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# Project Memorandum

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| **To:** | **SWCA Environmental Consultants** | **Doc. No.:** | **N/A** |
| **Attention:** | **Chris Garrett** | **cc:** | |
| **From:** | **Amir Karami, Mike Henderson** | **Date:** | **July 21, 2020** |
| **Subject:** | **Subsidence Uncertainties at the Proposed Resolution Panel Cave, Response to Malach Consulting LLC.** | | |
| **Project No.:** | **1704007** | | |

## 1.0 INTRODUCTION

BGC Engineering Inc. (BGC) is a subcontractor to SWCA Environmental Consultants (SWCA) for third-party preparation of the U.S. Forest Service (USFS) Environmental Impact Statement (EIS) on the Resolution Copper Project and Land Exchange, located near Superior, Arizona. BGC's role is to provide SWCA with geological, hydrogeological and geotechnical engineering services in support of analyzing the environmental effects of the proposed panel cave mining project and assisting in preparation of the EIS. Resolution Copper Mining, LLC (RCM) prepared the Resolution Copper Project General Plan of Operations (GPO) pursuant to USFS National Environmental Policy Act regulations under 36 CFR 220 in 2014 which was subsequently updated in 2016 (RCM, September 23, 2014; May 09, 2016).

RCM presented the predicted extent of surface subsidence at the end of mine life (year 41) in terms of Crater depth, Fractured Zone Limit and Continuous Subsidence Zone Limit in GPO as predicted by the Beck Engineering three-dimensional (3D) numerical assessment (RCM, September 23, 2014). RCM also retained Itasca Consulting Group (Itasca) to conduct 3D numerical modeling of ground surface subsidence anticipated from the proposed panel cave mining project. Itasca (July 17, 2017) reported ground surface subsidence predictions over the life of mine.

A Geology and Subsidence Workgroup (Workgroup) was formed by the Resolution Copper Project EIS team. Members of this Workgroup included technical experts from the third party EIS contractor (SWCA/BGC) and members of the USFS Inter-disciplinary (ID) team. The purpose of the Workgroup was to review RCM's data collection and interpretation procedures, data, geologic and geotechnical baseline documents and subsidence modeling approach and predicted subsidence. Following completion of the review, the Workgroup compiled and documented its findings of the review in detail in a report entitled "Geologic Data and Subsidence Modeling Evaluation Report - Draft" (BGC, November. 30, 2018). A summary of the findings was included in the Draft Environmental Impact Statement (DEIS) for the Resolution Copper Project (USFS, August 01, 2019).

As part of the public comment period for the DEIS, the Arizona Mining Reform Coalition submitted an independent review by Malach Consulting LLC. (Malach) of the RCM geologic and geotechnical data and surface subsidence prediction modeling, which provided comment on whether RCM had correctly predicted the land subsidence that would result from panel caving. Dr. Steven Emerman of Malach completed the review and presented his findings from this review in a report (Malach, March 17, 2019). RCM and its consultant (Itasca) subsequently provided responses to some of Malach's comments (Itasca, February 26, 2020; RCM, February 26, 2020) which are discussed in this memorandum.

This memorandum is intended to provide BGC's third party evaluation and expert opinion on each of the issues raised by Malach, through a review of Malach's report and cited references and based on data and reports from RCM and their consultants, and discussions within the Workgroup. It begins, in Section 2.0, with a brief description of the review work that was completed by the Workgroup, and issued prior to completion of Malach's independent review, followed by background information on caving-induced subsidence and a summary of caving-induced subsidence predictions and anticipated ground movements in areas beyond the Continuous Subsidence Zone, in Section 3.0 and Section 4.0, respectively. The memorandum continues with the review of Malach report in Section 5.0 followed by summary and conclusions in Section 6.0. Text in italic indicate direct quotes from Malach's report or the other referenced sources.

## 2.0 EIS GEOLOGY AND SUBSIDENCE WORKGROUP REVIEW

The purpose of the Workgroup was to review RCM's geotechnical data collection and procedures, geotechnical data, and geologic and geotechnical baseline documents to (BGC, November 30, 2018):

1. Determine whether the methods employed by RCM in collecting and documenting geologic data are appropriate, adequate, and consistent with industry standards.
2. Determine whether RCM's interpretations of geologic structures, faults, geotechnical data, rock properties, and assumptions are reasonable and adequate.
3. Identify any significant data gaps.
4. Identify uncertainty with the interpretations, with consideration of data gaps.
5. Determine if there are cases where RCM's interpretations are not considered reasonable and, if so, provide alternative interpretations and supporting rationale.

The EIS Workgroup reviewed RCM's data collection procedures, data validation and Quality Assurance/Quality Control (QA/QC) processes and analyses methods and subsidence modeling approach. The reviewed data included those supplied by RCM and their consultants in the GPO, and other data made available through formal baseline data requests (by the Workgroup) to RCM to provide more information on data and procedures used to interpret geologic and geotechnical data for use in predictive modeling of surface subsidence. The Workgroup reviewed RCM responses and requested additional data after further discussions. In order to understand the impact of uncertainty in geologic and geotechnical data on predicted surface subsidence, the Workgroup requested sensitivity analyses simulations of the predictive model. SWCA held several formal meetings with RCM and other stakeholders in which RCM and its consultant, Itasca, presented and discussed with the Workgroup the geologic and geotechnical data and methodologies used in the subsidence assessment as well as the results of the sensitivity analyses on the predicted extent of surface subsidence.

Following completion of the review, the Workgroup compiled and documented the findings of its review in a report entitled "Geologic Data and Subsidence Modeling Evaluation Report - Draft" (BGC, November 30, 2018). A summary of the findings was included in the Draft Environmental Impact Statement (DEIS) for the Resolution Copper Project (US Forest Service, August 01, 2019).

## 3.0 PREDICTED SUBSIDENCE AT RESOLUTION

Itasca (July 17, 2017) completed a 3D numerical assessment of surface subsidence associated with planned panel caving at Resolution (Base Case Model) using the FLAC3D code (Itasca, 2017). The following criteria were used to define Crater Limit, Fractured Zone Limit and Continuous Subsidence Zone Limit:

- Crater Limit - defined as the boundary at which vertical displacements exceed 6.6 ft, (2 m)
- Fractured Zone Limit - defined as the limit of visible fracturing and was determined where total strain reached 0.005 (0.5%)
- Continuous Subsidence Zone Limit - characterized by small continuous displacements, delineated by the combination of horizontal strain and angular distortion that exceed the 0.002 (0.2%) and 0.003 (0.3%), respectively (Figure 2 of Appendix A).
- Tilt Limit - a tilt limit of 7.5 degrees was used to determine if slender and tall rock formations could collapse at Apache Leap (Itasca, June 18, 2018).

The justifications for using the stated criteria for delineating the Fractured Zone Limit and the Continuous Subsidence Zone Limit are discussed in Section 2.0 of Appendix A.

## 4.0 PREDICTED CAVING-INDUCED GROUND MOVEMENTS AT APACHE LEAP, HIGHWAY US-60 AND DEVIL'S CANYON

Itasca predicted, from numerical modeling results, the extent of the Crater Limit, Fractured Zone Limit and Continuous Subsidence Zone Limit for the planned mine production for Resolution over the proposed 41 year active mine life. The model predicted that the Crater, Fractured Zone and Continuous Subsidence Zone Limits would not reach Apache Leap, Highway US-60 or the Devil's Canyon during the active mine life. Following cessation of mining activities, subsidence will slow down and eventually stop. Ground monitoring will remain active as per the schedule provided in the Resolution Subsidence Monitoring and Management Plan (RCM, June 2020) to track the rate of changes in ground movements after mining ceases.

The predicted damage from caving-induced surface subsidence to each zone at the Resolution site, as defined in Section 2.0 and Figure 1 of Appendix A, is summarized below:

- The Crater could be up to (maximum) 1115 ft (340 m) deep with a N-S diagonal span of approximately 8860 ft (2700 m) and E-W diagonal span of approximately 8200 ft (2500 m). The Crater is predicted to be approximately 1640 ft (500 m) from Apache Leap at the closest point (Itasca, July 17, 2017, Figure 16).

- The predicted Fractured Zone Limit is approximately 1115 ft (340 m) from Apache Leap at the closest point (Itasca, July 17, 2017, Figure 16).
- The predicted Continuous Subsidence Zone Limit is within approximately 100 ft (30 m) to 715 ft (218 m) from the Fractured Zone Limit (Itasca, July 17, 2017, Figure 17).
- Tilt was calculated from the modeling results and plotted in plan view over the life of mine (RCM, June 29, 2018, Attachment C2). The results show that tilt at Apache Leap is expected to be less than 1 degree which is significantly less than the threshold of 7.5 degrees where tall slender formations may collapse (Turichshev et al., 2010). Therefore, slender tall formations are not anticipated to collapse at Apache Leap.

It is important to note that at the limit of the Continuous Subsidence Zone masonry buildings (if there were any located in the area) could experience cracks from 0.2 to 0.6 in. (5 to 15 mm) wide. Such damage in an already jointed and fractured rock mass would, however, not be detectable without high resolution instruments. At Apache Leap the angular distortion is predicted to be much less than 0.001 (0.1%) which places it within the Negligible Damage Zone in the building damage chart (Figure 2 of Appendix A). Thus, cracking is not anticipated to occur at Apache Leap and actual ground displacements are not expected to be visible without the use of high-resolution survey instruments.

Likewise, model results show that the limit of the Continuous Subsidence Zone, at the closest point, is 1475 ft (450 m) and 3450 ft (1050 m) from Highway US-60 and the Devil's Canyon, respectively. At these distances, the angular distortion is predicted to be much less than 0.001 (0.1%). Therefore, visible cracking or visible ground movements is not anticipated to occur at Highway US-60 or at Devil's Canyon.

It is also important to emphasize that while numerical modeling predicts up to 20 in. (0.5 m) of horizontal and/or vertical displacement at Apache Leap, the corresponding horizontal strains and/or angular distortions are predicted to be less than 0.1%. This is significantly less than the strain threshold that could cause disturbance (i.e., angular distortion of 0.3%). This also is consistent with the crack monitoring data and observations at the New Afton mine that indicated hairline cracks may only form if the vertical displacements reach approximately 1 m.

For additional description of caving-induced subsidence and associated zones and the criteria used to delineate Fractured Zone and Continuous Subsidence Zone, refer to Appendix A.

## 5.0 MALACH'S INDEPENDENT REVIEW

The objective of Malach's review was to answer the following question: *Has Rio Tinto correctly predicted the land subsidence that would result from panel caving at the proposed Resolution Copper Mine?* Malach further subdivided this objective into the following questions:

- *Did the prediction model of subsidence use correct input data and was modeling carried out correctly?*
- *Does the mining project have an adequate subsidence monitoring program?*
- *Do the predictions of the subsidence models have appropriate error bounds?*

Malach stated that *the questions were addressed by comparing the information in the proposal (RCM, September 23, 2014) with Google Earth images, the standard manual on block caving (Laubscher, 2000) and compilations of past experiences with land subsidence caused by block caving (Blodgett and Kuipers, 2002; Woo et al., 2013)*. Malach also referenced Canadian Dam Association (2013) for information on appropriate error bounds for discussion on the impact of dam failure on cultural values as being relevant to the possible failure of other types of mining infrastructure.

Malach's review was completed and published on March 17, 2019. This review was completed prior to publication of the DEIS (Aug. 01, 2019), the EIS Workgroup draft report (BGC, November 30, 2018) and prior to the results of subsidence modeling completed for the DEIS being made available. The EIS Workgroup Geologic and Subsidence Evaluation Draft Report (BGC, November 30, 2018) was included in the DEIS as an appendix and therefore was available for public review post DEIS publication. In response to whether his findings would have changed had Malach reviewed the Workgroup's Geologic and Subsidence Evaluation Draft Report prior to publishing his report, Malach responded, in a memorandum, that the information in the Workgroup's report does not change his opinion on the Resolution Copper panel cave project (Malach, October 20, 2019).

## 5.1. Correct Input Data and Modeling

On the question around correct input data and modeling, Malach commented that *"The actual data that were used in the subsidence modeling are not presented in any documents…. The only information that has been provided are the types of data and, in some cases, statistical summaries of the data…".* Malach continues to state, *"Even the description of the data is inadequate for assessing the validity of the subsidence modeling. The most important information that is missing are the numbers of drill cores and the depths of the drill cores…".*

The Geologic and Subsidence Workgroup reviewed RCM's data collection and interpretation procedures in detail. The Workgroup conducted a phased approach to data validation which included an initial review of the RCM internal procedures and methods in the first phase followed by a second phase in which more in-depth review was conducted on the coring, logging and core sampling processes, database management and data analyses, the Vulcan model and geological interpretations, internal validation and quality control (QC) procedures and subsidence modeling. The second phase of the review included a site tour of RCM facilities and discussions with geology and geotechnical staff. RCM staff discussed the internal core logging, core logging QC and data validation procedures during the site visit. RCM also provided this information to the Workgroup in a response to a data request (RCM, March 24, 2017). The Workgroup members also toured the RCM core logging facility, met with the core logging team and observed the core logging in practice. The findings of the Workgroup from the site visit were summarized in a report (BGC, Dowl, Geostat, July 07, 2017). The details of the Workgroup in-depth review are discussed in the draft Geologic Data and Subsidence Modeling Evaluation Report (BGC, November 30, 2018).

During the Geology and Subsidence review, the Workgroup requested RCM to provide additional geology and geotechnical information (Data Request #4, USFS, October 12, 2017) including core log data, information about faults intersected by drill holes, horizontal, vertical and plan view cross sections (to include drill holes and major structures/faults) as well as a 3D model of the major structures and drill holes for 3D visualization of the spatial distribution of the cored and logged holes. RCM provided this information in a response to Data Request #4 (RCM, January 09, 2018). In its response, RCM stated the total footage of core drilled and logged are 443,000 ft (135,000 m) and 430,000 ft (131,000 m), respectively from 135 drill holes and that 96% of the cored holes were logged. The depth of each hole can be obtained from the provided core data, and the 3D PDF structure model with core hole traces provided spatial distribution of the drill holes where geotechnical data were collected. RCM also provided detail about fault/fault zones that were intersected in drill holes including the depth, fault zone length, and its geotechnical characteristics. The fault/structure model that was provided to the Workgroup was used in the 3D numerical subsidence prediction model.

> On geotechnical properties for each geotechnical domain Malach commented that *"A valid subsidence model requires an adequate number and distribution of samples, which cannot be assessed. The geotechnical properties of the deepest layers (or geotechnical domains) can have a great influence on the extent of the subsidence zone on the surface. However, there is no information as to how many or whether any of the drill cores penetrated as deeply as the No. 10 Shaft (the 6943-foot deep primary access shaft)".*

RCM provided the Physical Characteristics of Rock Types and Rock Mass Characterization in Appendix F of the GPO (RCM, September 23, 2014; May 09, 2016). RCM later updated that information with data collected through 2016 and provided an updated version of Appendix F (RCM, October 05, 2017) to the Workgroup as part of the response to Data Request #4 (RCM, January 09, 2018). The updated Appendix F of GPO provides information on geological settings at the Resolution Copper project including site geology, regional faults, anhydrite mineralized zones and surfaces and alteration types and effects. The report continues with a summary of the methods used for geological and geotechnical data collection, a description of the collected data, and the data analyses and rock mass characterization methods used in the surface subsidence prediction modeling. It also states that a large number of laboratory tests including 495 uniaxial compressive strength (UCS) tests, 507 triaxial compressive strength (TCS) tests, 212 Brazilian tensile strength (BTS) tests, 66 acoustic velocity tests (under various confining pressures) and over 35000 point load tests (PLT) on core samples with associated UCS correlation estimates. The test samples were distributed between 12 geotechnical domains. The report further states that large volume of data derived from drill core data and photogrammetry mapping, and ground monitoring conducted during sinking of the Shaft No. 10 and its subsequent lateral developments were used for rock mass characterization of various geotechnical domains.

In-situ stresses were estimated using various methods including borehole breakout analysis of geophysical logs of the drill holes, overcoring (two campaigns) in the No. 10 Shaft, and hydrofracturing (29 successful tests) in three separate surface drill holes. In-situ stress measurement is a complex and highly specialized field test to estimate the in-situ stress regime in the mining area which is directly incorporated into the surface subsidence prediction modeling.

Rock mass monitoring and ground behavior observations made during the sinking of the No. 10 Shaft were also used to confirm the Whitetail and Apache Leap Tuff material properties that was exposed within the shaft alignment.

Geotechnical rock mass characterization completed by RCM used multiple empirical rock mass rating systems to characterizes the rock mass including Norwegian Rock Tunnel Index, Q, system (Barton el al., 1974), the rock mass rating system (Bieniawski, 1989), the Geological Strength Index, GSI (Cai et al., 2004) and the intact Rock Mass Rating (IRMR) system (Laubscher, 2000). The results of the rock mass characterization were summarized in the updated rock mass characterization report (RCM, October 05, 2017). The geotechnical domains for the Resolution Project have been developed primarily with consideration of lithology and alteration; however, multiple domains have been assigned to the same lithology where warranted by significant differences in rock properties. A 3D geotechnical model was developed for the Resolution Copper project which was included in the GPO. The 3D geotechnical model has since been updated based on the data collected through 2016 and includes the 12 geotechnical domains as stated in the updated rock mass characterization report (RCM, October 05, 2017).

Discontinuity orientations have been measured using conventional core orientation methods as well as the Acoustic Borehole Imaging (ABI) and dominant discontinuity sets were determined using stereoplot projections. Major structures and their true thickness were estimated from core data and were used to determine dominant structures within each geotechnical domain.

RCM has also reported the results of the laboratory testing on core samples in statistical form in a table or on a plot for each geotechnical domain in the updated rock mass characterization report. The report also included a 3D plot of spatial distribution of intact rock strength (UCS) within the mining zone. In addition, following the Data Request #9 by the Geology and Subsidence Workgroup, RCM provided a 3D PDF color-coded plot of point load test results indicating the spatial distribution of PLT test results within the mining zone (RCM, June 29, 2018). The rock mass strength properties for geotechnical domains have been estimated based on the core data, an estimation of Geological Strength Index (GSI) as a function of rock mass character and scale, and the UCS and TCS laboratory test results using Generalized Hoek-Brown criterion (Hoek et al., 2002). These rock mass properties were used in the surface subsidence prediction numerical model.

In addition, through Data Request #9, the Workgroup requested additional information on the rationale for the base case rock mass properties of Apache Leap Tuff (Tal) and Whitetail (Tw) domains. RCM provided this information in response to Data Request #9 (RCM, June 29, 2018, August 03, 2018; RCM, August 31, 2018 and RCM, September 10, 2018). This information was provided in dated addendums to Itasca subsidence modeling report (July 17, 2017).

In summary, although the geologic and geotechnical data, referred to by Malach, were only partially provided in the GPO, RCM provided additional geotechnical data to the Workgroup in response to subsequent baseline data requests (RCM, January 09, 2018; RCM, June 29, 2018; RCM, August 03, 2018; RCM, August 31, 2018 and RCM, September 10, 2018). The Workgroup evaluated this information as part of its review and summarized its findings in the Geologic Data and Subsidence Modeling Evaluation Report (BGC, November 30, 2018).

## 5.2. Geological Structures and Faults Map

By superposition of the West Boundary Fault on a Google Earth image, Malach identified a pronounced feature (labeled as a lineament) that is subparallel the West Boundary Fault and is offset from the fault by about 2000 ft (610 m) (Figure 1). The lineament is described by Malach as a fracture trace, and not strictly a fault, that is visible from aerial photography or satellite imagery and may represent surface expressions of deep-seated zones of structural weakness such as faults.

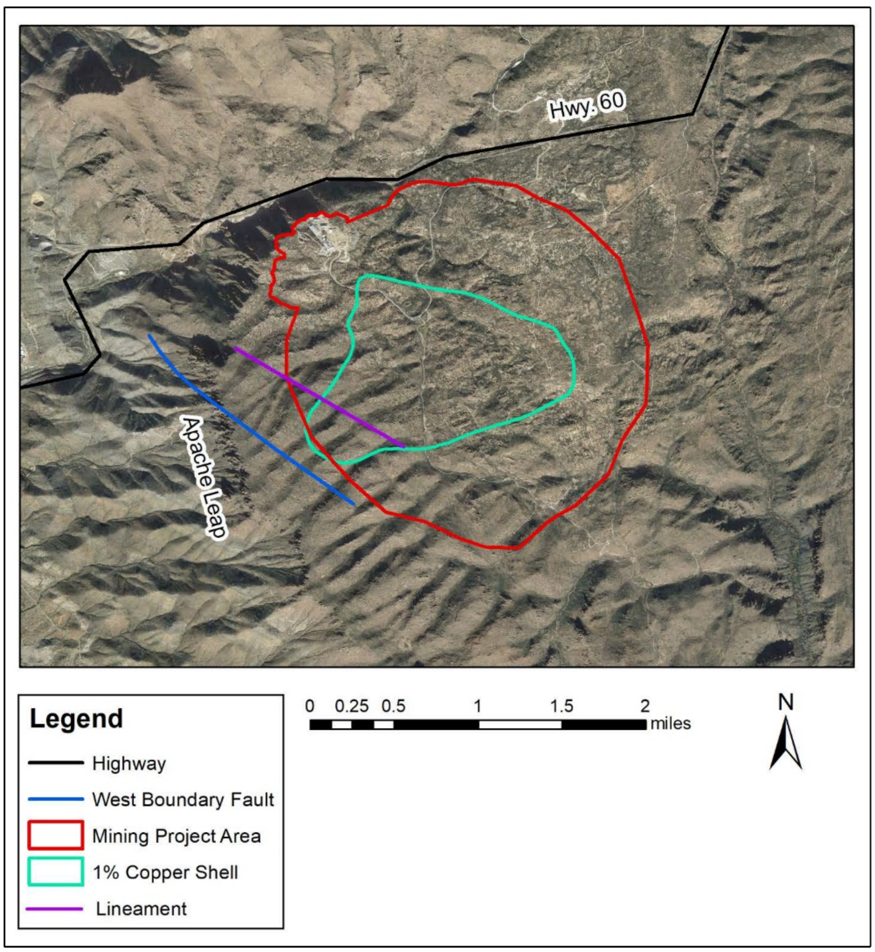


**Figure 1. The West Boundary Fault and the lineament identified by Malach from aerial photography and satellite imagery (Malach, March 17, 2019).**

> Malach stated that *"the nearly-parallel orientations of the West Boundary Fault and the lineament are certainly suggestive that the West Boundary Fault has been incorrectly mapped, and there is no other mapped fault that could be correspond to the lineament".* Malach further added that *"Unlike the mapped West Boundary Fault, the lineament intersects the caved rock zone, so that there is potential for deformation to be transmitted from caved rock zone to Apache Leap if the lineament is indeed a plane of structural weakness, such as a fault. On that basis, there could have been an underestimation of the extent of the subsidence zone".*

RCM responded to this comment in a report (RCM, February 26, 2020). RCM compared Malach's lineament with Resolution's geologic model wireframe and demonstrated that the lineament identified by Malach corresponds almost exactly with the Gant West Fault previously mapped by Resolution. Figure 2 compares the lineament and Malach's projected West Boundary Fault (Figure 2, left) with the Resolution's geologic model superimposed with the 3D model wireframes of Gant West and West Boundary Faults (Figure 2, right).

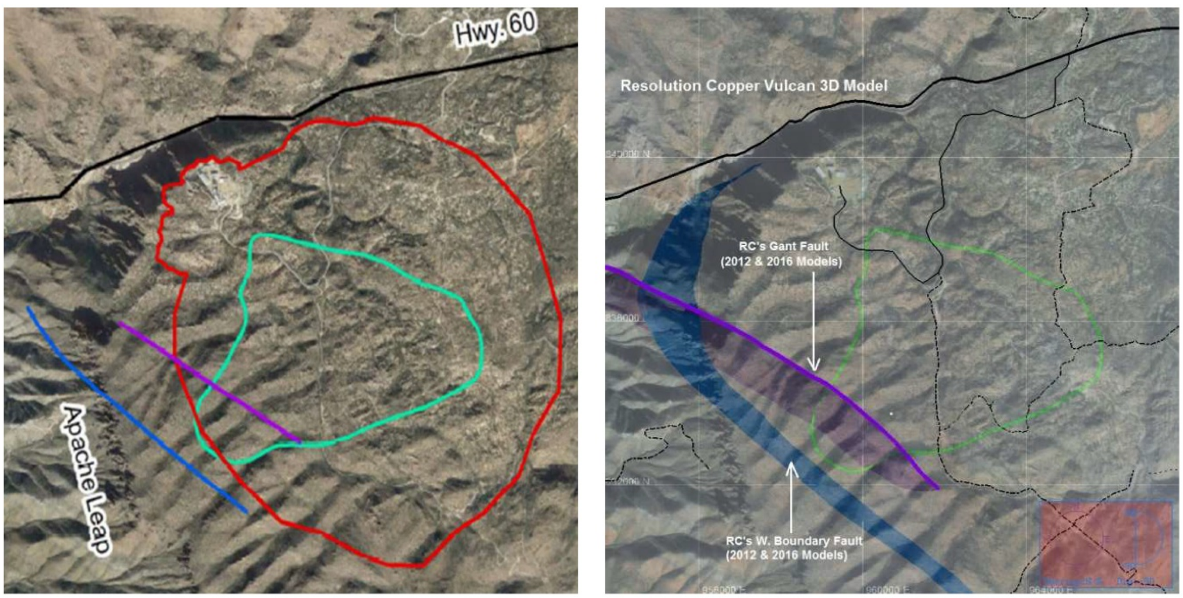


**Figure 2. Malach's plan view of West Boundary Fault and the lineament (left) and RCM's geologic model (right) superimposed with 3D model wireframes of Gant West and West Boundary Faults (RC's Gant Fault and RC's W. Boundary Fault labels on the right refer to Gant West Fault and West Boundary Fault, respectively).**

Itasca also provided a plan view as well as east-west and north-south cross-section plots of the structural model that were implemented in Itasca's predictive subsidence modeling confirming that the Gant West Fault and West Boundary Fault have been included in the Resolution subsidence modeling (Figure 3, Figure 4 and Figure 5) (Itasca, February 26, 2020).

> On the question around validity of the subsidence modeling, Malach stated that "*Even if all of the input data were adequate, it would be difficult to assess the validity of the subsidence modeling since no details have been provided, except for the names of the*

> *consulting companies and their numerical codes. Not even the titles or the lengths of the consulting reports have been provided (GPO, 2014)".*

While details of the subsidence modeling were not provided in the GPO (RCM, September 23, 2014; May 09, 2016), the structural geology model, other geotechnical properties as well as full details on cave modeling methodology were provided in Itasca's subsidence modeling report (Itasca, July 17, 2017). The EIS Geologic and Subsidence Workgroup review of the Itasca modeling report was also available for Malach to review post-DEIS publication.

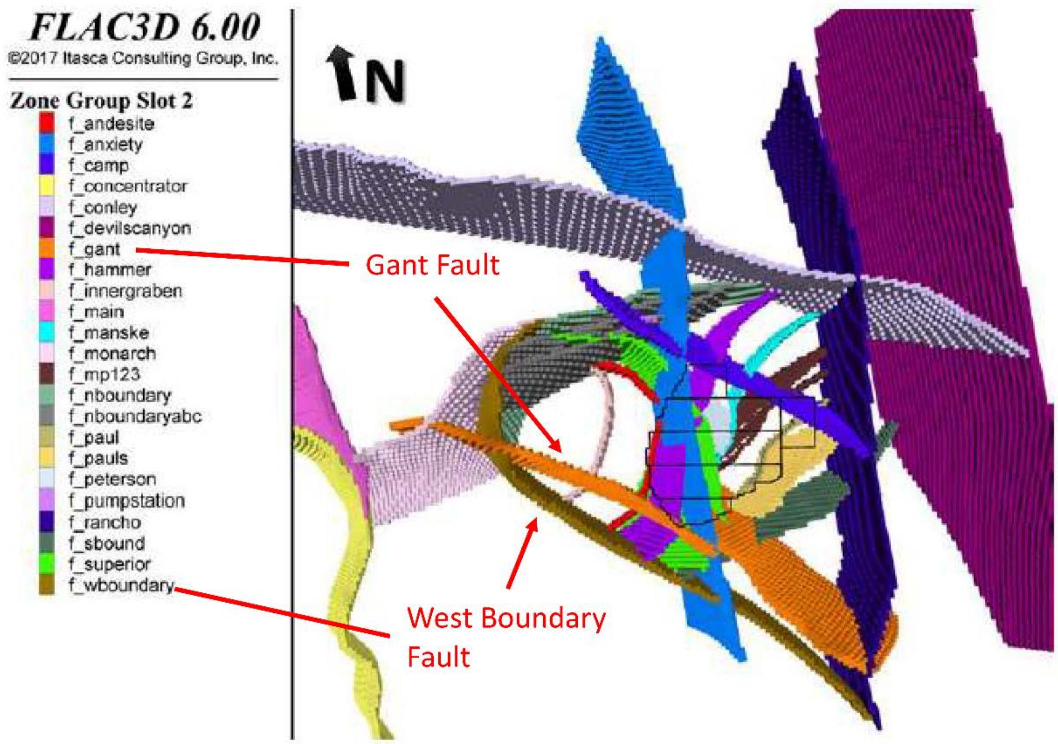


**Figure 3. Flac3D implicit representation of the faults in the region of the Resolution mine footprint (RCM, February 26, 2020).**

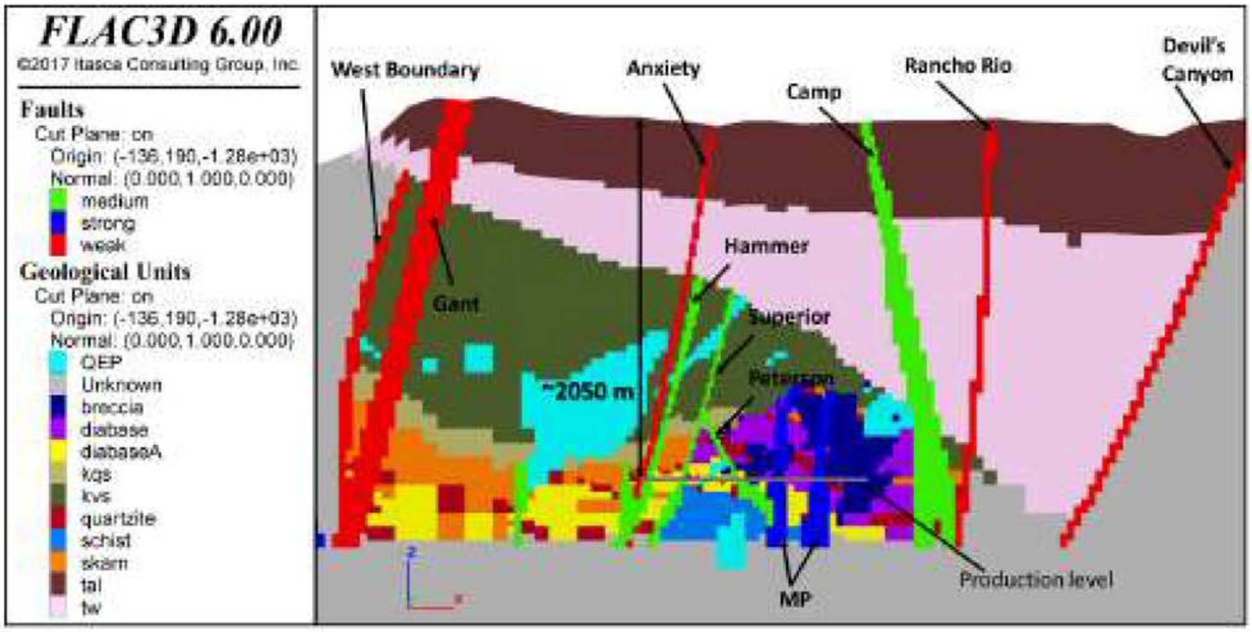


**Figure 4.** **Spatial distribution of lithology on an east-west cross-section looking north. The intersected faults are colored based on their qualitative ranking (strong, medium and weak) (RCM, February 26, 2020).**

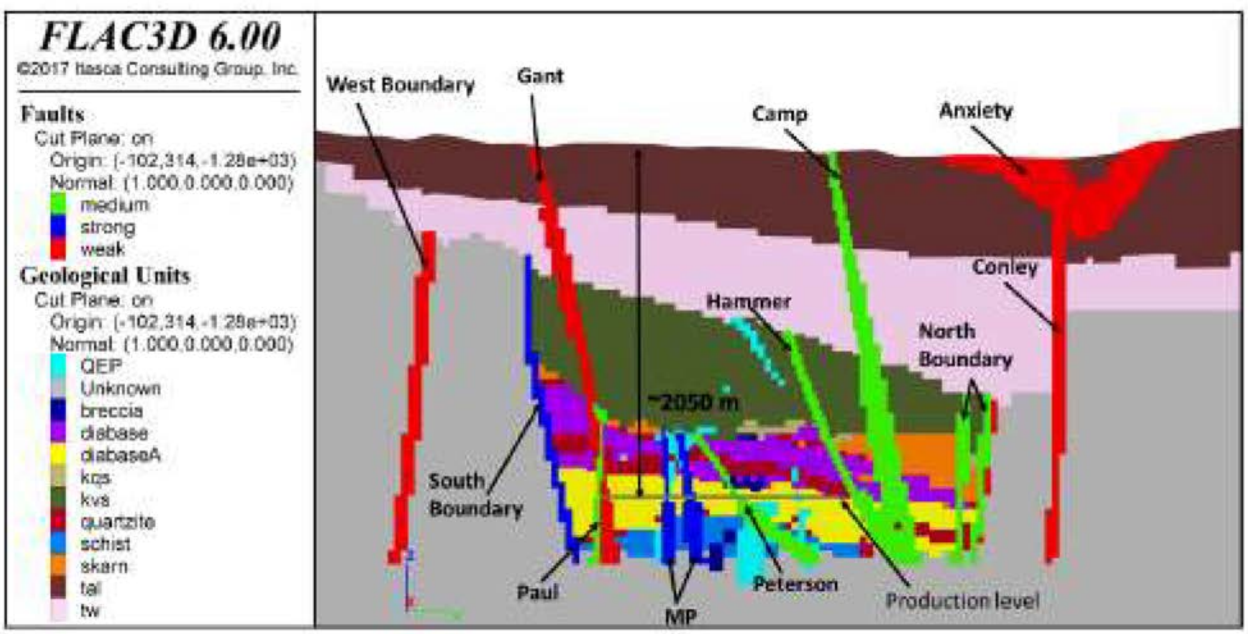


**Figure 5.** **Spatial distribution of lithology on a north-south cross-section looking west. The intersected faults are colored based on their qualitative ranking (strong, medium and weak) (RCM, February 26, 2020).**

### 5.3. Adequate Subsidence Monitoring Program

> Malach acknowledges that RCM is planning an extensive program of subsidence monitoring using a wide variety of instrumentation. Malach, however, argues that "*The primary issue is not Rio Tinto's ability to document subsidence, but their ability to take appropriate action in response to unanticipated subsidence*". Referencing Tetra Tech & R Squared (2006) and Woo et al. (2013), Malach further adds that "*A comprehensive database of subsidence caused by block caving reported that unanticipated subsidence has occurred in 20% of block caving projects with most of the anomalies being related to geological faults*". Quoting several statements from GPO (RCM, September 23, 2014), Malach continues "*The connection between observation and action is based on the explicit assumption that 'subsidence is a slow and gradual process that is predicted, closely monitored, and controlled (RCM, 2014) and that 'Subsidence is a rather slow and continuous process, and as such there would be time to apply an adaptive monitoring plan if required (RCM, 2014).*" With regard to the latter quote Malach adds *"note that 'monitoring' is not the same concept as 'action'"*.

Tetra Tech and R Squared (2006) describe a geotechnical assessment of two sinkholes development at the Troy Mine, Montana and evaluation of the implications for such a failure for the proposed Rock Creek Mine in Montana. In this study, Tetra Tech and R Squared referenced a database (Enclosure 3, Tetra Tech and R Squared, 2006) of hard rock underground mines consisting of 36 active and inactive mines from which 12 reported as caving or block caving, 11 reported as sublevel or open stope caving and the remainder were non-caving operations. Out of 36 cases, 8 (over 20%) were reported to have experienced unexpected failure, from which two occurred at sublevel caving operations. None of the unexpected cases were reported from block cave operations. Most of failures that were reported at block cave and sublevel cave operations were not unexpected and related to known major structures and faults. The 8 unexpected failures in the referenced database were reported from hard rock underground mines in general and were not specific to block cave operations, as claimed by Malach. Regarding the 8 cases of unexpected failure, Tetra Tech and R Squared concluded that "*This low number is an indication that the problem of unexpected surface subsidence in hard rock mines is not widespread*" and that *"… most of these mines operated more than 20 years ago* (as at Tetra Tech and R Squared report publication) *and did not have specific measures in place to mitigate subsidence*". Woo et al. (2013) also referred to all cases (not only caving operations) reported in the Tetra Tech and R Squared database and stated that about 20% of all cases experienced unexpected failure with most anomalies relating to geologic structures (faults). Therefore, the statement by Malach that "*A comprehensive database of subsidence caused by block caving reported that unanticipated subsidence has occurred in 20% of block caving projects…"* is at variance with the referenced database and accompanying reports.

The objective of the Tetra Tech and R Squared study was to assess the cause of the sinkholes at Troy mine. They concluded that "*failures at the level of mine workings propagated upward as chimney failures through the intensely fractured and deeply weathered rock of the East Fault and* *resulted in two sinkholes*". The report adds that consideration of a buffer zone between mine workings and the East Fault may have prevented the failure along the East Fault and the formation of sinkholes. It however adds that the mine was not required as part of its Mine Permit to develop such buffer zone. Tetra Tech and R Squared concluded that the sinkholes that occurred over the Troy Mine were the result of a progressive chimney cave up at a weak fault zone with a relatively shallow depth of cover. Tetra Tech and R Squared (2006) also assessed the possibility of chimney failure occurring at the Rock Creek project and asserted that the possibility of such failure at Rock Creek was minimal to nonexistent because core data and surface mapping suggested that faults at Rock Creek project were more competent than the East Fault at Troy mine. In addition, Rock Creek was required to leave a buffer zone between the fault zone and the mine workings.

A comparison between Troy mine and Resolution Project indicates significant differences. The Troy Mine implemented a room and pillar mining method and mine workings were within 270 ft (82 m) to 320 ft (98 m) of the ground surface where chimney failures occurred and the failures were directly located next to the highly fractured and intensely weathered East Fault with no buffer zone between mine workings and the fault zone. It was reported that the East Fault was intersected by 20 ft (6.1 m) wide mine workings at more than 70 locations and chimney type failure was not uncommon when driving through the fault zone. Resolution, in contrast, is a panel cave project at 7000 ft (2133 m) depth and there are no intensely weathered fault zones similar to East Fault at Troy Mine. At Resolution, while a large number of faults have been identified and interpreted within Resolution property, only those formed post-mineralization extend to ground surface. With the exception of the Camp Fault and Monarsh Fault (which were modelled as medium strong and strong based on their character), these post-mineralization faults are characterized as weak fault rock masses of variable thickness and not as a discrete fault plane based on surface mapping and core data. The weak faults are modelled with only frictional shear strength and no cohesion in the 3D predictive subsidence model (see Figure 3, Figure 4 and Figure 5). Model results include the impact of the fault zone strength (weak rock mass) on ground subsidence extent on the surface.

The results of the 3D subsidence modeling and the characteristics of faults at Resolution indicate chimney failure that could impact Apache Leap from Resolution's mining activities is unlikely to occur. Model results have shown that the Fractured Zone Limit at Resolution is most strongly controlled by the extraction level depth and shape of the orebody (Itasca, April 10, 2018). In addition, the planned ground monitoring during mining operations, as outlined in the Resolution Subsidence Monitoring and Management Plan (June 2020), provides methodologies and strategies to track ground movements progression towards Apache Leap, Devil's Canyon and Highway US-60. RCM monitoring plan includes a multi-phased approach and begins with the pre-caving phase (Phase 1) to develop baseline ground movement trends, to identify any observable displacement that might be occurring in the absence of mining and to establish fixed ground control targets and system calibration. Phase 2 begins with initiation of caving (undercutting) during which cave is tracked as it progresses upward to surface. Phase 3, 4 and 5 are tied to gradual radial progression of the subsidence footprint over the remaining life of mine. Phase 6 deals with ground monitoring after mining activities have ceased and involves time-dependent compaction of broken material in the crater (residual subsidence or creep) (RCM, June 2020). At any stage during mining, (Phase 2 through Phase 5), should the measured ground movements and the resulting subsidence boundary exceed the predicted limit (Itasca, July 17, 2017), as defined by an offset distance in the trigger action response plan (TARP), appropriate actions will be taken by RCM to control and mitigate impact on Apache Leap, Devil Canyon and Highway US-60.

> Malach referred to several case studies of rapid cave breakthrough to surface (Henderson Mine and Miami Inspiration Mine) or sudden collapse of the ground above cave operation (Athens Iron Mine) as reported by Blodgett and Kuipers (2002).

In the cases of the Henderson and Miami Inspiration Mines, there was no monitoring in place to track the vertical movements or formation of tension cracks on surface although survey data indicated ground settlement as the cave progressed to ground surface. Blodgett and Kuipers (2002) reported that piping was observed at early stages of block caving over each of the major ore bodies at Miami Inspiration, which may have been caused by uneven draw or too wide spacing of the draw points. The rock mass at Inspiration is described as having a relatively weak cap rock and a highly fractured and altered ore body, creating favorable conditions for rapid subsidence. In both cases, lack of monitoring, poor ground conditions and possibly poor mine planning likely contributed to rapid cave propagation and breakthrough to surface. In case of Athens Mine, Blodgett and Kuipers (2002) stated that the collapse of the ground above the cave was due to local geologic factors including a vertical fault (dip ~95º) and a vertical dike (dip ~91º) that bounded the ore body on the south and north, respectively. The outer portions of both structures were characterized as "*composed of fault gouge and were planes of shearing weakness. This left little or no support for the jasper capping on its north and south borders over the mined area*". The report does not state if there was a monitoring program in place at the time of collapse. In the three cases Malach refers to poor mine planning practice (draw points too widely spaced), weak geological structure and weak rock masses were the causes of rapid caving and lack of an adequate and detailed monitoring program prevented these events from being identified prior to failure. At Resolution, the instrumentation and monitoring program has been designed to detect small ground settlement and changes in the rate of ground subsidence well before the occurrence of larger settlements. Blodgett and Kuipers (2002) concluded that subsidence damage may be controlled or mitigated by alteration in mining technique as has been considered by RCM as part of its subsidence monitoring and TARP (RCM, June 2020).

Gilbride et al. (2005) provides a description of surface monitoring employed at Molycorp Inc. Questa Mine in New Mexico where a large network of survey monuments provided information on the rate of ground movements towards the Crater. Clayton et al. (2018) presented a summary of an extensive surface and subsurface monitoring and instrumentation program at New Gold's New Afton mine in Kamloops, British Columbia. The Questa mine block cave propagated to the surface at an average rate of 2 ft/day (0.6 m/day) through 1800 ft (550 m) of overburden after 900 days. New Afton block cave propagated to the bottom of historical Afton pit after about 15 months

(Davies et. al., 2018) at an average rate of 2.7 ft/day (0.8 m/day). These cave propagation rates are consistent with rates reported by Gillbride et al. (2005) at Henderson mine at 2.3 ft/day (0.7 m /day), San Manuel (south) at 1.6 ft/day (0.49 m/day) and Lakeshore at 6.5 ft/day (1.98 m/day).

Ground Instrumentation and monitoring at the Questa and New Afton mines have provided valuable information to the mine operation team to track ground movements and deepening of the subsidence zone. Davies et. al., (2018) reported that the ground movement data at New Afton Mine have allowed for developing a calibrated 3D model and that subsidence predictions have been tracking well with all field data. This demonstrates how ground monitoring data along with an adequate TARP can efficiently track surface subsidence lateral progression towards sensitive infrastructure (a tailing storage facility in case of New Afton) while maintaining worker safety as mining operations continue.

> Malach referred to A Practical Manual on Block Caving (Laubscher, 2000) to raise concern about rapid propagation of subsidence and quotes Laubscher "*Lateral extension…occurs when adjacent mining has removed lateral restraint on the block being caved*". Malach further raises concern that mining induced seismicity can lead to rockburst through shear displacement on faults and shear zones. Malach continues to add that caving of deep competent orebodies could lead to mining induced seismicity and rockburst.

On the point regarding rapid propagation, the subsidence will extend laterally as mining progresses to adjacent panels. However, once the cave has been developed to its ultimate footprint, the lateral progression of the subsidence zone slows as the cave progresses upward. The presence of faults may influence lateral expansion of subsidence as some faults naturally serve as a limiting boundary for further cave growth and other faults at depth pull out the fractured and mobilized (crater) zones, effectively increasing its footprint (Itasca, July 17, 2017). All predictive subsidence model results for Resolution represent the caving when it is fully expanded to the ultimate footprint.

Regarding mining-induced seismicity, Itasca (October 01, 2019) assessed the potential for caving-induced fault-slip seismicity at Resolution using the numerical model for caving-induced surface subsidence for Resolution (Itasca, July 17, 2017). Through this assessment, Itasca demonstrated that out of 31 faults identified within the caving zone, only 19 are predicted to have seismic activity due to mining with the maximum seismic moment magnitude of M 2.9 on Anxiety Fault, Gant Fault and South Boundary Fault. On the West Boundary Fault, which is the fault closest to Apache Leap, Itasca predicts a magnitude of only M 1.5. Itasca states that these predictions are conservative as the model assumes seismic energy is released at once, but the energy could be released over multiple events at smaller magnitudes. Lettis Consultants International, Inc. (LCI) (April 13, 2020) also finds this a very conservative assumption. More details on this study can be found in Itasca (October 01, 2019). The latter Itasca report along with the LCI report were provided to the EIS Workgroup as part of RCM response to Action Item GS-16 (Geology, Subsidence, Seismicity) (RCM, April 14, 2020).

BGC's review of potential seismic activity at Resolution (July 09, 2018) indicated that, since 2013, mining-induced seismicity has been observed in two locations in Arizona with recorded magnitudes up to M 3.1. This review found the observed mining-induced seismic activities in Arizona are in line with worldwide observations that mining-induced seismic events smaller than M 3 are not unusual and events greater than M 5 are rare. LCI (April 13, 2020) states that mining-induced seismicity in the western US is uncommon and that the only seismic events larger than M 3 are associated with the silver, lead and zinc mining in Coeur d'Alene, Idaho and the coal-mining induced seismic events at Book Cliffs in Utah and in western Colorado. Keefer's (April 1984) review of data from 40 historical world-wide earthquakes which resulted in landslides (rock falls, rockslides, rock slumping and rock avalanches) found no reports of earthquake-induced landslides from earthquakes of magnitudes lower than M 4. Therefore, the predicted seismic activities at Resolution (Itasca, October 01, 2019) are in the range of the observed mining-induced seismic events in Arizona and worldwide and are smaller than have been observed to cause rock fall, rockslide or rock slumping.

LCI (April 13, 2020) estimated the damage above the Resolution cave footprint and at Apache Leap for two seismic events predicted by Itasca (October 01, 2019): on Anxiety Fault (M 2.9) and on Camp Fault (M 2.6) through estimation of the peak horizontal ground acceleration (PGA) and correlation with Modified Mercalli (MM) intensities. LCI estimated PGAs using Atkinson (2015) and McGarr and Fletcher (2005) ground motion models. LCI reported that Atkinson (2015) model is based on a database of tectonic-induced earthquakes and McGarr and Fletcher (2005) model is based on a database of mining-induced seismic events in coal mines in Utah. LCI estimated the resulting median PGA range of 0.024 g to 0.028 g above mine footprint and range of 0.011 g to 0.015 g at Apache Leap which was caused by the larger magnitude seismic event (M 2.9) on Anxiety Fault. LCI then correlated the estimated PGAs to the MM intensities using a correlation table proposed by USGS (Table 1) from which LCI estimated damage to rock surface due to induced ground motions. LCI stated that the estimated PGA range above Resolution footprint corresponds to MM intensity of IV or Light in perceived ground shaking at which no potential damage is anticipated (Table 1). At Apache Leap, the estimated PGA range corresponds to MM intensity of II-III to IV or Weak to Light in perceived shaking and no potential damage at surface (Table 1). For more details on methodology to estimate damage from ground motions refer to LCI (April 13, 2020).

**Table 1. Correlation of perceived ground shaking and damage with PGA, peak horizontal ground velocity (PGV) and MM intensity (LCI, April 13, 2020)**

| Perceived Shaking | Not Felt | Weak | Light | Moderate | Strong | Very Strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| Potential Damage | None | None | None | Very Light | Light | Moderate | Moderate/ Heavy | Heavy | Very Heavy |
| PGA (g) | 0.0017 | 0.0017 to 0.014 | 0.014 to 0.039 | 0.039 to 0.092 | 0.092 to 0.18 | 0.18 to 0.34 | 0.34 to 0.65 | 0.65 to 1.24 | > 1.24 |
| PGV (cm/s) | < 0.1 | 0.1 - 1.1 | 1.1 - 3.4 | 3.4 - 8.1 | 8.1 - 16 | 16 - 31 | 31 - 60 | 60 - 116 | > 116 |
| MM Intensity | I | II-III | IV | V | VI | VII | VIII | IX | X |

RCM has recognized the potential for seismic activity following cave initiation and has planned for an extensive microseismic monitoring program that will run throughout the life of the mine and during closure. In addition to microseismic monitoring, RCM has planned for an observational and instrumentation-based monitoring plan which includes an array of aerial, surface and subsurface instrumentation to monitor ground movements and cave lateral progression (RCM, June 2020). To develop a ground movement baseline RCM plans to begin ground movement monitoring prior to commencement of caving operation (RCM, June 2020). The frequency of data collection will be adjusted as mining initiates.

> On post-mining monitoring, Malach states "*…it is difficult to understand the purpose of the post-mining monitoring, at which point it will no longer be possible to correct the procedures of panel caving mining. This disconnect between observations and subsequent preplanned actions should be regarded as a misuse of the Observational Method, which is used implicitly throughout the General Plan of Operations (RCM, 2014)"*. Malach further quoted the Independent Expert Engineering Investigation and Review Panel (2015) that investigated the tailing dam failure at the Mount Polley Mine in British Columbia as stating "*The Observational Method 'uses observed performance from instrumentation data for implementing preplanned design features or actions in response'*" and adds that "*Observational Method is not simply a license to figure things out later*".

According to GPO (RCM, May 09, 2016), RCM will begin caving at the east end of Panel 2 (Figure 6) which is farthest away from Apache Leap to provide time to monitor cave propagation towards Apache Leap through a combination of aerial, surface and subsurface instrumentation. The RCM monitoring plan includes continuation of monitoring after the end of mining. The post-mining monitoring, RCM states, is to monitor time-dependent compaction of broken material within the crater which will result in residual subsidence or "creep" that can occur over several years (RCM, June 2020). The purpose of the post-mining monitoring is not to be used to correct mine plans in response to ground movements, as Malach suggested, rather it is to monitor the subsidence, any trends and potential impacts on key areas and infrastructure after mining activities have ceased. All remaining functional monitoring instruments used during mining (Phase 3, 4 and 5) will remain active during post-mining monitoring (RCM, June 2020).

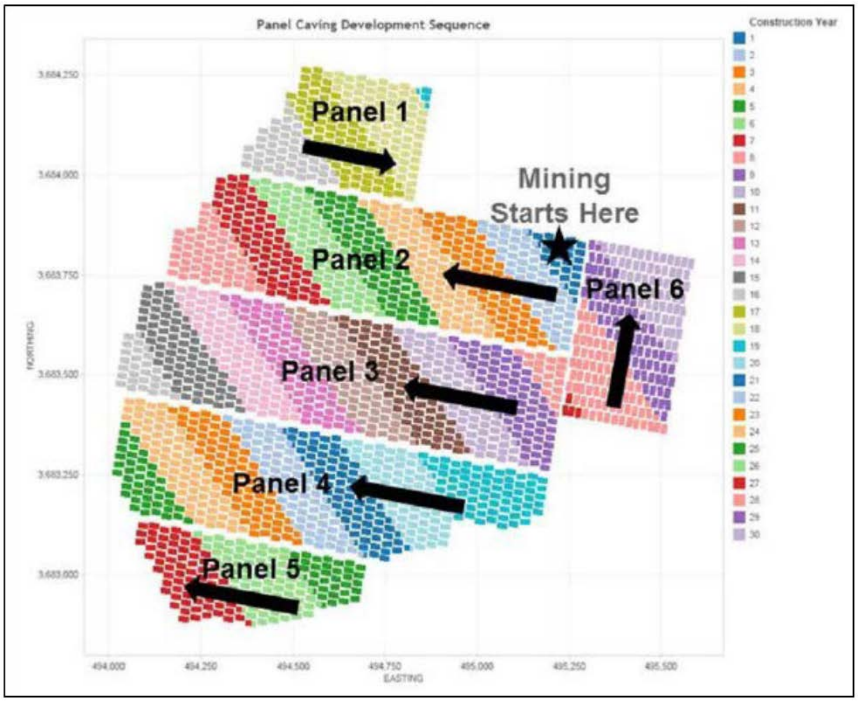


**Figure 6. Resolution Copper planned panel caving sequence.**

RCM's monitoring plan includes a TARP in which an offset is defined based on the distance the actual subsidence boundary exceeds the predicted boundary (Itasca, July 17, 2017) indicating subsidence is laterally progressing closer than predicted to the critical areas (Apache Leap, Highway US-60 or Devil's Canyon). Three trigger levels have been considered in the TARP based the offset distance being i) less than 490 ft (150 m) (Level 1), ii) between 490 ft (150 m) to 820 ft (250 m) (Level 2) and iii) greater than 820 ft (250 m) (Level 3). Each trigger level represents a geotechnical event and is accompanied by a plan of actions to address the changes in ground movements and potential impact on critical areas. RCM plans to determine the measured subsidence boundary based on measured angular distortion which itself is calculated from the ground displacements measured by multiple instruments. For details on RCM subsidence monitoring plan refer to Resolution Subsidence Monitoring and Management Plan (RCM, June 2020).

The range of planned responses in the TARP that apply during mining operations are consistent with proper application of the Observational Method.

### 5.4. Appropriate Error Bounds on subsidence Predictions

On appropriate error bounds on subsidence predictions, Malach states that *"the predictions of the limits of the caved rock, fractured and continuous subsidence zone contain no uncertainties or error bounds of any kind. Presumably, all predictions are simply the best estimates and not the worst-case scenarios. The only exception to the lack of* *error bounds in subsidence predictions are the predicted maximum depth of the crater above the ore body".*

This conclusion is not representative of the studies completed by RCM and its consultants and the review conducted by the EIS Geology and Subsidence Workgroup since the GPO was issued in 2014. These studies include an update to the GPO (RCM, May 09, 2016), Itasca reports on subsidence predictive modeling (Itasca, July 17, 2017) and sensitivity analyses results (Itasca, April 06, 2018), and review of the RCM data collection, analyses and subsidence modeling methodology by the EIS Workgroup (BGC, November 30, 2018).

As described earlier in this memorandum, as part of the EIS, the Workgroup has reviewed the RCM data collection procedures, data analyses and subsidence modeling methodology and the predicted subsidence at Apache Leap, Highway US-60 and Devil's Canyon. As part of this review and to address uncertainty or variability in geotechnical data, rock mass properties, fault strength properties, in-situ stress regime (including stress orientation and magnitude), and the bulking factor, the Workgroup requested RCM to conduct sensitivity analyses on these parameters to evaluate the impact of uncertainty of each parameter on the predicted subsidence at Resolution property. RCM's consultant, Itasca, conducted the sensitivity analyses and presented its results in a meeting with the EIS Workgroup and US Forest Service on March 24, 2018. The results of these analyses were submitted to the Workgroup in a memorandum (Itasca, April 06, 2018). To assess the conservativeness of the estimated Apache Leap Tuff rock mass strength properties, Itasca ran Monte Carlo simulation analyses that involved randomly varying the input parameters, based on the distributions of the GSI, UCS and $m_i$ value of the Apache Leap Tuff unit to calculate a distribution of the global rock mass strength using the Hoek-Brown strength criterion. This evaluation indicated that the deterministic base case Apache Leap Tuff global rock mass strength corresponds to $27^{th}$ percentile strength (i.e., if Apache Leap global rock mass strength is sampled a large number of times, the strength of 73% of samples will be higher than the base case value of 26 MPa). Details of these sensitivity analyses and results have been discussed in Itasca report (April 06, 2018) and in the EIS Workgroup Evaluation Report (BGC, November 30, 2018).

Subsidence model sensitivity analyses results indicated that the Fractured Zone Limits at Resolution are predominately controlled by the extraction depth and shape. Weaker global rock mass strength would extend the Fractured Zone Limit in all directions. Lower fault strengths would extend the Fractured Zone Limit to the southwest, due to location and orientation of the Gant fault. The Fractured Zone Limit is not impacted significantly by the bulking factor and in-situ stress orientation and magnitude (Itasca, April 06, 2018). The sensitivity analyses results are also reviewed and discussed in the "Geologic Data and Subsidence Modeling Evaluation Report - Draft" (BGC, November 30, 2018).

To estimate the probability that the outer limit of the subsidence zone will extend onto or beyond the Apache Leap, Malach used the predicted Crater depth range of 820 ± 164 ft (250 ± 50 m) and assumed the standard deviation of the maximum Crater depth is 164 ft (50 m). He then determined the coefficient of variation (COV) of the predicted maximum Crater depth to be 20%. Malach applied the same COV to the predicted limit of subsidence and concluded that the probability of the limit of subsidence reaching the Apache Leap is 5.3%.

Itasca responded to Malach's critique in a memorandum (Itasca, February 26, 2020). Itasca asserted that "*it is completely erroneous to extrapolate from an incorrectly calculated coefficient of variation of the predicted maximum crater depth for calculation of the probability of the extent of surface subsidence*". Comparing the distance from the predicted base case Fractured Zone Limit to Apache Leap with the same distance between the Fractured Zone Limit of sensitivity cases to Apache Leap along a series of rays that intersect the Apache Leap (Figure 7), Itasca estimated the standard deviation of the distance of Fractured Zone Limit to Apache Leap at 360 ft (110 m). Itasca concluded that for the base case, the minimum distance of Fractured Zone Limit to Apache Leap of 1115 ft (340 m), is more than three times the standard deviation therefore, the probability of Fractured Zone Limit reaching the Apache Leap is less than 0.1%.

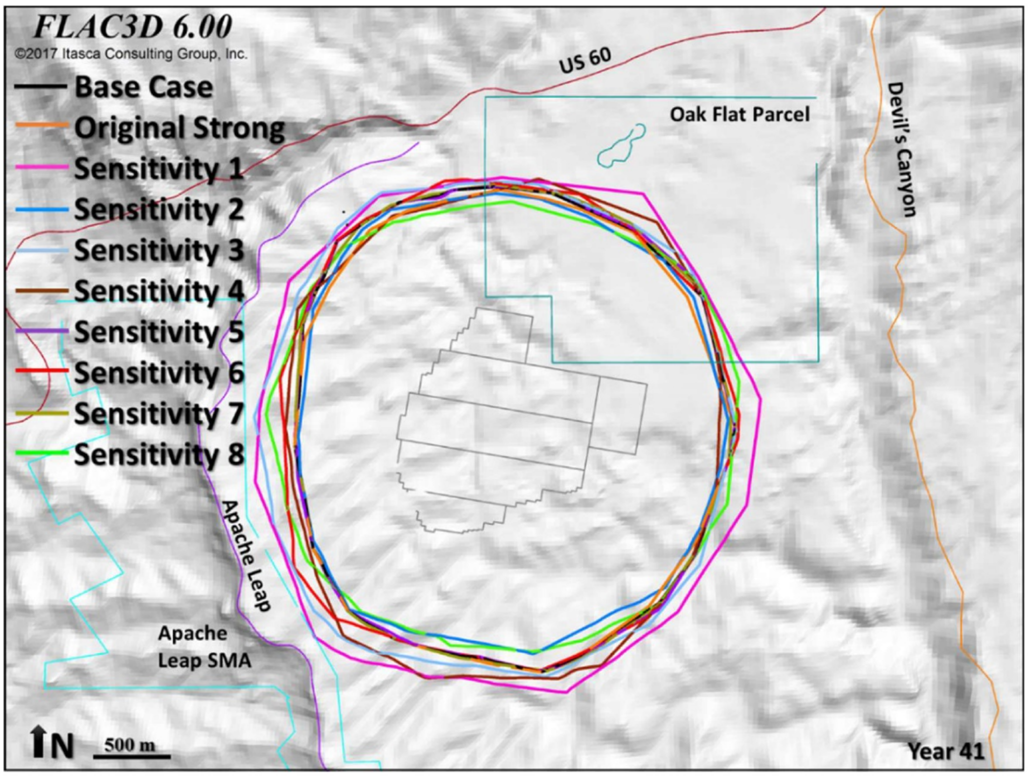


**Figure 7. Comparison of predicted Fractured Zone Limits for base case and all sensitivities (Itasca, February 26, 2020).**

## 5.5. Damage to/Loss of Cultural Sites Risk Assessment

On discussions around probability of destroying cultural and religious sites, Malach referred to Dam Safety Guidelines (Canadian Dam Association (CDA), 2013) and stated that "*It should be clear that any mining infrastructure, for which the failure would result in the destruction of a landscape feature with profound spiritual significance, should be placed in the strictest category of 'extreme consequences'*". Malach then refers to the minimum initial target frequency levels for the flood and earthquake hazards (under Risk-Informed Approach) and assuming the same applies to cultural sites with “extreme consequences”, concludes that damage to Apache Leap should meet the Minimum Annual Exceedance Probability (AEP) of 1/10,000 frequency as recommended by the Dam Safety Guidelines (CDA, 2013).

The CDA (2013) guidelines suggest AEPs for loading due to earthquake ground motions and floods for various categories of downstream consequences in the event of dam failure, but these are not the same as the AEP for dam failure or downstream damage. Applying dam safety guidelines to a block caving operation is uncommon because the operation and modes of failure for each are distinct. A significant difference between dam failure and subsidence progression is the rate at which each happens and the time available for mitigation. A flood resulting from dam failure may inundate the downstream area in a few hours, with little time to react. Subsidence at Resolution will develop over years, providing opportunity for calibration of predictive models with actual performance and adjustment of the TARP.

Planned instrumentation and monitoring within subsidence zones and at Apache Leap will provide data to monitor changes in ground conditions which can then be used to take appropriate action, as required according to RCM’s TARP (RCM, June 2020). The monitoring includes but is not limited to surface inspections, surface surveys, InSAR satellite imagery, aerial photogrammetry, and LiDAR scans. Multiple instruments will also provide redundancy and a way to verify that the subsidence measurements are valid and accurate. RCM’s TARP takes into account situations that are considered as critical events at Apache Leap that may require changes to the mine plan or operations, and may require immediate response. RCM’s plans for monitoring and responding to potential critical events have been developed to meet or exceed industry’s best practice to prevent or minimize caving-induced damage to Apache Leap, Highway US-60 and Devil’s Canyon.

# 6.0 SUMMARY AND CONCLUSIONS

## 6.1. Summary

An independent review of geologic and geotechnical data considered in the assessments and ground surface subsidence prediction modeling presented in RCM’s GPO (RCM, September 23, 2014) was completed by Dr. Steven Emerman of Malach (March 17, 2019) raising questions about availability of data and uncertainties in geologic structures mapped at Resolution, geotechnical data and the predicted surface subsidence impact on Apache Leap. RCM and Itasca have provided responses to Malach’s critiques (RCM, February 26, 2020; Itasca, February 26, 2020). The EIS Geology and Subsidence Evaluation Workgroup reviewed RCM’s data collection procedures, data validation and QA/QC processes, analysis methods and subsidence modeling approach and compiled its findings in a draft report entitled “Geologic Data and Subsidence Modeling Evaluation Report - Draft” (BGC, November 30, 2018). BGC also reviewed Malach’s report as well as Resolution and Itasca responses.

Malach referenced and compared the information in the RCM General Plan of Operations (RCM, September 23, 2014) with Google Earth images, the standard manual on block caving (Laubscher, 2000) and compilations of past experiences with land subsidence caused by block caving (Blodgett and Kuipers, 2002; Woo et al. 2013). Malach also referenced the Canadian Dam Association (2013) Dam Safety Guidelines for information on appropriate annual exceedance probability of earthquake loading and flooding for dams, assuming these were relevant to the progression of subsidence and effects on adjacent cultural values.

Malach's review was completed and published on March 17, 2019, several months prior to the August 2019 publication of the DEIS. The EIS Workgroup Geologic and Subsidence Evaluation Draft Report was issued on Nov. 30, 2018 and was included in the DEIS as an appendix and therefore was available for public review post DEIS publication. In a follow-up response Malach indicated that his opinions concerning the Resolution Copper panel cave project would not have changed had he reviewed the Workgroup's Geologic and Subsidence Evaluation Draft Report (Malach, October 20, 2019).

This memorandum provides BGC's third party evaluation and expert opinion on each of the issues raised by Malach through a review of Malach's report and cited references and based on data and reports from Resolution and their consultants, and the discussions within the EIS Geology and Subsidence Workgroup.

## 6.2. Conclusions

This section summarizes the responses to Malach's comments and questions.

- The geologic and geotechnical data that Malach referred to, although not provided in the GPO, were provided to the Workgroup by RCM in response to subsequent data requests. The Workgroup evaluated this information as part of its review and summarized its findings in the Geologic Data and Subsidence Modeling Evaluation Draft Report (BGC, November 30, 2018).
- Malach identified a lineament on a Google Earth image that was subparallel to and offset from the West Boundary Fault by 2000 ft (610 m). Malach interpreted this lineament as the West Boundary Fault and claimed that it was incorrectly mapped by RCM and therefore subsidence predictions at Apache Leap could have been underestimated. RCM, in a response to Malach (RCM, February 26, 2020), demonstrated that the lineament in question is actually the surface trace of the mapped Gant West Fault, and that West Boundary Fault had correctly been interpreted. RCM also demonstrated that both Gant West Fault and West Boundary Fault were included in the 3D subsidence prediction model.
- Referencing a comprehensive database of subsidence cases reported by Tetra Tech and R Squared (2006), Malach asserted that unanticipated subsidence has occurred in 20% of block caving projects. Upon review of the Tetra Tech and R Squared report, BGC found that the database compiles subsidence from underground hard rock mines in general and is not specific to block cave operations. Out of 36 subsidence cases reported in the

database, there were 8 reported unexpected failures of which only 2 cases were related to sublevel caving operation and none from block cave or panel cave operations.

- Malach stated that subsidence is a rapid process and that RCM will not be able to take action in time to mitigate impacts to Apache Leap, should subsidence progress towards this area. In support of this argument, Malach referred to several case histories of chimney failure above mining areas or collapse of the overlying rock mass above the cave. A review of those cases revealed that the main causes of those failures were local ground conditions (weak rock masses), presence of highly altered and intensely fractured faults zones (generally absent at the Resolution property), and poor mining practices. The absence of a surface monitoring program to monitor ground settlement and surface cracking further exacerbated the situation at those cases. Implementation of the planned subsidence instrumentation and monitoring program (RCM, June 2020) will allow RCM to track ground movements and changes in subsidence boundary, and to take appropriate action as per the TARP developed, should monitoring indicate that subsidence boundary is progressing farther than the predicted location towards the critical areas (Apache Leap, Highway US-60 and Devil's Canyon), which indicates the onset of potential critical geotechnical events.

  Gilbride et al. (2005), and Clayton et al. (2018) and Davies et al. (2018) reported successful implementation of surface instrumentation and monitoring programs at Molycorp. Inc.'s Questa Mine and at New Gold's New Afton Mine, respectively, where large networks of instruments provide information on the rate of ground movements towards the sensitive areas. In particular, through extensive surface and subsurface instrumentations, New Afton has been able to monitor and track ground movements towards the New Afton Tailings Storage Facility. Davies et al. (2018) reported that the ground movement data at New Afton Mine have allowed for developing a calibrated 3D model and that subsidence predictions have been tracking well with all field data. This demonstrates how ground monitoring data along with an adequate TARP can efficiently track the lateral progression of surface subsidence while maintaining worker safety.

  Malach also raised concern about microseismic activity at Resolution and its potential impact on Apache Leap. Itasca (October 01, 2019) carried out a numerical assessment and estimated the magnitude of caving-induced fault-slip seismic events at Resolution. Itasca predicted that the induced seismic events will not exceed M 2.9 magnitude. LCI (April 13, 2020) estimated the anticipated ground motions and damage resulting from Itasca's predicted induced seismic events. LCI correlated the induced seismic events at Resolution with the perceived ground motions above the Resolution footprint and at Apache Leap and demonstrated that the induced seismic events correspond to Light and Weak ground shaking categories, respectively and that no damage to ground surface is anticipated at Apache Leap. Nonetheless, RCM has recognized the potential for mining-induced seismic activity following initiation of caving and has planned for an extensive microseismic monitoring program that will run throughout the life of the mine and during closure. It is important to note that historical worldwide earthquake data indicate no landslides (rock fall, rockslide or rock slumping) had occurred as a result of an earthquake of less than M 4 magnitude. In addition, review of the mining-induced seismicity records show that such events are uncommon in western US and there have been only a few cases where seismic events exceeded M 3 magnitude (BGC, July 09, 2018, LCI, April 13, 2020, and Keefer, April 1984).

RCM has developed an observational and instrumentation-based monitoring plan which includes an extensive array of aerial, surface and subsurface instrumentation to monitor ground movements and cave progression. To develop a ground movement baseline, RCM plans to begin ground movement monitoring prior to commencement of caving operation (Phase 1 Monitoring, RCM, June 2020). RCM will begin caving at the east end of Panel 2 which is farthest away from Apache Leap, to provide time to monitor cave propagation and surface subsidence towards Apache Leap (Phase 2, 3, 4 and 5 Monitoring, RCM, June 2020). RCM's monitoring plan includes continuation of monitoring after the end of mining (Phase 6 Monitoring, RCM, June 2020). The purpose of the latter is to monitor the subsidence, any trends and potential impacts on key areas and infrastructure after mining activities have ceased (RCM, June 2020).

RCM's monitoring plan includes a TARP in which an offset is defined based on the distance the actual subsidence boundary exceeds the predicted boundary (Itasca, July 17, 2017) indicating subsidence is laterally progressing closer to the critical areas (Apache Leap, Highway US-60 or Devil's Canyon). Three trigger levels have been considered in the TARP based the offset distance being i) less than 490 ft (150 m) (Level 1), ii) between 490 ft (150 m) to 820 ft (250 m) (Level 2) and iii) greater than 820 ft (250 m) (Level 3). Each trigger level represents a geotechnical event and is accompanied by a plan of actions to address the changes in ground movements and potential impact on critical areas. RCM plans to determine the measured subsidence boundary based on measured angular distortion which itself is calculated from the ground movements measured by multiple instruments. For details on RCM subsidence monitoring plan refer to Resolution Subsidence Monitoring and Management Plan (RCM, June 2020). The range of planned responses in the TARP that apply during mining operations are consistent with proper application of the Observational Method.

- Malach states that there are no appropriate error bounds on subsidence predictions. During its review, the Workgroup requested that RCM conduct sensitivity analyses to address uncertainty in geotechnical data, rock mass properties, fault strength properties, in-situ stress regime (including stress orientation and magnitude) and the bulking factor. Itasca conducted a sensitivity analysis for RCM, which indicated that the Fractured Zone Limits at Resolution are most strongly controlled by the extraction level depth and shape. Weaker global rock mass strength would extend the Fractured Zone Limit in all directions. Lower fault strengths would extend the Fractured Zone Limit to the southwest, due to the location and orientation of the Gant fault. The Fractured Zone Limit is not impacted significantly by the bulking factor and in-situ stress orientation and magnitude. Itasca provided the detailed results of the analyses to the Workgroup in a report (Itasca, April 06, 2018). The sensitivity analyses results were also reviewed and discussed in the "Geologic Data and Subsidence Modeling Evaluation Report - Draft" (BGC, November 30, 2018).

- In an attempt to estimate the probability that the outer limit of the subsidence zone will extend onto or beyond the Apache Leap, Malach assumed that the published uncertainty in maximum Crater depth equals the standard deviation of the maximum Crater depth and applied this to estimate the probability of the subsidence limit reaching the Apache Leap at 5.3%. In response, Itasca asserted that "*it is completely erroneous to extrapolate from an incorrectly calculated coefficient of variation of the predicted maximum crater depth for calculation of the probability of the extent of surface subsidence*". Comparing the distance from the predicted base case Fractured Zone Limit to Apache Leap with the same distance between the Fractured Zone Limit of sensitivity cases to Apache Leap along a series of rays that intersect the Apache Leap (Figure 7), Itasca estimated the standard deviation of the distance of Fractured Zone Limit to Apache Leap at 360 ft (110 m). Itasca concluded that for the base case, the minimum distance of Fractured Zone Limit to Apache Leap of 1115 ft (340 m), is more than three times the standard deviation therefore, the probability of Fractured Zone Limit reaching the Apache Leap is less than 0.1%.
- To assess the probability of destroying cultural and religious site, Malach referred to the dam classification scheme provided in the Dam Safety Guidelines (CDA, 2013) and classified Apache Leap as "extreme consequences" case because restoration of site or compensation in kind is considered impossible. Applying dam safety guidelines to a block caving operation is uncommon because the operation and modes of failure for each are distinct. A significant difference between dam failure and subsidence progression is the rate at which each happens and the time available for mitigation. A flood resulting from dam failure may inundate the downstream area in a few hours, with little time to react. Subsidence at Resolution will develop over years, providing opportunity for calibration of predictive models with actual performance and adjustment of the TARP. Planned instrumentation and monitoring within subsidence zones and at Apache Leap will provide data to monitor changes in ground conditions which can then be used to take appropriate action, as required according to RCM's TARP (RCM, June 2020). RCM's plans for monitoring and adequate responses to potential critical events have been developed to meet or exceed industry's best practice to prevent or minimize caving-induced damage to Apache Leap.

## 7.0 CLOSURE

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Attachment(s): Appendix A – Ground Deformation at Apache Leap, Highway US-60 and Devil's Canyon

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# APPENDIX A
# GROUND DEFORMATION AT APACHE LEAP, HIGHWAY US-60 AND DEVIL'S CANYON

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# Project Memorandum

| | | | |
|---|---|---|---|
| **To:** | **SWCA Environmental Consultants** | **Doc. No.:** | |
| **Attention:** | **Chris Garrett** | **cc:** | |
| **From:** | **Amir Karami, Mike Henderson** | **Date:** | **July 21, 2020** |
| **Subject:** | **Caving-Induced Subsidence Impact on Apache Leap, Highway US-60 and Devil's Canyon** | | |
| **Project No.:** | **1704007** | | |

## 1.0 INTRODUCTION

BGC Engineering Inc. (BGC) is a subcontractor to SWCA Environmental Consultants (SWCA) for third-party preparation of the U.S. Forest Service (USFS) Environmental Impact Statement (EIS) on the Resolution Copper Project and Land Exchange, located near Superior, Arizona. BGC's role is to provide SWCA with geological, hydrogeological and geotechnical engineering review services in support of analyzing the environmental effects of the proposed panel cave mining project and assisting in preparation of the EIS. Resolution Copper Mining, LLC (RCM) prepared the Resolution Copper Project General Plan of Operations (GPO) pursuant to USFS National Environmental Policy Act regulations under 36 CFR 220 in 2014, with a subsequent update in 2016 (RCM, September 23, 2014; May 09, 2016).

RCM retained Itasca Consulting Group (Itasca) to conduct 3D numerical modeling of ground surface subsidence anticipated from the proposed panel cave mining project over the life of the mine (Itasca July 17, 2017). Itasca further conducted sensitivity analyses to assess the impact of variations in the structural, and geotechnical properties as well as the in-situ stress regime on the extent of predicted Crater and Fractured Zone Limits (Itasca, April 06, 2018).

A Geology and Subsidence Workgroup (Workgroup) was formed by the Resolution Copper Project EIS team. Members of this Workgroup included technical experts from the third party EIS contractor (SWCA/BGC) and members of the USFS Inter-disciplinary (ID) team. The Workgroup reviewed RCM's data, including data collection and interpretation procedures, supporting geologic and geotechnical baseline documents, subsidence modeling approach and predicted subsidence.

As part of the EIS Workgroup, BGC reviewed the 3D numerical assessment of ground surface subsidence at Resolution completed by Itasca. BGC reviewed the numerical assessment methodology, criteria used to delineate the extent of the subsidence zone, the geotechnical properties used in the modeling work and their derivation, and the assumptions considered. This was followed by a review of the modeling results including the extent and magnitude of the predicted subsidence, and the predicted strains and tilt angles resulting from the planned panel cave mining at Resolution.

This memorandum summarizes the results of our review and provides a description of predicted ground deformations anticipated to occur at Apache Leap, Highway US-60 and Devil's Canyon as a result of caving-induced subsidence at Resolution.

## 2.0 BACKGROUND

Itasca (June 18, 2018) prepared a memorandum to describe surface subsidence associated with block and panel cave operations. RCM provided this memorandum to the Workgroup as part of its response to Data Request #9 (RCM, June 29, 2018). A summary of information provided in the Itasca memorandum is presented here to establish background information on caving-induced surface subsidence. Predicted deformations/strains and anticipated deformations/strains at Apache Leap, Highway US-60 and Devil's Canyon are then discussed with reference to the background information.

Mining-induced subsidence is the settlement of the ground surface as a result of underground mining, particularly in cave mining operations where it can be pronounced. In caving operations, as ore is extracted at depth, voids are created and then filled by the overlying rock mass as it loosens and moves downward. As the cave propagates towards surface a characteristic depression is formed which is generally referred to as "discontinuous subsidence". This is typically associated with large, discontinuous step-shaped vertical displacements (Brown, 2003). The extent and shape of the caving-induced surface subsidence can be influenced by many factors including but not limited to (Brown, 2003):

- the dip of the orebody;
- the shape of the orebody in plan;
- the depth of mining and the associated *in-situ* stress field;
- the strengths of both the caving rock mass and the rocks and soils closer to the surface;
- the slope of the ground surface;
- major geological features such as faults and dykes intersecting the orebody and cap rock;
- prior surface mining;
- the placement of fill in a pre-existing or the newly produced crater; and
- nearby underground excavations.

Surface disturbances by block and panel caving have been described by Lupo (1998), Van As et. al. (2003) and Sainsbury et al. (2010) as zones characterized by the Crater, Large-Scale Surface Cracking (Fractured Zone), Small-Scale Displacement Zone (Continuous Subsidence Zone) and the Stable Zone. Van As et al. (2003) and Sainsbury et al. (2010) proposed the terminology shown in Figure 1 to describe caving-induced subsidence features.

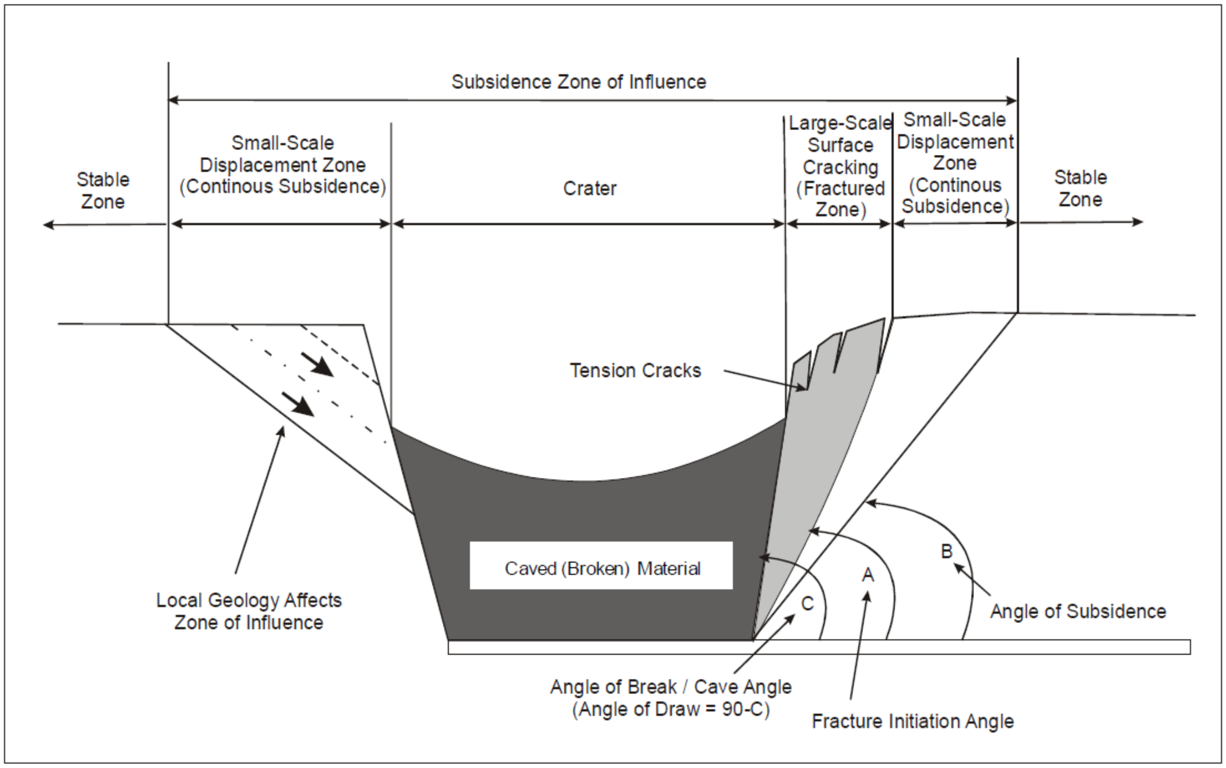


**Figure 1. Terminology used to describe caving-induced surface subsidence features (Van As, et al., 2003, Sainsbury et al., 2010).**

The Crater is located immediately above the undercut footprint in which the rock mass has experienced the greatest disturbance and is usually filled with broken irregular rocks (Woo et al., 2013). The magnitude of vertical displacement in the Crater is normally in hundreds to thousand feet (tens to hundreds of meters), depending on the size, shape and depth of the orebody. The Large-Scale Surface Cracking (Fractured Zone) is characterized by open cracks with large vertical displacements and a step-shaped profile. Within this zone, hairline cracks may be visible. Detailed crack mapping and ground monitoring at the New Afton mine (Clayton et al. 2018) indicated that hairline cracks tend to occur at ground surface after approximately 3.3 ft (1 m) of vertical subsidence has occurred. The Continuous Subsidence Zone is characterized by small-scale displacement, with ground movements generally only detected using high resolution instrumentation (LiDAR scan, ground survey, high resolution photogrammetry, etc.). The area beyond the Continuous Subsidence Zone is considered as the Stable Zone; this zone typically experiences negligible ground movements that are undetectable without high resolution instruments and are not expected to cause damage to the surrounding rock mass. Refer to Section 3.0 of this memorandum for more details.

Surface displacements from mining-induced subsidence can be broken down into five major components (Harrison, 2011) including:

- Vertical displacement
- Horizontal displacement

- Tilting
- Horizontal strain
- Angular distortion.

Uniform vertical and horizontal displacements alone do not generally cause damage to surface infrastructure (Harrison, 2011). Itasca (June 18, 2018) referred to examples provided by Singh (2003) of an observation tower that sank 30 ft (9.2 m) in a coalfield, mining structures that subsided a similar amount around the sulfur mining areas off the coast of Louisiana and a church in a potash-mining district that settled 20 ft (6.2 m), all without significant damage.

Tilting is defined as the rigid body rotation of rock blocks as a result of differential vertical displacements and can impact the stability of tall slender rock formations, such as those observed at Apache Leap. Turichshev et al. (2010) suggested that tall slender formations are susceptible to toppling at tilt angles greater than 7.5 degrees.

Strain is the relative change in shape or size resulting from applied forces (stresses). Horizontal strain is the ratio of horizontal displacement over horizontal length between two points. Angular distortion is the ratio of the differential settlement over horizontal length between two points (slope) minus the tilt angle, if the object has tilted (Laefer et al., 2010).

The limits of the Continuous Subsidence Zone associated with cave mining are normally related to strain (rather than displacement), as this is what causes damage to the surrounding rock mass and surface infrastructure (Itasca, June 18, 2018, Harrison, 2011). Harrison (2011) suggested that serviceability governs whether or not subsidence can be tolerated, and that ground movement is tolerable if it does not require repair. The concept of tolerability of ground movements has led to the development of empirical classification schemes that correlate potential damage to infrastructure to the anticipated strain in the infrastructure. The application of one of these schemes to classify caving-induced damage to rock mass is discussed in Section 2.2..

## 2.1. Fractured Zone Limit

The Fractured Zone Limit is the boundary between Fractured Zone and the Continuous Subsidence Zone (Figure 1). The primary failure mechanism associated with Fractured Zone is shear failure of the rock mass. Tensile failure and other modes of ground movement including toppling and block rotation are also present but appear to be secondary mechanisms (Itasca, June 18, 2018). Hairline cracking within this zone is possible, however, ground monitoring at other sites (Clayton et al., 2018) has demonstrated that subsidence has to reach a threshold before hairline cracks form on the ground surface.

In order to determine the Fractured Zone Limit from numerical model results, Cavieres et al. (2003) carried out a back analysis of the Fractured Zone Limit at El Teniente mine and demonstrated that a total strain criterion of 0.005 (0.5%) is a good indicator of the Fractured Zone Limit from numerical modeling results. Itasca (June 18, 2018) reported that this criterion has been used extensively and has been validated through back analysis of Fractured Zone Limits at the Kiruna Mine (Sainsbury and Stockel, 2012), the Grace Mine (Sainsbury et al., 2010) and the

Century Mine (Sainsbury et al., 2016) as well as the Andina, Venetia, Pampa Escondida and La Encantada mines (Itasca confidential reports).

### 2.2. Continuous Subsidence Zone Limit

The Continuous Subsidence Zone, as stated earlier, is the area beyond the Fractured Zone Limit where ground movements can only be detected with high resolution instruments. The limit of the Continuous Subsidence Zone is not as well defined as the Fractured Zone Limit because delineation of this zone in practice is a function of the precision of the monitoring system used (Itasca, June 18, 2018) and this varies between mine sites. As a result, strain-based thresholds are recommended (Flores and Karzulovic, 2004; and Harrison, 2011) to define the limits of the Continuous Subsidence Zone. These thresholds are based on site specific acceptability criteria, rather than vertical or horizontal displacement thresholds to define this boundary. Empirical criterion for damage to masonry-founded buildings and structures have been proposed (Boscardin and Cording, 1989) and subsequently used to estimate mining-induced damage to the rock mass (Sainsbury et al., 2010). This empirical method relies on the anticipated magnitude of horizontal strain and angular distortion to provide an estimate of the rock mass damage. This method is considered conservative, as masonry buildings tend to be more sensitive and susceptible to damage by both horizontal strain and angular distortion than rock masses. Rock masses are typically jointed and can tolerate more strain without fracturing (Itasca, June 18, 2020). Building damage criteria have been used to develop a conservative limit of the Continuous Subsidence Zone even in the absence of buildings within the caving impacted areas (Sainsbury et al., 2010).

The empirical strain-based building damage criterion recommended by Boscardin and Cording (1989) takes into account horizontal strain and angular distortion to establish strain-based criteria for the limit of the Continuous Subsidence Zone (Figure 2). Sainsbury et al. (2010) developed a calibrated 3D numerical model to delineate the limit of small displacements for the Grace Mine as all areas where horizontal strain was greater than 0.002 (0.2%) and angular distortion was greater than 0.003 (0.3%) (Figure 2). At these thresholds, according to Wahls (1994), masonry buildings may experience cracking without any visible cracking of the rock mass. Variations of this criterion have been used at other mines based on horizontal strain only (to correlate model results with fracturing behavior of concrete), or based on different strain thresholds to correlate model results to the observed damage in the field.

It is very important to note that areas beyond the Continuous Subsidence Zone Limit may still experience limited vertical and horizontal displacements; however, the resulting horizontal strain and angular distortion would be less than the critical threshold to be considered damage for the purpose of delineating the Continuous Subsidence Zone Limit. These zones would be classified as experiencing Slight, Very Slight or Negligible Damage, as shown on Figure 2. The damage to masonry buildings in these zones could range from hairline cracks to cracks less than 5 mm wide, according to Wahls (1994). Surface cracking at this scale is not anticipated in a jointed, fractured rock mass where the ground surface is irregular and covered with debris and soil.

Itasca used the criterion that was developed for the Grace Mine to delineate the Continuous Subsidence Zone Limit for Resolution. Figure 2 shows the projection of the building damage criterion estimated for Resolution (purple star).

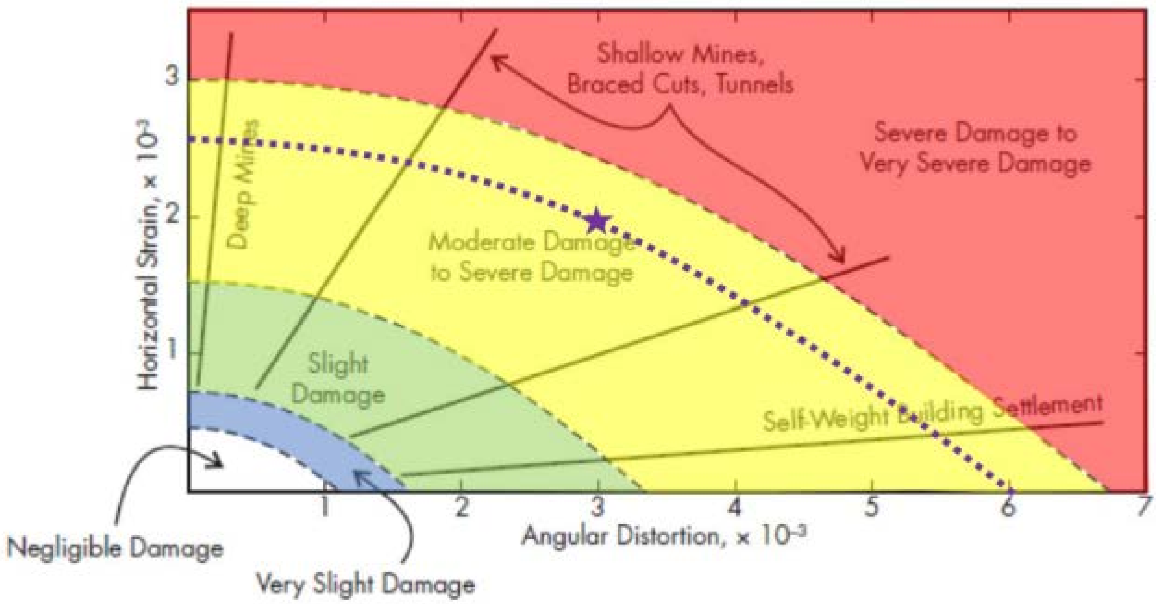


**Figure 2. Empirical building damage criterion proposed by Boscardin and Cording (1989). Star shows the minimum horizontal strain and minimum angular distortion considered as threshold values to delineate Continuous Subsidence Zone at Resolution (Itasca, June 18, 2018)**

## 3.0 PREDICTED SUBSIDENCE AT RESOLUTION

Itasca (July 17, 2017) completed a 3D numerical assessment of surface subsidence associated with planned panel caving at Resolution (Base Case Model) using the FLAC3D code (Itasca, 2017). The following criteria were used to define Crater Limit, Fractured Zone Limit and Continuous Subsidence Zone Limit:

- Crater Limit - defined as the boundary at which vertical displacements exceed 6.6 ft, (2 m)
- Fractured Zone Limit - defined as the limit of visible fracturing and was determined where total strain reached 0.005 (0.5%)
- Continuous Subsidence Zone Limit - characterized by small continuous displacements, delineated by the combination of horizontal strain and angular distortion that exceed the 0.002 (0.2%) and 0.003 (0.3%), respectively (Figure 2).
- Tilt Limit - a tilt limit of 7.5 degrees was used to determine if slender and tall rock formations could collapse at Apache Leap (Itasca, June 18, 2018).

The justifications for using the stated criteria for delineating the Fractured Zone Limit and the Continuous Subsidence Zone Limit were discussed in Section 2.0.

## 4.0 PREDICTED CAVING-INDUCED GROUND MOVEMENTS AT APACHE LEAP, HIGHWAY US-60 AND DEVIL'S CANYON

Itasca predicted, from numerical modeling results, the extent of the Crater Limit, Fractured Zone Limit and Continuous Subsidence Zone Limit for the planned mine production for Resolution over the proposed 41 year active mine life. The model predicted that the Crater, Fractured Zone and Continuous Subsidence Zone Limits would not reach Apache Leap, Highway US-60 or the Devil's Canyon during the active mine life. Following cessation of mining activities, subsidence will slow down and eventually stop. Ground monitoring will remain active as per the schedule provided in the Resolution Subsidence Monitoring and Management Plan (RCM, June 2020) to track the rate of changes in ground movements after mining ceases.

The predicted damage from caving-induced surface subsidence to each zone at the Resolution site, as defined in Section 2.0 and Figure 1, is summarized below:

- The Crater could be up to (maximum) 1115 ft (340 m) deep with a N-S diagonal span of 8860 ft (2700 m) and E-W diagonal span of 8200 ft (2500 m). The Crater is predicted to be approximately 1640 ft (500 m) from Apache Leap at the closest point (Itasca, July 17, 2017, Figure 16).
- The predicted Fractured Zone Limit is approximately 1115 ft (340 m) from Apache Leap at the closest point (Itasca, July 17, 2017, Figure 16).
- The predicted Continuous Subsidence Zone Limit is within approximately 100 ft (30 m) to 715 ft (218 m) from the Fractured Zone Limit (Itasca, July 17, 2017, Figure 17).
- Tilt was calculated from the modeling results and plotted in plan view over the life of mine (RCM, June 29, 2018, Attachment C2). The results show that tilt at Apache Leap is expected to be less than 1 degree which is significantly less than the threshold of 7.5 degrees where tall slender formations may collapse (Turichshev et al., 2010). Therefore, slender tall formations are not anticipated to collapse at Apache Leap.

It is important to note that at the limit of the Continuous Subsidence Zone masonry buildings (if there were any located in the area) could experience cracks from 0.2 to 0.6 in. (5 to 15 mm) wide. Such damage in an already jointed and fractured rock mass would, however, not be detectable without high resolution instruments. At Apache Leap the angular distortion is predicted to be much less than 0.001 (0.1%) which places it within the Negligible Damage Zone in the building damage chart (Figure 2). Thus, cracking is not anticipated to occur at Apache Leap and actual ground displacements are not expected to be visible without the use of high-resolution survey instruments.

Likewise, model results show that the limit of the Continuous Subsidence Zone, at the closest point, is 1475 ft (450 m) and 3450 ft (1050 m) from Highway US-60 and the Devil's Canyon, respectively. At these distances, the angular distortion is predicted to be much less than 0.001 (0.1%). Therefore, visible cracking or visible ground movements is not anticipated to occur at Highway US-60 or at Devil's Canyon.

It is also important to emphasize that while numerical modeling predicts up to 20 in. (0.5 m) of horizontal and/or vertical displacement at Apache Leap, the corresponding horizontal strains and/or angular distortions are predicted to be less than 0.1%. This is significantly less than the strain threshold that could cause disturbance (i.e. angular distortion of 0.3%). This also is consistent with the crack monitoring data and observations at the New Afton mine that indicated hairline cracks may only form if the vertical displacements reach approximately 1 m.

## 5.0 CLOSURE

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AK-MH/WH/rm/syt

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