BGC ENGINEERING USA INC.
AN APPLIED EARTH SCIENCES COMPANY
710 Tenth Street - Suite 170, Golden, CO USA 80401
Telephone (720) 598-5982

Project Memorandum

To:	**SWCA Environmental Consultants**		
Attention:	**Chris Garrett, P.HGW.**		
From:	**Mark Zellman, P.G., C.PG., GISP., and Diana Cook, Ph.D., P.E.**	**Date:**	**July 9, 2018**
Subject:	**Resolution Copper Project EIS – Mining-Induced Seismicity: Causes and Possible Impacts – FINAL**		
Project No.:	**1704004**		

1.0 INTRODUCTION

In support of the broader assessment of mine subsidence and stability, which will be addressed in the Resolution Copper Project Draft Environmental Impact Statement (DEIS), BGC Engineering USA, Inc. (BGC) is providing geological and geotechnical expertise to SWCA Environmental Consultants (SWCA) and the Tonto National Forest (TNF). The TNF is the lead Federal agency for the EIS, and SWCA is the TNF's third-party EIS contractor. The TNF, SWCA and their consultants, including BGC, comprise the EIS project team.

This internal draft memorandum provides a summary of mining-induced seismicity as it may relate to the Resolution Copper Project block-caving mine currently proposed near Superior, Arizona (Resolution Copper Mining (RCM) 2016). This document includes a brief discussion of the causes, mechanisms, and occurrences of induced seismicity, particularly as it relates to the proposed mine and possible impacts from the proposed mining activities.

2.0 MINING INDUCED SEISMICITY

Induced seismicity refers to earthquakes that occur as the result of human activity (Hitzman 2013). Fluid injection and extraction, hydraulic fracturing, impoundment of water behind large dams, and mining are some of the ways in which humans can trigger earthquakes. Induced earthquakes in mines can be the result of slip along a pre-stressed structure (i.e. fault, joint, bedding plane), rockburst (violent burst of rock into mine opening), pillar burst, bump (sudden slip of a weak seam), and outburst (sudden violent ejection of coal into mine opening) (Hasagewa et al. 1989). Induced seismicity has been recognized and observed in mines around the world for over 100 years (Gibowicz 1994). Not all mines are seismically active, and many exhibit little to no seismicity.

Geology, stress, and tectonic setting are all factors that affect seismicity in mines. In deep mines, mine depth, production rates, mine geometry, existing geologic structures, and discontinuities are important factors (Gibowicz 1994). In his study of focal mechanisms of large seismic events at a variety of mine sites, Wong (1993) found that higher rates of mine seismicity are often associated with mines within regions of high horizontal compressive stress and in areas where natural seismicity occurs. These events are generally the result of strike slip or reverse faulting; however, Gibowicz and Lasocki (2001) notes that at a deep gold mine in South Africa, seismicity is occurring on normal faults caused by stope closure, and that tectonic stresses do not seem to be a dominant factor. The primary requirement for inducing seismicity appears to be human activity that changes the state of stress in highly pre-stressed rocks (Gibowicz and Lasocki 2001). Mechanisms for seismicity can include pore pressure changes, volume changes, and applied force or loads (McGarr et al. 2002).

Mine seismicity is categorized into two types (Gibowisz 1994; Richardson and Jordan 2002). Type A events are smaller in magnitude (M<1), are related directly to mining activities (i.e. digging, blasting), and occur at or near the active mining face. Type B events have larger magnitudes, and they occur as a result of shear failure along a pre-existing structure (i.e. fault, joint bedding plane, or other zones of weakness). They may occur on structures not exposed at the active mine face, but which are affected by the perturbed stress field. Events as large as ~M_b[1] 5.6 have been observed in underground mines, globally (Foulger et al. 2018; Bennett et al. 1997; Gibowicz 1994). In the United States, the largest observed mine-induced event was M_L[2] 5.1, caused by a collapse at the Solvay mine in southwestern Wyoming in 1995 (Pechman et al. 1995).

The proposed Resolution Copper Mine is located approximately 90 km east of Phoenix, Arizona (Figure 1). It is within the Central Highlands Transition Zone (CHTZ), between the southern Basin and Range province and Colorado Plateau. Historical natural seismicity sparsely aligns along the CHTZ. The nearest historical earthquakes > M 3 are: a M 4.2 in 1963 at 35 kilometers (km), a M 4.4 in 1969 at 45 km, and a M 3.1 in 2010 at 35 km (USGS 2018a). The nearest mapped Quaternary surface fault (Sugarloaf fault zone) is about 55 km to the northwest (USGS 2018b). The regional stress field is extensional (Levandowski et al. 2018). Within the Colorado Plateau to the NE, minimum horizontal stress is oriented WNW-ESE, and within the Basin and Range to the SW, minimum horizontal stress is oriented N-S. The site is located between these two zones, where locally variable orientations of stress should be anticipated.

Because of the many variable anthropogenic and natural factors, it is difficult to make predictions about mine induced seismicity at the proposed Resolution Copper Mine. Since 2013, mine-induced seismicity in Arizona (Figure 1) has been observed in two locations: 1) in southeastern Arizona near Morenci (up to M 3.1), and 2) in northeastern Arizona, south of Shonto (up to M 2.9) (USGS 2018c). Over 100 years of world-wide observations of induced mine seismicity show that induced events ≥M 5 are rare, whereas events ≤ M 3 are more common.

The potential surface effects for induced earthquakes that might occur at the proposed Resolution Copper Mine could include ground shaking on a local scale, which could include the town of Superior, AZ. Damage to well-built structures is rarely observed for earthquakes ≤ M 5. Events ≥ M5 could be strong enough to damage vulnerable structures (i.e., unreinforced masonry), but as stated previously, events of this magnitude have only rarely been observed in mining-induced events. Surface faulting is not expected because the events in question fall far below the observed threshold (about M 6.5) for surface faulting (Youngs et al. 2003).

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[1] Body-wave magnitude (M_b)
[2] Local magnitude (M_L)

3.0 CLOSURE

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Yours sincerely,

BGC ENGINEERING USA INC.
per:

Diana Cook

Mark Zellman, P.G., GISP
Senior Geologist

Diana Cook, PhD., P.E.
Senior Geotechnical Engineer

Reviewed by:

Martin Zaleski, M.Sc., P.Geo., C.E.G.
Senior Engineering Geologist

MSZ/DC/MPZ/sjk

Attachment: Figure 1

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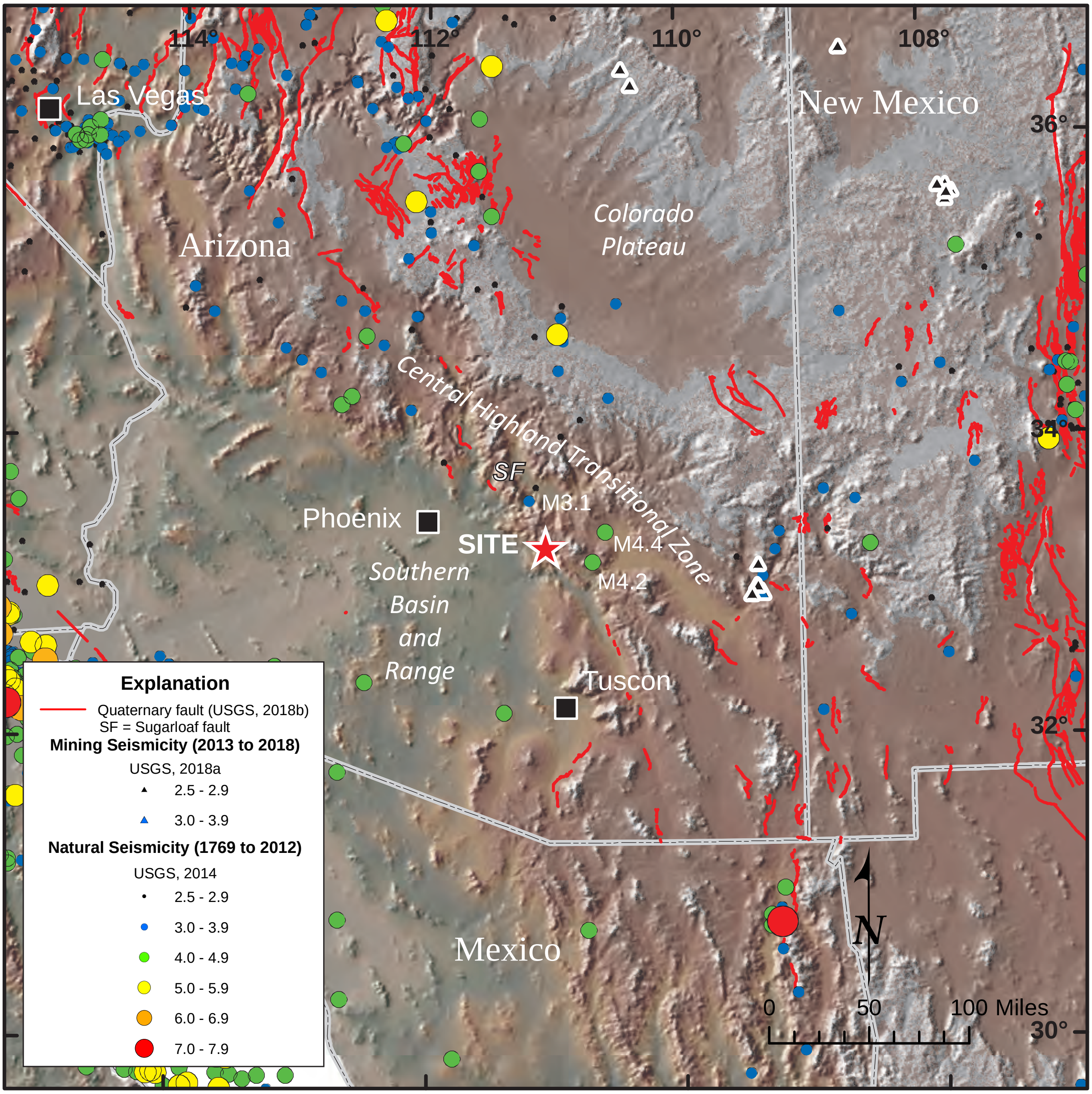

Figure 1. **Location Map**