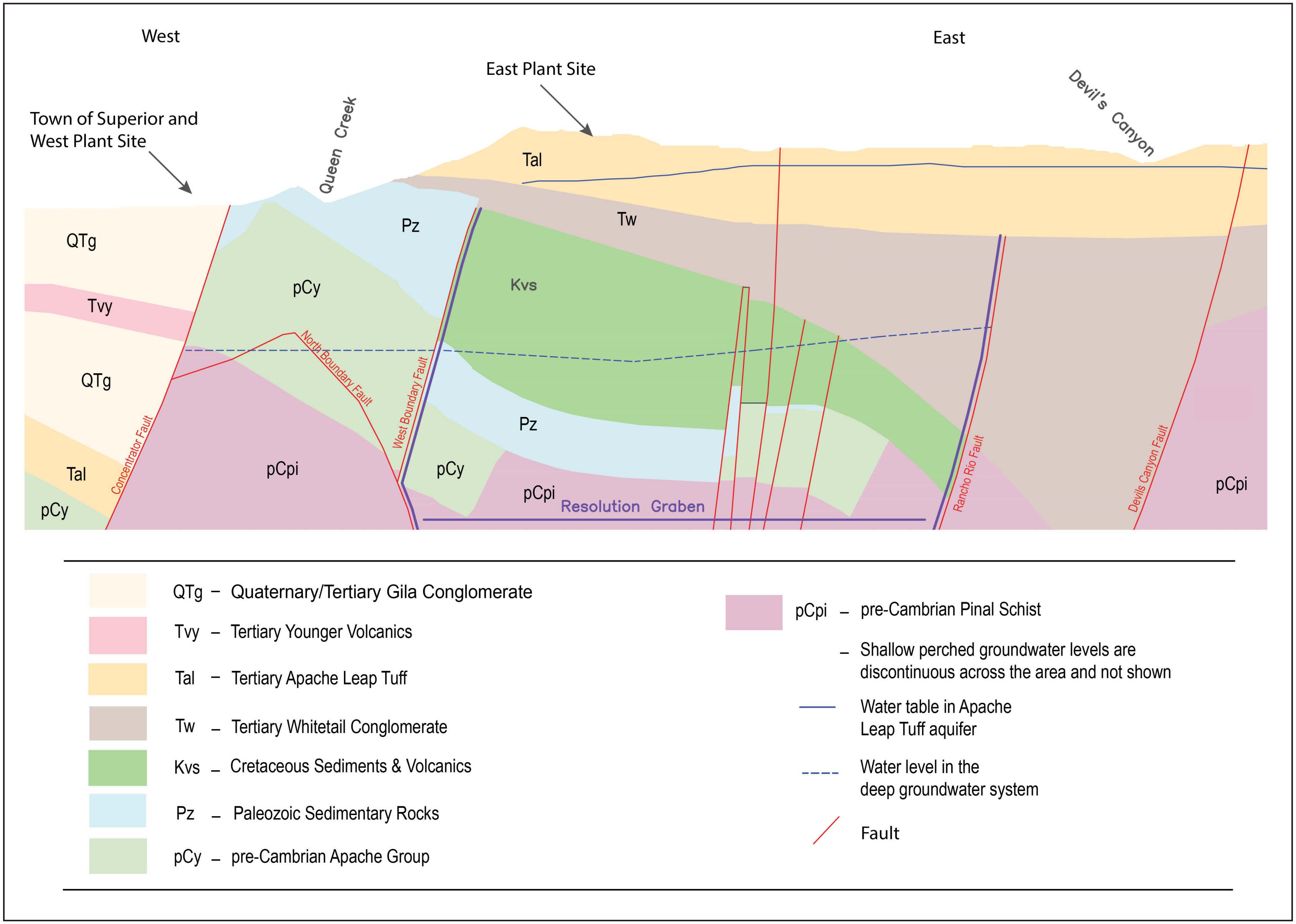

Figure 3.2.3-2. Generalized geological cross section

described in more detail later in this section), but these units are not known to outcrop anywhere in the analysis area (Kloppenburg 2017).

TERTIARY VOLCANOCLASTIC UNITS

Two units of key importance to both the analysis of subsidence and the analysis of impacts from groundwater drawdown are the Tertiary-aged Whitetail Conglomerate (Tw) and the Apache Leap Tuff (Tal). The older and deeper of these two geological units is the Whitetail Conglomerate, which consists of non-volcanic conglomerate and sandstone, as well as sedimentary breccia and mudstone. Overlying the Whitetail Conglomerate is the Apache Leap Tuff. The Apache Leap Tuff is a welded tuff of volcanic ash. It caps the Oak Flat plateau and forms the escarpment of Apache Leap. The Apache Leap Tuff also forms the most important aquifer unit in the area, supporting the perennial flow in springs and in Devil's Canyon. The Whitetail Conglomerate is important hydrologically because it largely isolates groundwater in the Apache Leap Tuff from dewatering taking place in the deep groundwater system (see section 3.7.1).

GILA CONGLOMERATE

The Gila Conglomerate (Qtg) is widespread throughout the Superior Basin and elsewhere in Arizona, including at the Skunk Camp location. The Gila Conglomerate 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, is over 3,000 feet thick in places, and forms much of the surface geology near the Alternative 2 and Alternative 3 tailings storage facility. The Gila Conglomerate has portions that are unconsolidated or only weakly consolidated, as well as consolidated areas. The Gila Conglomerate is generally Tertiary aged but has also been mapped along with Quaternary deposits. For the purposes of the mapping presented in this section, it is presented as both Quaternary and Tertiary deposits.

QUATERNARY ALLUVIAL DEPOSITS

Quaternary deposits (Qal) 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 generally unconsolidated but may be weakly to strongly cemented by calcite (i.e., caliche deposits). These deposits underlie most streams in the area, forming shallow, alluvial aquifers that store and transmit groundwater, and in places support riparian vegetation and perennial flow (see section 3.7.1).

Structural Geology and Faults

Many of the faults of importance to the structural geology in the analysis area are typical of Basin and Range faults. These are north- to northwest-trending normal faults with downward movement to the west, with movement dating from Tertiary or Quaternary time (Hehnke et al. 2012). The Superior Basin is bounded by the Concentrator Fault to the east and by the Elephant Butte Fault to the west. The Concentrator Fault is historically important as it displaces the Magma ore vein to an unknown depth and therefore defined the western limit of production in the Magma Mine. 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 ore deposit, lying about 4,500 to 7,000 feet below Oak Flat, is located in a structural feature called the "Resolution Graben." A graben is an area that is bounded on the sides by normal faults and is downthrust below those faults. The Resolution Graben is bounded by the West Boundary, North Boundary, South Boundary, Conley Springs, and Rancho Rio Faults. The Resolution Graben is hydrologically important because these faults tend to impede groundwater flow (WSP USA 2019). As such, much of the lowering of groundwater levels due to the dewatering that has taken place in the deep groundwater system since 2009 has been limited to the Resolution Graben (see section 3.7.1).

The analysis area has undergone multiple episodes of folding and faulting dating to the Precambrian. During the Tertiary period, two separate widespread orogenic (or mountain-building) events contributed to the structural geology of the analysis area, as well as the entire Southwest (the Late Sevier-Early Laramide Orogeny, and the Basin and Range extension) (Kloppenburg 2017). Regional extension, normal faulting, and tilting ended after Tertiary volcanism and during the deposition of Gila Conglomerate and Sandstone (Tcg) (Spencer and Richard 1995). The rotation, thickness, and offset of the geological units in the area (see figure 3.2.3-2) are the result of this series of large-scale structural movements.

Mineral Resources

GENERAL MINERAL OCCURRENCE

Mineral occurrences in the analysis area include a range of metallic, non-metallic, and industrial minerals. There is a more than 100-year history of silver and copper mining near the analysis area, and several operations continue to contribute to the region's economy. In addition to the nearby formerly producing Magma and Silver King mines, over 30 (active or inactive) mines are regionally located near what is known as the "Copper Triangle." These represent a variety of operations but primarily include copper, gypsum, and marble mining. The closest currently active major copper mines are the Ray Mine, approximately 9 miles south of the analysis area, the Pinto Valley Mine, approximately 14 miles northeast of the analysis area, and the Carlota Mine, also northeast of the analysis area. These mines are open-pit operations, but, like the Resolution ore deposit, they are large tonnage, low-grade copper porphyry deposits (Kloppenburg 2017).

RESOLUTION ORE DEPOSIT

The Resolution ore deposit is approximately 64 million years old and is a porphyry copper-molybdenum deposit. It lies approximately 4,500 to 7,000 feet below Oak Flat. As defined by the 1 percent copper shell, the deposit extends over an area of at least 1.2 miles in an east-northeast direction, and 0.9 mile in a north-northwest direction. 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 Cretaceous-Tertiary 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 hydrothermal breccia body and hosted primarily in breccia and diabase. The total mineral resource at the Resolution ore deposit is currently estimated (indicated and inferred) to be 1,970 million tons (1,787 million metric tonnes), with an average grade of 1.54 percent copper and 0.035 percent molybdenum (Rio Tinto 2018).

The location and geometry of the mineralization are structurally controlled by several generations of faulting that occurred before, during, and after mineralization. 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 up to 14 percent pyrite. This mineralization has ramifications for water quality, as all of these are sulfide-bearing minerals and have the potential to interact with oxygen and cause water quality problems (acid rock drainage), as discussed in detail in section 3.7.2.

Tailings Storage Facility for Alternatives 2 and 3 – Near West

GENERAL GEOLOGY

The proposed tailings storage facility site for Alternatives 2 and 3, known as the 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. A number of geological units underlie the tailings storage facility footprint. Quaternary alluvial deposits are found along the washes, separated by a series of parallel ridges formed of older rocks. The majority of the area is underlain by Gila Conglomerate, with older Pinal Schist under the southwestern portion of the proposed tailings embankment, and smaller areas of Apache Group, Paleozoic sedimentary rocks, Apache Leap Tuff, and other volcanics (Spencer and Richard 1995).

FOUNDATION CONSIDERATIONS

The Near West location is unique out of the alternative tailings locations in that Resolution Copper has completed geotechnical investigations at the site (Golder Associates Inc. 2017; Klohn Crippen Berger Ltd. 2017). 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 foundation considerations, which would need to be factored into the design:

- Some units exhibit weak foundation conditions. These include zones with weak clay layers, zones of potentially collapsible soils (including in the Gila Conglomerate), and weakness parallel to foliation (in the Pinal Schist). These conditions potentially could affect embankment stability.
- Dissolution features, such as voids and open joints, are present in the Mescal Limestone (part of the Apache Group), particularly near the contact between the limestone and an intruded diabase. Resolution Copper has noted open joints in numerous units, including the Gila Conglomerate, and a single high-angle fault with approximately 6 feet of normal displacement was also observed in the Gila Conglomerate. Heavy fracturing was observed in the Pinal Schist. These conditions potentially could affect embankment stability or seepage movement and capture.
- An abandoned mine, Bomboy Mine, is within the southwest corner of the tailings storage facility.

Tailings Storage Facility for Alternative 4 – Silver King

GENERAL GEOLOGY

The Alternative 4 – Silver King tailings storage facility site is approximately 2 miles from the West Plant Site and would occupy the lower end of Silver King Canyon, the lower portion of Whitford Canyon, and Peachville Wash. The Silver King site is approximately 5 miles northeast the Alternative 2 tailings site and shares similar foundation geology. The majority of the geology underlying the tailings facility footprint is Precambrian Pinal Schist, but numerous other geological units are present, including Apache Group units, Bolsa Quartzite, and Tertiary volcanic rocks. Unconsolidated Quaternary alluvial deposits are limited to ephemeral drainages.

Historical mining and exploration have taken place within or near the Silver King 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 Silver King Wash, and within the footprint of the tailings facility.

FOUNDATION CONSIDERATIONS

No site-specific geotechnical investigations have been performed at the Silver King 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. The following foundation considerations have been noted that would need to be factored into the design:

- One major difference noted by Klohn Crippen Berger (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 in landslide deposits associated with weak foliation in Pinal Schist. These conditions potentially could affect embankment stability.

- Abandoned mine workings within the tailings storage facility footprint could collapse beneath the tailings piles (Klohn Crippen Berger Ltd. 2018c), but none are known specifically to exist at this time.

Tailings Storage Facility for Alternative 5 – Peg Leg

GENERAL GEOLOGY

Most of the project facilities are located within the East Salt River valley (filter plant and loadout facility, Desert Wellfield), the Superior Basin (West Plant Site, tailings storage facilities under Alternatives 2, 3, and 4), and Oak Flat (East Plant Site). However, two of the alternative tailings storage facilities are located at some distance from the Superior Basin: Alternative 5 (Peg Leg) and Alternative 6 (Skunk Camp).

The Alternative 5 tailings storage facility (also known as the Peg Leg location), is located approximately 15 miles south of the West Plant Site and south of the Gila River, in a flat, northwest- to southeast-trending valley with Donnelly Wash (a tributary to the Gila River) as its main drainage (figure 3.2.3-3). This drainage lies at the eastern edge of the Basin and Range province and is typical of that geology. Alternative 5 is primarily underlain by a flat valley of Quaternary alluvial material, bounded by sedimentary and granitic rocks, although these hard rock areas do not rise to a great height and instead form a series of low hills at the margins of the valley.

The PAG tailings for Alternative 5 would be located to the east side of the facility and would be underlain by granitic rocks that include Precambrian Ruin Granite and Tertiary Tea Cup Granodiorite. The NPAG tailings would be located on alluvial deposits, including some travertine near the western boundary of the project site (Golder Associates Inc. 2018a).

FOUNDATION CONSIDERATIONS

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 (Fleming, Kikuchi, et al. 2018; Golder Associates Inc. 2018a; hydroGEOPHYSICS Inc. 2017). The following foundation considerations have been noted that would need to be factored into the design:

- 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, and seismicity is expected to be similar to the Near West location.
- The Precambrian Ruin Granite and Tertiary Tea Cup Granodiorite are expected to have low permeability and high strength. However, well logs in the tailings storage facility area reviewed by Golder Associates (2018a) 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. These conditions potentially could affect embankment stability or seepage movement and capture.
- The presence of travertine may indicate shallow perched groundwater zones exist. These conditions potentially could affect embankment stability or seepage movement and capture.

Tailings Storage Facility for Alternative 6 – Skunk Camp

GENERAL GEOLOGY

Alternative 6 (also known as the Skunk Camp location) is located in a narrow northwest- to southeast-trending valley with Dripping Spring Wash (a tributary to the Gila River) as its main drainage. The Quaternary alluvium within the valley is bounded to the southwest by the Dripping

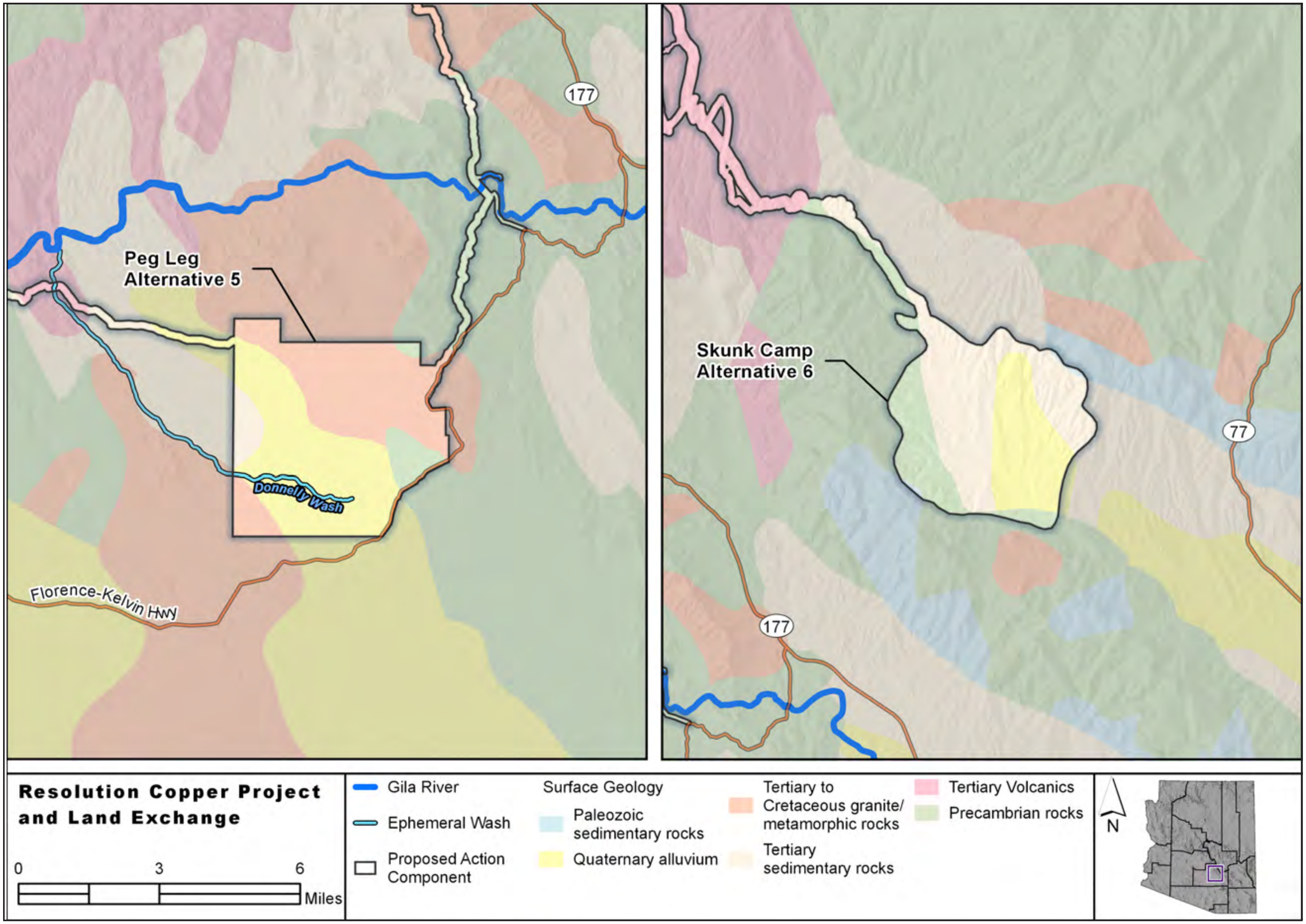

Figure 3.2.3-3. Generalized geological map of Peg Leg and Skunk Camp locations

Spring Mountains, and to the northeast by the Pinal and Mescal Mountains.

Underlying geological units are similar to Alternatives 2, 3, and 4, primarily Precambrian units such as Pinal Schist, overlain by Apache Group units, and Troy Quartzite (see figure 3.2.3-3). The valley itself is infilled with Gila Conglomerate, estimated to be over 1,500 feet thick in some locations. Quaternary alluvium partially covers the conglomerate and is present along the valley bottom and drainages. Occasional travertine deposits have been observed in valley walls.

FOUNDATION CONSIDERATIONS

Foundation characterization is based on recent site reconnaissance visits, limited well logs, regional geological maps, and assumptions based on similar sites given the similar geology (i.e., Near West) (Fleming, Shelley, et al. 2018; Klohn Crippen Berger Ltd. 2018e). The following foundation considerations have been noted that would need to be factored into the design:

- Potential strength reduction could result in areas due to saturation of the Gila Conglomerate. These conditions potentially could affect embankment stability.
- 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. These conditions potentially could affect embankment stability or seepage movement and capture.
- Potential for groundwater flow paths—it is not known whether the faults on-site act as preferential flow paths or low-permeability boundaries for groundwater flows at this time.
- The presence of travertine may indicate shallow perched groundwater zones exist. These conditions potentially could affect embankment stability or seepage movement and capture.

Geological Hazards

SEISMICITY

Regional Seismicity

Historical natural seismicity is low within this general region. Within approximately 30 miles of the proposed mine site there have been three historical earthquakes with a magnitude greater than 3: a magnitude 4.2 in 1963; a magnitude 4.4 in 1969; and a magnitude 3.1 in 2010 (U.S. Geological Survey 2018c).

Lettis Consultants International completed site-specific hazard analyses for the proposed Near West tailings storage facility (Wong et al. 2017) and the mine site (Wong et al. 2018). A historical catalog was compiled including earthquakes within a 124-mile radius of the mine, and includes 26 events of moment magnitude 5 to 5.9, three events of magnitude 6 to 6.9, and three events of magnitude 7 and greater. However, one of the magnitude 7 events, dated 1830 in the record, is considered poorly documented and suspect (DuBois et al. 1982).

The largest earthquake in the record is a magnitude 7.4 earthquake that occurred in 1887 in northern Sonora, Mexico, approximately 200 miles southeast of the site (DuBois et al. 1982; Suter and Contreras 2002). Ground shaking was felt throughout Arizona and as far north as Albuquerque, New Mexico, and would also have been felt in the analysis area. The maximum felt intensity was measured as between Modified Mercalli (MM) intensity XI and XII, and MM VI would have been observed at the mine site (DuBois et al. 1982).[23]

The closest significant earthquake to the mine was a magnitude 5.0 event that occurred in 1922 near Miami, Arizona, approximately 13 miles east-northeast of the site (DuBois et al. 1982). The event was felt in the town of Miami, but no structural damage was reported (DuBois et al. 1982). Lettis Consultants International (Wong et al. 2018) surmised that the felt intensity likely would have been MM IV. This event was recorded on a seismograph over 80 miles away in Tucson; therefore, the location and size of the event are highly uncertain (Wong et al. 2008).

More recently, in 2014, there was a magnitude 5.3 event near the town of Duncan, Arizona, close to the Arizona–New Mexico border, and approximately 120 miles east-southeast of the mine site. This event was widely felt in Arizona and western New Mexico, with a reported intensity of MM V near the epicenter. Based on reported intensities surrounding the site, an intensity between MM II and III would have been observed at the mine (Wong et al. 2018). Following this event, there were over 40 likely aftershocks ranging from magnitude 2.0 to 4.0.

It should be noted that regional seismic hazard is a consideration handled explicitly during the design of tailings storage facilities, beyond the brief narrative provided here (see section 3.10.1).

Induced Seismicity

Seismic events due to human activity can and do occur, and are commonly referred to as "induced seismicity" (National Academy of Sciences 2013). There are two types of mine-induced seismicity (Gibowicz and Kijko 1994; Richardson and Jordan 2002). Type A events are smaller in magnitude (less than 1), related directly to mining activities (i.e., digging, blasting), and occur at or near the active mining face. Type B events have larger magnitudes and are the result of shear failure along a pre-existing structure (i.e., fault, joint bedding plane, or other zones of weakness). They may occur on structures not exposed at the active mine face, but which are affected by the perturbed stress field.

Induced seismicity has been recognized and observed in mines around the world, although not all mines exhibit seismicity (Gibowicz and Kijko 1994); over 100 years of worldwide observations of induced mine seismicity show that induced events of greater than magnitude 5 are rare, whereas events of magnitude 3 or less are more common. Since 2013, seismic activity has been has been observed in two mines in Arizona: in southeastern Arizona near Morenci (up to magnitude 3.1), over 120 miles east of the analysis area, and in northeastern Arizona, south of Shonto (up to magnitude 2.9) (U.S. Geological Survey 2018b), approximately 300 miles north of the analysis area. These minor magnitudes are within the range of seismicity currently observed in the region. However, these events consist of mine explosions, not earthquakes induced by mining. The closest occurrences of

23. The Modified Mercalli scale is a method of measuring the intensity of an earthquake at a given location, and is based on the real-world effects people would experience and observe. The intensities described above are generally described as follows:

VI – Generally noted as being felt by all, and strong enough to frighten many; strong enough to move some heavy furniture; and slight damage like falling plaster.

V – Generally noted as being moderate. It is felt by nearly everyone, and many are awakened. Some dishes and windows are broken, and unstable objects overturned. Pendulum clocks may stop.

IV – Generally noted as being relatively light. It typically can be felt indoors by many but outdoors by only a few people; at night, some people are awakened; dishes, windows, and doors are disturbed, and walls make cracking sounds; and standing vehicles will rock noticeably.

III – Weak. Many people do not recognize it as an earthquake, standing vehicles may rock slightly, and vibrations are similar to the passing of a truck.

II – Weak. Felt only by a few persons.

mining-induced seismicity are in the coal mines of the Wasatch Plateau in eastern Utah and western Colorado (Wong 1993).

The nearest mapped Quaternary "active" surface fault relative to the mine is the Sugarloaf fault zone, located about 35 miles to the northwest (U.S. Geological Survey 2018a) of the mine, and 30 miles southeast of the proposed Near West tailings storage facility site (Wong et al. 2017). The Sugarloaf fault zone runs along the western margin of the Mazatzal Mountains (Pearthree et al. 1995). The fault likely experienced little Quaternary movement, as indicated by the minimal relief across the fault (Pearthree 1998); trenching to examine sediments shows that the fault disturbed deposits older than 12,000 years, but did not disturb younger deposits (Pearthree et al. 1995).

Faults are located within the footprints of several of the alternative tailings storage facilities. The Concentrator, Main, and Conley Springs Faults cross the Silver King site, but previous research indicates that these faults are healed (Cross and Blainer-Fleming 2012), and are not believed to be active within the last 2.6 million years (Wong et al. 2017). The Skunk Camp site includes two mapped faults, the Dripping Springs and Ransome Faults, neither of which are believed to have been active during the past 12,000 years (Wong et al. 2017).

As noted, numerous faults are also located near Oak Flat, bounding the Resolution Graben. These faults are key to how the subsidence area would develop and were incorporated into the subsidence modeling.

LANDSLIDES AND ROCKFALL

Landslides, in the form of general "earth slides," have been mapped in several locations near the analysis area (Arizona Geological Survey 2018). These include (1) immediately north of U.S. 60, approximately 0.5 mile northeast of the town of Superior, (2) less than 1.0 mile southwest of the mine, and another approximately 2.0 miles south of the mine, and (3) immediately adjacent to and within the northwestern footprint area of the Silver King alternative tailings storage facility site.

Public concern has been raised about the stability of Apache Leap itself, in light of the subsidence that would occur on Oak Flat. The height and steepness of the Apache Leap escarpment speaks to the strength of the Apache Leap Tuff and its overall stability. Observations related to Resolution Copper's ongoing exploration work confirm the stability of the Apache Leap Tuff, including the strength of the rock observed as Shaft #10 was sunk (Tshisens 2018b).

The stability of Apache Leap is also demonstrated by actual monitoring of the Apache Leap escarpment using LiDAR techniques, which has taken place since 2011 and is still ongoing. This monitoring uses 11 measurement stations and has an accuracy to 0.2 feet. No significant movement has been observed since monitoring began; all movements are attributable to vegetation changes or to small rockfalls (Maptek Pty Ltd. 2011, 2012, 2014a, 2014b, 2015, 2016, 2017).

ABANDONED MINES

Abandoned mine workings or adits pose a safety hazard if they are not properly sealed from public access, and are also a concern with respect to stability of foundations for tailings embankments built in historical mining areas.

Historic-era mining features have been noted on several of the offered land parcels, most notably the Apache Leap South End Parcel on the west side of Oak Flat. Here there are multiple historical mining features and remnants of old mining-related roads located throughout the parcel, including small open cuts, shafts, tunnels, raises, crosscuts, and more extensive underground workings. The major underground mines in this area were principally known as the Grand Pacific and Belmont mines. Entrances to these mines are found on portions of the parcels and appear to date to the early 1900s. The Dripping Springs parcel has also been noted for historic mine activity.

The historic Bomboy Mine was identified in the vicinity of the embankment of the tailing site, in Roblas Canyon. This was an underground copper mine started in 1916, with last production noted in 1971.

Paleontological Resources

Paleontological resources are the fossilized remnants of life. The majority of rock types in the analysis area are igneous (volcanic and plutonic), volcaniclastics, metamorphic rocks, and coarse clastic sedimentary rocks, which are either environments that never had biological activity or were environments that were not conducive to the preservation of fossils or evidence of biological activity. The only formations with potential for paleontological resources are the sequence of Paleozoic sedimentary rocks, namely the Naco Limestone, the Escabrosa Limestone, and the Martin Limestone. These rocks outcrop in the Apache Leap escarpment below the Apache Leap Tuff and extend down to the western edge of the town of Superior.

The following are descriptions of the potential fossil-bearing formations and the fossils typically associated within those formations:

<u>Naco Limestone.</u> The Naco Limestone is roughly 300 million years old, and is a medium- to thin-bedded, gray, white, pale blue to pink limestone (Resolution Copper 2016d). Shallow-shelf marine fossils are common and locally abundant in Naco Limestone and they include foraminifera (especially fusulinids), brachiopods, mollusks (gastropods, clams and other bivalves, cephalopods), tabulate and rugose corals, sponges, bryozoans, echinoderms (crinoids), and rarely, vertebrates like shark teeth and fish bones (Reid 1966; Resolution Copper 2016d).

<u>Escabrosa Limestone</u>. The Escabrosa Limestone is roughly 350 million years old and is equivalent to the Redwall Limestone prevalent in the Grand Canyon. It is a thick-bedded, cliff-forming, resistant, white to dark gray limestone (Blainer-Fleming et al. 2013; Resolution Copper 2016d). This formation potentially contains mostly crinoids and rugose corals with some brachiopods and trilobites. However, it is sparsely fossiliferous and preservation of these fossils is generally poor because they are worn, fragmented, and nearly inseparable from the host limestone.

<u>Martin Limestone</u>. The Martin Limestone is roughly 400 million years old and contains dark to light gray limestone and shale (Pye 1959; Resolution Copper 2016d). This formation can be fossiliferous and potentially contains brachiopods, crinoids, and corals (Blainer-Fleming et al. 2013).

Cave Resources and Karst Landforms

In addition to their preservation of fossils, limestone units also have the potential for cave formation by dissolution of the carbonate rock by groundwater. Of the three Paleozoic limestone formations discussed in the previous section, the Naco and the Escabrosa have the greatest potential for cave formation. According to Huddle and Dobrovolny (1952), the Escabrosa Limestone formation contains karst features that are infilled with rubble breccia and Naco Limestone, indicating extensive karst topography in Central Arizona more than 300 million years ago. The Kartchner Caverns of the Whetstone Mountains of southern Arizona (near Benson), for example, are formed in the Escabrosa Limestone. There are no caves currently mapped in the Paleozoic limestone units within the analysis area and, due to the extensive intrusions and veins, cave formation is likely limited to small, discontinuous cavities.

While several karst features have been noted in Queen Creek Canyon upstream of Superior, only one existing cave has been identified in the area: Hawks Claw Cave is located near Alternative 2 tailings site.

Unpatented Mining Claims

Numerous unpatented mining claims—both lode and placer—are located within the footprint of the mine components. These are summarized in the GPO in appendix A and figure 3.2-1 (Resolution Copper 2016d) for Alternatives 2 and 3, and have been compiled separately for Alternatives 4, 5, and 6 (Garrett 2019a).

- No unpatented claims unrelated to Resolution Copper are located within the Oak Flat Federal Parcel, or on the East Plant Site.

- The West Plant Site is privately owned. No unpatented claims unrelated to Resolution Copper are located around the periphery of the West Plant Site.
- The MARRCO corridor right-of-way is already existing and in use. No unpatented claims unrelated to Resolution Copper are located within the MARRCO corridor.
- Unpatented claims unrelated to Resolution Copper are located within the various alternatives tailings storage facility footprints and/or the tailings pipeline corridor footprints. In Section 3.2.4, impacts on these claims are assessed specific to each alternative.

3.2.4 Environmental Consequences of Implementation of the Proposed Mine Plan and Alternatives

3.2.4.1 Alternative 1 – No Action Alternative

Under the no action alternative, the mine would not be constructed, block-caving would not occur, and there would be no impacts from subsidence, induced seismicity, increased potential for landslides or rockfall, impacts on caves, karst, or paleontological resources, or impacts on mining claims.

3.2.4.2 Impacts Common to All Action Alternatives

Effects of the Land Exchange

The land exchange would have effects on geology and mineral resources.

The Oak Flat Federal Parcel would leave Forest Service jurisdiction. The role of the Tonto National Forest under its primary authorities in the Organic Administration Act, Locatable Regulations (36 CFR 228 Subpart A), and Multiple-Use Mining Act is to ensure that mining activities minimize adverse environmental effects on NFS surface resources. The removal of the Oak Flat Federal Parcel from Forest Service jurisdiction negates the ability of the Tonto National Forest to regulate effects on these resources from the proposed mine and block-caving. With respect to mineral development, no unpatented mining claims other than those associated with Resolution Copper are located on the Oak Flat Federal Parcel (see figure 1.3-2 in the GPO (Resolution Copper 2016d)).

The offered land parcels would enter either Forest Service or BLM jurisdiction. Section 3003 of the NDDA specifies that any land acquired by the United States is withdrawn from all forms of entry, appropriation, or disposal under the public land laws, location, entry, and patent under the mining laws, and disposition under the mineral leasing, mineral materials, and geothermal leasing laws.

Specific management of mineral resources on the offered lands would be determined by the agencies, but in general when the offered lands enter Federal jurisdiction, mineral exploration and development would not be allowed. Given these restrictions, no or little mine-related activity would be expected to occur on the offered lands.

Effects of Forest Plan Amendment

The Tonto National Forest Land and Resource Management Plan (1985b) provides guidance for management of lands and activities within the Tonto National Forest. It accomplishes this by establishing a mission, goals, objectives, and standards and guidelines. Missions, goals, and objectives are applicable on a forest-wide basis. Standards and guidelines are either applicable on a forest-wide basis or by specific management area.

A review of all components of the 1985 Forest Plan was conducted to identify the need for amendment due to the effects of the project, including both the land exchange and the proposed mine plan (Shin 2019). A number of standards and guidelines (18) were identified applicable to management of mineral, cave, or paleontological resources. None of these standards and guidelines were found to require amendment to the proposed project, either a forest-wide or management area-specific basis. For additional details on specific rationale, see Shin (2019).

Summary of Applicant-Committed Environmental Protection Measures

A number of environmental protection measures are incorporated into the design of the project that would act to reduce potential impacts on geology and mineral resources or reduce potential impacts from subsidence and other geological hazards. These are non-discretionary measures, and their effects are accounted for in the analysis of environmental consequences.

In appendix E of the GPO (Resolution Copper 2016a), Resolution Copper has committed to various measures to reduce impacts from subsidence:

- Subsidence will be monitored to collect data to validate model calibration and refinements; to develop threshold and alarm levels for early warning and detection of subsidence impacts before surface impacts occur; to identify surface movements due to mining of the Resolution ore body; and to implement corrective actions and contingency plan.
  - Apache Leap, Queen Creek Canyon, and the surface area above the planned underground mine are currently monitored (prior to mining) using LiDAR, Interferometry Synthetic Aperture Radar (InSAR), and select rock spires using digital tilt meters.
  - During mining, the surface area above the ore deposit would be subdivided into a no-go zone, consistent with the limit of the subsidence fracture zone (where no person may enter) and a restricted public access zone consistent with the continuous subsidence limit (where Resolution Copper personnel are permitted for geotechnical monitoring and inspections). These zones would be reassessed during mining based on information collected from cave propagation monitoring.

    Surface subsidence will be monitored through the use of available industry best practice and demonstrated technology including, extensometer, survey prisms, crack displacement monitors; Time Domain Reflectometer (TDR) cables; aerial photography; InSAR; microseismic monitoring system; and smart markers and cave trackers.
  - Post-mining monitoring would continue for at least 15 years. Resolution Copper would continue to monitor the impact of surface subsidence on key infrastructures
    - Apache Leap, cliffs, and pillars
    - Queen Creek and Devil's Canyons
    - Highway U.S. 60
    - The surface subsidence area and Oak Flat Campground
- Resolution Copper will document and store all the results of surface subsidence inspection and monitoring. Results will be reported annually to the Forest Service for the Apache Leap Special Management Area. The reporting would include a summary of subsidence management actions undertaken to protect the Apache Leap SMA, a summary of observed and/or reported subsidence impacts, and a summary of cave performance and subsidence development based on monitoring.

Additional applicant-committed environmental protection measures by Resolution Copper are identified in the draft subsidence monitoring plan (Tshisens 2018a) and would reduce impacts from subsidence to Apache Leap, Queen Creek Canyon, or Devil's Canyon, staged depending on the level of effect observed:

- If monitoring indicates formation of new cracks or extension of existing cracks in the area, Harrison plots show slight damage based on monitoring data, small seismic events in the area, an average tilt up to 4 degrees, or measured subsidence angle is between 72 and 78 degrees, measures implemented would be as follows:

- Resolution Copper would continue monitoring as per subsidence monitoring program; and
- Resolution Copper would update subsidence model predictions based on measured data or observations.

- If monitoring indicates extensive formation of new cracks or extension of existing cracks in the area; Harrison plots show moderate to severe damage based on monitoring data, major seismic events in the area, an average tilt of 5 degrees, or measured subsidence angle is less than 72 degrees; measures implemented would include the following:
  - Resolution Copper would increase monitoring frequency;
  - Resolution Copper would inform the Forest Service;
  - Resolution Copper would update subsidence model predictions based on measured data or observations; and
  - Resolution Copper would change draw strategy and mine plans.

Additional applicant-committed environmental protection measures by Resolution Copper would reduce impacts from subsidence to U.S. 60, mine roads and buildings, and Oak Flat Campground, staged depending on the level of effect observed (Tshisens 2018a):

- If monitoring shows formation of new cracks or extension of existing cracks in the area or on U.S. 60, Harrison plots show slight damage based on monitoring data, small seismic events in the area, an average angular distortion between 2×10^{-3} and $4 \times 10^{-3,}$ or measured subsidence angle is between 72 and 78 degrees; measures would include the following:
  - Resolution Copper would continue monitoring as per subsidence monitoring program; and
  - Resolution Copper would update the subsidence model predictions based on measured data or observations.
- If monitoring shows extensive formation of new cracks or extension of existing cracks in the area or on U.S. 60, Harrison plots show moderate to severe damage based on monitoring data, major seismic events in the area, an average angular distortion of more than $4 \times 10^{-3,}$ or measured subsidence angle is less than 72 degrees; measures implemented would be as follows:
  - Resolution Copper would increase monitoring frequency;
  - Resolution Copper would inform relevant public authorities;
  - Resolution Copper would update subsidence model predictions based on measured data or observations; and
  - Resolution Copper would increase road maintenance programs and repairs.

To prevent exposure of the public to geological hazards, Resolution Copper would use fencing, berms, locking gates, signage, natural barriers/steep terrain (25 to 30 percent or greater), and site security measures to limit access roads and other locations near areas of heavy recreational use.

Subsidence Impacts

TIMING AND EXTENT OF SUBSIDENCE CRATER DEVELOPMENT, INCLUDING UNCERTAINTY

Resolution Copper proposes to use panel caving for underground mining at about 4,500 to 7,000 feet beneath the ground surface. The total mineralized rock to be removed is estimated to be about 1.4 billion tons of ore. Caving of this ore material is induced by undercutting the ore zone, which removes its ability to support the overlying rock material.

Fractures then spread throughout the area to be extracted, causing it to collapse and form a cave, which then propagates upward. This caving of the ore is predicted to be accompanied by surface subsidence. Subsidence occurs when the underground excavation caves and movement of material propagate all the way to the surface, and the land surface is subsequently deformed.

The depth of the land surface depression is a result of the properties of the collapsed rock material and the amount of rock removed below it. The geographic extent of surface disturbance is a function of the rock properties, local geological structure, regional geological stresses, and the amount of material removed through mining. The predicted surface subsidence is depicted in figure 3.2.4-1, at 6, 10, 15, 20, 30, and 41 years after the start of mining.

Figure 3.2.4-1 illustrates three areas: the crater limit, fracture limit, and continuous subsidence limit.

- The crater limit is the area of active caving, directly above the ore body. The surface in this area would be actively mobilized and moving during mining. This is defined in the subsidence model as areas with more than 6 to 7 feet of vertical displacement.
- The fracture limit is at the fringe of the crater limit and is the area where visible fracturing would be expected, including radial cracks and possible rotation and toppling of rocks. For the purposes of the EIS analysis, the fracture limit is generally considered to be the area where physical impacts from subsidence are likely to occur. This area is defined in the subsidence model as areas where the total measure of strain exceeds 0.5 percent.
- The continuous subsidence limit is characterized by extremely small rock deformations that can only be detected using high-resolution monitoring equipment. If deformations are significant enough, in some cases they can create small hairline cracks in the surface of concrete but would not be visible in the soil or on the ground. This area is also commonly referred to as the elastic zone, because the deformations are usually below the threshold where rock fractures. This area is defined in the subsidence model by a combination of horizontal strain and angular distortion.

Figure 3.2.4-2 provides a detailed depiction of the anticipated subsidence at the end of the mine life; the fracture limit is estimated to extend to within approximately 1,115 feet (340 m) from Apache Leap, and to approximately 3,445 feet (1,050 m) from Devil’s Canyon. The fracture limit area is roughly 1.8 miles in diameter.

The Geology and Subsidence Workgroup requested a number of sensitivity model runs as part of the evaluation of the subsidence model (BGC Engineering USA Inc. 2018a; Garza-Cruz and Pierce 2018). These model runs assess what would change if various input parameters or assumptions in the model were different, including rock mass strength, in-situ strength, fault strength, and bulked rock porosity. The size of the fracture limit under these different sensitivity runs does not differ substantially from the base case model, and while at least one sensitivity run brings it closer to the boundary of the Apache Leap SMA, it remains outside that boundary. Similarly, under all scenarios the first breakthrough of subsidence occurs in year 6 or 7 of mining, and subsidence ends very soon after ore extraction ends.

The primary difference in results among all the sensitivity model runs is the ultimate depth of the subsidence crater. Under the base case model, an ultimate depth of about 800 feet is anticipated. Under other sensitivity runs, the depth of the subsidence crater can vary between 800 and 1,115 feet.

POTENTIAL IMPACTS ON APACHE LEAP AND OTHER RESOURCES

While the fracture limit predicted by the subsidence model remains distant from Apache Leap, and Resolution Copper modelers concluded that there would be no anticipated damage to Apache Leap, there are still smaller modeled changes that are anticipated for Apache Leap. The

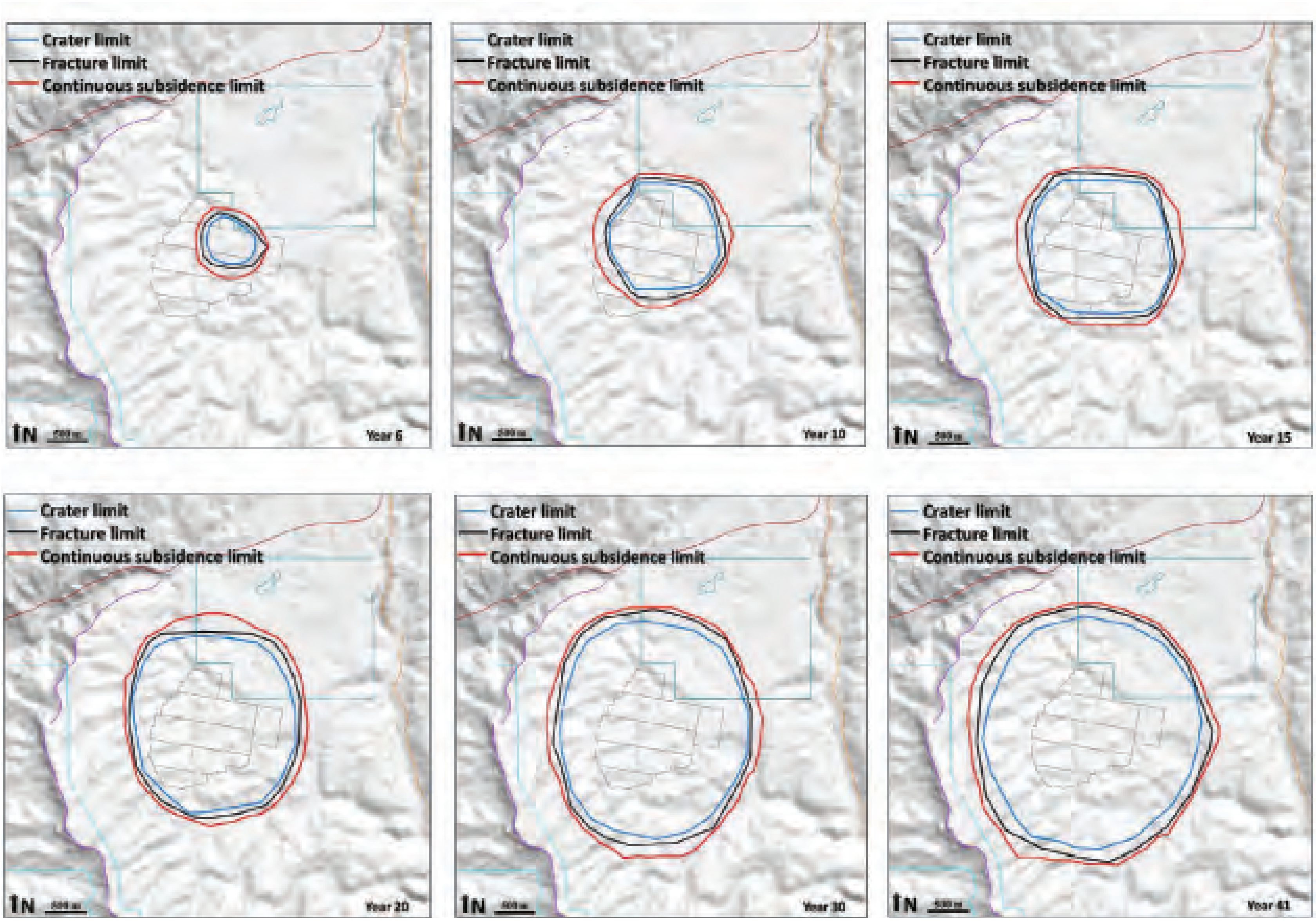

Figure 3.2.4-1. Evolution over time of the crater, fracture, and continuous subsidence limits predicted to exist (reproduced from Garza-Cruz and Pierce (2017))

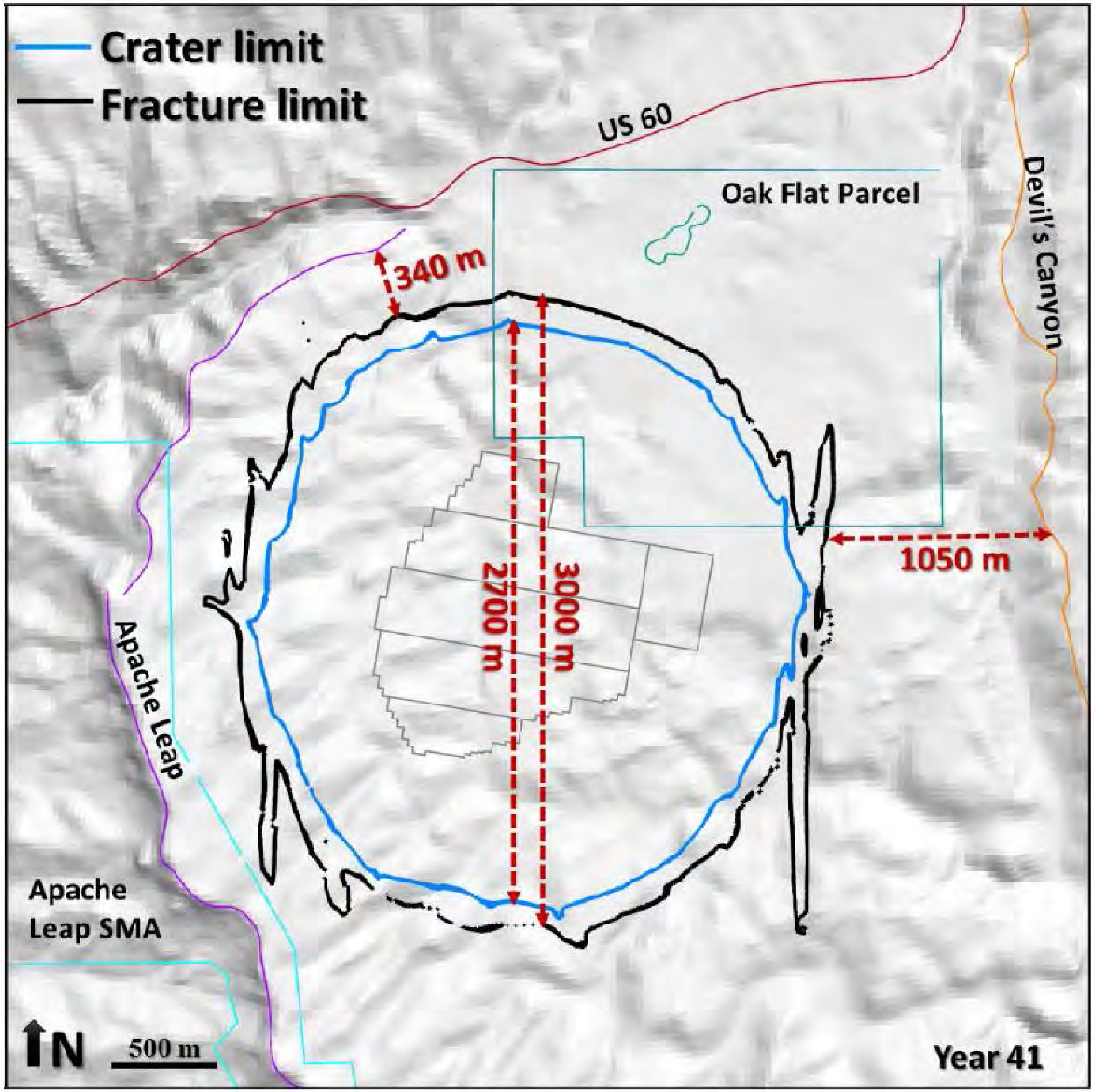

Figure 3.2.4-2. Final anticipated subsidence crater boundaries at end of mine life (reproduced from Garza-Cruz and Pierce (2017))

Geology and Subsidence Workgroup assessed predictions of horizontal displacement, vertical displacement, strain, and angular distortion.

- Roughly 1.5 feet (0.4 to 0.5 m) of horizontal and vertical displacement is anticipated at Apache Leap. Horizontal and vertical displacement by itself does not necessarily lead to damage.
- The angular distortion at Apache Leap is anticipated to be less than 1×10^{-3} meter/meter (BGC Engineering USA Inc. 2018a; Morey 2018b). The approximate threshold for damage is 3×10^{-3}, indicating that damage would not be expected at Apache Leap (BGC Engineering USA Inc. 2018a; Garza-Cruz and Pierce 2017).

The Geology and Subsidence Workgroup generally agreed with the conclusion that damage to Apache Leap would not be anticipated and found that many of the modeling choices were conservative (i.e., these choices would tend to overestimate the extent of subsidence, not underestimate it). However, after assessing a number of sensitivity analyses, some remaining uncertainties were recognized, including (BGC Engineering USA Inc. 2018a):

- The geographic extent of subsidence changes with the rock mass properties of the Apache Leap Tuff and Whitetail Conglomerate formations. When rock mass properties were reduced by 25 percent during a sensitivity run, the fracture limit extended closer to Apache Leap. However, even during this sensitivity run, angular distortion at Apache Leap did not exceed the 3×10^{-3} threshold for damage.
- The geographic extent of subsidence also changes with assumed fault strength. When fault strength was reduced during a sensitivity run, the fracture limit extended closer to Apache Leap. However, even during this sensitivity run, angular distortion at Apache Leap did not exceed the 3×10^{-3} threshold for damage.

Considering these uncertainties, the Geology and Subsidence Workgroup identified that the combination of horizontal displacement and vertical settlement could potentially cause angular distortion to locally exceed the damage threshold at Apache Leap and lead to localized rock block failure, but large-scale failures are not anticipated (BGC Engineering USA Inc. 2018a). A localized rock block failure refers to the gradual movement or sudden fall of one or more individual rock blocks due to progressive ground movement over time; these small rockfalls are a possibility but not anticipated to be substantially different from those observed in ongoing monitoring. Large-scale failure refers to progressive or sudden failure of a large mass of rock in response to ground movements over time; large failures, collapses, or major rockfalls are not anticipated and are considered to be unlikely.

In addition to Apache Leap, similar concerns were raised for Devil's Canyon and U.S. 60. These locations are located even farther than Apache Leap from the fracture limit. Damage is not anticipated at these locations, subject to the same uncertainties described in this section.

MINE INFRASTRUCTURE AND EFFECT OF SUBSIDENCE MONITORING

As noted, a number of applicant-committed environmental protection measures related to subsidence monitoring would occur. The intent of this monitoring is to understand the real-world progression of the block-caving and subsidence. Public comments have raised the concern that once block-caving begins, such monitoring would provide useful information but would ultimately not be effective at preventing impacts on Apache Leap or other areas if the subsidence modeling turns out to be incorrect.

While it is accurate that subsidence would progress unchecked once block-caving begins, there are several aspects of the mine plan that would make the subsidence monitoring effective at preventing damage to Apache Leap or U.S. 60.

The mine plan calls for the block-caving to occur in six discrete panels, described in detail in GPO section 3.2.9.1 (Resolution Copper 2016d).

The phasing of these panels is to mine from east to west, or in other words, starting farther from Apache Leap and working toward Apache Leap. In this manner, the results of subsidence monitoring from the initial panel caving would be available prior to any mining near Apache Leap. This would allow time for modifications to be made to the mine plan, if necessary, before damage occurred at Apache Leap.

In addition, the primary mine infrastructure at the East Plant Site is located closer to the subsidence fracture limit than Apache Leap. In the event that real-world subsidence is more extensive than anticipated by the subsidence modeling, the infrastructure needed to continue mining would be anticipated to be impacted prior to impacts occurring at Apache Leap. This would allow time for modifications to be made to the mine plan before damage occurred at Apache Leap.

Geological Hazards

INDUCED SEISMICITY

In general, the primary requirement for inducing seismicity is human activity that changes the state of stress in highly pre-stressed rocks (Gibowicz and Lasocki 2001); mining and subsidence at the project site could impact the existing state of stress. The potential for induced seismicity was assessed for the project (BGC Engineering USA Inc. 2018b).

It is not possible to make specific predictions about mine-induced seismicity at the proposed Resolution Copper Mine. However, the potential surface effects for induced earthquakes that might occur at the proposed mine could include ground shaking on a local scale, which could include the town of Superior. While mine-induced seismicity is possible, based on 100 years of worldwide observations, events greater than magnitude 5 are rare, and events of magnitude 3 or less are more common. This is observed in the most recent mine-related earthquakes in Arizona, which ranged from magnitude 2.9 to 3.1. For reference, damage to structures is rarely observed for earthquakes less than magnitude 5. Surface faulting is not expected because the magnitude of possible induced seismic events falls far below the observed threshold (about magnitude 6.5) for surface faulting (Youngs et al. 2003).

Induced mine seismicity is possible, but unlikely to be of sufficient magnitude to cause structural damage.

SUBSIDENCE AREA ACCESS

With the exception of the southeast portion, the entirety of the subsidence area would be on Resolution Copper private land, after exchange of the Oak Flat Federal Parcel. Access to the subsidence area would be restricted on these lands using fencing, berms, signage, and natural barriers or steep terrain (25 to 30 percent or greater).

The southeast portion of the subsidence area would be on Arizona State Trust land; the future ownership or use of this land is not known. Regardless of ownership, it is anticipated that the entire subsidence area would be under the jurisdiction of both the Arizona State Mine Inspector, requiring adherence to the Arizona mining code, and MSHA, requiring adherence to national mining regulations. Both these entities take public safety into account when regulating and inspecting mines and would dictate access restrictions.

Paleontological Resources

No known paleontological resources, or surface geological units amenable to paleontological resources (Naco, Escabrosa, and Martin limestones), would be impacted by subsidence or other activities at the East Plant Site, West Plant Site, MARRCO corridor, or filter plant and loadout facility.

Caves and Karst Resources

No known cave/karst resources, or surface geological units amenable to cave/karst resources (Naco and Escabrosa limestones), would be impacted by subsidence or other activities at the East Plant Site, West Plant Site, MARRCO corridor, or filter plant and loadout facility. Several caves have been identified in the vicinity of these facilities

(Umbrella Cave, Superior High School Cave); these are considered in section 3.8 as suitable wildlife habitat but would not be impacted or disturbed by the project footprint.

Unpatented Mining Claims

No unpatented mining claims unassociated with Resolution Copper would be impacted by activities at the East Plant Site, West Plant Site, MARRCO corridor, or filter plant and loadout facility.

The development of the Resolution Copper Mine potentially could encourage additional exploration and staking of mining claims on Federal lands at the periphery of the mine. This type of activity has been observed to be spurred by the permitting or development of known ore bodies. This ultimately could drive additional ground disturbance for well pads and access roads; any such development would be subject to Forest Service analysis and permitting. Known exploration projects have been considered for cumulative effects.

3.2.4.3 Alternative 2 – Near West Proposed Action

Paleontological Resources

No known paleontological resources have been observed within the footprint of the Alternative 2 tailings storage facility. Naco and Escabrosa limestone have not been observed at the surface under the Alternative 2 tailings storage facility footprint. A small outcropping of Martin limestone is located on the west side of the tailings storage facility footprint. Although paleontological resources have not been observed here, this geological formation has the potential to host fossils, and this outcrop likely would be destroyed during tailings storage facility construction (Klohn Crippen Berger Ltd. 2018a).

Caves and Karst

No known cave/karst resources, or surface geological units amenable to cave/karst resources (Naco and Escabrosa limestones), would be impacted by the footprint of the Alternative 2 tailings storage facility (Klohn Crippen Berger Ltd. 2018a).

Unpatented Mining Claims

A number of unpatented lode and placer claims are located within the footprint of the Alternative 2 tailings storage facility and tailings pipeline corridor footprint that are not associated with Resolution Copper (see figure 1.3-2 in the GPO). These include the Bomboy Placer claim and about 10 to 20 lode claims within the tailings storage facility footprint, along with 20 to 30 lode claims within the tailings pipeline corridor.

3.2.4.4 Alternative 3 – Near West – Ultrathickened

Impacts from Alternative 3 would be identical to those under Alternative 2 for caves, karst, paleontological resources, and mining claims.

3.2.4.5 Alternative 4 – Silver King

Paleontological Resources

No known paleontological resources, or surface geological units amenable to paleontological resources (Naco, Escabrosa, and Martin limestones), would be impacted by the footprint of the Alternative 4 tailings storage facility. All three of these units are in the vicinity but are not exposed at the surface within the tailings facility footprint (Klohn Crippen Berger Ltd. 2018c).

Caves and Karst

No known cave/karst resources, or surface geological units amenable to cave/karst resources (Naco and Escabrosa limestones), would be impacted by the footprint of the Alternative 4 tailings storage facility. Both of these units are in the vicinity but are not exposed at the surface within the tailings facility footprint (Klohn Crippen Berger Ltd. 2018c).

Unpatented Mining Claims

A number of unpatented lode claims are located within the footprint of the Alternative 4 tailings storage facility and tailings pipeline corridor footprint that are not associated with Resolution Copper. Roughly 70 to 80 unpatented claims, associated with three different owners, are within the tailings storage facility footprint.

3.2.4.6 Alternative 5 – Peg Leg

Paleontological Resources

No known paleontological resources, or surface geological units amenable to paleontological resources (Naco, Escabrosa, and Martin limestones), would be impacted by the footprint of the Alternative 5 tailings storage facility (Golder Associates Inc. 2018a).

Caves and Karst

No known cave/karst resources, or surface geological units amenable to cave/karst resources (Naco and Escabrosa limestones), would be impacted by the footprint of the Alternative 5 tailings storage facility (Golder Associates Inc. 2018a).

Unpatented Mining Claims

A number of unpatented lode claims are located within the footprint of the Alternative 5 tailings storage facility and tailings pipeline corridor footprint that are not associated with Resolution Copper. Roughly 80 to 90 unpatented claims, associated with two different owners, are located along the eastern tailings pipeline corridor, and roughly 40 to 50 unpatented claims, associated with five different owners, are located along the western tailings pipeline corridor.

3.2.4.7 Alternative 6 – Skunk Camp

Paleontological Resources

No known paleontological resources, or surface geological units amenable to paleontological resources (Naco, Escabrosa, and Martin limestones), would be impacted by the footprint of the Alternative 6 tailings storage facility (Klohn Crippen Berger Ltd. 2018d).

Caves and Karst

No known cave/karst resources, or surface geological units amenable to cave/karst resources (Naco and Escabrosa limestones), would be impacted by the footprint of the Alternative 6 tailings storage facility (Klohn Crippen Berger Ltd. 2018d).

Unpatented Mining Claims

While the Alternative 6 tailings storage facility is located on Arizona State Trust lands and private lands and therefore no Federal unpatented mining claims are present, a number of unpatented lode claims are located within the footprint of the Alternative 6 tailings pipeline corridor that are not associated with Resolution Copper. Roughly 120 to 130 unpatented claims, associated with three different owners, are located along the southern tailings pipeline corridor, and roughly 10 to 20 unpatented claims, associated with five different owners, are located along the northern tailings pipeline corridor.

3.2.4.8 Cumulative Effects

The Tonto National Forest identified the following reasonably foreseeable future actions as likely, in conjunction with development of the Resolution Copper Project, to contribute to cumulative impacts on geology, minerals, and subsidence. However, it should be noted that no other mining or other human activities in the cumulative impact assessment area were identified as likely to result in geological subsidence. The analysis presented here therefore focuses on effects on area geology and mineral resources. As noted in section 3.1, past and present actions are assessed as part of the affected environment; this section analyzes the effects of any RFFAs, to be considered cumulatively along with the affected environment and Resolution Copper Project effects.

- *Pinto Valley Mine Expansion.* The Pinto Valley Mine is an existing open-pit copper and molybdenum mine located approximately 8 miles west of Miami, Arizona, in Gila County. Pinto Valley Mining Corporation is proposing to expand mining activities onto an estimated 1,011 acres of new disturbance (245 acres on Tonto National Forest land and 766 acres on private land owned by Pinto Valley Mining Corporation) and extend the life of the mine to 2039. The company estimates average annual copper production rates of between 125 and 160 million pounds to continue through the extended operational life of this mine.
- *Ripsey Wash Tailings Project.* ASARCO is planning to construct a new tailings storage facility to support its Ray Mine operations. The environmental effects of the project were analyzed in an EIS conducted by the USACE and approved in a ROD issued in December 2018. As approved, the proposed tailings storage facility project would occupy an estimated 2,574 acres and be situated in the Ripsey Wash watershed just south of the Gila River approximately 5 miles west-northwest of Kearny, Arizona, and would contain up to approximately 750 million tons of material (tailings and embankment material). ASARCO estimates a construction period of 3 years and approximately 50 years of expansion of the footprint of the tailings storage facility as slurry tailings are added to the facility, followed by a 7- to 10-year period for reclamation and final closure. The effects of this project on geology and minerals would include what is assumed to be irreversible loss to future use of any aggregate (i.e., sand, gravel, or decorative rock) or other mineral resource that would be permanently buried beneath the estimated 625-foot-high, nearly 2,600-acre facility.
- *Ray Land Exchange and Proposed Plan Amendment*. ASARCO is also seeking to complete a land exchange with the BLM by which the mining company would gain title to approximately 10,976 acres of public lands and federally owned mineral estate located near ASARCO's Ray Mine in exchange for transferring to the BLM approximately 7,304 acres of private lands, primarily in northwestern Arizona. It is known that at some point ASARCO wishes to develop a copper mining operation in the "Copper Butte" area west of the Ray Mine; however, no specific details are currently available as to potential environmental effects resulting from this future mining operation. Also, while no data have been made publicly available regarding ASARCO's estimates of the overall size or estimated grade of the ore body at the Copper Butte location, the deposit is known to be relatively shallow and composed entirely or nearly entirely of oxide ore. ASARCO has stated that the ore would be mined via an open-pit operation.
- *Florence Copper In-Situ Mining Project.* This mining project, located on the northwestern outskirts of the town of Florence, is an underground copper leaching, recovery, and processing operation that is now in a production testing phase. The operational life of the mine is estimated at approximately 20 years. The mine owner, Florence Copper, estimates that the operation would produce an average of 55 million pounds of copper annually for the first 6 years and 85 million pounds annually for 14 years, equating to approximately 1.5 billion pounds of copper that would be permanently removed from this location.

With respect to these RFFAs, although no Resolution Copper Project effects from subsidence, geological hazards, paleontological resources, or cave/karst resources would overlap the effects from these mining projects, cumulatively, all would contribute to the overall regional effects of continued mineral extraction in the Copper Triangle. It is reasonable to assume that during the projected life of the Resolution Copper Mine (50–55 years), some mineral material extraction operations like the mines identified here may exhaust the supply of desired rock materials in a given location and close, while other similar operations may start up elsewhere within the cumulative effects analysis area.

At any given time in this region of Arizona, it is extremely common for various mineral exploration projects, often involving the drilling of assay or test boreholes to evaluate the potential presence of an economically valuable mineral resource, to be ongoing. However, these types of activities are nearly always short term (typically lasting a few weeks to a few months) and generally have no effect or only the most negligible effect on the landscape and on area geological and mineral resources. It is reasonable to assume similar activities will continue into the foreseeable future.

3.2.4.9 Mitigation Effectiveness

The Forest Service is in the process of developing a robust mitigation plan to avoid, minimize, rectify, reduce, or compensate for resource impacts that have been identified during the process of preparing this EIS. Appendix J contains descriptions of mitigation concepts being considered and known to be effective, as of publication of the DEIS. Appendix J also contains descriptions of monitoring that would be needed to identify potential impacts and mitigation effectiveness. As noted in chapter 2 (section 2.3), the full suite of mitigation would be contained in the FEIS, required by the ROD, and ultimately included in the final GPO approved by the Forest Service. Public comment on the DEIS, and in particular appendix J, will inform the final suite of mitigations.

This section contains an assessment of the effectiveness of mitigation and monitoring measures found in appendix J that are applicable to geology, minerals, and subsidence.

Mitigation Measures Applicable to Geology, Minerals, and Subsidence

Subsidence monitoring plan (FS-222): Extensive subsidence monitoring has been proposed by Resolution Copper and is included in this document as an applicant-committed environmental protection measure, as discussed earlier in this resource section under “Summary of Applicant-Committed Environmental Protection Measures.” The Forest Service generally has concluded that this monitoring would be effective at identifying potential effects of subsidence in time to inform a response to prevent damage.

However, as subsidence has the potential to affect Tonto National Forest surface resources, particularly within the Apache Leap SMA, the Forest Service will require that a final subsidence monitoring plan be completed and approved by the Forest Service prior to signing a decision. Given the unique and technical nature of subsidence modeling and monitoring, the Forest Service would engage with appropriate industry professionals (such as those involved in the Geology and Subsidence Workgroup) to review the subsidence monitoring plan, funded by Resolution Copper if deemed appropriate.

Mitigation Effectiveness and Impacts

The mitigation measure would focus on all aspects of the subsidence monitoring, including monitoring equipment, techniques, frequency, trigger levels, and remedial actions. As discussed earlier, the phasing of the panel caving is such that remedial actions can be taken if monitoring indicates subsidence impacts are more extensive than anticipated. The final subsidence monitoring plan is therefore anticipated to be effective at mitigating any damage to Apache Leap or other Tonto National Forest surface resources, once appropriate trigger levels and actions have been identified.

There would be no additional physical impacts associated with this mitigation.

Unavoidable Adverse Impacts

Unavoidable adverse impacts would occur through disturbance caused by the subsidence, to a small area of Martin limestone with potential paleontological resources (Alternatives 2 and 3), and to unpatented mining claims not associated with the Resolution Copper Project (all tailings facilities and/or pipeline corridors). Impacts on cave/karst resources and to the public from geological hazards from access to the subsidence area, induced seismicity, or damage to Apache Leap are not considered likely to occur.

3.2.4.10 Other Required Disclosures

Short-Term Uses and Long-Term Productivity

Construction of the project would convert some undeveloped lands into an industrial mining operation, and construction of mine facilities would alter the area's topography. Impacts related to subsidence and the tailings storage facilities would permanently impact long-term productivity.

Irreversible and Irretrievable Commitment of Resources

Irreversible commitment of geological and mineral resources would occur with the excavation and relocation of approximately 1.4 billion tons of rock and with the recovery of approximately 40 billion pounds of copper, as well as the burying of any mineral resources below the alternative tailings facilities.

With respect to paleontological and cave/karst resources, a commitment of resources is considered to be irretrievable when project impacts limit the future use or productivity of a nonrenewable resource over a limited amount of time—for example, structures built on top of paleontologically sensitive geological units that might later be removed. A commitment of resources is considered to be irreversible when project impacts cause a nonrenewable resource to be permanently lost—for example, destruction of significant fossils and loss of associated scientific data.

An irreversible commitment of paleontological resources could occur at the Alternative 2 and 3 tailings storage facility location, where potentially fossil-bearing rocks associated with the Martin limestone could be destroyed in site preparation or buried permanently.