Resolution Copper Project & Land Exchange
Environmental Impact Statement

Geologic Data and Subsidence Modeling Evaluation Report

EIS Team - Geology and Subsidence Workgroup

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1.0 SUMMARY OF DATA REVIEWED AND REVIEW PROCESS

1.0 Introduction

A Geology and Subsidence Workgroup (Workgroup) was formed by the Resolution Copper Project EIS team. The purpose of the Workgroup was to review Resolution Copper Mining's (RCM) procedures, data, and geologic and geotechnical baseline documents to:

1. Determine whether the methods employed by RCM in collecting and documenting geologic data were appropriate, adequate, and according to industry standards.
2. Determine whether RCM's interpretations of geologic structures, faults, geotechnical data, rock properties, and assumptions are reasonable.
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 members of the Workgroup, and their respective areas of expertise within the group, are summarized in Table 1 below. The credentials of the team members are summarized in Section 8.0.

Table 1. Geology/subsidence workgroup team members.

Team Member	Company	Expertise
Laurie Brandt, CPG	DOWL	General geology, faults, structures, geologic interpretations
Nick Enos, CPG	BGC	General geology, faults, structures, geologic interpretations
Amir Karami, PhD, P.Eng.	BGC	Geotechnical data, rock mechanics, industry standards, geologic and subsidence modeling, panel caving methods
Diana Cook, PhD, PE	BGC	Geotechnical and seismic data, industry standards, rock properties, geologic and subsidence modeling
Michael Henderson, PE	BGC	Geotechnical data, industry standards, rock mechanics, geologic and subsidence modeling
Rex Bryan, PhD	Geostat Systems	Geostatistics, statistical adequacy and QA/QC of procedures and interpretations

1.1. Timeline and Summary of Data Collection Process

The EIS team was assembled and led by SWCA in 2016. The General Plan of Operations (GPO) and other documents provided by RCM and others were provided to the EIS team at that time. An initial site visit by the EIS team on November 15 and 16, 2016 provided an opportunity for interaction with RCM staff and their consultants and to view the site geology, components of the existing RCM operation, and the proposed RCM sites as presented in the GPO. Field trips and presentations were given to the EIS team during the November 2016 meetings. Of the personnel listed in Table 1 above, A. Karami was not on the EIS team until January 2018, when he replaced a previous BCG geotechnical engineer and rock mechanics expert, Gastón Gonzales, who left the firm at that time. Of the Workgroup members listed in Table 1, L. Brandt, N. Enos, D. Cook, and M. Henderson were present for the initial November 2016 site visit, field trips and presentations.

Following the initial site visit, various baseline data requests were submitted for geologic and geotechnical information, as summarized in the Appendix A Table A1, which lists the key activities and data submittals relating to geological, geotechnical, and subsidence components of the proposed project. Details of the data requests, meetings and RCM responses are detailed in Table A1 and are not repeated here. Instead, a narrative of the main activities is provided, in chronological order, of the data collection process to assemble sufficient baseline data, as well as the explanations relevant to understanding that data, to support the EIS analysis.

A second site visit was performed by L. Brandt, G. Gonzales, and R. Bryan on May 4-5, 2017, and hosted by RCM geologic, geotechnical, hydrologic, and metallurgic staff. The purpose of this trip was to tour the East Plant Site (EPS), Oak Flats, the core storage and processing building, and other areas near Superior, to view the geologic setting, faults, and current RCM operation. The process of in-house logging and testing of core and their QA/QC protocols were observed and discussed. Presentations and discussions of the Vulcan model and acQuire software (Pere et al., 2011) were also part of the site visit. A summary of this field visit was documented in a memo dated July 7, 2017 (Brandt et al., 2017).

Later in July 2017, data validation workgroups were set up by SWCA, including Geochemical and Water Quality, Hydrologic Data and Modeling, Geotechnical (Subsidence)/Seismic, and Geologic Workgroups. Because of the overlap in data and topics, the geology and geotechnical teams were soon combined into one workgroup, the Geology/Subsidence Workgroup. A series of formal meetings between the Geology/Subsidence Workgroup and RCM staff and consultants were conducted as follows:

September 13, 2017	- Meeting #1
November 29, 2017	- Meeting #2
January 26, 2018	- Meeting #3
March 16, 2018	- Meeting #4
May 16, 2018	- Meeting #5
June 12, 2018	- Meeting #6
August 8, 2018	- Meeting #7

Several Forest Service geologists, and related specialists, also participated in the Geology/Subsidence Workgroup meetings and contributed greatly to the review. These included J. Sampson, P. Werner, D. Tafoya, G. Olsen, J. Gurrieri, and T. Stroope.

As shown in Table A1 (Appendix A), there are meeting minutes available for each of these meetings. Generally, the purpose of the meetings was to discuss RCM responses to data requests, to get further explanations and presentations by RCM staff and consultants, and to identify additional information needed by the Workgroup to perform their analysis.

1.2. Summary of Review Process

The Geology/Subsidence Workgroup initially reviewed data supplied by RCM and their consultants in the GPO, and other available data. As formal baseline data requests were initiated to RCM in March 2017, RCM responded with reports, letters, graphics and other documents. As these were reviewed by the Workgroup, internal discussions and memos ensued (see Table A1, Appendix A,) and additional data requests were generated. Formal Workgroup meetings were initiated in September 2017, which included presentations and detailed discussions for the benefit of the Workgroup. These were effective forums to allow for in-depth discussions with RCM staff who performed much of the data collection, analysis, and geologic modeling, as well as consultants such as M. Pierce with Itasca/Pierce Engineering, who performed the subsidence modeling. Five total data requests were submitted to RCM and seven Geology/Subsidence Workgroup meetings were held with RCM.

2.0 REFERENCE STANDARDS

This section summarizes those standards, methods, and best practices applicable to the geological and geotechnical programs associated with the Resolution Copper project. However, it is not intended to include an exhaustive list of all standards for geological or geotechnical field programs, laboratory testing, data analysis, geological modeling, or subsidence modeling. In some cases, a formal standard may exist, such as American Standards for Testing and Materials (ASTM) protocols or International Society for Rock Mechanics (ISRM) guidelines pertinent to laboratory testing procedures. However, in most cases methods and procedures rely on the "state-of-practice", or industry "best practices", followed by the majority of the industry, and/or on peer-reviewed industry research and literature. Due to the variety of topography, geology, and site-specific issues often encountered in mining projects, some level of flexibility in exact methods and procedures and the interpretation of geological and geotechnical data must, to some extent, be accommodated. This section therefore largely focuses on best practices as they specifically relate to the RCM site, while also considering general best practices for mining and other large-scale civil projects. Finally, this section covers the general approach taken by the Workgroup in reviewing and validating the work performed by RCM and their consultants.

2.1. Industry Best Practices

Resolution Copper is a limited liability company with 55% ownership by Rio Tinto (the operator) and 45% ownership by BHP-Billiton. Under ownership of Rio Tinto, which is a publicly traded company, RCM's exploration field program (i.e., drilling, sampling, logging, assay testing) is required to follow mineral resource and reserve reporting requirements for such programs set forth in the U.S. Security and Exchange Commission (SEC) Industry Guide 7 (Recently updated in SEC, 2018) and the Australasian Joint Ore Reserves Committee (JORC) code (JORC, 2012). The SEC and JORC, as well as industry best practices, require that disclosure of exploration results and mineral resources and reserves be based on, and accurately reflect, information and supporting documentation prepared by a mining expert, defined by the SEC as a "qualified person", or a "competent person" as defined in the JORC code. This is important because mineral resource and reserve estimates are based on interpretations of geologic information, and therefore rely on the competence and qualifications of those preparing or verifying that information. In the case of Resolution Copper, the geological Program Manager, who oversees the entire geologic field program, fills this role. In addition, the field program is reviewed periodically by qualified independent third parties who verify that the geologic and ore body models meet the standards set forth in the SEC and JORC codes. Besides the SEC and JORC requirements, there are other mineral resource reporting frameworks in use throughout the industry, and specific requirements vary by country. One common example is Canada's National Instrument 43-101 (NI 43-101), which includes *Standards of Disclosure for Mineral Projects* for mining projects within Canada. NI 43-101 is a codified set of rules and guidelines for reporting and displaying information related to mineral properties owned by, or explored by, companies which report these results on stock exchanges within Canada. While NI 43-101 is more prescriptive than JORC, it shares the same intent of involving qualified and competent expertise in the reporting of mineral resources. It is not the role of this Workgroup to comment on which reporting standards are applicable for the purposes of securities reporting. However, the

Workgroup finds that RCM's geologic program, and its adherence to JORC and SEC standards, meets or exceeds industry best practices.

This approach used to publicly disclose mineral resources for the Resolution Copper Deposit also incorporates or overlaps with industry standards for geological or geotechnical field programs in general, including the estimation of rock properties and input parameters for geological and engineering analyses (e.g., subsidence modeling). RCM's base geotechnical information and geotechnical analyses are also reviewed on a periodic basis by an independent third-party Geotechnical Review Board (GRB) and by various reviewers who audit the process and review procedures and conclusions. The GRB and auditors are independent consultants and industry experts retained by RCM for internal quality management and due-diligence. In order to protect the rigorous and frank openness of the due-diligence process, reports from these internal reviews are generally not available to the public, or this Workgroup.

2.2. Applicable Industry Standards

The following general procedures were used by RCM, and either meet or exceed industry standard methods, which are outlined in Table A2 (Appendix A). In some cases there are multiple methods or alternative procedures that would be considered an "industry standard". The typical methods and industry standards used by RCM are discussed below:

2.2.1. Drilling

- Drilling of core oriented using Acoustic Borehole Imaging (ABI) geophysical logs to provide data on rock conditions at depth.
- Boreholes oriented in a variety of directions - in general, vertical boreholes show lithology, and angled boreholes are used to show structures and to better define the ore body.
- Sub-foot accuracy of drill collar survey is established by repeat surveys by multiple Registered Land Surveyors. The coordinate system was standardized with the current realization of US Arizona State Plane of 1983 (NAD 83) Central Zone for horizontal and North American Vertical Datum of 1988 (NAVD 88).
- Down-hole surveys on directional holes are primarily north-seeking gyroscopic surveys. Rigorous quality control (QC) including repeat surveys, and comparison to multiple magnetic survey techniques (Single Shot and ABI) are used.

2.2.2. Sample Recovery and Logging

- An initial log of core is completed as core is received daily (i.e., drill logging). Rock Quality Designation (RQD) measurements are taken using standard methods (e.g., Deere, 1989; Deere and Deere, 1988).
- Drill logging is checked randomly on a weekly basis.
- All core is photographed prior to cutting and boxing.
- All recovered core is logged in detail, and each borehole is usually logged by at least three different geologists.
- Borehole logging includes lithology, mineralogy, alterations, anhydrites, fractures/faults (orientation and types), and geotechnical parameters as inputs for rock mass classification systems used by RCM.

- A geotechnical engineer re-logs every 300 feet of core and signs off on each re-logged section to ensure consistency with the logging procedure and the lithologic and geotechnical domains. The primary geotechnical characteristics recorded in the core are RQD, open joints, structures (>2 cm width), cemented joints/veins, and degree of alteration.
- Borehole fractures are compared to on-screen ABI logs to verify orientation and other details. The lead logger (geotechnical QC) will review a random (blind) domain once a week to check on the consistency of the logging amongst the geologists.

2.2.3. Data Management

- Resolution uses a quantitative digital logging system called acQuire (Pere et al., 2011) to manage the borehole data. In addition to capturing detailed lithology, alteration and mineralization attributes, the system emphasizes the capture of detailed geotechnical data, with all data gathered in a single pass by a geologist. It includes a formal training program, as well as quality control systems to ensure consistency and accuracy for both geologic and geotechnical logging in support of geologic and resource modeling, and mining and metallurgical studies.
- The database contains a total of 438 drill holes (including 135 boreholes drilled by RCM between 2001-2016, which include both geology and geotechnical features and properties), archived geologic data from the Magma Mine shafts, and the new RCM shaft (Shaft No. 10).
- Data have been verified through third party review, as previously discussed.

2.2.4. Laboratory Testing

- Most of the laboratory testing was performed by independent laboratories and are understood to generally follow ASTM or ISRM guidelines.
- Testing included:
    - Unconfined Compressive Strength (UCS) testing.
    - Point load tests (PLT) correlated with Unconfined Compressive Strength (UCS) testing (ASTM D5731-05).
    - Tri-axial Compressive Strength (TCS) testing (at various confinement pressures).
    - Brazilian tensile strength testing.
    - Sonic testing (also under confinement) to evaluate dynamic elastic moduli.

The following summarizes the reasons why it is important that laboratory tests follow established ISRM guidelines or ASTM standard methods:

- Standard specimen size and shape due to scale effects and considering the natural variability in intact rock conditions.
- Standard method for specimen preparation.
- Standard testing method to obtain comparable results regardless of the laboratory facility used.
- Quality assurance and quality control on laboratory test results.

2.3. Data Analysis and Subsidence Modeling

This section provides a brief overview of the typical methods used in the assessment of rock mass properties and subsidence modeling, and the general application of these methods by RCM. The input parameters and subsidence modeling are covered in greater detail in Section 5 of this report.

2.3.1. Assessment of Input Parameters

Several rock mass rating systems are commonly used in mining and other applications that rely on rock mass characterization and behavior. These systems were used by RCM and include the Rock Tunneling Quality Index system or Q system (Barton et al., 1974), the Rock Mass Rating, RMR (Bieniawski, 1989), the Geological Strength Index, GSI (Cai et al., 2004), and the Mining Rock Mass Rating, MRMR (Laubscher, 2000). In addition, the well-established Generalized Hoek-Brown constitutive model was used by RCM to derive rock mass strength for the geotechnical domains based on statistical distributions of the UCS, TCS, and GSI data (Hoek et al., 2002) within each domain. Rock mass strength distribution was assessed for sensitivity analyses using a Monte Carlo statistical analysis, which is a well-established technique that, in this case, involved randomly sampling the input parameters for the Hoek-Brown model parameters (e.g., Li et al., 2012; Sari et al., 2010). UCS values were scaled by a factor of 0.8 to account for the drop in intact strength expected when moving from laboratory-scale to cave-scale (Hoek and Brown, 1980). The 0.8 factor is considered reasonable because RCM reported that 75% of samples taken for intact rock strength testing were defective, meaning the failure occurred along defects or along a combination of defects and intact rock segments. As such, the measured strength (referred to as the defective strength (GPO, 2018)) already takes into account impact of defects on intact rock strength. The 0.8 factor was applied to the defective strength value further degrading the (intact) rock strength. As a check, by applying the Laubscher and Jakubec (2001) approach to degrade intact rock strength by taking into account the rock hardness range and fracture frequency (ff/m), an 85% adjustment of intact rock strength (defective strength, in case of Resolution) would have been required which is a less conservative degradation factor in comparison with the 0.8 factor used.

Data gathered from instrumentation (SMART Multiple Point Borehole Extensometers) at the No. 10 Shaft at Resolution Copper were used by RCM to back-analyze the performance of the rock mass and evaluate the appropriateness of the rock mass properties used for subsidence modeling. This is considered good practice by the Workgroup, and meets industry standards for characterizing rock mass strength at the No. 10 shaft.

2.3.2. Subsidence Modeling

As is typical for modeling that requires a high level of judgement and interpretation, there is no set standard or method that is applied to the evaluation of subsidence due to block caving, but rather evaluation relies on industry-accepted approaches. In general, estimates of subsidence should consider major geological structures, rock mass strength, current in-situ and induced stresses, and depth of mining. One empirical method often used during the early stages of block cave mine planning is based on Laubscher's MRMR system (Laubscher, 2000). The system considers the geological environment through Bieniawski's (1989) rock mass ratings, and then adjusts for the effect of the mining operation on the rock mass. The ratings and specifics of the mining operation and its impact on the surrounding geology are used to define the caveability, subsidence angles, fractured zones, fragmentation, undercut-face shape, cave-front orientation, undercutting sequence, overall mining sequence, and ground support design (Laubscher, 1994).

RCM has evaluated the Resolution panel cave using this approach and their results are reported in Section 5.5. RCM notes that while such empirical methods largely account for macro deformations (caving angles), and that they cannot properly account for anisotropy in the rock mass, the influence of large structures such as faults, varying topography, or the extent of fracturing and continuous subsidence zone (Woo et al., 2013), they do provide a first approximation to the cave angle at early stages and with limited available data. The Workgroup agrees with this statement, and the results of this empirical assessment are discussed in Section 5.0.

To address the limitations of the empirical approach, in later stages of mine planning, numerical analyses are typically performed, which can better account for these complexities (e.g., Flores and Karzulovic, 2002; Sainsbury, 2010). These models are supported and informed by studies of other block caving mines and their subsidence patterns relative to site specific rock mass properties, geological structures, and topography (e.g., Woo et al., 2009, 2013).

One program frequently employed in numerical analyses, and generally considered to be industry standard, is FLAC3D, by Itasca (2017b). Specifically for use within FLAC3D, an algorithm to simulate cave growth was developed by Itasca and has been successfully compared with cave behavior at many other mines around the world (e.g., Northparkes E26 [Pierce et al., 2006], Palabora [Sainsbury et al., 2008], Grace Mine [Sainsbury, 2010], Henderson Mine [Sainsbury et al., 2011], Ghaghoo mine [Fuenzalida et al., 2015a], and Henderson 7700SW [Fuenzalida et al., 2015b]). This modeling approach was used by Itasca on behalf of RCM and included sensitivity analyses to better understand the parameters with the largest influence on cave growth and subsidence specific to Resolution Copper. The Workgroup believes the modeling approach and use of FLAC3D is appropriate and consistent with industry standards and best practices.

2.4. Data Validation Approach

Validation of the field program, laboratory testing, geological modeling, data analysis, and subsidence modeling was based on a phased approach. For the first phase, the Workgroup requested documentation from RCM on their internal data validation procedures, reviewed the received documents for adequacy, and reviewed the baseline data to see whether internal procedures were followed by RCM. Following the first phase, some questions and uncertainty remained regarding the validity of the data and procedures used for the mine plan and subsidence evaluation. Therefore, a second phase was initiated, incorporating a more in depth review of coring and logging processes, database management and data analyses, the Vulcan model and geological interpretations, subsidence modeling (geotechnical domains, geologic structures, rock mechanics, hydrogeology, and other input parameters and assumptions), and internal validation and quality control procedures.

This second phase approach included:

- On-site tours and discussions with RCM staff.
- On-site and direct observation of work procedures, processes, and results (e.g., core handling, logging, and storage).
- Virtual tours, with RCM staff, of the acQuire database, the Vulcan geological model, the Itasca FLAC3D subsidence model, and the surface and groundwater models.
- Reviewing modeling input parameters – for example, rock mass strengths and fault modeling assumptions used in subsidence modeling, against measured field conditions.
- A series of data requests from the Workgroup to RCM, and subsequent in-person and/or phone meetings with RCM, TNF, SWCA and Workgroup members from various supporting consulting agencies to discuss the data acquired through RCM's request responses. For example, this process resulted in a request for, and performance of, a sensitivity analysis on the subsidence modeling input parameters, so that the Workgroup could better assess the validity of the subsidence predictions supplied by Itasca on behalf of RCM.

3.0 ADEQUACY OF RCM QA/QC PROCEDURES

A review, with conclusions, on the adequacy of the internal Resolution Copper Mine (RCM) quality assurance and quality control (QA/QC) program for sampling geotechnical data is described in this section. An objective for acquiring this data is to adequately simulate surface subsidence caused by future panel cave mining. Two cases, "near case" and "far case", have been reviewed for data adequacy in meeting this objective using Data Quality Indicators (DQI). Seven DQIs were selected by the Workgroup as those that are universally recognized (and used) in determining the adequacy of RCM's sampling and testing program. The terms "near case" and "far case" are discussed in more detail below.

3.1. QA/QC, DQI and DQO

This section reviews the adequacy of quality assurance and quality control (QA/QC) procedures, data quality indicators (DQI), and data quality objectives (DQO). On May 4 and 5, 2017, Workgroup members Laurie Brandt, Gastón González and Rex Bryan attended on-site field and office meetings with staff of RCM (Brandt et al., 2017). The purpose was to discuss the site geology, drilling program, internal procedures for data validation, and quality assurance and quality control (QA/QC) pertaining to their use in modeling subsidence. Other items reviewed included database management, input parameters/assumptions (i.e. geotechnical domains, geology, structure, rock mechanics, hydrogeology) and the Vulcan 3D block model.

This section uses the terms: Quality Assurance (QA), Quality Control (QC), and data quality objects (DQO). According to the ISO, QA consists of that "part of quality management focused on providing confidence that quality requirements will be fulfilled." By contrast, QC is that "part of quality management focused on fulfilling quality requirements." In the context of geologic data management, QA identifies the right standard or procedure, whereas QC checks that the results are consistent with that standard. Put another way, QA "assures" that sampling will result in quality data, and QC "controls" quality by identifying and correcting poor quality data. The Data Quality Objective (DQO) method considers data to be of sufficient quality if it can successfully be applied to achieving a pre-defined objective (EPA, 2006).

Most of the sampling data collected at Resolution is derived from drill core. Their drilling program targeted areas that have the most promising economic viability, which is the mineralized zone (1% copper shell). As a consequence, this has produced a pattern of drill hole locations that may not be optimized for geotechnical data collection and subsequently for the modeling of surface subsidence. For modeling of the future block cave mine, RCM has used Vulcan, a sophisticated 3D mine modeling software. Vulcan's primary purpose is to produce a 3D block model which is used for mineral resource estimation and mine planning. It applies geostatistical theory to classify the mineral resource into indicated and inferred categories (RCM, 2017a). Such resources reported to the financial community requires documentation of each step of this estimate.

As described previously in Section 2.1, financial disclosure requirements for reporting of mineral resource and mineral reserve estimates include that those estimates are based on an assessment by a "Qualified Person" or "Competent Person" (RCM 2017a; JORC, 2012). This includes discussion of the QA/QC results within the resource estimation process (RCM, 2017a).

To meet these requirements, RCM developed a comprehensive data quality assurance (DQA) plan (RCM, 2017a). RCM's modeling effort has been discussed by other authors such as Parker (2017, 2018), Hart (2016a) and Kloppenburg (2017). The Vulcan model has been adapted to include geotechnical data such as rock strength and the position and orientation of faults. A list of geotechnical and geology data types is shown in Appendix B in Table B1. These data are measured using a mixture of measurement schemes. They include classification (nominal), ranked lists (ordinal), ranked scale (interval) and graded values (ratio) measurements.

3.2. DQI and DQA: Adequacy of Sampling Rock Properties

RCM has developed a formal DQA project plan that details the necessary quality assurance procedures, quality control activities, and other technical activities that were to be implemented to ensure that the results will satisfy performance or acceptance criteria. A review of the DQA plan indicated the data possess seven critical data indicators (DQI) of precision, bias, accuracy, representativeness, comparability, completeness and sensitivity. Their definitions and application are shown in Appendix B in Table B2. A partial list of steps within the DQA and their DQIs that are affected is shown in Appendix B in Table B3.

The steps that are needed to produce acceptable statistical adequacy and representativeness include items such as utilizing a third party of independent experts to periodically critique and refine sampling and data evaluation procedures. RCM has implemented a formal process of reviewing the base geotechnical information and its analysis by a third-party Geotechnical Review Board (GRB). The GRB and various experts and consulting companies are directed to challenge the process and review validation procedures and conclusions. The Workgroup determined that RCM continually adjusted its sampling protocols as recommended by the GRB. These adjustments are reflected in the current DQA project plan. The Workgroup noted that RCM has its own sampling protocols and methods of applying internal QA/QC procedures (RCM, 2017a); RCM uses industry standard methods (such as those from ASTM, ISRM and "industry best practice" techniques, as noted previously) and implements its own internal data validation procedures, including peer review. In addition, a Competent Person oversees the entirety of the data acquisition program at RCM. Finally, outside consultant companies have been tasked to re-sample and re-analyze core data as a confirmatory check. The Workgroup concluded that the QA/QC program in general, and the DQIs specifically, are appropriate, rigorous and relevant. Further discussion of QA/QC procedures, methods, and protocols were addressed in *Section* 2.0 of this document.

3.3. Geotechnical Work Flow Procedures

Figure 1 shows the geotechnical logging work flow and process control for the sampling program. Figure 2 shows some of the QC process control steps of the geotechnical logging that evaluates logging accuracy and consistency to identify discrepancies before input to the subsidence modeling. It requires the 3D data to be stored in Vulcan, such as position and characteristics of faults, rock strength properties and lithologic and geotechnical domains. RCM developed a detailed set of process control diagrams to maintain quality and consistency in data input (RCM, 2017a). Typical industry standards used by RCM in the analysis of geotechnical and geologic data are presented in Table A2 (Appendix A).

Some of the process control steps follow ASTM standard analysis methods. For instance, Rock Quality Designation (RQD) measurements are taken using an ASTM method (Deere, 1989; Deere and Deere, 1988). RQD is a measure of core recovery and rock mass quality characteristics measured in percentages ranging from poor (<25%) to excellent (90-100%). Other measurements follow industry best practice protocols. For example, core recovery is estimated from driller blocks which is corroborated from detailed ABI logging (where possible) to generate a final core recovery number. Core orientation is also verified by ABI data, which is industry standard, when available. Various workflow diagrams, as shown in Figures 1 and 2, incorporate process controls to find and correct errors in data.

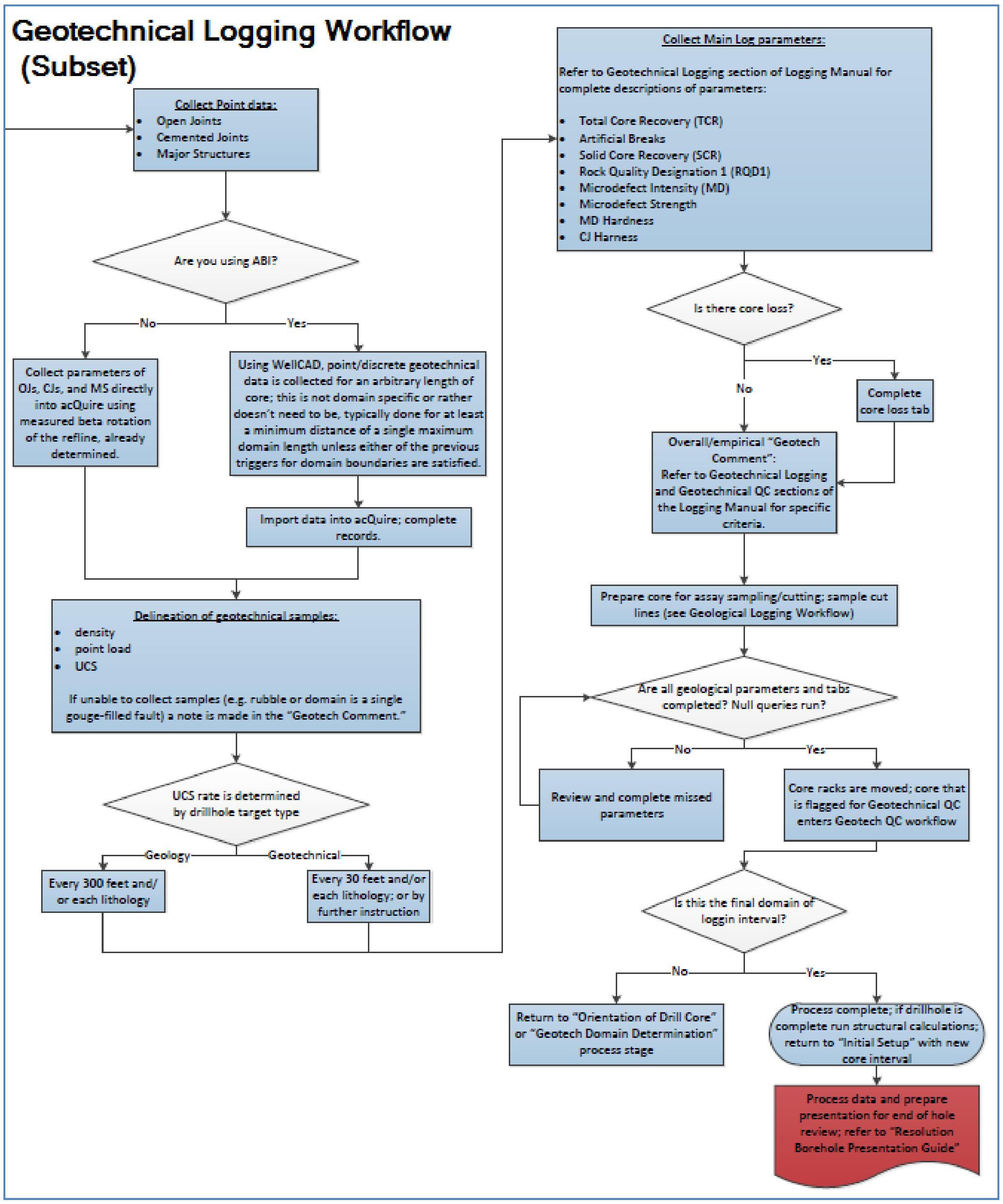


Figure 1. Portion of Geotechnical Logging Workflow (Subset) – Process control diagrams are a QA element in the RCM sampling program (RCM, 2017a).

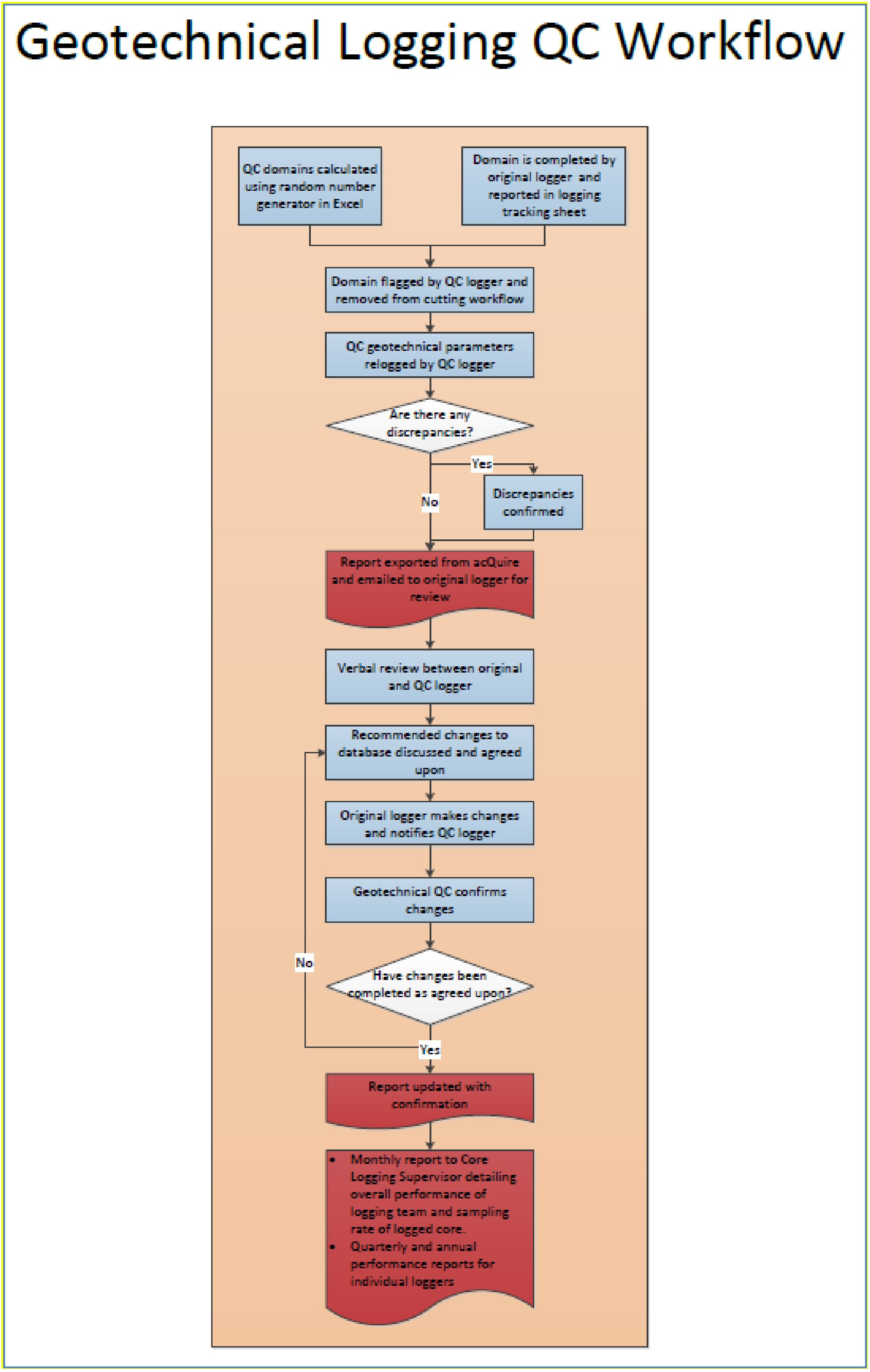


Figure 2. Geotechnical Logging QC Workflow (Subset) – Process control diagrams that provide additional detail on the model quality control (RCM, 2017a).

3.4. AcQuire Database: Analysis of Drill Hole Core Data

The primary source of geotechnical and metallurgical data for RCM is from the extensive analysis of drill hole core. The initial focus of the drilling was to develop a mineral resource model, with copper as the primary target. This has resulted in a higher density of drill holes within higher grade mineralized zones and less dense drilling in low-grade areas. External reviewers indicated that the database and the logging of lithology, alterations and mineralogy meets high industry standards (RCM, 2016a; 2016b, 2017a; Parker, 2017; 2018).

RCM realizes several benefits in its use of a sophisticated, quantitative, digital logging system like acQuire. This geotechnical database program is designed to capture detailed lithology, alteration and mineralization attributes as well as geotechnical data. To assure consistency, RCM has instituted a training program for their geologists and all loggers who are all are degreed geologists. An important part of acQuire are the QC protocols designed to ensure consistency and accuracy for both geologic and geotechnical data. Figure C1 in Appendix C shows the program being used in real-time at a core logging facility. The corresponding ABI is also displayed at the core logger's station for visual details of the borehole. Figure C2 shows the arrival of the core in secured boxes and the warehouse where core is archived after logging. The top photo of Figure C3 shows a core during the logging process (Brandt et al., 2017) and the bottom photo shows a laptop computer used at the core logging station to input data directly into the acQuire database.

The sequence of how the core is logged is shown in Table 2. It illustrates a portion of the geotechnical logging workflow designed to assure sufficient data quality that will allow for future management and engineering decisions (RCM, 2016a; 2016b, 2017a). Figure C2 in Appendix C has photos of step 1 (core delivery) and step 12 (secure archiving of core), while Figure C3 shows photos of step 6 (logging by geologist and real-time data entry).

Table 2. Geotechnical and geologic data input steps using acQuire (Pere et al., 2011).

1. Core delivery
2. Clean-up
3. Orientation
4. Preparation
5. Photography
6. Logging by geologist
Real-time data entry
Training and reference (chip-boards) to maintain consistency in lithologic description
Checking of logging by supervisor geologist
Ability to review and correct data entry in real time
7. Multiple test data entered into the acQuire database e.g., IR spectrometers, X-ray fluorescence meters, density, rock strength, ABI, etc.
8. Input into the acQuire database
9. Statistical analysis and side-by-side data tables and charts of multiple data types
10. On-going data validation and secure error correction
11. Variance checks of re-logged data
12. Secure archiving of core

3.5. Near and Far Inference Cases

Two cases of data adequacy for this objective are considered using DQIs. The "near" and "far" cases consider how well sampling data can be used to infer the geotechnical properties of the in-place rock. As depicted in Figure 3, the near case (shown in green) is related to information available in the acQuire drill database, and the far case (shown in red) is related to the interpreted geology within the Vulcan wireframe model. The bottom panel in Figure 3 shows an E-W section through the 2016 Resolution deposit model. Again, green signifies the area with interpolated data and dense drill sampling, whereas the red depicts the area where the geology has been extrapolated from more limited sampling.

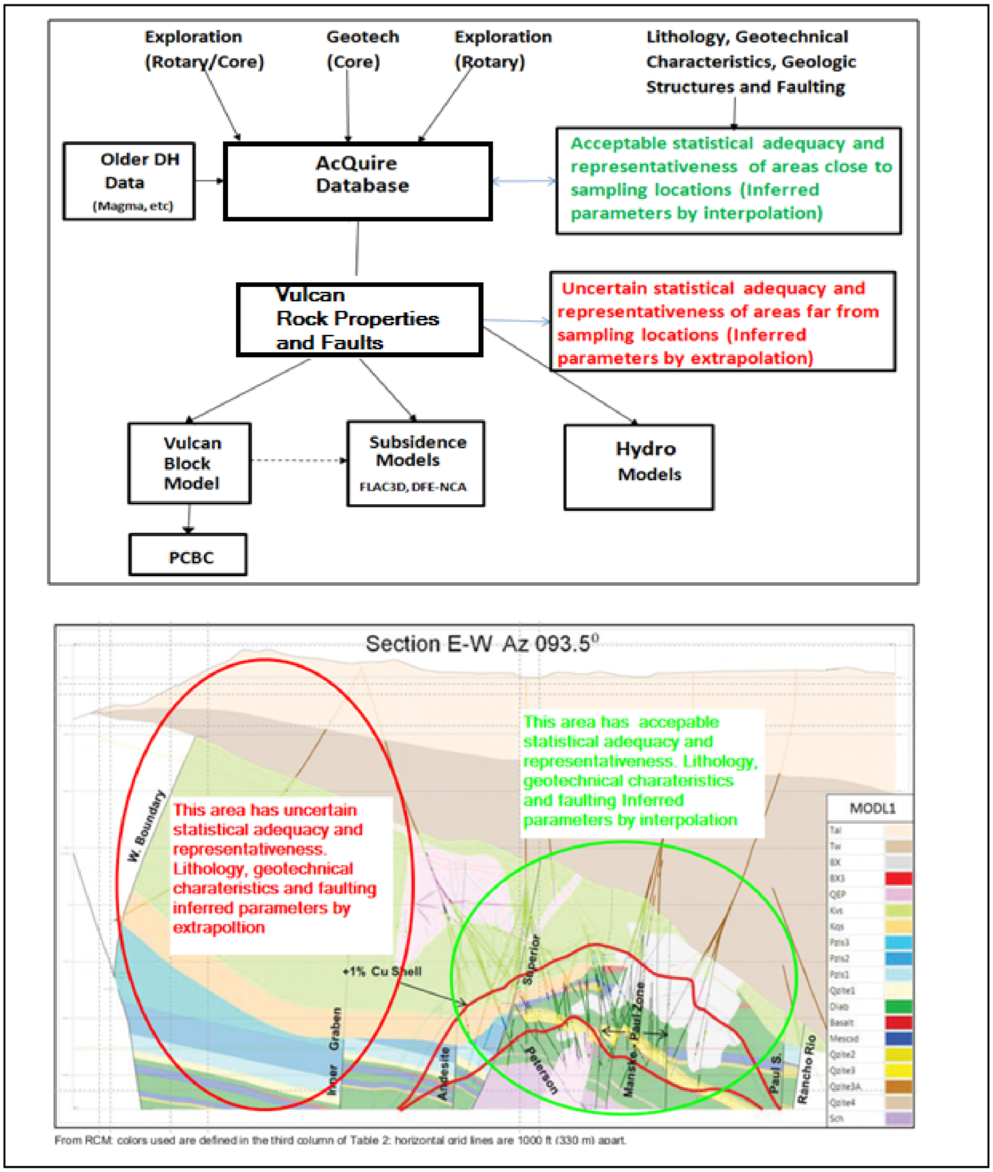


Figure 3 Top panel: Data flow from acQuire to vulcan rock properties and fault databases.
Bottom panel: Statistical adequacy of data in vulcan model based on extrapolation distance.

The near case considers whether there is acceptable statistical adequacy and representativeness of areas close to the sampling locations. This can be generalized as inferring data within the acQuire database to in-situ rock by **interpolation.** The far case can be considered as inferring data within the Vulcan model by **extrapolation**.

For the near case, the Workgroup concludes that RCM's program of logging drill hole geotechnical data meets and exceeds industry standards when checked against seven DQIs shown in Appendix B Table B3. These DQIs have been applied to the rock properties within the drill holes, such as lithology, fracture intensity, and rock strength (RCM, 2016c), as shown in Appendix B Table B1. DQI applies to how a sample is *statistically representative* of those parameters within the in-place rock being sampled. At the local scale, the Workgroup concludes that RCM's sampling program meets this DQI. The sample is representative of the population. In addition to representativeness, the sampling program also meets the six other DQIs shown in Appendix B Table B2 (precision, bias, accuracy, comparability, completeness, and sensitivity). This conclusion is supported by these observations:

1. The observations of the rock mass quality in the No. 10 shaft, although limited, indicated that geotechnical data from drill hole cores are conservative.
2. Outside consulting companies produce similar geotechnical results.
3. Historical mines within the same rock units have similar properties.
4. Multiple measurement methods produce confirmatory results.
5. Re-logging by different geologists produce similar results.

For the far case, the inference of geotechnical data becomes less certain as extrapolation distances increase. Observation of the drilling density indicates that most sampling occurs within the mineralized zone (1% copper shell). That is reasonable, as most drilling was completed to delineate the mineral resource. Outside the mineralized zone, sampling density falls, requiring sampled rock properties to be extrapolated over large distances. Visual inspection of the location of drill holes show large areas, including where subsidence is projected to occur, with limited or no sampling. These areas are outside of the mineralized zone and have rock properties extrapolated for distances of more than 1000 feet. In addition, fault positions are important as they can play an important role in the final shape of surface subsidence (Vyazmensky et al., 2010). Figure C4 in Appendix C shows a section detailing a portion of the area within the 1% copper shell. This is the densest sampling at the Resolution deposit and illustrates a complexity of fault geometry that most likely exists at unsampled areas as well. A quote from a consultant (Parker, 2017) describing the 2016 geologic and mineral resource model emphasizes how new drill holes in poorly sampled areas may change the interpretation of fault geometry:

> *"... the 2016 geologic model saw the addition of two new faults and significant revisions to five other faults, significant changes to the shapes and extents of the main Laramide intrusive and breccia bodies... Where substantial changes in the interpretation have occurred, these can be related to augmented interpretations based on new drill holes."*

With very limited data for the far case, the existence and/or position of a fault must be based on extrapolation of limited available data and professional judgement and not geostatistical analyses alone. This is where detailed surface mapping, an understanding of regional tectonics and faulting, and the application of structural geology principles are critical for proper fault interpretations.

3.6. Summary of Adequacy of RCM QA/QC Procedures and relevancy of DQIs.

This review of RCM's internal QA/QC procedures concludes that for the near case (the area of dense drill sampling in the mineralized zone), RCM's program of logged drill hole geotechnical data meets and exceeds industry standards. The procedures were checked against seven DQIs selected by the Workgroup. These DQIs have been applied to the rock properties probed by the drill holes such as lithology, fracturing intensity, and rock strength (RCM, 2016c; 2017b). These seven DQIs are universally recognized and were used in determining that RCM's sampling and testing program was appropriately conducted. At the local scale, the Workgroup concludes that RCM's sampling program meets this DQI. The sample is representative of the population. The sampling program meets all seven DQIs for the near case.

For the far case (area outside of the mineralized zone), the Workgroup concludes that the extent of the extrapolation impacts DQIs. Outside of the mineralized zone, sampling density falls rapidly, which requires rock properties to be extrapolated from fewer samples to greater distances. The Workgroup concludes that these areas may not be representative based on data at a long distance away. This does not mean that the interpretations of rock properties and geologic data in the far case are wrong. Rather, it simply highlights that the rock property and fault information used in the subsidence modeling involved extrapolation of sampled data, and interpretation using professional judgement.

It is common, particularly for a project covering such a large area, to perform some extrapolation of sampled data to unsampled areas; there will generally be some level of extrapolation in such cases, as the subsurface in its entirety cannot be explicitly known and observed. The Workgroup finds that the interpretations of far case rock properties and assumptions are generally reasonable. Section 5.5.1.1 reviews the justification for extrapolating Tw rock mass properties that is back-analyzed using Tw rock unit behavior observed during the sinking of Shaft #10, to the entire mining area.

4.0 REVIEW OF RCM’S GEOLOGIC INTERPRETATIONS

This section provides a review of RCM’s methodology for interpretation of geological units (within fault blocks) and faults using drill hole data and geology mapping of surface structures. Beginning in 2002, RCM has developed and revised a robust methodology and procedures for interpretation of geological structures and geological rock units. RCM has retained external consultants to review its geological and structural geology model to ensure it meets mineral resource and mineral reserve reporting standards.

The most recent updates to the structural and geological model were completed in 2014 and 2016 in which the data from the latest infill drilling were used to confirm the existing interpretation and/or to update the lithology and the fault model interpretations. The latest review of RCM geological and structural models was completed in March 2018 (Parker, 2018).

4.1. Geology and Geotechnical Database

The acQuire geology and geotechnical database contains data from 438 drill holes within the Resolution property, the majority of which are drilled within the 1% copper shell at depths targeting the ore body. As a result, the drill hole density is high within the 1% copper shell but is low away from the caving area and near the surface. Out of 438 drill holes, 135 holes (over 131,000 m) have been logged for geotechnical information. RCM has also conducted photogrammetric mapping of No. 10 shaft and its lateral developments during sinking and has information from historic surface mapping in the area and from the former Magma mine. Subsurface mapping will provide information to further refine modelled geological units and structural geology (faults). This information has been used to interpret and develop geological units and structural geology models.

In interpreting geological units and structural geology, RCM divides the rock mass into several fault blocks. Each fault block refers to a volume of rock mass within which layers of rock types separated by bedding planes are interpreted based on the drill hole and surface mapping data. Each fault block is constrained by several faults and/or distinct boundaries or geological contacts.

4.2. Geologic Units Interpretation

The ore grades at the Resolution Copper property are strongly controlled by lithology. As such, RCM has incorporated the reliability of geological interpretation (lithology and faults) into mineral resource classification. This includes the confidence level in location, thickness, and elevation of the geological units, as well as the confidence in the interpreted faults that delineate various fault blocks.

The RCM lithology interpretation heavily relies on bedding plane location and orientation. RCM uses a nine-step procedure to interpret lithological units within a fault block beginning with identification of the bedding plane contacts on horizontal and vertical sections followed by developing contact surfaces from digitized contacts on multiple sections. This process is repeated, and contact surfaces of all lithologies are constructed. Reference geology and contact surfaces and fault planes are used to delineate the extent of each fault block. As a check, RCM uses radial sections through each drill hole to confirm that the modeled (interpreted) contact surfaces correspond with the logged lithology contact in the core. RCM has applied this nine-step procedure to interpret lithology where there are sufficient drill hole data or surface mapping data available.

Based on the level of confidence in Resolution's geological (rock type) interpretation within a fault block, the interpretation of that fault block is qualitatively rated as "Inferred", "Low Indicated", "Indicated", and "High Indicated" (Parker, 2018). These terms are used qualitatively by RCM, depending on the amount of geologic information available from drill holes within those blocks and based solely on professional judgement. This qualitative rating is dependent on the number of significant holes piercing through the fault block and the amount of information available from each hole to help geologists interpret the fault. A drill hole is generally considered significant if it pierces through multiple geological units within the same block. Fault blocks are interpreted as "Inferred" if there are less than three significant holes to characterize the lithology. Likewise, at least three significant holes are required to characterize the block as "Indicated". The "High" or "Low" prefix is assigned based on the number of significant holes and the geologic data available from the significant holes. The Workgroup finds that this approach to rating the confidence levels in fault block interpretations to be reasonable, with enough information for the reader to understand the assumptions behind these ratings.

Figure 4 shows a map indicating the confidence level in interpreting geological units in all fault blocks within the Resolution property. All blocks within the center of the caving operation are rated as Indicated or High-Indicated. The interpretation of fault blocks outside this zone are considered Inferred based on limited core and mapping data, which could result in lack of certainty about the strike, dip, and position of the contacts and geological units.

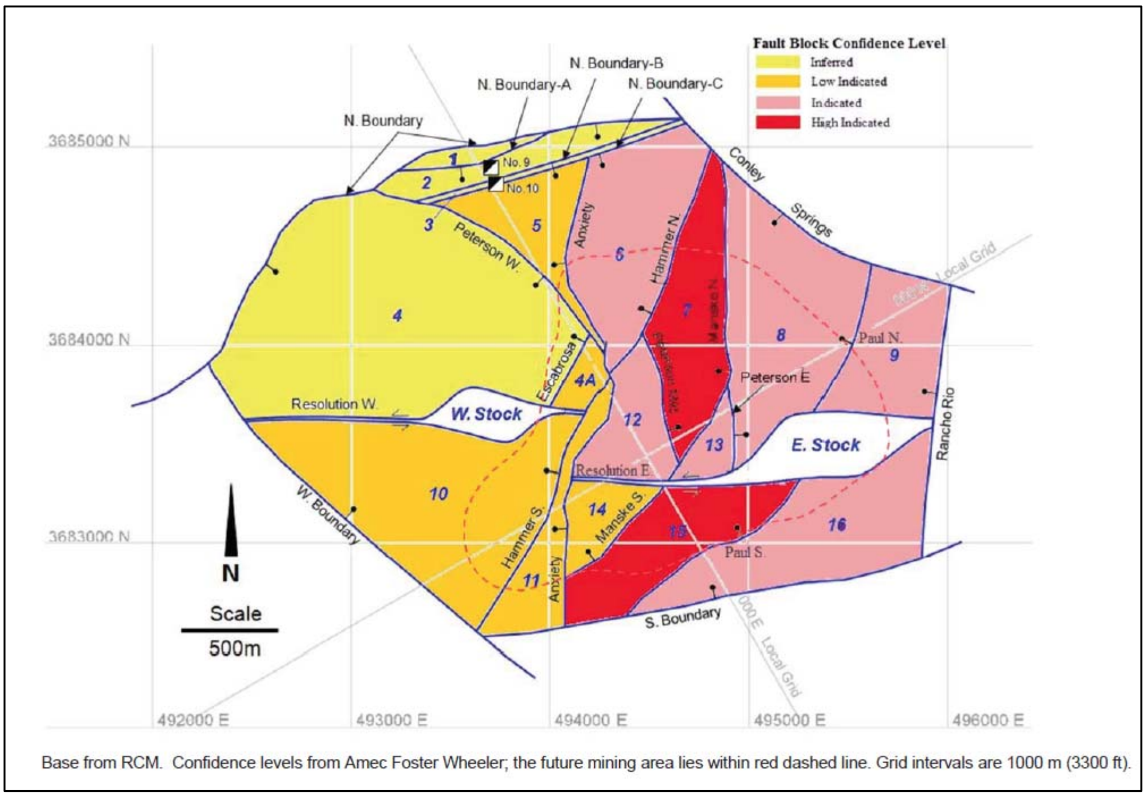


Figure 4. Confidence level for fault blocks (geological units) (Parker, 2018)

RCM has also evaluated the uncertainty in elevation and thickness of the geological units using conditional simulation. In this approach, equi-probable images of the geological units and faults are simulated according to pre-defined uncertainty estimates provided by Resolution geologists. The simulated rock types within each fault block are compared with the modelled geological units and the (perpendicular) distance of the modelled unit to the simulated one is calculated on either side of the geological unit contact. The uncertainty on one side could be higher than the other side. In the simulation, the limit of variation for the geologic unit elevation was assessed to be ±30m and that for the geologic unit thickness was assessed as ±20% of the interpreted thickness (Verly et al., 2009). This variation limit represents variability within two standard deviations for each parameter. A comparison of the simulation volume with that of the interpreted model shows a change in volume of less than 2%, which is considered very good (Parker, 2018). The Workgroup agrees with Parker's (2018) conclusions and considers that comparison to be a good fit.

4.3. Structures/Faults Interpretation

Faults are represented in the drill core as broken core zones with gouge infills of variable thickness. Slickensides are normally associated with faulting and displacement across a fault plane. Faults can also be identified from disruption in continuity of geologic units when projected across multiple drill holes. The fault (zone) orientation, thickness and depth along hole can be more accurately measured from acoustic televiewer images of the borehole walls after it is surveyed by an acoustic televiewer.

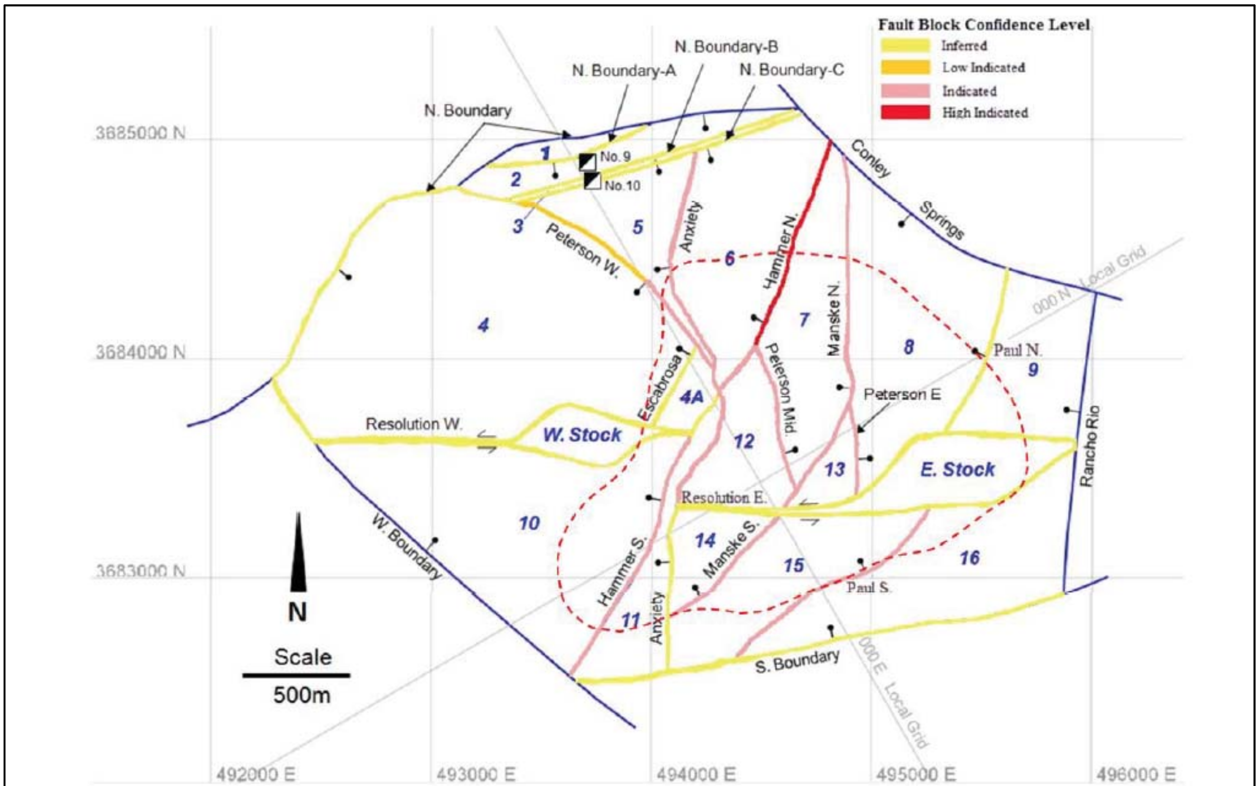
RCM makes use of acoustic images, core data and core photos to identify and characterize faults and fault zones. As part of the structure picking process to orient the core, fault surface orientation is also accurately measured from televiewer images. In addition to drill hole data, discontinuities including faults and fault zones have also been mapped while sinking the No. 10 shaft and in the lateral development. The structural data is then plotted on a stereonet and key structural controls (faults, joint sets etc.) are determined. RCM has associated major faults/fault zones to having a displacement (across fault plane) of greater than 50 ft. Faults with displacements less than 50 ft have not been considered by RCM as major structures. The Workgroup agrees that this is a reasonable cutoff for fault displacement used in modeling, because such small fault displacement is not indicative of structures that could influence subsidence behavior.

RCM has improved its fault model since 2012 with additional infill drilling. It has updated the interpretation of the existing faults and/or has identified new faults within the Resolution property. Through additional drilling, RCM has identified marker bedding planes (quartzites) within the stratigraphic sequence that can be used to confirm approximate bedding plane orientations measured from core (Parker, 2018). With the majority of drill holes targeting the orebody within the 1% copper shell, the faults and fault zones within the 1% copper shell are well defined and characterized. Infill drilling after 2012 and 2014 has improved the fault interpretation in the outlying areas outside the 1% copper shell.

While televiewer data can be used to identify a fault and measure its orientation, the location of the fault can vary ±50-200 ft. RCM has retained AMEC Foster Wheeler (Parker, 2018) to evaluate and develop a confidence level for each interpreted fault. Parker has evaluated each fault using two adjacent fault blocks and associated drill holes that pierce through the fault plane.

Similar to fault blocks, Parker (2018) has rated faults as Inferred, Low Indicated, Indicated, and High Indicated. To rate a fault plane as Indicated, a minimum of three holes are required to pierce through the fault plane. The latter is also required to confirm the orientation of a fault. The Low and High prefix refers to the length of the fault trace between fault blocks and the number of holes piercing through the fault plane.

Parker (2018) has evaluated all identified faults and created a color-coded map showing the confidence level used in interpretation of each fault (Fig. 5). As shown, faults in the center of mining area are considered to have Indicated or High Indicated confidence levels. It is notable that the faults in the perimeter of the map (colored in blue) were not rated at the time of the study due to a lack of drilling data. These faults, however, have been rated as Inferred based on the information from subsequent surface infill drilling.



From RCM. Confidence levels assigned by Amec Foster Wheeler; the future mining area lies within the red dashed line; grid intervals are 1000 m (3300 ft).

Figure 5. Confidence levels for faults (Parker, 2018)

The uncertainty about fault position has also been evaluated using conditional simulations. In a similar approach to geological unit position uncertainty, fault surfaces are interpreted and created from borehole data. Fault surfaces are then simulated based on the geologist's estimate of limit of variation of fault position (the standard deviation of the distance from the simulated fault plane to the modeled/interpreted fault plane). The latter is estimated for both sides of the fault plane and may not be the same on both sides. Close to drill hole pierce points the standard deviation of distance is low, but away from pierce points and where there are few holes, standard deviation is high. Parker (2018) results indicate the average percent change between a simulated fault position and the corresponding modeled/interpreted fault position is reasonably low and unbiased.

The Camp and Gant faults were not intersected with boreholes. These are important west boundary faults in the proposed subsidence cave zone. However, there has been extensive field mapping and conservative values have been used in the model to capture geologically reasonable behavior of these faults (see Sections 5.3.3 and 5.3.4 for discussion of conservatism and fault properties), as well as sensitivity analyses (Section 5.4.2) to evaluate a range of properties and impacts on subsidence.

4.4. Geological Modeling and Interpretation

At Resolution, geologic modeling and interpretation has been informed by regional studies and mapping, site-specific mapping of lithology and faults, borehole data, and sound geological principles. Modeling and interpretation of mineralization and alteration has also been informed by classic porphyry copper deposit models (e.g., Lowell and Gilbert, 1970).

As is conventional in the mining industry, RCM uses the Vulcan software platform for their three dimensional (3D) geological model. The Vulcan model uses faults/structures, and lithologic and geotechnical domains to produce a structural wireframe model. The process of identifying and interpreting fault blocks and fault structures was reviewed in previous sections.

The Vulcan model is updated periodically with new borehole data. The resulting block model is based on each block representing a geotechnical domain with a characteristic lithology, rock strength, mineralization, and alteration. Finally, RCM confirms the interpreted geology and structural models in Vulcan by infill drilling in areas already drilled and used in the model (Parker, 2018), and by comparing the distribution of similar rock types to nearest-neighbor geology models. These practices are generally considered industry standard.

4.5. Summary of RCM's Geologic Interpretations

RCM has developed a robust and complex process from data collection (core logging, acoustic televiewer surveys, surface and underground/shaft mapping, and statistical methods) to interpretation of geological data and has generated and refined geological and structural (faults) models for the Resolution property. RCM has improved its geological and structural interpretations through continuing data collection programs and using industry-standard methodology and tools.

RCM has placed great emphasis on developing a reliable and accurate geological model mainly because lithology is a key control on grade within the orebody. Various lithologies are identified and modeled using core and televiewer data. RCM has also revised and updated its structural geology and fault block (geological units) models over the last several years. Faults are interpreted in the geological model where discontinuities are present indicating displacement of the marker bedding planes or contacts across fault plane(s). A large number of faults have been identified and interpreted within the Resolution property. Those faults pre-dating mineralization are strongly annealed by veins of hydrothermal quartz or anhydrite, and intrusive dikes and sills. The infill in some faults is stronger than the surrounding rock, increasing the rock mass strength. The post-mineralization faults are generally reported to be weaker. The majority of faults that are observed on surface and are mapped are post-mineralization. Surface subsidence may be impacted by those post-mineralization faults that are located around the perimeter of the cave zone and may work to extend the subsidence zone laterally. Parker (2018) states that RCM interpretations of faults and fault blocks are considered high quality and acceptable for subsequent geotechnical modeling and subsidence prediction and impact assessment.

The Workgroup concludes that the interpreted structural and geologic models presented by RCM are reasonable and supported by adequate data collected according to industry-accepted methods, tools, and standards.

5.0 REVIEW OF THE SURFACE SUBSIDENCE MODEL

RCM retained Itasca Consulting Group Inc. (Itasca) to conduct an advanced 3D numerical modeling assessment of ground surface subsidence resulting from the proposed panel cave operations at the Resolution Copper property. It is well understood that panel caving operations result in ground surface subsidence, the extent of which must be investigated and understood.

5.1. Review Scope

The main objectives of this review are to assess:

- The adequacy and appropriateness of the methods used to evaluate surface subsidence.
- Whether the assumptions considered are reasonable and the subsidence criteria used to predict subsidence are valid and acceptable, based on industry practice.
- Whether the rock mass and discontinuity strength properties used in the model are representative of the rock mass conditions at Resolution.
- Whether the key faults/fault zones are included in the model.
- The adequacy of the simulated cave mining operation and subsidence progression to surface.
- The appropriateness and reliability of model predictions and potential impacts to Apache Leap, Highway 60, and Devil's Canyon.

The RCM study also included an assessment of the potential impacts to mine infrastructure (shafts, surface facilities, etc.), however, these impacts fall outside the scope of this report. The subsidence impacts to mine infrastructure will therefore not be included herein.

RCM conducted an empirical assessment of the Resolution panel cave and determined a first approximation of the cave angle. The next section summarizes the results of this empirical assessment followed by a detail assessment of the 3D numerical model conducted by Itasca for the Resolution project.

5.2. Block/Panel Cave Empirical Assessment

Using Laubscher's method (1994) introduced in Section 2.3.2, RCM evaluated initial estimates of subsidence cave angle based on the MRMR ratings of the Resolution rock mass domains, height and density of the caved material, and the depth and span of the cave. The empirically-derived cave angle ranged from 72 to 84 degrees, with an average value of 76 degrees.

An empirical investigation has been conducted by Woo et al. (2013), using observations from a large number of caving operations, to characterize caving-induced surface subsidence. A comprehensive database has been developed from this study. In this work, the impact of depth of orebody and extraction level, geologic structures (faults), rock mass characteristics, topography, and insitu stress distribution on surface subsidence, fracture limit and cave angle have been evaluated. Also, in this study, data from caving operations were plotted and the impact of each parameter on cave angle, fracture limit and surface subsidence were evaluated. Figure 6 and Figure 7 show the empirical relationship between the cave angle and the fracture initiation angle with the undercut depth from caving operations included in the Woo (2013) database. Each line segment in the figures represents the range in caving angles measured from different sides of the undercut. The increase in range of caving angle indicates a higher degree of asymmetry in surface subsidence. Although there are few cases in the database that were developed at depths greater than 1000 m, the results of the empirical and base case simulation (presented and discussed in the subsequent sections) are generally in agreement with the Woo et al. (2013) findings in terms of cave angle, impact of major structures, topography and insitu stress regime.

It is important to note that, while allowing for the prediction of key controlling factors on a cave operation (e.g., surface subsidence, cave angle) at early stages and with limited data, empirical methods inherently include one or more assumptions that could impact the resulting surface subsidence and cave angle, and will likely ultimately contribute to uncertainties in the empirical cave design methodology and conclusions. These uncertainties should carefully be considered when an empirical approach is used. These uncertainties include, but are not limited to:

- Rock mass heterogeneity and strength properties, including spatial variability of rock mass properties.
- Major structures (fault/fault zones), their infill characteristics, spatial variabilities, and strength properties.
- Local insitu stress distribution including stress magnitude, orientation, and the stress ratio, which is a key factor in defining a local stress regime.

Considering the limitation above, RCM has used the empirical approach as a first approximation to estimate the cave angle and the Workgroup agrees with this approach. Proper assessment of the surface subsidence resulting from a caving operation requires detailed geological, structural, geotechnical and numerical assessments to adequately address the uncertainties mentioned above.

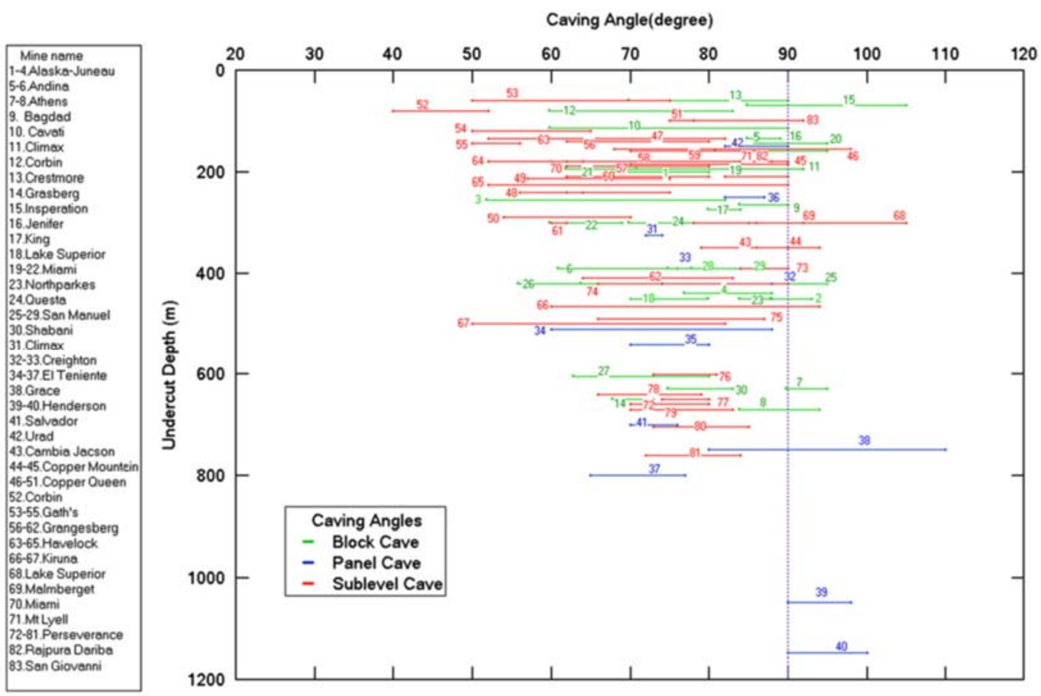


Figure 6. Empirical relationship between the cave angle and the undercut depth from caving operations included in the Woo (2013) database

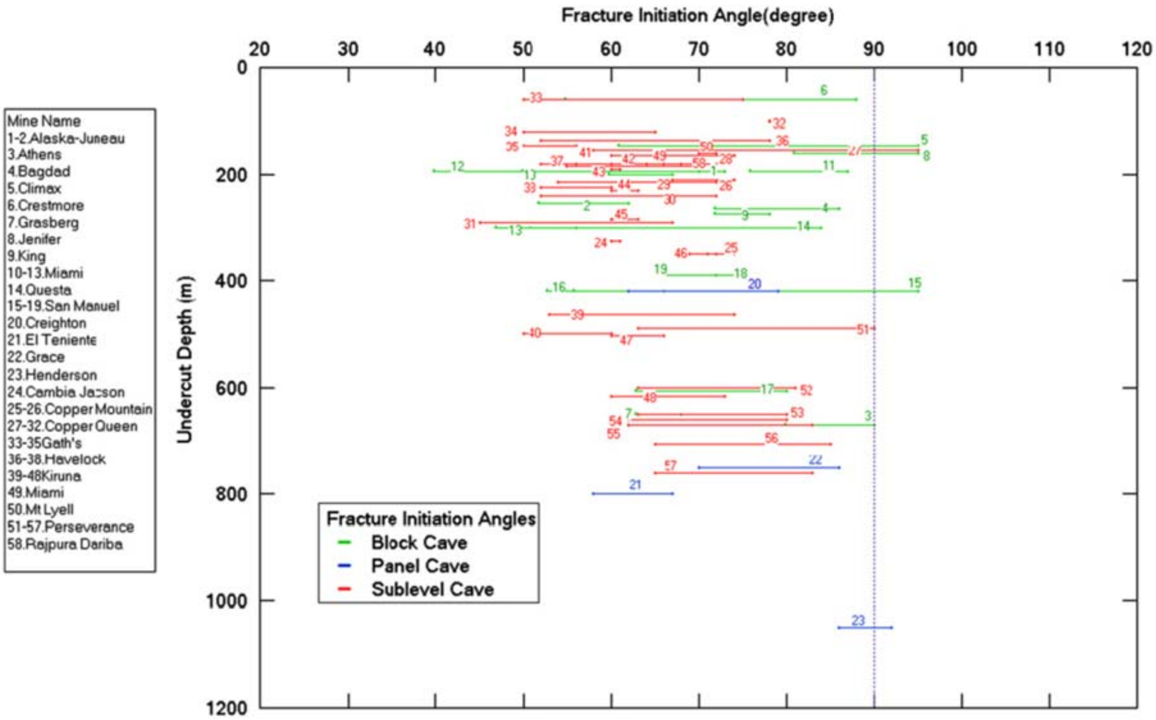


Figure 7. Empirical relationship between the fracture initiation angle and the undercut depth from caving operations included in the Woo (2013) database

5.3. Surface Subsidence Prediction Model

A 3D numerical model was developed for the proposed RCM panel caving operation based on the Cave-Hoek constitutive model using FLAC3D finite difference code (Itasca, 2017a; 2017b). FLAC3D has widely been used to simulate block cave operations and has become the industry standard tool to predict the extent of ground surface subsidence from caving operations, as discussed in Section 2.3.2 The Flac3D model simulates cave operations and predicts surface subsidence according to a mine production schedule. Flores and Karzulovic (2002) stated that only a numerical model can predict the full extent of surface subsidence above the property and in the surrounding areas.

RCM provided geologic units, a structural geology model, geotechnical domains and geotechnical properties associated with each domain, and the mine production schedule for input into the numerical model. The following assumptions were considered in the development of the numerical model.

5.3.1. Model Assumptions

- Faults were simulated implicitly as distinct weak rock masses rather than interfaces. This assumption is considered reasonable because, at the Resolution property, faults are generally comprised of zones of relatively weaker rock mass (compared to the surrounding host rock) and are not necessarily a discrete feature.
- Geological Strength Index (GSI), which is a measure of the state of relative blocky-ness of the rock and joint surface conditions, was considered applicable to all rock

mass domains to characterize rock mass structure. Typically, the application of a GSI value to a specific rock domain depends on the state of rock fracturing and the number of joint sets present in the rock mass. Therefore, the global application of GSI to a rock domain at the site may result in conservative rock mass properties where this criterion is not applicable to a specific rock domain (i.e., Tw domain for the interpreted GSI value where three joint sets would be required).

- Only faults and faults zones are included in the model. Rock mass discontinuities (dominant joint sets) are not included in the model. Although they provide more flexibility to the rock mass to deform, discontinuities are at much smaller scale (rock fabric scale) compared to faults/fault zones and their impact on surface subsidence is more local and is strongly controlled by discontinuity orientation. Therefore, this assumption is considered acceptable.

The following sections summarize details on numerical model geometry, structural geology, and material properties used in the numerical model.

5.3.2. Subsidence Model Geometry

The subsidence model dimensions are approximately 15.2 km x 12.64 km x 3 km, with the panel cave located in the center of the model. Model geometry was large to maintain model boundaries at a distance from the subsidence area, to minimize boundary effects on the subsidence simulation. The mesh consists of 940,000 "zones", with the smallest zone length, or element dimension, of 20 m applied to the extraction level, near ground surface areas, and near faults. The zone length is increased to 160 m at the limits of the model, where less detail is required.

5.3.3. Geology and Structural Geology

The validity of procedures for interpretation of geological units and the structural geology (faults) model were discussed in Section 4.0. In this section, the geological units and structural geology for input into the model are reviewed.

RCM provided the geologic units and structural geology model for the Resolution property in the form of a series of DXF wireframes and triangulated surfaces, respectively. The geologic units and faults are based on the latest model update in 2016. In the subsidence model, faults were modeled implicitly as a zone of weak rock mass, rather than as a planar interface. As stated previously, this is considered reasonable when faults are comprised of zones of weak rock mass rather than a distinct fault plane, with competent rock on either side.

As part of the interpretation, faults were characterized as strong, medium, or weak, based on the infill character:

- Strong – faults that are strongly annealed.
- Medium – faults described as mixed, with open and annealed shears with local gouge and local intense damage.
- Weak – faults described as slickensided shears, heavily damaged, brecciated and/or with gouge.

Among the faults that are observed on surface, only Monarch fault and Camp fault are rated by RCM as strong and medium faults, respectively. The remainder of the faults (exposed on ground surface) are modeled as weak. Table 3 lists the qualitative ranking of the faults used in the subsidence model. Figure 8 shows the faults that are persistent to ground surface and their qualitative ranking (Itasca, 2017a).

Table 3. Qualitative ranking of the faults at Resolution used in the subsidence model (Itasca, 2017a)

Strong (75% σ_{cm})	Medium (50% σ_{cm})	Weak (Residual Properties)
Manske	Andesite	326 Pump Station
Monarch	Camp	Anxiety
MP-1	Hammer N	Concentrator
MP-2	Hammer S	Conley Spring
Mp-3	Hammer SW	Devil's Canyon
South Boundary	Intergraben	Gant E
	North Boundary A	Gant W
	North Boundary B	Main
	North Boundary C	North Boundary
	Paul	Rancho Rio
	Paul S	West Boundary
	Peterson	
	Superior	
	Superior A	

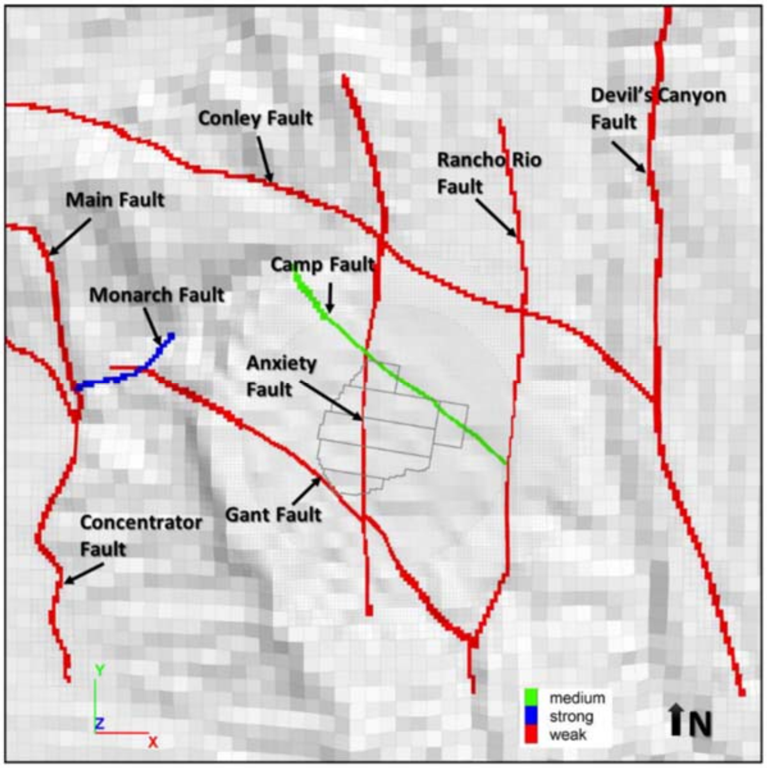


Figure 8. Fault zones persistent to ground surface and their associated strength ranking (Itasca, 2017a)

5.3.4. Geotechnical Properties

5.3.4.1. Rock Mass Properties

The methodology used to develop rock mass properties meets the industry's best practice. Geotechnical properties of the rock mass within each geotechnical domain have been derived based on GSI rating, laboratory strength testing (UCS, TCS, DS etc.), including UCS correlated point load test results, and were input into the subsidence model.

Apache Leap Tuff (Tal) is the lithology observed at ground surface, followed by Whitetail Conglomerate (Tw). The strength properties of these two units is a key parameter controlling the extent of subsidence near surface. GSI was applied to both units, however, RCM stated that due to a lack of three joint sets in the Tw unit, application of GSI results in a conservative estimate of the Tw rock mass strength. The conservatism of Tw and Tal rock mass strengths is discussed in Section 5.5.1.

To adequately simulate the behavior of the rock mass adjacent to the cave (the rock mass within the fractured zone), where the rock mass is yielded, but not mobilized, the rock mass strength was reduced to residual strength. This was accomplished by applying a modified Hoek-Brown strain softening constitutive model in which peak rock mass strength is reduced to residual strength after a critical plastic strain has been accumulated. The critical plastic shear strain defines the brittleness of the rock mass failure. It is a subjective matter and is difficult to determine for a rock mass. As reported by Lorig and Varona (2000), a relationship was developed between the critical plastic strain and GSI, as part of the International Caving Study, by back analysis of rock mass failure in caves and other openings. Itasca used this relationship to calculate an initial estimate of critical plastic strain (Itasca, 2017a). When the critical plastic strain is reached, the strength of the rock mass within this zone is set to residual strength (i.e., zero cohesion, zero tensile strength and 50 degrees friction angle). The Workgroup agrees with the methodology used to obtain a first estimate of the critical plastic shear strain.

5.3.4.2. Fault Strength Properties

As stated earlier, faults were modeled implicitly as zones of weak rock mass in Flac3D. The strengths of the faults that are rated strong or medium are represented using 75% or 50%, respectively, of the global rock mass strength of the host rock mass. The weak faults are characterized by a frictional strength only (zero cohesion, zero tensile strength and a friction angle of 35 degrees).

These percentages used to characterize medium and strong faults represent a qualitative characterization of the possible fault strength relative to the host rock, and are considered by RCM to be conservative because:

1. Strong, annealed faults are generally stronger than the surrounding rock mass.
2. Modeled faults are assumed to be fully persistent (i.e., a continuous discontinuity for the full length of the fault), which may not necessarily be the case.

As discussed in Section 5.3.3 and shown in Figure 8.0, with the exception of the Camp fault and Monarch fault, all other faults observed on ground surface have been characterized as weak with residual frictional strength. Mechanical strength of weak faults is not proportional to the host rock global strength. The Camp and Monarch faults are located within the cave crater and only locally intersect the cave boundary. They are characterized as medium and strong faults and therefore, may only locally impact the extent of cave crater and fracture zone.

The Workgroup is not aware of any standard for assigning fault strengths without sampling and testing specific fault infill materials. The Workgroup therefore requested that RCM perform sensitivity analyses for all relative fault strengths to better evaluate the stated conservatism of the modeled fault strengths, and the impact on subsidence for a range of fault strength values (see Section 5.5.2).

5.3.5. In-situ Stresses

The in-situ stress regime was provided by RCM and is based on hydrofracturing tests completed at site. The in-situ stresses are simulated in the Flac3D model with the major principal stress (σ_1) oriented vertical, the intermediate principal stress (σ_2) at 0.8 σ_1 and oriented north-south, and the minor principal stress (σ_3) at 0.5 σ_1 and oriented east-west.

5.3.6. Numerical Model Subsidence Criteria

The following criteria have been considered (Itasca, 2017a) to determine cave crater limit, fracture limit, and continuous subsidence limit.

- **Crater limit** (zone) is defined as the area where vertical settlement exceeds 2 m. This is also referred to as the mobilized zone in the subsidence report. This criterion has been used extensively and validated further through back-analysis of crater limits at other cave operations, as reported by Itasca (2017a).
- **Fracture limit** is defined by the area where the total strain exceeds 0.5%. This criterion has been developed by back-analysis of the fracture limit induced by caving at the El Teniente mine (Cavieres et al., 2003). This analysis indicated that a total strain of 0.005 is a good indicator for delineation of fracture limit in a numerical model. Although this criterion was developed through back-analysis of fracturing limit at one mine (El Teniente), it has been used extensively and has been validated further through back-analysis of fracture limits at other cave operations including Kiruna, Grace, and Century mines, as well as Andina, Venetia, Pampa Escondida and La Encantada Mines, as reported by Itasca (2018d).
- **Continuous subsidence limit** is the area beyond the fracture limit and is where the horizontal strain is greater than 0.002 and angular distortion[1] is greater than 0.003 (Itasca, 2017a). Sainsbury and Lorig (2005) proposed this criterion, which provide an indication of the amount of settlement required to cause damage to a masonry building during active subsidence. Building damage criteria are used for continuous subsidence mainly because masonry buildings are generally more susceptible to damage (than a rock mass) during subsidence and as such, will provide a conservative limit for continuous subsidence. These criteria correspond to 'moderate to severe damage' to buildings.

5.3.7. Base Case Surface Subsidence Model Results

As part of this review, the results of the Flac3D model (base case) were reviewed by the Workgroup and discussed in subsequent meetings with Resolution and their consultants. The Workgroup then requested further sensitivity analyses to evaluate the sensitivity of the model to variations in several key parameters, including rock mass global strength properties and residual strength properties, fault strength properties, in-situ stress orientation and magnitude, and maximum bulking factor. The results of the base case analysis are presented below. The results of the requested sensitivity analyses are presented in the following section (Section 5.0.).

Based on the results of the base case subsidence model, RCM predicts no damage to Apache leap, Devil's Canyon, or to the serviceability of Highway 60. The base case model predicts a subsidence cave angle on the order of 70--78 degrees with the cave breaking through to surface by Year 6. This calculated cave angle compares reasonably well with the empirically-derived cave angle of 72-84 degrees, discussed previously in Section 5.2. At the end of mine life, the fracture limit (at the closest point) is predicted to be at approximately 340 m from Apache Leap, and approximately 1050 m from Devil's Canyon. The base case model also

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[1] Angular distortion is defined as the differential settlements and the distance between the two points under consideration. Distance refers to the spacing between point before ground settlement occurred (Negulescu and Foerster, 2010).

predicts the caving rate (defined as the ratio of the height of yielded zone (fractured zone) to the height of draw (height of solid rock pulled from draw points)) to vary between 5.8 and 16.8, which is within the range reported in the other caving operations around the world (Itasca, 2017a). The bulking factor within the mobilized zone is also predicted to gradually increase from 11.4% in Year 5 to 15.8% at year 41. The latter is also within the range observed in other caving operations (Itasca, 2017a).

As part of the review, the Workgroup requested RCM/Itasca to provide plots and data for several key ground deformation indicators along five section lines for review. The section lines were selected by the Workgroup and represents areas where the distance from subsidence zone to key areas (Apache Leap, Devil's Canyon and HW-60) is perceived to be minimum. The key ground deformation indicators included: vertical and horizontal displacements, total predicted strain along each section line (used by RCM to identify fracture limit in the model), and the yielded zone within the cave boundary. RCM also provided angular distortion plots along section lines 3 and 4 for the base case model. The latter is used to identify potential areas where angular distortion may exceed the continuous subsidence limit described in Section 5.3.6. Figure 6 shows the location of the section lines.

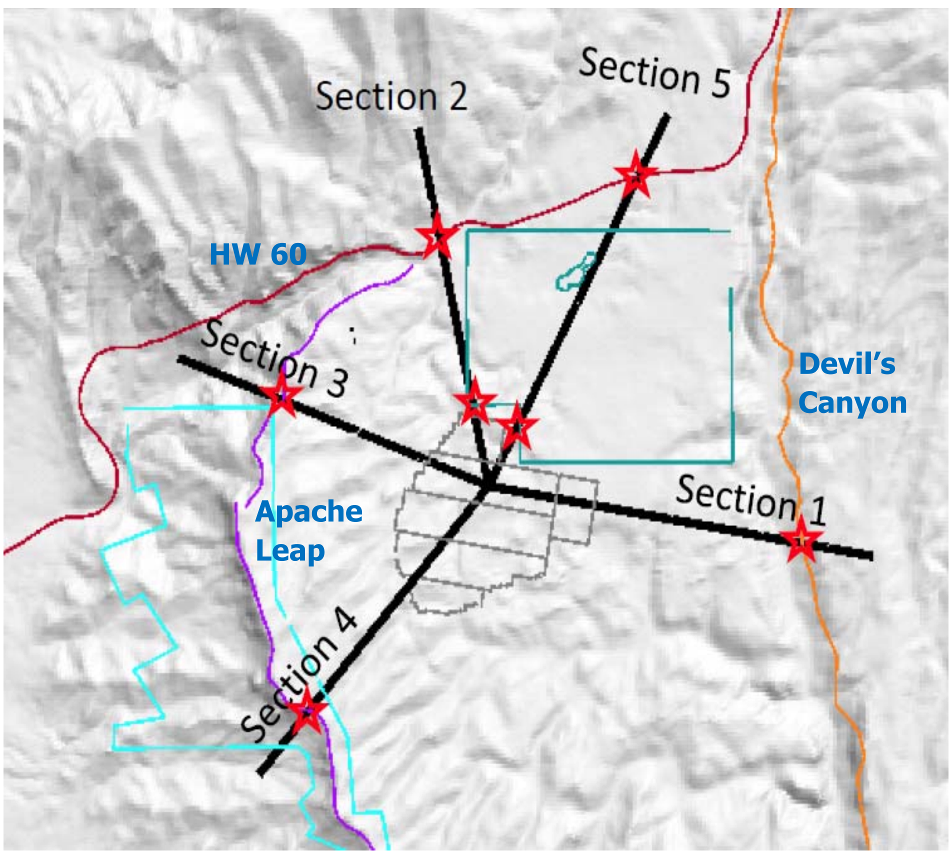


Figure 9. Locations of sections lines for review of subsidence model results

The angular distortion plot at the end of mine life (Year 41) along section 3.0 and 4.0 are shown in Figure 10 and Figure 11, respectively. Both plots in the base case analysis predict that the angular distortion at the Apache Leap and the Devil's Canyon as well as the HW-60 is below

$1x10^{-3}$, which is far below $3x10^{-3}$ threshold. Therefore, no damage, as defined by the damage criterion in Section 5.3.6, is expected to occur. The Workgroup generally agrees with this conclusion. However, the following additional interpretations can also be made from the base case subsidence model.

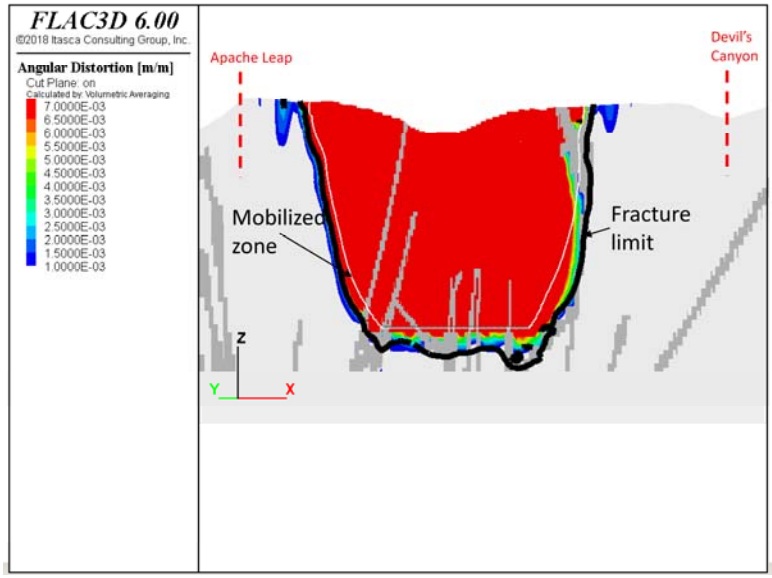


Figure 10. Angular distortion contour at Year 41 along Section 3

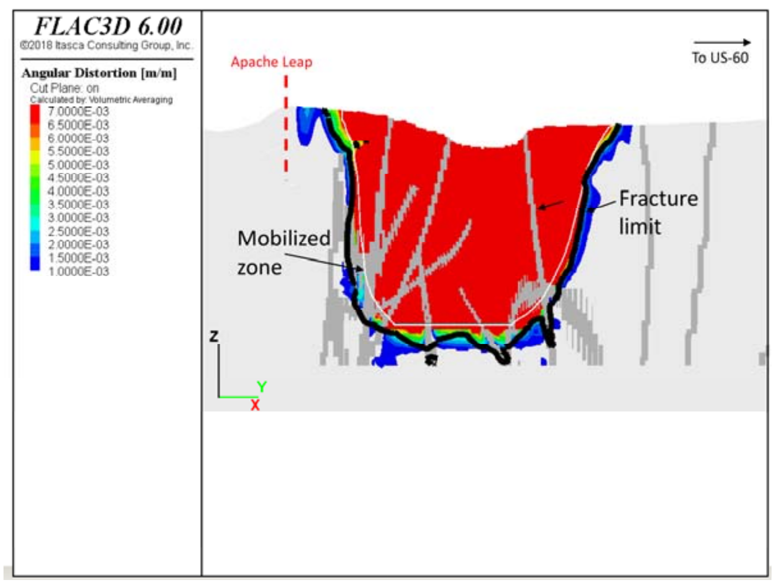


Figure 11. Angular distortion contour at Year 41 along Section 4

The horizontal and vertical displacement contour plots along section 1.0 and section 4.0 (Figure 12) predict that there are approximately 0.4 m to 0.5 m of horizontal displacement and vertical displacement (settlement) at Apache Leap. Similar magnitude of displacement is also predicted along the extension of the section 1.0 (towards Apache Leap) as shown in contour plots in Figure 7. While Figure 10 and 11 above indicated that predicted angular distortion is less than the damage threshold for moderate to severe damage criterion, the combination of horizontal displacement and vertical settlement could potentially cause angular distortion to locally exceed the damage threshold at Apache Leap or the Devil's Canyon, and lead to localized rock block failure. However, large-scale failures at either location are not expected. A localized rock block failure refers to gradual movement or sudden fall of one or more individual rock blocks due to progressive ground movement over time resulting from differential movements induced by caving operation. Large-scale failure refers to progressive or sudden failure of a mass of rock in response to ground movements over time induced by caving operation. The occurrence of either mode of failure is a function of local topography, rock mass strength, fracture intensity, and presence of steeply dipping discontinuities leading to sliding or toppling of individual rock blocks or a mass of rock.

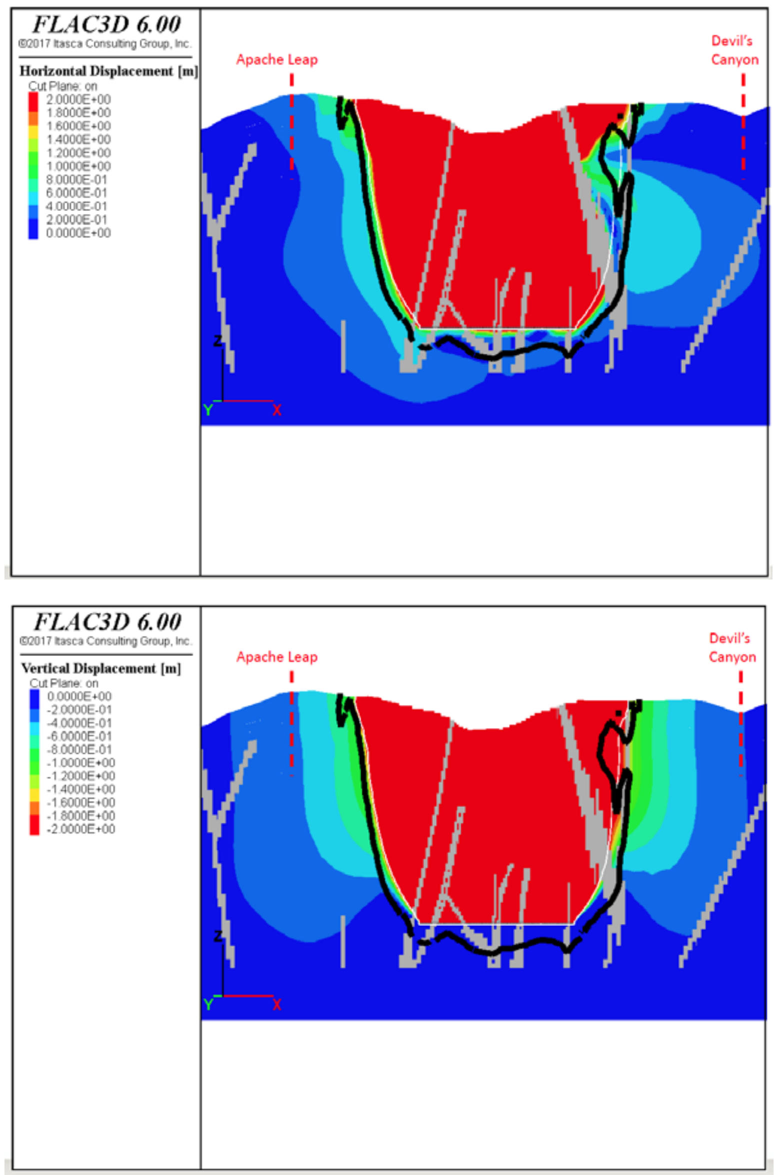
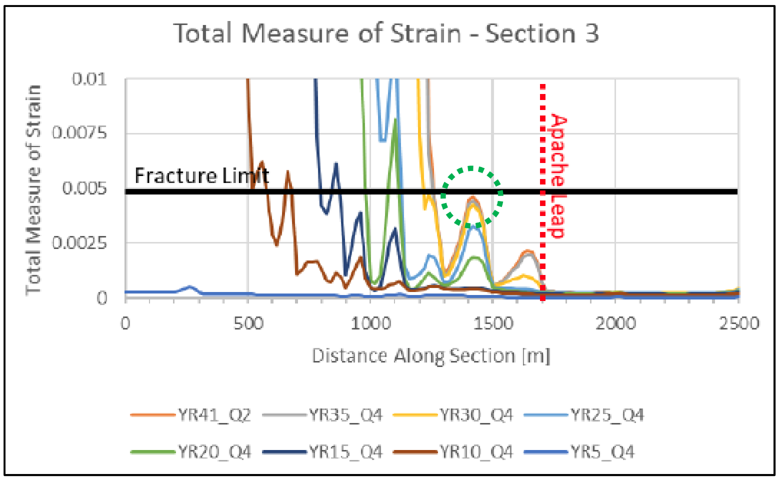


Figure 12. Horizontal displacement contour at Year 40 along Section 1 (top) and vertical displacement contour at Year 41 along Section 1 (bottom)

Line plots of total strain are also plotted and indicate the fracture limit along section line 3 and 4 (Figure 13). Based on the 0.5% total strain criterion, the distance from the fracture limit to Apache Leap is approximately 400 m along section 3, and 300 m along section 4. It is important to note, as model results show, that at much closer distances to Apache Leap, the total strain is as high as 0.48% along section 3 (within 300 m from Apache Leap, see Figure 13 top plot), and 0.45% along section 4 (within 150 m from Apache Leap, see Figure 13 bottom plot). Although not meeting the fracture limit criterion, considering the variability of material properties in the rock mass, the fracture limit could potentially extend further than the base case results predict. Sensitivity analyses were therefore requested, and thereafter provided by RCM, to aid in the Workgroup's understanding of the variation in parameters that could influence these prediction results, as discussed in detail below.



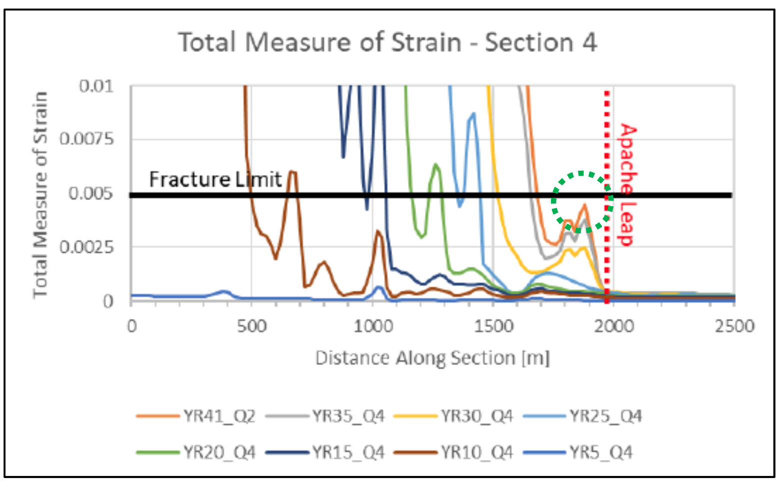


Figure 13. Total strain line plots along Section 3 (top) and Section 4 (bottom) depicting the distance from fracture limit to Apache Leap

5.4. Sensitivity Analysis Results

Based on the results of the Resolution base case model and findings from the Woo et al. study (2013), RCM was requested by the Workgroup to carry out sensitivity analyses to assess the impact of variability in several model parameters on surface subsidence at Resolution, including fault strength properties, rock mass global and residual strength properties, bulking factor, and in-situ stress distribution orientation and magnitude. Table 4 summarizes the sensitivity scenarios that were analyzed. In each scenario, the parameter subject to sensitivity analysis is shown in bold.

Table 4. Subsidence sensitivity analyses scenarios.

Model Name	Rock Mass Strength		Fault Strength[1]	Max. Caved Rock Porosity	Insitu Stress	
	Peak	Residual			K_0 Value	σ_H Orientation
Base Case	100% σ_{cm}	$\varphi = 50°$	Base Case	40%	Base Case	N-S
Original Strong	100% σ_{cm}	$\varphi = 50°$	**Strong Case**	40%	Base Case	N-S
Sensitivity 1	**75% σ_{cm}**	$\varphi = 50°$	Base Case	40%	Base Case	N-S
Sensitivity 2	**125% σ_{cm}**	$\varphi = 50°$	Base Case	40%	Base Case	N-S
Sensitivity 3	100% σ_{cm}	$\varphi = 50°$	**Weak Case**	40%	Base Case	N-S
Sensitivity 4	100% σ_{cm}	**$\varphi = 43°$**	Base Case	40%	Base Case	N-S
Sensitivity 5	100% σ_{cm}	$\varphi = 50°$	Base Case	**30%**	Base Case	N-S
Sensitivity 6	100% σ_{cm}	$\varphi = 50°$	Base Case	40%	**125% K_0**	N-S
Sensitivity 7	100% σ_{cm}	$\varphi = 50°$	Base Case	40%	**75% K_0**	N-S
Sensitivity 8	100% σ_{cm}	$\varphi = 50°$	Base Case	40%	Base Case	**E-W**

Note:

1. Under sensitivity scenario 1 and scenario 2 (global rock mass strength sensitivity cases), fault strength of the strong and medium strength faults is also varied because the strength of strong and medium faults is a function of global rock mass strength of the host rock.

RCM has considered a range of ±25% for sensitivity analyses of peak global rock mass strength. The 25% range for sensitivity analyses is based on the factor of safety acceptance criteria as stated in the Guidelines for Open Pit Slope Design Study (Read and Stacey, 2009). This range addresses the long-term stability with an associated high consequence of failure. While there are limited number of published recommended design acceptance levels for factors of safety in mining industry, the Workgroup believes the considered sensitivity range is acceptable for the target level of confidence in geotechnical data and the expected consequence of ground instability at the current level of study of the Resolution project.

In each sensitivity analysis scenario, only one parameter was varied, and all other parameters were kept at the base case value. The only exception was the strength properties of the strong and medium strength faults, where fault strength is a function of the rock mass properties and was therefore changed when rock mass strength was changed for the sensitivity analyses.

Overall, based on sensitivity analyses results, RCM concluded that fracture limit, crater depth, and cave angle were not significantly impacted by the parameter modifications imposed under each sensitivity scenario. This conclusion, and the sensitivity analyses results, will be examined further in detail in the next section.

5.4.1. Rock Mass Strength Properties

In sensitivity analyses scenario 1 and scenario 2, the subsidence was simulated using 75% and 125% of the global rock mass strength properties used in the base case, and varied for rock mass in all domains, accordingly. Simulation results indicated that the fracture limit extends further in all directions under lower-bound global rock mass strength case (scenario 1) compared to the base case analysis. In this scenario, the fracture limit is generally much closer to Apache Leap, in particular at the southwest corner of the subsidence zone. The latter is discussed further in the next section (Section 5.4) where the results of sensitivity cases are interrogated. RCM's stated conservative assumptions built into the rock mass properties and their impact on predicted surface subsidence will also be discussed in the next section.

5.4.2. Fault Strength

Faults were modeled in Flac3D as strong, medium, or weak in the base case analysis, as described earlier. For the purposes of sensitivity analyses, two other cases were considered (Table 5).

Table 5. Fault strength for base case and sensitivity analyses scenarios.

Fault Category	Base Case Scenario	Sensitivity Analyses	
		Original Strong Scenario	Weak Scenario (Scenario 3)
Strong	75% σ_{cm}	88% σ_{cm}	50% σ_{cm}
Medium	50% σ_{cm}	72% σ_{cm}	25% σ_{cm}
Weak	Cohesion = 0, Tensile Strength = 0 Friction Angle (φ)= 35^o	Cohesion = 0, Tensile Strength = 0 Friction Angle (φ)= 35^o	Cohesion = 0, Tensile Strength = 0 Friction Angle (φ)= 35^o

Original Strong case refers to the upper-bound fault strength scenario which is increased from the base case as shown in Table 5. Sensitivity scenario 3 refers to the lower-bound fault strength case where the strength of the strong, medium, and weak faults was reduced from the base case to 50% of global rock mass strength, 25% of global rock mass strength, and to a friction angle of 25 degrees, respectively.

Based on the sensitivity analyses results, for the upper-bound fault strength (Original Strong case) the fracture limit is not impacted by increased fault strength, but in the lower-bound case (scenario 3), the fracture limit extends towards the southwest due to the lower frictional strength of the Gant fault, which is located in this area (Itasca, 2018b).

5.4.3. Rock Mass Residual Strength

The sensitivity of the surface subsidence was also assessed by reducing the residual friction angle to 43 degrees (scenario 3) from the base case. Model results show no significant change to the extent of the fracture limit in comparison to the base case results.

5.4.4. Caved Rock Maximum Porosity

Sensitivity analysis scenario 5 considered a lower porosity of 30% for the caved rock. Results of this analysis show that a lower porosity does not impact the extent of the fracture limit zone.

5.4.5. In-situ Stress Ratio (K_0)

Sensitivity analysis scenario 6 and scenario 7 represent the impact on fracture limit of the lower- and upper-bound horizontal to vertical stress ratio (K_0) by varying the base case ratio by ±25%. Results show minimal impact on the extent of the fracture limit in either scenario. Itasca relates this behavior to the absence of locked-in stresses at ground surface, and little difference in stress regime in the near surface.

5.4.6. Horizontal Principal Stresses Orientation

In sensitivity analysis scenario 8, the orientation of the horizontal principal stresses was rotated by 90 degrees, while the magnitude of all stress components were kept the same as in the base case. This resulted in a rotation of the long axis of the fracture limit from N-S to E-W. As a result, the fracture limit extended slightly closer to Apache Leap on the west side, and farther away from Highway 60 on the north side. This slight extension does not, however, significantly increase the impact on Apache Leap or Devil's Canyon.

5.5. Interpretation of Findings and Predicted Subsidence

5.5.1. Review of Tal and Tw Global Rock Mass Strength

A review of UCS data for all rock domains (RCM, 2017b, Figure 1-16) indicates that Whitetail Conglomerate (Tw) is a relatively weak geologic unit and therefore the subsidence crater and fracture limit could potentially extend laterally within this unit. Any instability in the Tw unit could also extend into the Apache Leap Tuff (Tal) unit stratigraphically located immediately above. As such, it is important to understand the level of conservatism in strength properties of the Tal and Tw rock units used in the subsidence model.

As discussed in Section 5.3.1, the application of GSI to the Tw unit results in conservative rock mass properties for this unit because GSI inherently assumes there are at least three joint sets in the Tw unit to form blocks in this rock mass. However, rock mass structure analysis carried out on the Tw unit has indicated that there is only one joint set present within this rock domain. This may have resulted in the underestimation of GSI for the Tw unit.

During sinking of Shaft No. 10, RCM carried out geotechnical instrumentation and monitoring to evaluate rock mass behavior in the Tw unit. RCM used borehole camera surveys of probe holes drilled ahead of the advancing face and installed extensometers in the shaft wall over about 400 m of shaft length (520 m to 920 m). Borehole camera surveys of probe holes indicated no signs of stress damage within the Tw unit rock. RCM used this monitoring and observational information and conducted a back-analysis to assess the conservatism of the Tw rock mass properties. The back-analysis is discussed in the next section.

5.5.1.1. Monte Carlo Simulations

To investigate the level of conservatism in the rock mass properties of Tw and Tal rock units used in the base case analysis, RCM/Itasca conducted Monte Carlo simulations of the global rock mass strength properties for these geologic units. To achieve this, RCM developed a cumulative distribution of global rock mass strength properties for each domain by randomly sampling the input distributions of GSI and UCS (keeping m_i fixed at 22 for Tw and 25 for Tal), and calculating the global rock mass strength using Generalized Hoek-Brown failure criteria (Hoek et al., 2002). UCS distribution was developed using point load test data correlated to UCS and then downgraded by 20% to add a degree of conservatism into it (i.e., accounting for differences between "sample sizes" between the laboratory and the site-wide rock mass). As discussed in Section 2.3.1, the 0.8 is a reasonable scale factor to account for the impact of micro-fracturing and weathering and alteration on the intact rock strength. GSI distribution was estimated based on block volume using the methodology proposed by Cai et al. (2004). Block volume was estimated from core data using both apparent spacing and the joint weighted density methodology (Palmstrom, 2005). By plotting the base case GSI and UCS values on their respective cumulative distributions, the level of conservatism of the base case GSI and UCS values is well demonstrated. Similarly, the level of conservatism of the base case global rock mass strength was evaluated for each rock unit from the respective cumulative global rock mass strength distribution.

In consideration of the experience gained during shaft sinking, as well as the Tw rock mass strength distribution (from Monte Carlo simulation), RCM carried out a numerical back-analysis to determine the impact of varying rock mass properties on the shaft behavior. In this study, Tw rock mass strength values representing a range from 10th to 70th percentiles of the cumulative global rock mass strength distribution were used, and rock mass deformation in the shaft was estimated. While ground monitoring during shaft sinking indicated zero deformation in the Tw unit, numerical modeling estimated a minimum of 1.7 m deformation in the Tw unit at the highest rock mass strength modeled (70th percentile). RCM therefore concluded that the Tw global rock mass strength must be greater than the 70th percentile value. The Workgroup agrees with this conclusion.

Figure 14 shows the UCS and GSI distributions and the resulting global rock mass strength cumulative distribution for the Tw rock mass domain.

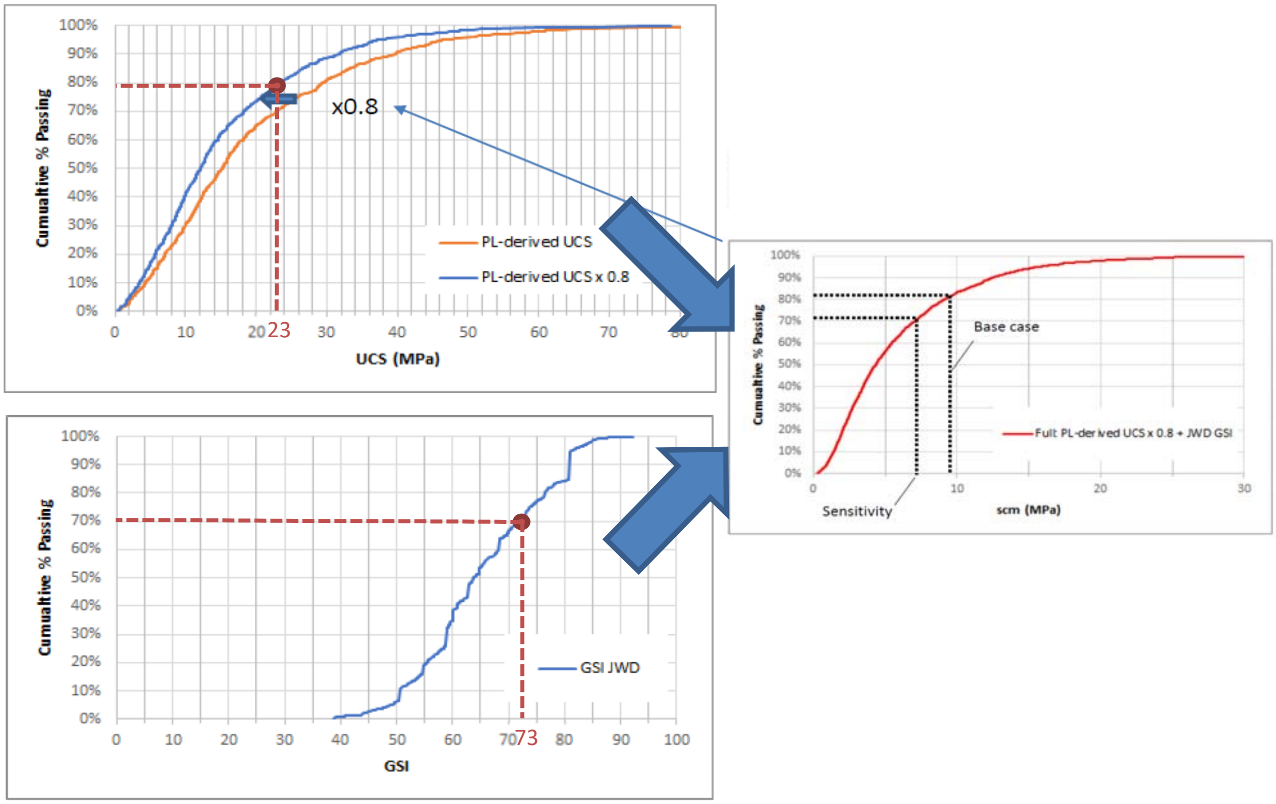


Figure 14. UCS and GSI distribution and the resulting global rock mass strength cumulative distribution for Whitetail Conglomerate rock mass domain

As can be seen, the input UCS and GSI values for the base case analysis fall at 79th percentile and 70th percentile, respectively, on their respective cumulative distributions. The calculated global rock mass strength for the Tw unit for the base case is 9.6 MPa, which corresponds to the 82nd percentile on the global rock mass strength cumulative distribution curve. Although the base case UCS and GSI and the resulting global rock mass strength of the Tw unit fall on the upper range of their respective distributions (greater than 70th percentile), the Tw base case global strength is still considered conservative by RCM, based on the results of the back-analysis and considering no deformation was observed during the shaft sinking within this rock unit.

For the Tw unit lower-bound sensitivity scenario 1 (75% σ_{cm}), the Tw global rock mass strength is 7.2 MPa, which falls just above the 70th percentile on the cumulative distribution plot (Figure 9); as discussed above, this is also considered conservative by RCM.

Itasca (2018b) states that, according to Pierce (2010), Lorig et al. (2018), and Rafiei Renani et al. (2018), a conservative global rock mass strength between the 30th and 40th percentiles on a cumulative global rock mass strength distribution is typically considered in cave-scale simulations. Itasca (2018), however, states that, in case of the Tw geologic unit, due to the level of conservatism of estimated GSI and the resulting global rock mass strength, adopting GSI and UCS values at 30th to 40th percentiles would result in extremely low strength properties that would not be representative of the Tw ground conditions at the Resolution property.

Considering the available monitoring and observational information from Shaft No. 10, the Workgroup agrees with this conclusion.

The shaft observations and monitoring data justify the application of the Tw rock mass properties, used in the base case, in the vicinity of Shaft No. 10. However, to justify extrapolation and application of the Tw base case properties to the entire mining area , RCM retained Itasca to carry out an assessment of the spatial variability of the Tw intact rock properties (UCS) (Itasca, 2018e). For this assessment, Itasca compared the range of the point load strength data collected from the Tw unit within the entire mining (cave) area with those from the Tw unit collected from the RES-008 hole (Shaft No. 10 pilot hole). The comparison indicated that while the mean point load strength data of the Tw unit from the RES-008 hole were higher than those from the entire mining area by 30%, the strength range of the samples collected and tested from the RES-008 hole extended the full spectrum of point load test results obtained from the entire mining area. The latter is one of the direct inputs into the Hoek-Brown strength model, and, as described, the variability of the Tw UCS within the entire Resolution property corresponds with its variability around the Shaft No. 10, therefore, the Tw base case properties (calibrated with back-analysis) can be used in the subsidence model to represent the Tw unit in the entire mining area. It is notable that the UCS value of the Tw unit used in the base case model is lower than the calibrated UCS value for this rock unit and is considered conservative.

Based on the discussions above, rock mass properties used for the Tw unit in the base case analysis, while conservative, are considered representative and acceptable for subsidence prediction at the Resolution property.

Similar analyses were carried out for the Apache Leap Tuff (Tal) unit. Figure 15 shows the UCS and GSI cumulative distributions and the resulting global rock mass strength cumulative distribution for the Tal rock mass domain.

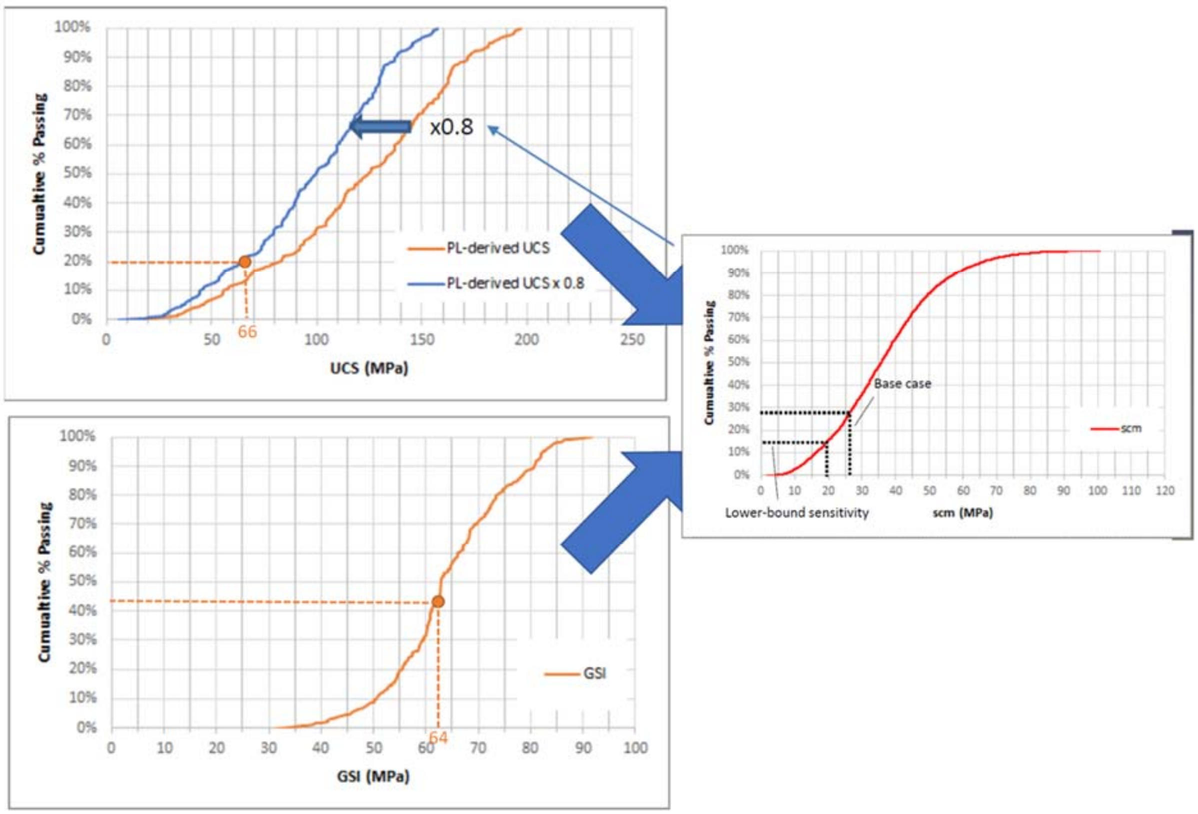


Figure 15. UCS and GSI distribution and the resulting global rock mass strength cumulative distribution for the Apache Leap Tuff (Tal) rock mass domain

The Tal rock mass domain UCS and GSI input values for the base case analysis are at 20th percentile and 42nd percentile, respectively, on their respective cumulative distributions. The calculated global rock mass strength for this domain for the base case is 26 MPa, which corresponds to the 27th percentile on the global rock mass strength cumulative distribution. In this case, the input data used to calculate the base case global strength are conservative and the resulting global rock mass strength at 27th percentile is also conservative. It can be concluded that it is more likely that global rock mass strength of the Tal unit may be higher than the base case, which would lead to a reduced fracture limit and subsidence crater, and a cave angle similar to, or possibly steeper than, the base case.

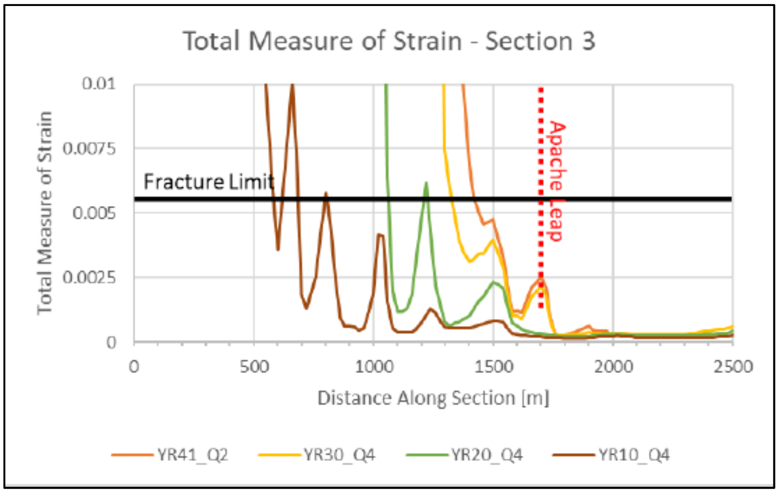
The global rock mass strength of the Tal unit for sensitivity scenario 1 (75% σ_{cm}) is also plotted on the cumulative distribution chart. The global rock mass strength of 19.5 MPa for this case is also conservative. It corresponds to the 15th percentile on the cumulative distribution plot (Figure 10). Looking at the upper-bound sensitivity scenario 2 (125% σ_{cm}), the global rock mass strength for the Tal unit is 32.4 MPa, corresponding to the 38th percentile on the cumulative global strength distribution plot. In the case of the Tal domain, one can conclude that the upper-bound global strength, although higher than the base case strength, could still be considered conservative. this means it is over 60% more likely that the Tal global rock mass strength would be higher than modeled, reducing the extent of the fracture limit and subsidence crater. The calculated global rock mass strength for the Tal unit is close to the 30th percentile on the global rock mass strength cumulative distribution, and is within the recommended range stated for cave-scale simulations by Pierce (2010), Lorig et al. (2018), and Rafiei Renani et al. (2018).

It should, however, be noted that since the relatively weaker Tw rock domain is below the stronger and more competent Tal unit, yielding and fracturing of the weaker Tw unit could undercut the stronger overlying Tal unit, potentially leading to fracturing of the Tal unit and expansion of the fracture limit and the cave crater.

5.5.2. Fracture Limit Criterion Sensitivity

5.5.2.1. Sensitivity Scenario 1: Lower-Bound Rock Mass Strength (75% σcm)

Fracture limits along section lines 1 to 5 were plotted for sensitivity scenario 1 (Fig. 16). Based on the 0.5% total strain criterion, the fracture limit along section 4 approaches Apache Leap by Year 30. The fracture limit along section 3, however, remains at approximately 300 m from Apache Leap for the life of mine. Although the Tw global rock mass strength values for the base case and sensitivity scenario 1 are conservative, there is a potential that the fracture limit will approach Apache Leap should global rock mass strength be lower than the values currently considered for the base case and the sensitivity scenario 1. This may result in small-scale and localized raveling, but no large-scale failures are expected to occur at Apache Leap. However, because some uncertainty does exist (and is to some extent unavoidable) in the application of site-wide rock mass strengths, which directly impacts the subsidence predictions, RCM must establish a robust ground monitoring program to identify any potential acceleration of movements and additional fracturing close to or at Apache Leap.



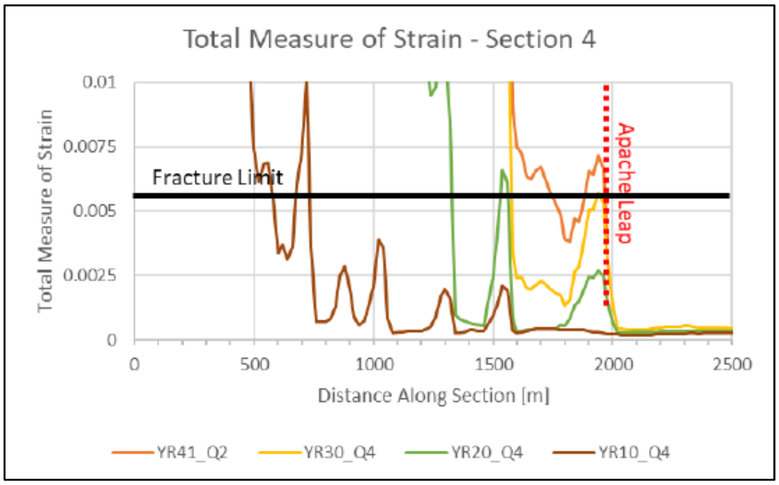
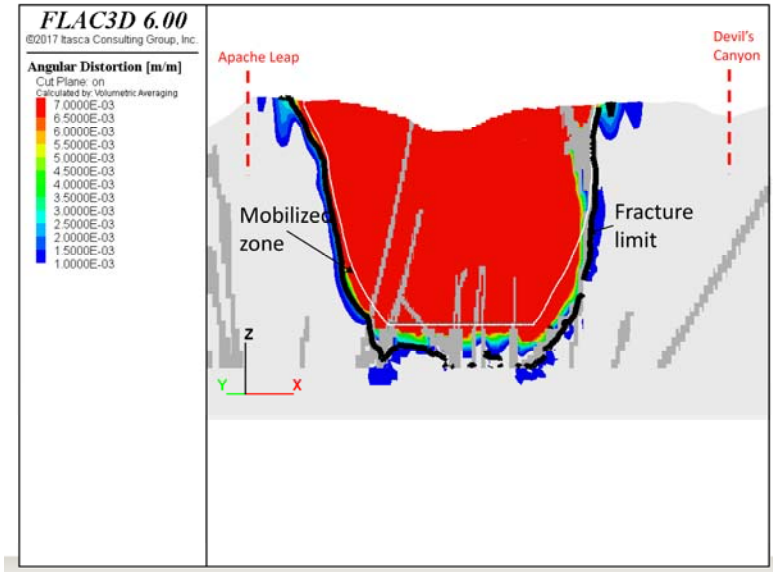


Figure 16. Total strain line plots along Section 3 (top) and Section 4 (bottom) depicting the fracture limit distance to Apache Leap for sensitivity scenario 1

Figure 17 shows the angular distortion contours along section 3 and section 4. The angular distortion distribution corresponds well with the observations above. Along section 4, angular distortion may approach Apache Leap as was predicted by the total strain (Figure 11).



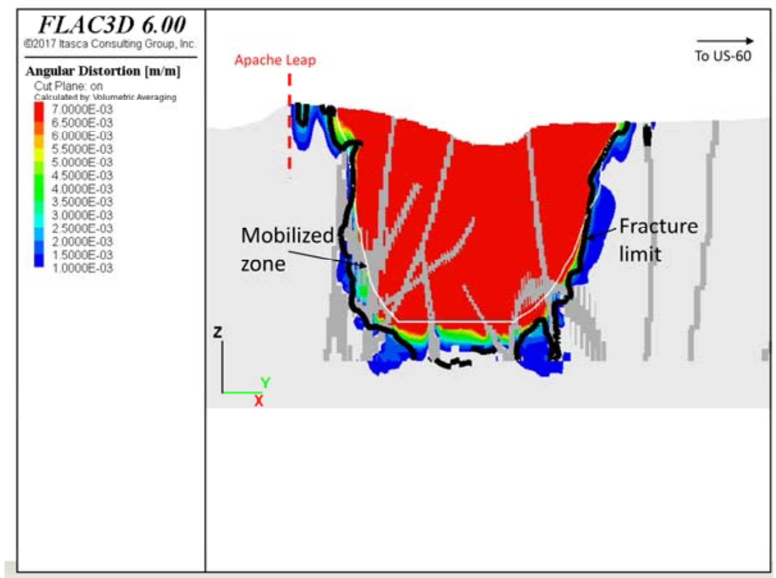


Figure 17. Angular distortion contour plot along Section 3 (top) and Section 4 (bottom) depicting the angular distortion approaching Apache Leap along Section 4 (bottom)

5.5.2.2. Sensitivity Scenario 3. Fault Strength

Line plots of fracture limits were also plotted along the 5 section lines for sensitivity scenario 3 (Figure 18). The distance from the fracture limit to Apache Leap along section 3 and 4 in this case is approximately 200 m and 250 m, respectively. Sensitivity scenario 3 shows that, for the lower-bound fault strength sensitivity case with weak faults (i.e., reduced frictional strength of φ=25 deg.), the fracture limit extends slightly outward, but remains at least 200 m away from Apache Leap. Angular distortion distribution also confirms this behavior.

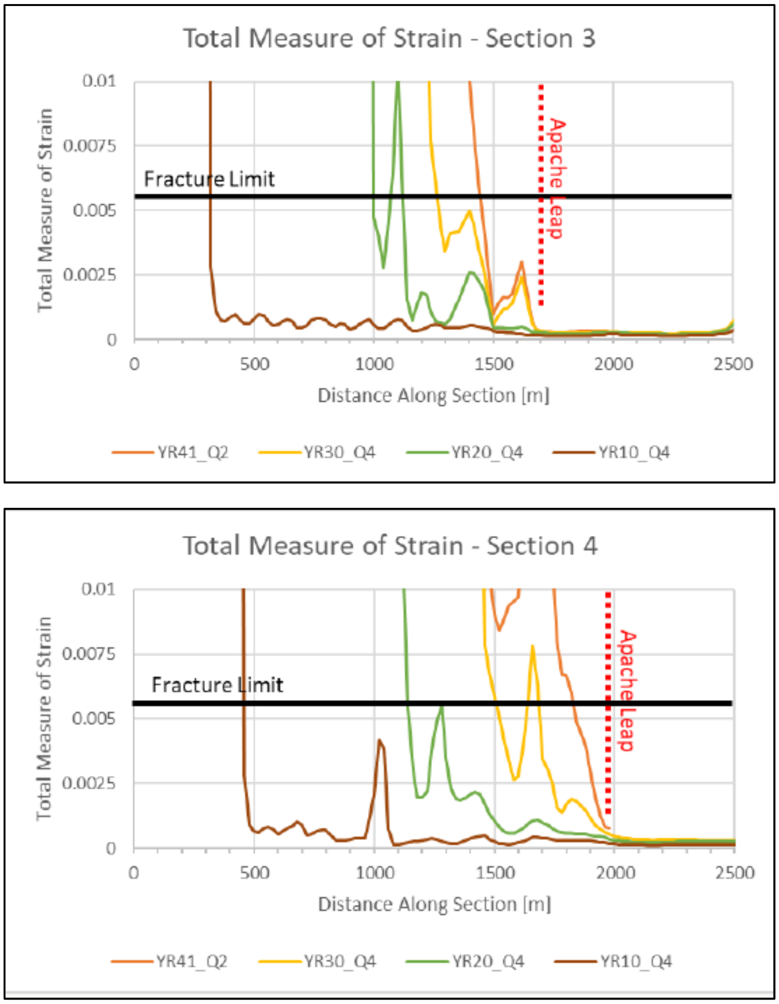


Figure 18. Total strain line plots along Section 3 (top) and Section 4 (bottom) depicting the fracture limit distance to Apache Leap for sensitivity scenario 3

5.5.2.3. Sensitivity 4: Residual Rock Mass Strength

Figure 19 shows line plots of total strain along sections 3 and 4, indicating the distance of the fracture limit from Apache Leap for the lower-bound residual rock mass strength (Sensitivity 4). Along section 3, the fracture limit is predicted to be at least 250 m from Apache Leap by Year 41. Along section 4, it is predicted to be at approximately 300 m from Apache Leap by Year 30, and at approximately 250 mat Year 41. Angular distortion distribution also confirms this behavior.

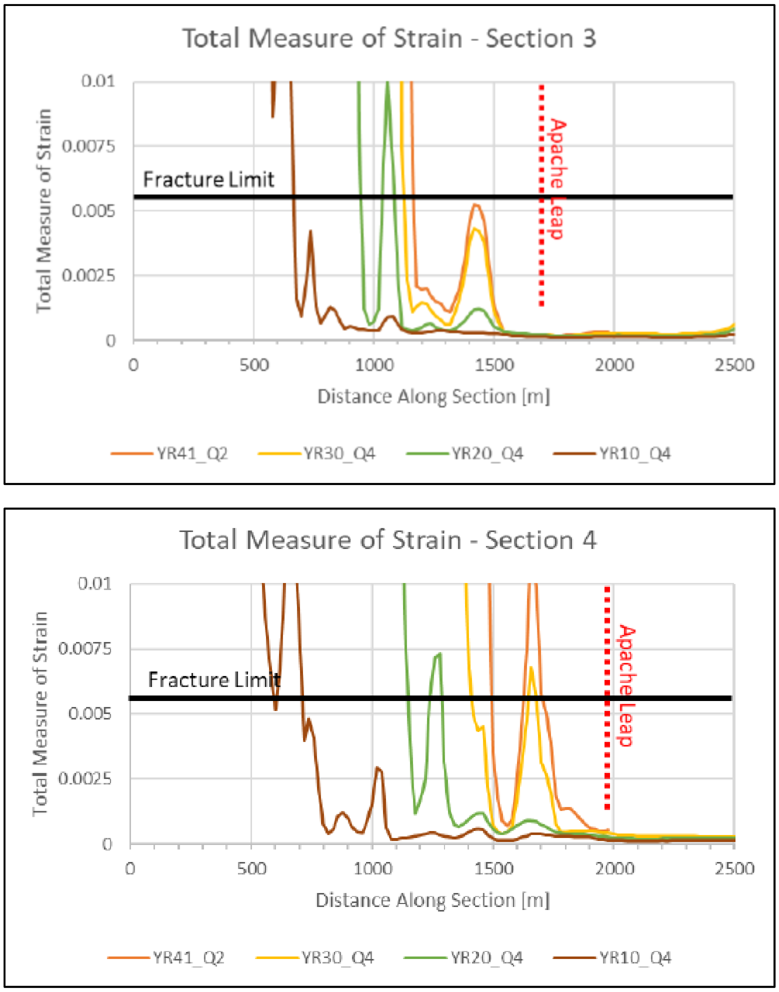


Figure 19. Total strain line plots along Section 3 (top) and Section 4 (bottom) depicting the fracture limit distance to Apache Leap for sensitivity scenario 4

6.0 SUMMARY OF RCM SURFACE SUBSIDENCE MODEL REVIEW

A numerical assessment has been carried out by Itasca to evaluate the environmental impact of RCM's proposed panel caving operations, including the extent of ground surface subsidence and fracture limit, the potential impact on Apache Leap, Devil's Canyon and the serviceability of Highway 60.

6.1. Summary of Assumptions

The following summarizes the assumptions and considerations in the subsidence model:

- Faults were simulated implicitly as distinct weak rock masses rather than interfaces. This assumption is considered reasonable because, at the Resolution property, faults are generally comprised of zones of relatively weaker rock mass (compared to the surrounding host rock) and are not necessarily a discrete feature.
- Geological Strength Index (GSI), which is a measure of the state of relative blocky-ness of the rock and joint surface conditions, was considered applicable to all rock mass domains to characterize rock mass structure. Typically, the application of a GSI value to a specific rock domain depends on the state of rock fracturing and the number of joint sets present in the rock mass. Therefore, the global application of GSI to a rock domain at the site may result in conservative rock mass properties where this criterion is not applicable to a specific rock domain (i.e., Tw domain for the interpreted GSI value where three joint sets would be required).
- Only faults and faults zones are included in the model. Rock mass discontinuities (dominant joint sets) are not included in the model.
- RCM characterizes faults in the model as strong, medium, or weak, based on the characteristics of their infill material. Faults are rated strong if they are strongly annealed; medium strength if they are a combination of open and annealed, with local gouge and local intense damage; and weak if they contain slickensided shears, are heavily damaged, brecciated and/or infilled with gouge.

The damage criteria used to define fracture limit and continuous subsidence zone were discussed in Section 5.3.6 and are summarized below:

- A minimum vertical settlement of 2 m is used to define the extent of the cave crater.
- A total strain criterion of 0.5% has been used to define the extent of the fractured zone.
- Conservative criteria consisting of a minimum 0.002 horizontal strain and 0.003 angular distortion are used to define the extent of the continuous subsidence zone. The latter criteria correspond to moderate to severe damage to masonry buildings, which is considered conservative for rock masses, as masonry buildings are more susceptible to damage at this rate.

6.2. Summary and Conclusions

The following summarizes the findings from this review:

- The RCM/Itasca numerical model adequately simulates the caving operation and can predict ground subsidence and fracture limit. Cave angle can be calculated from the numerical results.
- Flac3D has been used extensively to simulate caving operations and has become an industry standard.
- RCM methodology to interpret faults, geological units and rock mass domains are of high quality and meet established industry best practices and standards.
- GSI has been assumed to be applicable to all rock mass domains. Because the Tw unit lacks three joint sets as presumed by GSI, it results in underestimation of the Tw material properties and thus is considered conservative by RCM.
- Numerical back-analysis of the Tw rock mass response predicted 1.7 m deformation in the Tw unit for an upper-bound global rock mass strength corresponding to the 70^{th} percentile, while ground monitoring during sinking of the Shaft No. 10 indicated no deformation in this geologic unit.
- Based on the experience gained from shaft sinking and the results of the back-analysis, it can be concluded that the input strength properties (UCS and GSI) for the Tw unit for the base case and for sensitivity scenario 1 (lower-bound strength) are conservative. As such, the global rock mass strength of the Tw unit used in the base case analysis and in the sensitivity scenario 1 case are also conservative.
- A comparison of point load data obtained from samples in the Tw unit with those obtained from the RES-008 hole (Shaft No. 10 pilot hole), indicates that while point load strength of the Tw unit at the RES-008 hole is higher on average by 30%, the point load strength from samples collected from this hole extend nearly the full spectrum of the point load strength range obtained from the Tw unit in the entire project area. Therefore, the applied UCS value of the Tw unit in the subsidence model is representative of the Tw unit in the project area and is conservative based on observations from Shaft No. 10.
- Main joint sets found from stereographic analyses of borehole data within each domain have not been included in the numerical model. The presence of joint sets provides more flexibility for the rock mass to deform and break locally. This however, is not expected to change the results of the analyses at the large scale used for the model.
- The total strain threshold (0.5% of total strain) used to define the fracture limit is considered reasonable. It has been used in cave analyses for many caving operations and its reasonableness has been validated (see Section 5.3.6 for references). Nonetheless, fracture limit is very sensitive to this criterion. Considering the variability in the rock mass properties, there is some remaining uncertainty as to whether the fracture limit could extend closer to Apache Leap (due to higher strain in weaker rocks).
- The threshold used to define the continuous subsidence zone is considered conservative.
- Base case analysis indicates cave operation will have no impact on Apache Leap, Devil's Canyon, or on the serviceability of Highway 60, according to RCM. However, sensitivity analyses indicate that fracture limit is directly impacted by reductions in rock mass and fault properties, as described below:

- Fracture limits extended outward in all directions, including towards Apache Leap, when rock mass properties of the Tal and Tw units were reduced by 25% (sensitivity scenario 1) from the base case.
- The fracture limit is also sensitive to reductions in fault strength. Sensitivity analysis indicates that the fracture limit is closer to Apache Leap at lower-bound fault strengths, compared to the base case.
- The fracture limit is, however, less sensitive to reductions in rock mass residual strength. Sensitivity analysis indicates that the fracture limit is slightly closer to Apache Leap at lower residual strength values, but generally does not impact subsidence significantly.

Although the base case analysis shows no impact on Apache Leap, Devil's Canyon, or Highway 60, under the sensitivity analyses some horizontal and vertical displacement could occur at Apache Leap, and at Highway 60. Under these sensitivity scenarios, localized block failure at Apache Leap, as well as localized damage to Highway 60, could occur within the influence zone of the block cave. However, no large-scale failures at Apache Leap or damage to Highway 60 are expected.

7.0 CONCLUSIONS BY GEOLOGY/SUBSIDENCE WORKGROUP

As stated in Section 1.0, the purpose of the Geology/Subsidence Workgroup was to review RCM's procedures and geologic and geotechnical baseline documents to answer five basic questions regarding the methods, interpretations, QA/QC, and other procedures employed by RCM. Table 6 summarizes the key parameters and factors affecting the subsidence analysis and the related data quality available for this investigation.

Table 6. Key input parameters impacting surface subsidence and the quality of the associated data.

Input Parameters	Direct/Indirect Impact	Relative Significance on Subsidence Model	Relative Quality of Data
Methodology Used to Collect and Document Geologic Data			
Geologic Data Collection	Indirect	Medium	High
Sample Recovery	Indirect	Medium	High
Core Logging	Indirect	Medium	High
Laboratory Testing	Indirect	Medium	High
Data Management	Indirect	Medium to Low	High
Interpretations of Geologic Structures, Rock Properties and Geotechnical Data			
GSI	Indirect	Medium	High
UCS	Indirect	Medium	High
Geologic Structures, Faults	Direct	High	High
Geotechnical Data Quality	Indirect	Medium	High
Key Model Inputs (Including Uncertainties)			
Rock Mass Quality	Indirect	Medium	High at depth within 1% copper shell, Medium to low outside 1% copper shell
Rock Mass Strength Properties	Direct	High	Medium to High
Fault Strength Properties	Direct	High	Medium to High
Rock Mass Damage Criteria	Direct	High	Medium
Peak to Post-Peak Rock Mass Criterion	Direct	High	Medium

These five questions are discussed in detail within this report and are summarized below.

1. Determine whether the methods employed by RCM in collecting and documenting geologic data were appropriate, adequate, and according to industry standards. In other words, does the data and analytical approach meet the current industry standard-of-practice?
   Conclusion: As discussed in previous sections, all aspects of geologic data collection including drilling, sample recovery, core logging, data management, laboratory testing, analysis, interpretation, and modeling meets or exceeds industry standards. Generally, the Workgroup finds that RCM's geologic program meets or exceeds the industry standard-of-practice.

2. Determine whether RCM's interpretations of geologic structures, faults, rock properties, geotechnical data, and assumptions are reasonable.
   Conclusion: As discussed in Sections 3.0 and 4.0, internal RCM procedures require intensive evaluation of results in the acQuire geotechnical database system, assigning of geotechnical domains, interpretation of structures, faults, and lithologic units, and geologic model interpretation. Updates to the geologic model occur periodically to incorporate new borehole data, laboratory results, and field mapping. Internal QA/QC review is extensive and robust and occurs throughout the data acquisition, interpretation, and modeling processes. External review of interpretations by a Geotechnical Review Board and others provides adequate scrutiny of input data, interpretations, and assumptions. Therefore, the Workgroup finds RCM's interpretations of geologic structures, faults, rock properties, geotechnical data, and assumptions to be reasonable.

3. Identify any data gaps. In other words, are there weaknesses in the analysis?
   Conclusion: As discussed in Section 3.0, at the local scale, RCM's sampling program meets all seven DQIs for the near case because of the dense sampling within the 1% copper shell mineralized zone. Therefore, the samples are representative of the population. However, for the far case (i.e. those areas outside of the mineralized zone), the extent of the extrapolation reduces DQIs because, outside the mineralized zone, sampling density is much lower. Rock properties, faults, and lithologic boundaries in these areas are extrapolated over large areas. This extrapolation does not represent a "data gap", but rather it represents an area with less certainty in the interpretations of that data.

   As discussed in Sections 4.2 and 4.3, there are many fault blocks and faults, especially on the west side of the ore body that are "inferred" to "low indicated," which indicates a lack of data to ascribe higher levels of confidence on this data. This has implications that, although the quality of the data is high (meaning the data is painstakingly acquired, reviewed, and verified), the spatial distribution of the data is low or minimal. Two particular faults (Camp and Gant) were not intersected with drill holes. These are important west boundary faults in the proposed cave zone. However, there has been extensive field mapping and conservative values have been used in modeling the behavior of these faults.

Therefore, the Workgroup concludes that geologic data outside of the mineralized zone, as well as for the Camp and Gant faults, is not as well represented as in the mineralized zone. However, conservative modeling assumptions and sensitivity analyses have been used to account for sparse data in these areas. The discussion of surface subsidence in the DEIS will simply describe these areas of data uncertainty.

4. Identify how much uncertainty exists with these interpretations, with consideration of data gaps. What data and assumptions have the most influence on subsidence and the model?
   Conclusion: As discussed in Sections 3.0, 4.0 and 5.0, there is a great deal of interpretation required in the entire process, from data collection to testing and analysis, to model input and interpretations, and sensitivity runs. There are two approaches to consider the certainty of the geologic and subsidence models. One approach is empirical, meaning compare the model results with a conceptual model of the cave geometry based on what has been observed at other similar mines with similar geologic settings. The other is to change input parameters to reasonable limits to see the resulting cave geometric response (i.e. sensitivity analyses). Each approach is discussed below.

   For comparison with existing panel cave mines, the Woo et al. (2013) database of cave operations was consulted. Although very few cave operations have been included in the database with undercut depth greater than 1000 m, the results of the base case simulation of the Resolution panel cave are generally in agreement with other cases in that database. However, it is important to note that there are uncertainties associated with the use of empirical methods to estimate the cave angle. These include variability in rock mass strength and fault strength properties, and local in-situ stress distribution. These uncertainties are discussed previously in Section 5.0. The proper assessment of surface subsidence resulting from a caving operation requires detailed geological, structural, geotechnical and numerical assessments to adequately address these uncertainties.

   The results of the numerical simulations of the Resolution panel cave were also evaluated and discussed in the previous sections. The numerical simulations conducted considered a set of geological, geotechnical, and structural conditions representative of the Resolution property, and use a widely-accepted, industry standard numerical tool to predict ground surface subsidence at the Resolution property. Sensitivity analyses were performed to assess uncertainty and variability in several input parameters to the subsidence model. The uncertainties explored using sensitivity studies included:

   - Rock mass quality and intact rock strength properties – there are uncertainties associated with spatial variability of the rock mass properties, particularly in the Tw geologic unit, which is a relatively weak rock mass and situated immediately below the Tal unit. The UCS values were derived from point load test data that were completed on core samples obtained from diamond drill cores, where available. As a limited number of holes have been drilled in the Tw unit, the spatial variability of

UCS data could result in uncertainty in estimated global rock mass strength. There is also uncertainty in global rock mass strength in the Tw unit due to uncertainty in applying GSI to this unit. Application of GSI to the Tw unit at its interpreted value implies that there are three joint sets in the rock mass. The rock mass structure assessment, however, only indicated one joint set in the Tw unit, hence GSI is underestimated and results in low global strength for this rock unit.

- Fault strength properties – faults strength properties have been estimated based on infill characteristics, and as such, have been classified as strong, medium strength, or weak. Fault infill characteristics have been provided by RCM geologist and are mainly based on detailed logging of core and mapping of fault exposures on surface. Considering the limited amount of core and mapping data available from fault intercepts compared to the extent and depth of the faults that have been identified within the Resolution property, there is uncertainty associated with the fault characterization and the associated material properties assigned to each fault category. This is even more critical in the case of faults that are positioned near the perimeter of the subsidence crater and fracture limit.
- Fracture limit criterion (total strain limit at 0.5%) – determination of fracture limits numerically in Flac3D is directly dependent on the fracture limit criterion used. This criterion is empirical and has been used in and validated by its successful application to other cave operations (see Section 5.3.6 for references). Numerical results, however, have shown that total predicted strain may vary locally, but significantly. The empirical nature and total strain sensitivity creates a level of uncertainty in the predicted total strain and the resulting fracture limit. At this time, there is no explicit way to calibrate the model and to refine the fracture limit criterion to address this uncertainty.
- Critical plastic strain threshold as a criterion to reduce peak rock mass strength to residual– an empirically calculated critical plastic strain has been used in Flac3D to determine at what stage peak rock mass properties are reduced to residual strength to determine the fracture limit. As discussed in Section 5.3.3, Lorig and Varona (2000) reported that, as part of the International Caving Study, an empirical relationship was developed between critical plastic strain and GSI by back analysis of rock mass failure in caves and other openings, and was used to determine a first approximation of the critical plastic strain for each rock mass domain. Considering the GSI assigned to the Tw unit is conservative, as discussed earlier, this introduces a level of uncertainty into the calculated critical plastic strain used in the model, which could impact the extent of fracture limits predicted by the subsidence model.

5. Determine if there are cases where RCM's interpretations are not considered reasonable and, if so, provide alternative interpretations and supporting rationale.
<u>Conclusion</u>: Overall, the Workgroup concludes that RCM's interpretations are reasonable, and that the geologic data and modeling results represent the best available science for determining and disclosing subsidence impacts. Therefore, we do not propose alternative interpretations. However, as described in the previous sections, there are numerous input variables and several layers of interpretation involved in the modeling of surface subsidence. Therefore, the DEIS should fully disclose these areas of

uncertainty, areas of sparse or missing data, and that actual surface subsidence could vary from the modeled results.

8.0 CREDENTIALS OF REVIEWERS

8.1. Laurie Brandt, CPG

Laurie is a Certified Professional Geologist (AIPG) with a B.S. in Geography/Geology from the Pennsylvania State University (1984) and an M.S. in Remote Sensing/Geology from Cornell University (1986). She has worked for over 20 years in engineering geology and specializes in geotechnical site assessments, mineral resource evaluations, geologic hazards, and mine reclamation. Laurie is both MSHA and HAZWOPER certified and has been involved with Environmental Impact Statements (EIS) and Environmental Assessments (EA) in Colorado, California, and Arizona for mines, powerlines and Resource Management Plans (RMP). Laurie is also a Lecturer of Geology at the Montrose Campus of Colorado Mesa University where she has been teaching classes since 2000.

8.2. Robert (Nick) Enos, M.Sc., CPG

Nick is a Principal Geoscientist with BGC Engineering, and a Certified Professional Geologist (AIPG). He has a B.S. in Geology from California State University Chico (1988) and an M.S. in Geosciences from Oregon State University (1992), where his graduate research focused on structural geology, tectonics, and geophysics. Nick has over 25 years of experience in the mineral industry, with an emphasis on environmental permitting, Environmental Impact Statement (EIS) and National Environmental Policy Act (NEPA) review, integrated environmental baseline studies, and mine closure planning. Mr. Enos has extensive experience managing complex multidisciplinary projects, and has participated in several EISs, mine project feasibility studies, and third-party environmental reviews.

8.3. Amir Karami, PhD, P.Eng (BC, NS)

Amir is a senior geotechnical engineer with BGC Engineering, specializing in rock mechanics in underground and open pit geotechnical engineering. He has a Ph.D. in Rock Mechanics from University of Alberta (2002). Amir has been involved in many mining projects in Canada, the US, and overseas. Amir has been involved in 2D and 3D numerical investigations for a number of open pit and underground mine development projects. Amir has several years of underground mine operations experience and was the lead geotechnical engineer to support mine operations and mine technical services team. Amir has been involved in geotechnical investigations, numerical modeling, ground control management plan development, geotechnical monitoring and instrumentation, geotechnical audits and geotechnical incident investigations in consulting and/or at mine operation.

8.4. Diana Cook, Ph.D., PE

Ms. Cook is a Senior Geological Engineer with approximately fifteen years of experience in geotechnical and geological engineering, including design of earthen and rockfill dams, heap leach pads, tailings impoundments, pit stability analyses, and waste containment for mining projects. Ms. Cook has a Ph.D. in Geological Engineering from Colorado School of Mines (2009). Ms. Cook has worked on site-specific seismic hazard analyses for several mines around the world, and has also performed liquefaction studies for sites in the U.S., South America, and Canada. In addition, Diana manages and performs all phases of geological/geotechnical engineering for structures and earthworks, including developing and performing geotechnical investigations and laboratory testing programs.

8.5. Michael Henderson, PE

Mr. Henderson has extensive experience providing civil and geotechnical engineering design. He has a M.Sc. in Civil Engineering from University of Pittsburgh (1984) and has completed post-graduate studies in Geotechnical Engineering from University of Nevada and Colorado State University. Mike is responsible for senior review and leadership on a wide range of engineering projects, including underground mines, tailings impoundments, water storage reservoirs, heap leach facilities, and mine planning. Mike's technical background relating to designing mining facilities includes design-engineering experience on a wide range of projects in the US and overseas, operations experience at several large mines, mine and energy research for the US Bureau of Mines and Department of Energy, and expert witness testimony related to mining issues.

8.6. Rex Bryan, Ph.D., XX

Dr. Rex Bryan has a PhD in Mineral Economics from the Colorado School of Mines and a geology degree from Brown University. He has been a mining consultant for over forty years specializing in geostatistics. He has consulted to both the mining and environmental industries on sampling, geological computer modeling and resource estimation. He is a Qualified Person for mineral resource estimation. He has authored EPA guidance documents on sampling methods and statistics analysis for the Data Quality Objective process.

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10.0 APPENDICES

Appendix A

- Table A1. Summary of Key Activities/Data Submittals for Geology, Geotechnical and Subsidence Topics
- Table A2. Data Validation Reference Standards for Geology & Geotechnical Engineering

Appendix B - Tables

Table B1. List of Geotechnical Data Types.

· *Drill hole metadata (name, date, survey datum, collar coordinates, type, driller name, etc.)*
· *Core depth and orientation*
· *Acoustic Borehole Imaging (ABI)*
· *Major Structures recorded*
· *Total core recovery (1 cm or 0.4inch accuracy).*
· *Artificial breaks recorded.*
· *Rock quality designation (1 cm or 0.4-inch accuracy).*
· *Solid core recovery (1 cm or 0.4-inch accuracy*
· *Solid length (1 cm 0.4-inch accuracy).*
· *Micro-defects (intensity, hardness and strength).*
· *Cemented joints.*
· *Open joints.*
· *Photogrammetry of No. 10 shaft.*
· *Within Geotechnical Domain Delineation*
· *lithology*
· *mineralogy*
· *intensity of fracturing*
· *orientation of fracturing*
· *rock strength*
· *Geotechnical Structures with Domains*
· *open joints*
· *intensity of fracturing*
· *orientation of fracturing*
· *rock strength*
· *artificial breaks*
· *intensity of fracturing*
· *cemented joints or veins*
· *micro-defects*
· *Rock Strength Tests*
· *UCS testing*
· *Point Load Test*

Table B1. List of Geotechnical Data Types.

▪ *Triaxial and Uniaxial Strength Tests*
▪ *Brazilian Test*
▪ *Acoustic Velocity Test*
▪ *Rock Tunnel Quality Index (Q')*
▪ *Rock Mass Rating (RMR)*
▪ *Geologic Strength Index (GSI)*
▪ *Mining Rock Mass Rating (MRMR)*

Table B2. DQI Definitions.

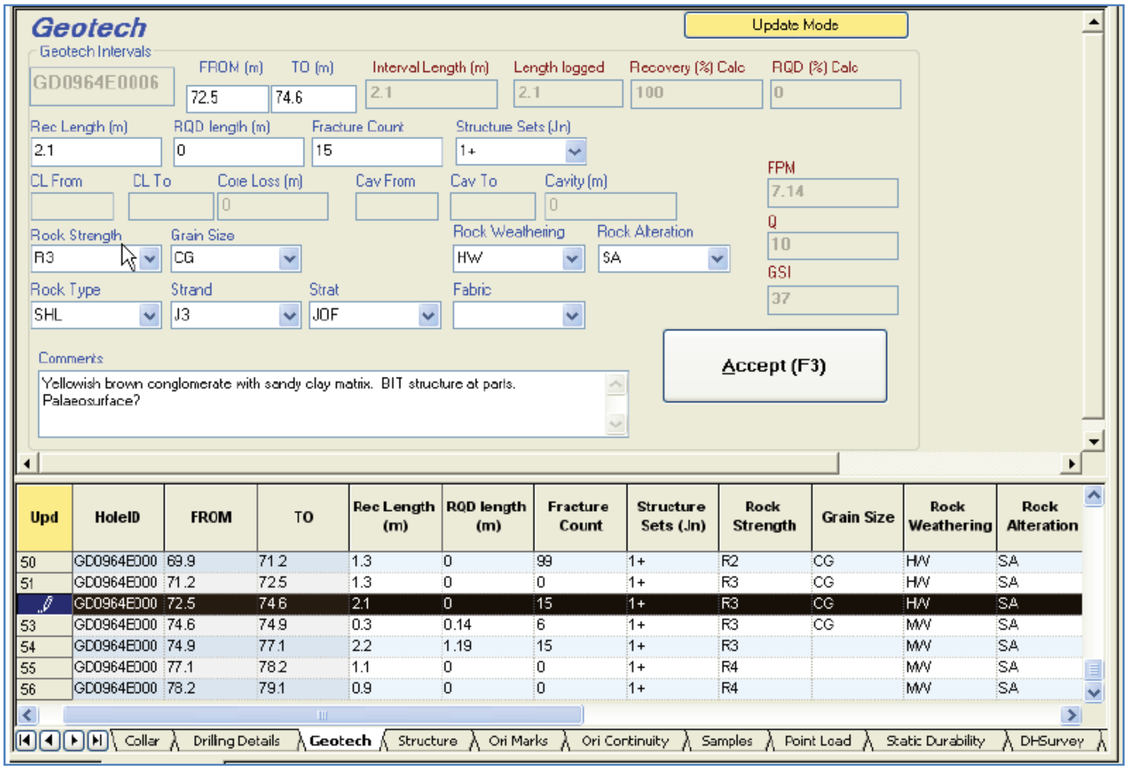
Data Quality Indicator (DQI)		Description
1	**Precision**	The measure of agreement among repeated measurements of the same property under substantially similar conditions.
2	**Bias**	The systematic or persistent distortion of a measurement or observation that deviates in one direction.
3	**Accuracy**	A measure of the overall agreement of a measurement to a known value or an observation to known condition. Contains a combination of random error (precision) and systematic error (bias).
4	**Representativeness**	A qualitative term that expresses "the degree to which data accurately and precisely represent a characteristic of a population.
5	**Comparability**	A qualitative term that expresses the measure of confidence that one data set can be compared to another and can be combined for the decision(s) to be made.
6	**Completeness**	A measure of the amount of valid data needed to be obtained from a measurement system.
7	**Sensitivity**	The capability of a method or instrument to discriminate between measurement responses or observations representing different levels of the variables of interest. (Analytical instrument design parameters or the skill and experience of the observer).

Table B3. Checklist of DQI steps in producing acceptable statistical adequacy and Representativeness.

Steps	DQI						
	1	2	3	4	5	6	7
- An integrated system of management activities involving planning, implementation, assessment, reporting, to assure that information derived is of sufficient quality for use in making decisions.				x		x	x
- QA project plan: A formal document describing in comprehensive detail the necessary quality assurance procedures, quality control activities, and other technical activities that need to be implemented to ensure that the results will satisfy performance or acceptance criteria.	x	x	x	x	x	x	x
- Integrated data base and plotting and analysis program (acQuire) to allow for real-time data entry, review, and analysis. Correlation between multiple measurements. Weight-of-evidence approach,		x	x	x		x	
-Intergraded 3D geologic modeling software (Vulcan) allowing for visualization of the geologic and analytical data. Visual correlation between numerous 3D data. Weight-of-evidence approach.				x		x	
guidance: a suggested practice that is not mandatory, intended as an aid or example in complying with a standard, specification or "best practice".	x	x	x				x
- RCC's base geotechnical information and analysis are also reviewed and amended by a third party Geotechnical Review Board (GRB) and various individuals and companies who challenge the process and review validation procedures and conclusions. RCC's internal data validation procedures with peer review and internal QA/QC along this process.	x	x	x	x	x	x	x
- Overall responsibility of data acquisition process under the supervision of a competent person.				x	x	x	
- Used the same analytical instrument or observation to make repeated analysis on the same sample.	x	x	x				
- Use of reference standards and state-of-practice" or "industry best practice" (See standards section)	x	x	x		x		x
- Compared the of analysis of reference materials or lead logger with the results of an outside laboratory or reviewer.	x	x	x		x		x
- Random review by the lead logger of a domain once a week.		x			x		
- Evaluated current industry "Best Practice" on whether physical samples, measurements, or observations appropriately reflect the condition of the population				x	x		
- Compared the number of valid measurements or observations with the project's established performance/acceptance criteria.						x	
- Used outside consultants to select the appropriate analytical instrument with the appropriate sensitivity of instrument.							x
- Safeguards in place to reduce data processing errors, minimize data transcription errors and to prevent unauthorized changes to the data.		x					

- Routine monitoring to reduce estimation and measurement error, limit bias.	**x**	**x**	**x**				
- Relevant training for project personnel in making appropriate observations along with continual feedback from lead logger.		**x**			**x**		
- Describe how and when internal data quality assessments will be implemented.	**x**	**x**	**x**				**x**
- Routine cross-checking protocols					**x**	**x**	
- Regular verification of consistency and compliance with methods and protocols	**x**	**x**	**x**				**x**
- Archival of in a secure location for future re-analysis.					**x**		
- The overall system of technical activities that measure the attributes and performance of a process against defined standards or industry best practices that fulfill the specifications of the required level of quality.							
- Low turn-over of logging staff					**x**		
- Maintaining consistency in lithologic description					**x**		

APPENDIX C – Graphics and Photos



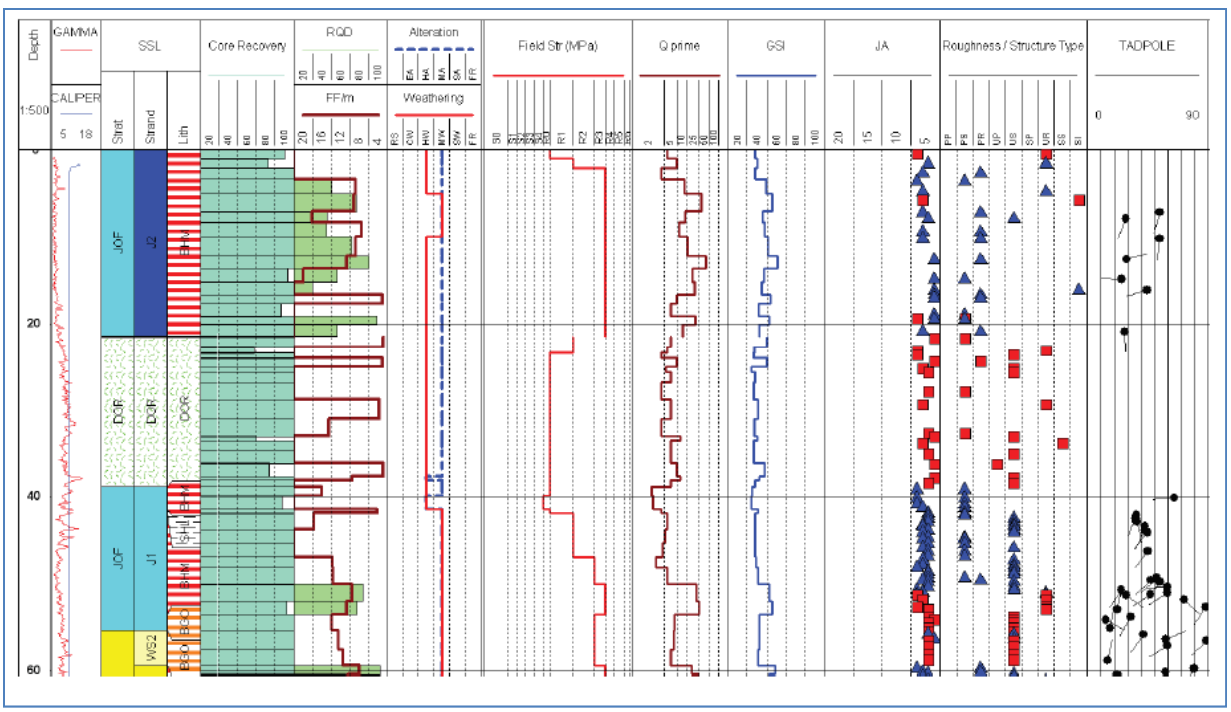


Figure C1. Example output from acQuire. Data entry panels (top graphic), simultaneous down-hole charts (center graphic) and statistical analysis graphs (bottom graphic) are designed to help maintain quality of a drill hole database (Pere et al., 2011).

Figure C2. Top photo: Drill core arriving for logging sequence in secure boxes. Bottom photo: Drill core archived after logging in secure facility. (Field visit to Resolution Copper by authors of Brandt et al., 2017)

Figure C3. Core being logged (upper photo) and real-time data entry into acQuire software on a laptop at a geologist's core logging station (lower photo). [Brandt et al., 2017; Pere et al., 2011]

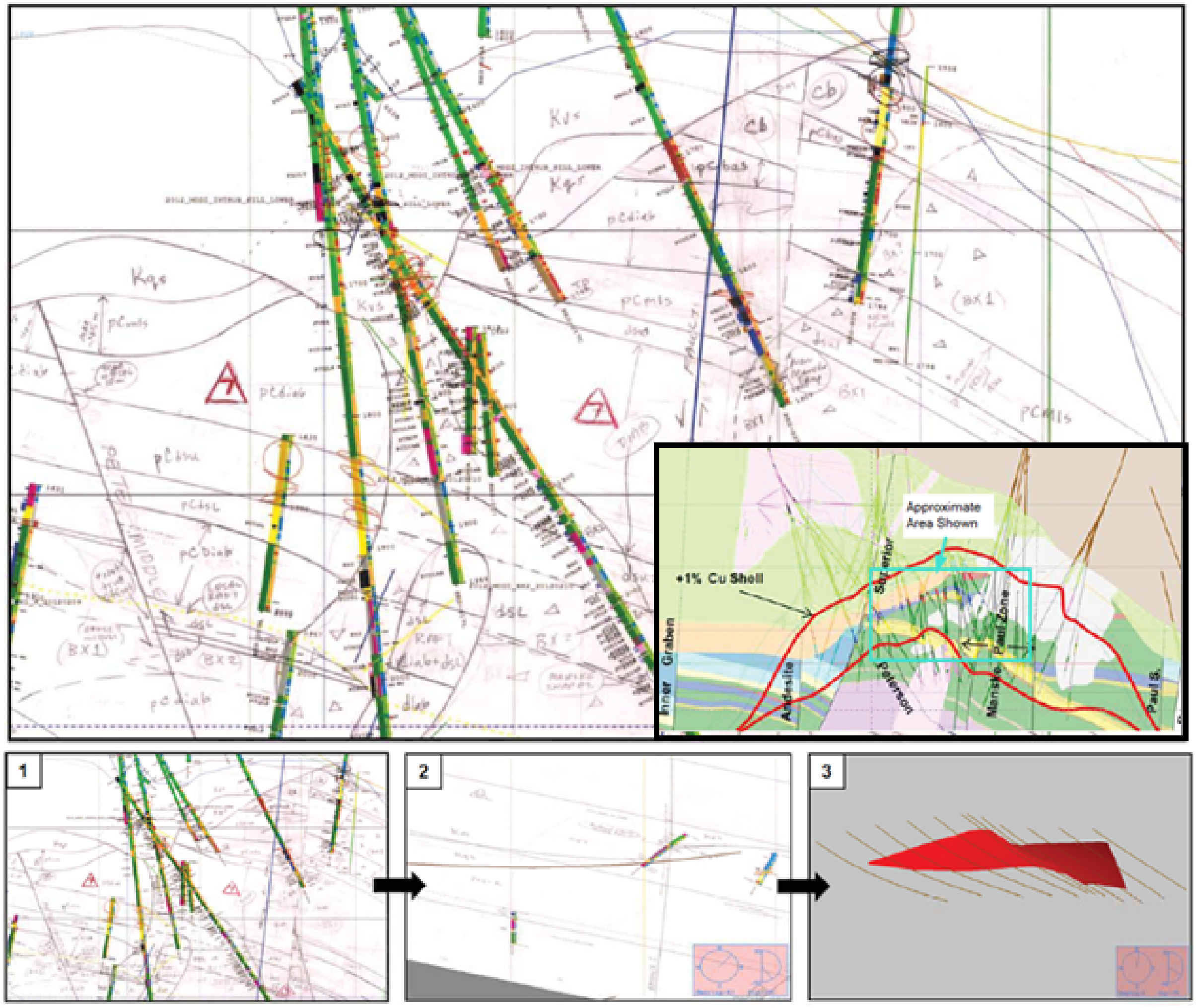


Figure C4. Composite figure showing the complexity of faulting within the 1% Copper Envelope (Parker, 2017).