Subsidence Monitoring Plan

May 05, 2018

By: Jacques Tshisens

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1 INTRODUCTION

Subsidence is a slow and gradual process that is predicted, closely monitored and controlled. Mining will start from a point away from Apache Leap, and after 40 years of block-cave mining, projections are that the subsidence zone will be at its deepest (1,100 feet) but will still be more than 1,100 feet from the Leap after mining has ceased. It is important to note that Resolution Copper (RC) mining production infrastructure (shafts) are located between the subsidence zone and Apache Leap and would be impacted before any impacts to Apache Leap. Also, of importance, subsidence impacts will be controlled by limiting the lateral extent of the block caving panels and not mining some ore to protect key surface features like Apache Leap.

The impact of subsidence will continue to be monitored and managed throughout the life of the mine and thereafter as described below.

1.1 Approach to subsidence monitoring

RC has been collecting field and laboratory data to understand and predict the impact of subsidence. Before, during and after operations RC will implement a subsidence monitoring program designed to:

- Collect data for continued understanding and validation of mining related impacts and ongoing model calibrations and refinements
- Develop threshold and alarm levels for early warning and detection of subsidence impacts before surface impacts occur
- Identify surface movements due to mining of the Resolution ore body
- Implement corrective actions and contingency plans if needed

The RC's overall strategy for subsidence monitoring and management is:

- Collect extensive data before mining starts to establish robust baseline and background data for the area above and adjacent to the mine
- Start mining at a point far away from Apache Leap, which will allow many years to gather technical information and inform cave and subsidence angles
- Declare sections of the orebody off limits to mining and leave a stable buffer zone between the fractured zone and Apache Leap after mining has ceased
- Continuously monitor the effect of mining on key features (Apache Leap, Devils Canyon, Queen Creek Canyon, US60) at key positions relating to the mining front. The early monitoring data will be collected far in advance of subsidence movement to protect Apache Leap
- Regularly assess, analyse and interpret monitoring data to identify substantive variations from predictions
- Supply annual subsidence monitor reports to the United States Forest Services (USFS), along with periodic review meetings to demonstrate compliance with the Apache Leap Special Management Area/Plan.
- Notable but not specifically part of the strategy is the placement of RC's mining production infrastructure (shafts) between the subsidence zone and Apache Leap so any impacts from subsidence would impact the mine infrastructure before Apache Leap.

Once the shaft infrastructure is damaged, mining stops and thus subsidence would not continue to propagate towards Apache Leap.

1.2 Pre-Mining Monitoring and Baseline Studies

Apache Leap, Queen Creek Canyon and the surface area above the planned underground mine are currently monitored using terrestrial Light Detection and Ranging (LIDAR) scans, Interferometry Synthetic Aperture Radar (InSAR) and select rock spires using digital tilt meters. This baseline data is being collected using biannual LIDAR scans of cliff faces and rock formations for future comparisons before, during and after mining. Terrestrial LIDAR scans use Maptek's I-Site 8800 scanner to provide the baseline coverage. The digital tilt meters have shown that surface pillars will tilt during strong winds. Experience from the use of tilt meters shows that it is feasible to accurately and remotely monitor pillar deformation on a nearly continual basis. RC is also conducting ongoing InSAR satellite image data collection and analysis at least once per year.

1.3 During Mining Monitoring

During mining, the surface area above the deposit will be subdivided into a no-go zone, consistent with the limit of the Fracture Zone (where no person may enter) and a restricted public access zone consistent with the Zone of Continuous Subsidence (where RC personnel are permitted for geotechnical monitoring and inspections). These zones will be re-assessed during mining based on information collected from cave propagation monitoring. Surface subsidence will be monitored through the use of available industry best practice and demonstrated technology including, but not limited to:

- Extensometers: These are electronic cable devices that will be installed and anchored in the bottom of a borehole casing with a recorder to measure relative displacements in the rock mass. This type of instrumentation can detect changes in land surface elevation to 1/100th of a foot.
- Survey prisms: Global Positioning System (GPS) survey stations or "Prisms" will be installed in selected locations around the proposed subsidence area and their three dimensional location will be surveyed automatically to provide the relative displacements of the ground.
- Crack Displacement Monitors: These are wire extensometers that will be installed in the ground to detect crack formation, propagation rate as well as crack extension.
- Time Domain Reflectometer (TDR) cables: TDR is a coaxial cable system to be installed and grouted into a borehole for monitoring ground deformations and movements
- Aerial photography: This technique is utilized to take pictures on an annual basis and process the pictures to detect relative changes. Digital Terrain Models (DTM) will be generated from aerial photography to calculate the relative displacements of the surface ground
- InSAR: This is a satellite monitoring technique that will be utilized to monitor surface deformation and relative digital elevation in the subsidence area
- Microseismic monitoring system: Although the Resolution Copper mine is in an area of low seismicity, an array of seismic sensors and geophones will be installed in the ground to detect and determine the location and magnitude of potential seismic events
- Smart Markers and Cave trackers: Electronic devices used to measure the propagation of the cave and cave shapes

1.4 Post Mining Monitoring

Examples and case studies of residual subsidence show that it can decay with good certainty within approximately 15 years, which is a conservative estimation as long wall mining and man-made rockfill studies have a much shorter duration for residual subsidence (up to 10 years). As such, RC will continue to monitor the impact of surface subsidence on key infrastructures for at least 15 years after mining using the same techniques that are used during mining. The frequencies as well as the areas of focus are further discussed in the following sections.

2 SUBSIDENCE RISK AND IMPACT ASSESSMENT

There are a number of prominent geologic features in and around the proposed mining operation that have been part of RC's baseline geotechnical monitoring program and include the Apache Leap Escarpment, Queen Creek Canyon, Devils Canyon, Highway US-60 and the Oak Flat Campground. Baseline data collection of these areas will assist with the understanding of monitoring of potential impacts during mining.

2.1 Apache Leap, Cliffs and Pillars

Apache Leap is an approximately one mile long cliff that rises to a height of approximately 4200 feet above sea level in the town of Superior Arizona. RC is committed to preserving the Apache Leap.

Both numerical and empirical subsidence modeling conducted to date indicates that the Apache Leap will be in the stable zone. In addition, RC will initiate mining far away from the Apache Leap and will monitor deformation due to subsidence to ensure that the prediction of subsidence is continuously improved and is in line with the observed and measured subsidence progression.

Pre-mining monitoring of Apache Leap is being conducted and will continue during and after mining operations. Results obtained from monitoring will be used to determine ongoing monitoring requirements, appropriate controls and responses to potential surface instability resulting from mining activities.

There are many small cliffs that are present in the area. Numerical modeling was conducted by geotechnical experts targeting stability of individual cliffs. The subsidence modeling conducted indicates that mining activities will induce tilts with magnitudes of less than a fraction of a degree indicating that the cliffs will remain stable during and after mining. Table 1 below shows a summary of the monitoring plans for Apache Leap (including the special management area) and in the area above the mine.

Table 1 Apache Leap Monitoring Schedule

Monitoring Period	Monitoring Techniques	Frequency
Baseline Studies Pre-Mining	- Aerial Surveys - LIDAR Scans of Apache Leap - Google Earth observation	Twice a year
	Tiltmeters installed on selected pillars on Apache Leap	Continuously
During Mining	- Aerial Surveys - LIDAR Scans of Apache Leap - Prisms survey - Extensometers - Google Earth observation	Annually
	InSAR Imaging	Twice a year
	Tiltmeters installed on selected pillars	Continuously
	Micro-seismic monitoring	Continuously
Post-Mining	- Aerial Surveys - LIDAR Scans of Apache Leap - Google Earth observation	Annually for 15 years after mining
	Seismic monitoring	Once every two years for 15 years after mining
	Tiltmeters installed on selected pillars	Continuously for 15 years after mining

2.2 Queen Creek and Devils Canyons

The subsidence modeling conducted to date has shown that both Devils Canyon and Queen Creek Canyon are outside the subsidence. Table 2 summarizes the monitoring techniques and frequencies.

Table 2 Monitoring Schedule for Queen Creek and Devils Canyon

Monitoring Period	Monitoring Techniques	Frequency
Baseline Studies Pre-Mining	Surface joint mapping	Once prior to mining
During Mining	Surface joint mapping	Once a year
	Subsidence Fracturing	Once a year
Post-Mining	Surface joints mapping	Once every 2 year for 15 years after mining

2.3 Highway US-60

The Highway US-60 constitutes the main man-made feature within the vicinity of the project. The highway cuts through the cliffs and pillars of the Apache Leap and is located north to north-west of the proposed mining operations. Based on the results of subsidence modeling, the highway is in the stable zone. Table 3 below summarizes the techniques and frequencies for monitoring of US-60.

Table 3 Highway US-60 Monitoring Schedule

Monitoring Period	Monitoring Techniques	Frequency
Baseline Studies Pre-Mining	Observation of road condition, Google Earth observation, survey marks and prisms	Once prior to mining
During Mining	Observation of road condition, Google Earth observation	Once every quarter
Post-Mining	Observation of road condition, Google Earth observation, survey marks and prisms	Once every two years for 15 years after mining

2.4 Surface Subsidence Area and Oak Flat Campground

Due to its proximity to the mining footprint, part of the Oak Flat Withdrawal will be subject to subsidence, however the actual campground is outside the fracture limit. The fracture zone will extend almost towards the middle of the Oak Flat withdrawal. This will occur towards the end of mine life. The monitoring techniques and frequencies are summarized in Table 4 below

Table 4 Surface Subsidence and Oak Flat Campground Monitoring Schedule

Monitoring Period	Monitoring Techniques	Frequency
Baseline Studies Pre-Mining	- Aerial Surveys - Google Earth observation	Twice a year
	Survey markers, prisms and extensometers	Once prior to mining
	Crack displacement monitors	Once prior to mining
	Tiltmeters installed on selected pillars	Continuously
During Mining	- Aerial Surveys - Google Earth observation	Once a year
	Survey marks, prisms and extensometers	Monthly
	Crack displacement monitors	Monthly
	Seismic monitoring	Continuously

	INSAR Imaging	Twice a year
	Tiltmeters installed on selected pillars	Continuously
	Smart Markers, cave trackers and TDR installed before cave initiation	Continuously
	Micro-seismic monitoring	Continuously

3 SUBSIDENCE TRIGGER ACTION RESPONSE PLAN

As mentioned in the previous sections, a series of instrumentation and monitoring devices will be installed prior to initiate mining to monitor cave propagation and subsidence. Because subsidence is a gradual and measurable process, a Trigger Action Response Plan is developed to ensure that a timely and planned action is ready to mitigate the risk when certain triggers are reached or detected by the monitoring and inspection system. The TARP is presented in Table 5. This TARP is to be used as a tool to manage the subsidence risks and prevent damage to the critical surface infrastructures discussed above. For simplicity the surface features to monitor have been subdivided into two categories:

- Features that are sensitive to Tilts include Apache Leap, Queen Creek Canyon, Devils Canyon
- Features that are sensitive to Angular distortion include all relatively flat features such as the US-60, the Oak Flat Campground and mine roads and buildings.

4 REPORTING

RC will document and store all the results of surface subsidence inspection and monitoring. The performance of the cave and subsidence development will be monitored and tracked and the results compiled into an annual status report that will be issued to the United States Forrest Service (USFS) for the Apache Leap Special Management Area. The annual subsidence management status report may include:

- A summary of any subsidence management actions undertaken by RC in the period subsequent to the last report related to the protection of the Apache Leap Special Management Area
- A summary of any observed and/or reported subsidence impacts
- A summary of cave performance and subsidence development based on monitoring information

Table 5 Subsidence Trigger Action Plan

Features	Trigger Levels	Action/Remediation Measures
Apache Leap, Queen Creek Canyon, Devils Canyon	**NORMAL** - No visible change or rock falls from cliffs - No formation of new cracks or extension of existing cracks in area - Harrison plots show negligible or very slight damage based on monitoring data - No seismic events in the area - Average Tilt of less than 2 degrees - Measured subsidence angle is more than 78 degrees	- Continue monitoring as per subsidence monitoring program
	LEVEL 1 - formation of new cracks or extension of existing cracks in area - Harrison plots show slight damage based on monitoring data - Small seismic events in the area - Average Tilt up to 4 degrees - Measured subsidence angle is between 72 and 78 degrees	- Continue monitoring as per subsidence monitoring program - Update subsidence model predictions based on measured data or observations
	LEVEL 2 - Extensive formation of new cracks or extension of existing cracks in area - Harrison plots show moderate to severe damage based on monitoring data - Major seismic events in the area - Average Tilt of 5 degrees - Measured subsidence angle is less than 72 degrees	- Increase monitoring frequency - RC to inform USFS - RC to update subsidence model predictions based on measured data or observations - RC to change draw strategy and mine plans
US-60, Mine Roads and building and Oak Flat Campground	**NORMAL** - No formation of new cracks or extension of existing cracks in area or on US-60 - Harrison plots show negligible or very slight damage based on monitoring data - No seismic events in the area - Average Angular Distortion is less than $2x10^{-3}$ - Measured subsidence angle is more than 78 degrees	- Continue monitoring as per subsidence monitoring program
	LEVEL 1 - formation of new cracks or extension of existing cracks in area or on US-60 - Harrison plots show slight damage based on monitoring data - Small seismic events in the area - Average Angular Distortion is between $2x10^{-3}$ and $4x10^{-3}$ - Measured subsidence angle is between 72 and 78 degrees	- Continue monitoring as per subsidence monitoring program - Update subsidence model predictions based on measured data or observations
	LEVEL 2 - Extensive formation of new cracks or extension of existing cracks in area or on US-60 - Harrison plots show moderate to severe damage based on monitoring data - Major seismic events in the area - Average Angular Distortion is more than $4x10^{-3}$ - Measured subsidence angle is less than 72 degrees	- Increase monitoring frequency - RC to inform relevant public authorities - RC to update subsidence model predictions based on measured data or observations - RC to increase road maintenance programs and repairs

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June 29, 2018

Mary Rasmussen
US Forest Service
Supervisor's Office
2324 East McDowell Road
Phoenix, AZ 85006-2496

Subject: Resolution Copper Mining, LLC – Mine Plan of Operations and Land Exchange – Subsidence Monitoring Report

Dear Ms. Rasmussen,

Enclosed for your review and consideration, please find the following document titled "*Subsidence Monitoring Plan*" dated May 5, 2018 by Jacques Tshisens.

Should you have any questions or require further information please do not hesitate to contact me.

Sincerely,

Vicky Peacey,
Senior Manager, Permitting and Approvals; Resolution Copper Company, as Manager of Resolution Copper Mining, LLC

Cc: Ms. Mary Morissette; Senior Environmental Specialist; Resolution Copper Company

Enclosure(s): *Subsidence Monitoring Plan*