24-021

Corrosion Strategies at the Resolution Copper Project, Arizona

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INTRODUCTION

Corrosion has long been identified as a potential risk to the long-term ground support stability due to degradation of internal ground support elements such as rock bolts but also to surface support from mesh, straps, bolt plates, and ancillary support of utilities such as hangers. The emphasis is to understand the corrosion mechanisms on the primary ground support elements and any supplemental steel or arch sets. The water and chemical processes from oxidation(rust), stress corrosion cracking, and even the electrical charge created during these reactions contribute to the corrosion of the steel support elements. The main goals are to mitigate the effects of corrosion and to be able to predict those areas of high water or high sulphide for potential rehab maps. It is also essential to identify and classify the visible corrosion as part of damage mapping and provide bolt testing to those areas of suspected internal damage from corrosion. This is important to get an estimate of the support longevity or expected life before rehab to minimize the overall cost of the operation.

Fully encapsulated bolts using resin provide the best protection from the low pH acids generated from oxidation of pyrite as well as alkaline waters with high particulate solids and higher salinity that can lead to corrosion. In addition, it can be demonstrated that pumpable resins using hollow bolts or rebar are more effective in ensuring the complete encapsulation of bolts than the partial encapsulation from resin-epoxy cartridges that must be placed in the holes manually and bolts spun to break the cartridges to complete the mixing. This is especially important in high water prone areas.

Resolution Copper completed the sinking of the No 10 shaft to a depth of 6,943' below the surface and was ultimately connected to the number 9 shaft. The deepest development at the mine is the second transfer pumping station (TPL2) or 68 level at 6,780 feet below the surface. The current 68 level and subsequent 58 level development and lower caving levels and shafts will be dependent on the long-term viability of the ground support given the high sulfide environment if coupled by the presence of hot water and associated high humidity (>60%).

WATER CHEMISTRY RESEARCH

Water sampling of the #9 and #10 shaft and of the TPL2 or 68L were collected and summarized in several reports. In a more recent study by Logsdon (2022), the kinds of water collected from deep water flows include Montgomery (2012) and are summarized in Table 1. The chemical concentrations of typical water collected vary in the number of dissolved solids and show that underground waters at Resolution are neutral pH and do not show evidence in total dissolved solids or high sulfate concentrations of high acid generation. The conceptual model is that native groundwater is not corrosive (neutral pH, very low oxygen), but where the groundwater becomes oxygenated (in mine voids, fractured rock around excavation development aided by ventilation), and passes through high sulfide rock, the water becomes corrosive. The suggestion is that if these were typical of most of the water and geology low in sulfides, the environment of rock bolts, mesh, and other steel-based infrastructure, there would be little or no risk of corrosion. However, the presence of abundant hot water

Table 1. Typical water samples from deepwater wells. DHRES01 and DRHES02 located in the ore body

	DHRES-01	DHRES-02	DHRES-06	DHRES-09
	mg/L	mg/L	mg/L	mg/L
Cations	28-Nov-08	20-Jul-11	9-Jan-11	20-Aug-12
Na +	130	160	48	32
K +	18	38	4.6	3.8
Ca 2+	32	250	53	110
Mg 2+	3	8.5	29	42
Anions				
HCO3 -	281	220	390	329
CO3 2-				
Cl -	20	21	5.8	26
SO4 2-	160	820	14	260
F -	3	3.9	0.57	0.20
SiO2	45	45	20	19
TDS-calc	692	1,566	565	822
TDS-meas	500	1,400	440	880
TDS(BAL)	0.161	0.056	0.124	0.034
pH - field	7.2	6.8	7.36	7.2
pH-lab	7.91	7.04	7.38	7.3
T (oC)	68.7	58.7	37.7	28.8

and high sulphides in the 68 L has generated a dichotomy of low pH (acidic) and high pH (alkali) solutions and an abundant amount of dissolved solids and precipitates.

Figure 1 shows the two characteristics of the water from the Never Sweat Tunnel, TPL2 boreholes, and the areas of highly corrosive and low ph efflorescent salts for portions of the 68L. The water from the NST and from the 68L boreholes waters show low to moderate dissolved solids(salinity), and, therefore low corrosion potential. The Hatch report (2018) from the 68 Level or TPL2 has shown moderate dissolved solids ranging from 1,100–1,400nmg/L the tendency to form Calcium Carbonate scale, and a high tendency for steel corrosion.

Note neutral to slightly alkaline PH with varied dissolved solids. The DHRES06 and DHRES-09 samples were collected outside the local orebody graben. Typical water samples from deepwater wells such as DHRES-01 and DHRES-02 were located in the ore body, with neutral to slightly alkaline PH with varied dissolved solids.

CURRENT TPL2(68L STUDIES)

More recently photographs and mineral precipitate samples were taken for field and laboratory analysis on the TPL2 or

68 Level. As part of the study, 4 field paste pH measurements and 7 solid samples were collected as well as investigating and collecting photographic evidence of corrosion. This sample testing is important in establishing the background processes and chemical reactions that are influencing corrosion. Table 2 is a summary of the testing of the precipitates and the PH.

Table 2. Test Results of precipitates for electrical conductivities and lab paste PH on 68L

Sample ITD	Primary Color	Lab Electrical Conductivity (μmhos/cm)	Lab Paste pH (s.u.)
VENT-BH-FLAKE	White	12020	8.61
#9-WV	White	11990	9.07
PR BULK	Yellow/ Orange	7860	2.75
PR-2	Yellow	3850	0.73
NORTH DRIFT	Yellow	3750	0.86
PR-1	White	3590	8.90
OLD-ER	White	1095	8.69

Figure 2 is a plan map of the 68-level showing where the samples were taken, with an overlay of the percent total Sulphur from the geologic block model. It shows a *bimodal* distribution of extremely highly acidic in the PR bulk, PR2 and North Drift, and primarily neutral to alkalic in the remainder of the drifts. Based on descriptions and pictures of the underground conditions, considers that the alkaline conditions that exist are associated with exposures of shotcrete, whereas the acidic locations are influenced by the oxidizing pyrite that is not protected by shotcrete. The higher

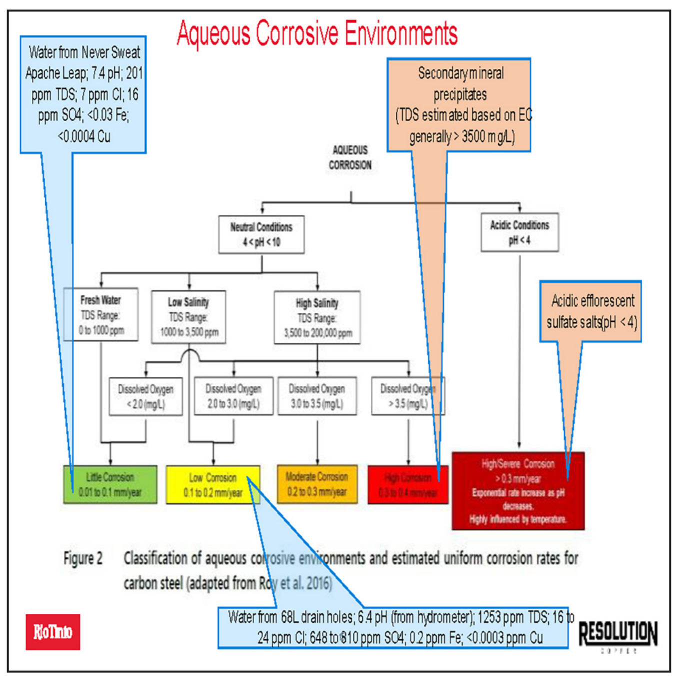

Figure 1. Water samples, and corrosive environments based on observations at RC. Information plotted on Aqueous classification chart. From Logsdon, 2022

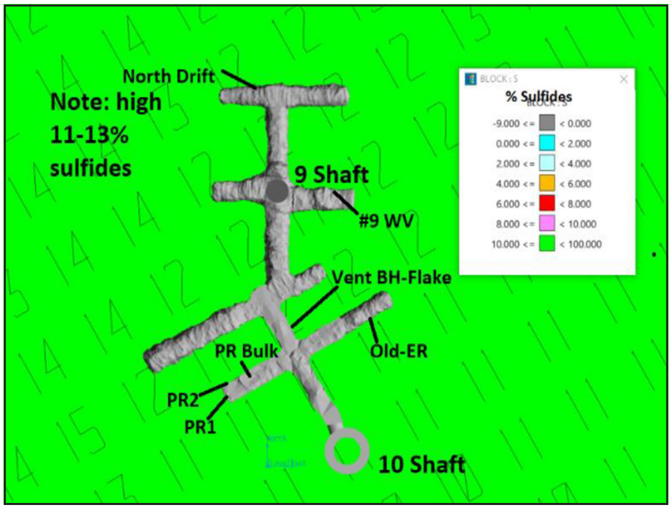

Figure 2. Plan map of TPL2(68 level) showing total percent sulfur from geology block model

pH is thought to be because of the presence of shotcrete in effect neutralizing the acids and precipitating salts.

A summary of the work to date substantiates that:

- Extremely corrosive aqueous conditions are present in the existing development.
- Ventilation enhances oxygen diffusion into the damaged wall rock(near surface)
- Near surface pyrite oxidation is occurring, and secondary mineral precipitation including acidic efflorescent sulfate minerals.
- Groundwater monitoring at depth in intact rock shows a low presence of O_2 to the deep saturated zone in isolated rock masses, and low-pH/acidic conditions should not be expected for most of the embedded bolts and intact rock mass. The acids produced are most likely confined to the first 1–1.5 meters into the rock.
- Susceptibility to water inflows, oxidation and subsequent corrosion from acid are influenced by blast damage or increased loosening between the shotcrete shell and the intact rock mass.
- Most of the mineralized subsurface is expected to be net acid generating once exposed by mining and ventilation. For these ventilated areas, wall rock and associated local seepage pH <4 should be common after a few months to years of exposing pyrite-bearing rock to atmospheric oxygen. High oxidation potential will be present everywhere in the ventilated zones.

Table 3. The types of corrosions and their effects and strategery priorities

Corrosion Type	Factors	Chemistry	Strategy
Aqueous(mine water)	PH (acid/alkali)	-Chlorides and sulfides -Dissolved oxygen -Concentration of H+ -Ca+2, Mg+2 ions -CO2, carbonic acid	-Dewatering -Seal off water from steel bolts -Sealant for fracs -Cathodic protection
Atmospheric	Humidity >60%	Microbial/Bacterial	Limit anion, ionic cathodic reaction

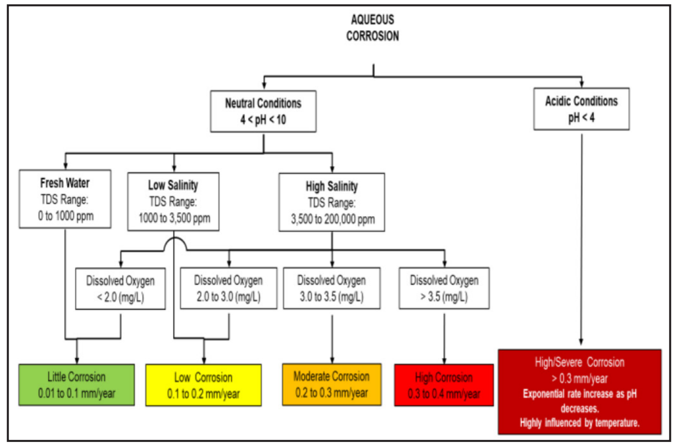

Figure 3. Classification of aqueous corrosion and estimated corrosion rates for salinities, dissolved oxygen, or total dissolved solids. From Preston and others, 2019

Nature and Causes of Corrosion

The two main types of corrosion are classified as aqueous (interstitial mine water), and from high humidity (>60%), and lesser amounts from stress corrosion cracking associated with very low PH< 2 for higher strength steels. Table 3 concentrates on the two main categories of corrosion and accepted mitigation of corrosion. Figure 3 is summary of classifications of aqueous corrosion based on pH and TDS (total dissolved solids). Corrosion is also therefore highly dependent on dissolved oxygen. Figure 4 shows that atmospheric corrosion (humidity) can be even more pervasive in stagnant versus moving exhaust or mixed air due to the concentrations of SO_2 vapors.

Corrosion from Electrolysis

The electrochemical corrosion involves the flow of electrons (+) and ions (–), and involves an anode, cathode and electrolyte. Reaction at the anode is oxidation; where electrons are generated, where metal atoms go into solution and the metal gets thinner. The anode is the site where the

Figure 4: Examples of corrosion precipitates in cracks through shotcrete

metal is corroded; the electrolyte solution is the corrosive mechanism with the cathode forming the other electrode. At the cathode, reductions take place consuming electrons. Increasing salinity and higher temperatures of the electrolyte promote the corrosion effects.

Aqueous Corrosion by Acidic Formation

Logsdon (2022) summarized the underlying geochemical reactions are summarized when pyrite (FeS_2) is exposed to oxygen (O_2) and water (H_2O), the sulfur and then the iron in the pyrite will oxidize, dissolved ferric ion (Fe^{3+}) will hydrolyze (react with hydroxyl ions, OH^-), precipitating secondary ferric minerals, and release yet addition H^+.

The long-term consequence is acidic, low-pH, and high Total Dissolved Solids (TDS) waters, plus conversion of reduced iron (Fe^{2+}) to oxidized iron (Fe^{3+}), i.e., corrosion. The classical conceptual reaction series is:

$$FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$$

$$Fe^{2+}\ 1/4O_2 + H \rightarrow Fe^{3+} + 1/2H_2O$$

$$Fe^{3+} + 3\ H_2O \rightarrow Fe(OH)_3 + 3\ H^+$$

$$\textbf{Total: } FeS_2 + 15/4\ O_2 + 7/2\ H_2O \rightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 4\ H$$

Corrosion Precipitates

In systems that evolve to very low pH (pH < 2) highly hydrated ferric sulfates such as copiapite [Fe_2+Fe_3+4[SO_4]6$(OH)_2$ .20H20]) form the sorts of efflorescent precipitates. Figures 4–6 show low pH paste and efflorescent salts effeection bolt corrosion.

BOLTS TESTING-METALLURGY RESULTS

Bolt testing has been done at the 68 level workings which summarize the service life of the bolts installed in similar

Figure 5: Examples of corrosion precipitates from TPL2(68L) indicates hydroxysulfates such as jarosite [KFe (SO) (OH)].From Logston, 2022

Figure 6; Corroded rock bolt extracted from 68 Level . Note corrosion although portion of the bolt was surrounded by shotcrete. Yellow (white to greenish) efflorescent minerals are recent/current precipitates

Figure 7. TPL2 or 68 level pump station area of bolt testing and overcoring in 2015

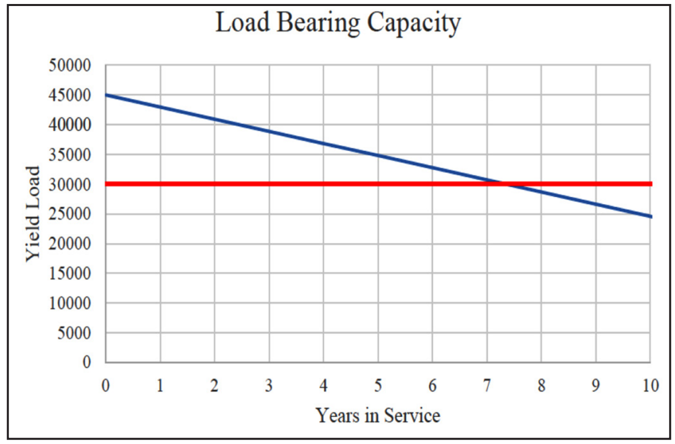

Figure 8. Predicted worst case of 7-year resin rebar bolt life based on worst case corrosion rate of 0.027 sq inches/year. From CTL, 2019 report

conditions and rate of strength deterioration from corrosive conditions from previous corrosion studies.

CTL Report

Results from TPL2(68 level) Pumping Station were published September 2019(CTL, 2019). Four eight-foot resin bolts installed between March and May 2015 were overcored and tested (see Figure 7). The primary finding was that corrosion was due to anions: heavy local corrosion at the anchor head. Worst case bolt life of about 7 years to maintain at least 15 tons capacity. Of the 4 reenforced rebar bolts tested, low pH was the primary corrosion element.

Assumptions are linear relationship to loss of cross- sectional area (see Figure 8) and Table 4 based on the worse case corrosion rate of 0.027 inches ^2/year. Each of the bolts analyzed were subdivided into thirds, and labeled near anchor, mid span, and deep end zones (see Figures 9 and Figure 10. Note heavy pits in the the near anchor section of the bolt, thought to be from exposed steel without resin.

Table 4. Surface area and % loss from (CTL, 2019) bolt tests

Sample Identification	Surface Area (Inches^2)	% Loss Versus Sample 36195-1
36195-1 (not in service)	0.60	N/A
36195-4	0.52	15.4
36195-5	0.58	3.3
36195-6	0.49	18.3
36195-7	0.55	8.3

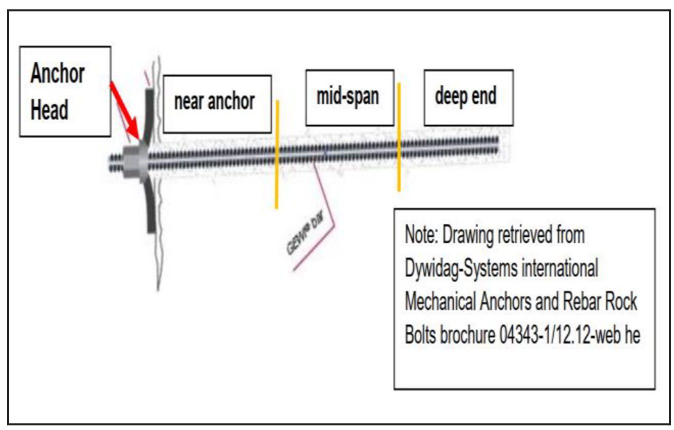

Figure 9. Diagram of bolt cross section showing zones of near anchor, mid anchor, and deep end zones from (CTL 2019)

Pump Room TPL2(68 L) failed pull tests

Major findings of the September 2019 CTL Report is as follows:

- Corrosive attack occurred on all extracted bolts in varying degrees along the length, but degree decreases with depth along the bolt. Heavy pitting attack and general attack was present in *first third of each bolt* (closest to tunnel, ear anchor). Pitting attack and general corrosion were present mid-span on each extracted bolt. General corrosion was present on the inner-most embedded section (the deep end) of each extracted bolt.
- A significant amount of form sulfur in the of sulfate was present in scale on the surface of the in-service bolts. Arsenic and chloride were also present in some areas.
- It also was reported that the used bolts possessed significant residual resin/grout and rock material from embedment; however, on delivery only one bolt possessed some grout and no rock material was observed on any of the bolts. The grout was easily removed

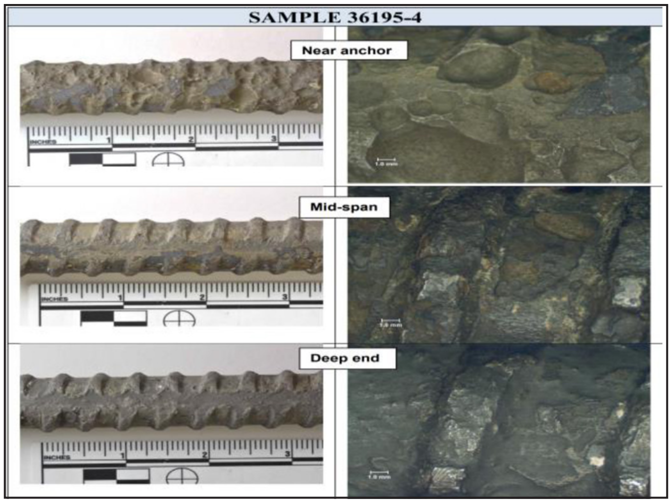

Figure 10. Corrosion loss for rebar bolts, and photos sample 36195 showing near anchor, mid-anchor and deep end corrosion from (CTL, 2019) bolt tests

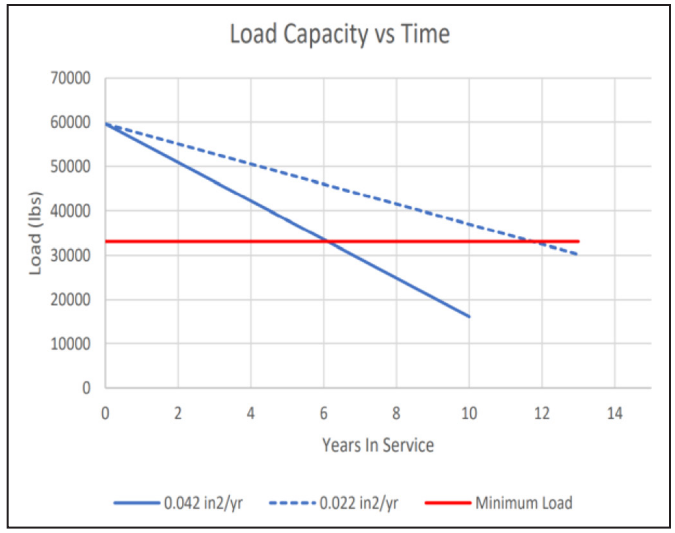

Figure 11. Graphical plot of load capacity vs time for 2 resin rebar bolts in 68L Pump Room based upon calculated corrosion rates (from PNL, 2023)

> from the one bolt by hammering. I suspect that this was because the bolts only had residual resin in the mid and deep span portions of the bolt. The more recent incidents of a failed bolts not holding weight and a poor pull test on the 69 level have led us to suggest more must be done to protect the entire bolt.

A GWO (geotechnical work order) was issued in October 2022 after a resin anchored bolt in the TPL2 Pump Room that was to be used as part of the rigging to change piping in the pump room began to move and started to come out of the hole with very minimal effort. Water has coming out of the hole, and approximately 2 feet of the bolt at the collar was shown not to have resin. Subsequently a bolt just above that bolt failed a pull test of only 7 tons (minimal to be 15 tons). The area was subsequently rehabbed with 8 bolts on 4 bolt per row pattern to insure ground support. Both bolts were pulled out intact and were sent to a material testing facility and a report generated (PNL, 2023).

PNL Test Results

The conclusions were that the two bolts were either not fully encapsulated or properly installed initially in October 2020. It also brings up the difficulty in installation of bolts with the current cartridge package resin systems and jacklegs. The presence of large amounts of hot water in weaker ground may also affect resin-bondage when mixing. The greatest loss in cross-sectional area was found in the #2 bolt (0.50 in^2) and yields a corrosion rate of 0.042 in^2/yr. The average cross-sectional loss of 0.54 in^2 (which was consistent on both bolts samples examined) yields a corrosion rate of 0.022 in 2/yr (see Figure 11). Based upon these values, the bolts are estimated to fall below the minimum pull strength at approximately 6 years for minimum and 12 years for average corrosion.

No evidence of any epoxy resin encapsulation was observed on any of the lengths of bolts provided for analysis. The corrosion pattern is suggestive of a leak path that existed around the bolt. The isolated leak path allowed for the first 1–4 feet of the galvanized coating to be attacked and allowed for pitting corrosion to initiate. The surface adjacent to the pits showed notable galvanized coating still present to varying thicknesses.

Partial Bolts

In addition to the two whole length bolts that were tested, 5 bolts were over cored, but only the first 1–2' were recovered. All 5 holes were difficult to properly over core, even with dip angle and bolt alignment techniques. There may be several reasons for this such as using the wrong drill, or seemingly bent bolts in the first few feet. We may need to specialize in a portable drill rig specifically for overcoring. There was no evidence any visible resin encapsulation on the surface of any of the samples received

CORROSION PROTECTION SELECTION

Figure 12 is a diagram from Preston and others (2019) that shows the relative corrosion resistance versus elongation capacity. It emphasizes the use of grouted or resin fully encapsulated bars as providing the most resistive to corrosion. The grout or resin provides a barrier between the steel and the mine water. Encapsulation using grout is shown as

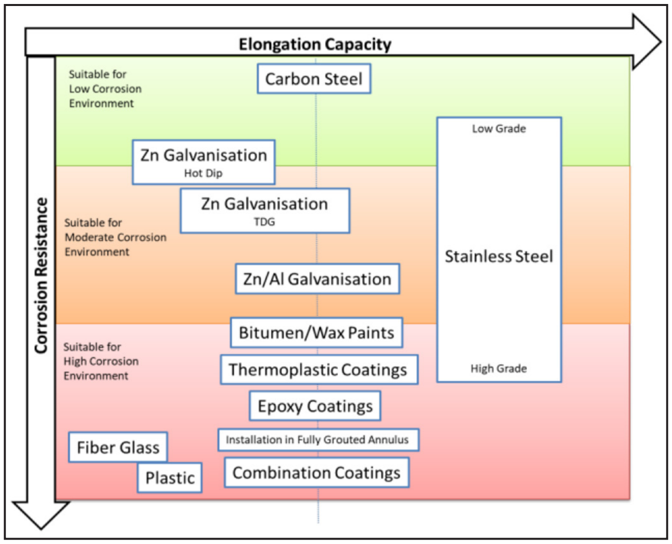

Figure 12. Relative corrosion resistance versus elongation capacity for corrosion protection measures. From Preston and others, (2019). Note: Installation in fully grouted anulus offers best corrosion protection next to any additional combinational coatings

being more effective than resin as it also has a neutralizing effect for acids. However, using resin instead of grout offers several advantages when pumping bolts. Resin from the factory is checked for quality control and provides a consistent product in both strength and viscosity when properly mixed with the proper hardener. Grout is mixed on the machine and the operator must be careful to add water at the proper ratio or strength will be greatly reduced and the grout will lose viscosity and run out of up holes.

Another potential option is the selection of support material as utilizing a fiberglass bolt or fiber mesh which will not corrode as no metal is involved. Bolts that do not react(nonmetal) and fiberglass reinforced rock bolts are more effective versus double coated steel bolts (Clarke and Sieders, 2014). Fiberglass bolts have as only 25% shear resistance of metal bolts and a much lower torsional strength (120–230NM versus 1160NM for steel bolt), but more shear resistance than inflatable bolts (Swellex).

The best mitigation in a practical sense is to limit the exposure of the steel to the either carbonic or sulpheric acid as corrosion agents. Other more expensive and complicated options are to coat the individual bolts and mesh with a coating to stop the anodic destruction from electrolysis, such as from galvanization or coatings of zinc, aluminum, or magnesium. Currently we have been using galvanized bolts including cables to minimize corrosion. Galvanization may not be good alternative for any elements when pH goes below 4.

Table 5. Corrosion Damage mapping scale based on Hadjigeorgiou and Dorian, 2013

Corrosion Level	Description	Corrosion Rate	Loss of Capacity	#6 Mesh Diam.	Required Intervention
C1: Negligible corrosion	Steel is in excellent condition and corrosion signs only on surface. A few localised spots, less than 10% of the surface is corroded.	<0.02 mm/yr	<10%	>4.75 mm	None
C2: Localised corrosion	Corrosion is characterised by localised spots on the surface. Between 10 and 75% of the surface is corroded. Steel is in good condition.	0.02 to 0.04 mm/yr	10 to 20%	4.50 to 4.75 mm	None
C3: Surface corrosion	Corrosion over 75% of the surface. Corrosion is only on surface. If a corrosion crust is present it is very thin. Can identify blisters.	0.04 to 0.15 mm/yr	20 to 35%	4.00 to 4.50 mm	None to follow up.
C4: Advanced corrosion	100% of the surface is corroded. Can identify blisters. Thin corrosion crust (<1 mm) easily removed.	0.15 to 0.30 mm/yr	35 to 50%	3.50 to 4.50 mm	Follow up. If installed over 12 months it will display signs of severe corrosion.
C5: Very advanced corrosion	100% of the surface is corroded. Thick corrosion crust (>1 mm) and flaky.	0.30 to 0.60 mm/yr	50 to 75%	2.50 to 3.50 mm	Consider replacement of installed units.
C6: Extreme corrosion	Corrosion goes through the steel. Integrity of steel has been damaged. Pieces are easily breakable by hand.	>0.50 mm/yr	>75%	<2.50 mm	Reconditioning. May require immediate intervention.

The least corrosion resistant ground support elements such as black steel may only last 10 years, but important infrastructure such as shafts and major haulage, development, may have to last 30–50 years or more depending on production. Goal should be to minimize potential shutdown due to rehab from bolting or shotcrete.

Corrosion Mapping Classification

The current practice in the GCMP (Ground Control Management Plan) has been to standardize elements based on Hadjigeorgiou and Dorian, 2013 for Corrosion Level damage (see Table 5). The guide is used as a guideline to establish corrosion levels rates and the required maintenance until corrosion is calibrated to the site. It is to be done on a biannual basis, as part of the regular inspections including damage mapping. Extra bolts will be installed for pull testing to failure, as it may be the only way to determine if rock support is compromised by corrosion or damage.

Water Sampling Requirements

Where water is encountered in sufficient quality, we need to collect the following for testing: ph, TDSor total dissolved solids (sometimes measured as conductivity), DO (dissolved oxygen), and temperature. These measurements are typically conducted as part of routine environmental groundwater sampling programs, often with small, specialized hand-held probes that can tolerate hot water.

Water has to be isolated from the atmosphere and cooled to measure DO.

These data can then be examined to determine the likely corrosion regime (acidic, neutral and low-salinity or, neutral and high salinity) and estimate expected corrosion rates. Water quality will be ranked as non-reactive, moderately reactive, or severely reactive based on the results.

The following parameters should be analyzed at several different testing locations in various lithologies/structures to be sent to labs for analysis: Elements and compounds such as HCO_3 (mg/L), Ca (mg/L), Cu (mg/L), Fe (mg/L), K (mg/L), Mg (mg/L), Na (mg/L), Zn (mg/L), Cl (mg/L), NO_3 (mg/L), and SO_4^{2-} (mg/L)

Recommendations for Bolt testing requirements based on Corrosion:

- C1–C3: Non-reactive actions: None, continue bi-annual inspections.
- C4: Moderately reactive actions: Pull test bolts bi-annually to check capacity. Target 3 bolts per 15' of development. C5–C6 Severely reactive actions: Pull test bolts quarterly to check capacity. Target 3 bolts per 15' of development

CURRENT CORROSION PROGRAM OUTLINE

The current corrosion program is based on the limited history and experiences occurrences experienced form the 68L, with high sulphides, and abundant corrosive waters developed over the past 6–7 years. Based on testing summarized in this report, the following have become evident:

TPL2(68L)

Figure 13 is a plan map of the 68 L showing the corrosion damage extents using Corrosion level classification system. Because of the recent bolt failures, and past testing showing inadequate encapsulation near the collar, any temporary rehab bolting, especially with jacklegs will eliminate using resin cartridges, and use pumpable resin. For permanent long-range support, a resin injection system is to be used to insure full encapsulation for weak and highly veined rock with high moisture content.

Ground Support System: Element longevity

The Ground Support System (GSS) used at Resolution is primarily based on rock mass classification systems like RMR (Bieniawski,1989) and Q system (Grimsted and Barton,1993). The primary corrosive elements as ground control elements currently in use include resin rebar bolts, MAI hollow bolts, and cable bolts. Of course, this includes, nuts, plates and accessory Occasional split sets are also utilized to hold in place wire mesh. Fibercrete or shotcrete is also used. The strategy going forward is to categorize the corrosion protection based on the ground conditions encountered versus the expected amount of corrosion in each category

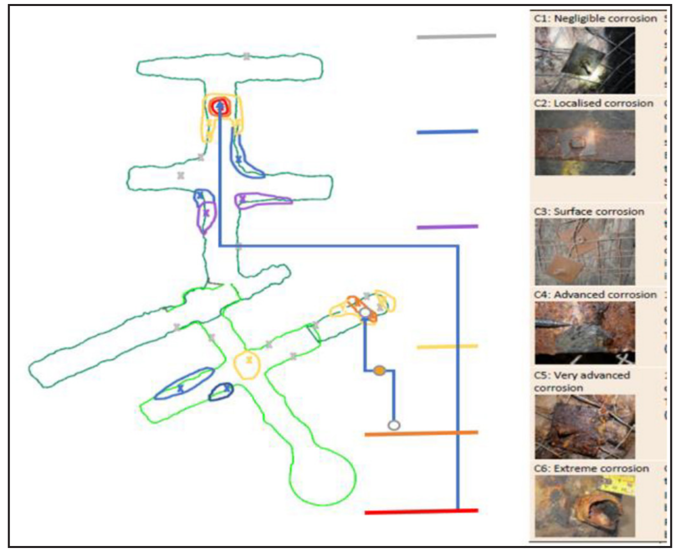

Figure 13. Corrosion Plan Map of TPL2(68L) based on Hadjigeorgiou and Dorian, 2013 corrosion classifications

Full encapsulation of black steel for the entire length of the bolt ranks high on the list to ensure bolt protection, but the next step for long term black steel,, several other options have been as a longer term alternative including epoxy and thermoplastic. Figure 14 is a preliminary estimate of black steel and steel with corrosion coatings longevity based on total sulphide by weight percent.

CORROSION STRATEGIES

The major corrosion mitigation strategies are subdivided as follows:

1. Full encapsulation of bolts in the entire drill hole with resin (no voids or partial fills, especially near the collar).
2. Coating options for ground support components (bolts, plates, nuts, mesh, accessories).
3. Bolt types and material types for longer duration in corrosive environments (fiberglass, stainless steel)
4. Shotcrete admixtures for corrosion protection and acid damage.
5. Surface coating for external wire mesh and shotcrete for rust protection.

		CORROSIVITY		
		NOT 5 ≥ pH ≤ 9 S^{2-} ≤ 10%	MODERATE pH < 5 or pH > 9 10% > S^{2-} ≤ 20%	SEVERE pH < 3 or pH > 12 S^{2-} >20%
COATING	BLACK STEEL	11 yrs	7 yrs	5 yrs
	EPOXY	19 yrs	11 yrs	7 yrs
	THERMO PLASTIC	35 yrs	19 yrs	11 yrs

Figure 14. Expected longevity of coating materials based on percent sulfides (S2) and potential ph based on limited testing and industry OEM information

Figure 15. Various type bolts and coatings for future corrosion overcoring and testing, Old Electrical Room, 68L

6. TPL spray coatings for shotcrete or mesh as an alternative to sealing with shotcrete.
7. Grouting injection for water sealing, especially in and around shafts and longest-term infrastructures.
8. Instrumentation and monitoring
9. Sacrificial bolts and coupons

CURRENT BOLT TESTING

Our current action plan to over the past year has been to try out several different bolts in highly corrosive areas for pull testing and overcoring to test for encapsulation voids and for degree of corrosion over time(see Figures 15 and Figure 16). The results for corrosion over 5 years will give us more accurate data, as we are testing various type bolts with various corrosion resistant coatings like epoxy and thermoplastic.

The resins used will also be tested for heat capability and suitability These have been provided from different vendors to a true may give us a better idea on encapsulation.

Figure 16. Pumping 2-part resin for test bolts in Old Electrical room, 68L

Future Research

During this investigation, we confirmed the three main corrosion factors affecting ground support at Resolution Copper are presence of water, oxygen saturation, and exposure of corrosive iron and steel (see Figure 17). Currently there are not enough tools available in the market to quickly quantify the corrosion level in underground excavations with an highly corrosive environment in the mine.

Table 5 summarizes what Resolution Copper must address to mitigate the effects of corrosion. It fully complements the scope of the wide range of conditions necessary to minimize corrosion and extend ground support longevity.

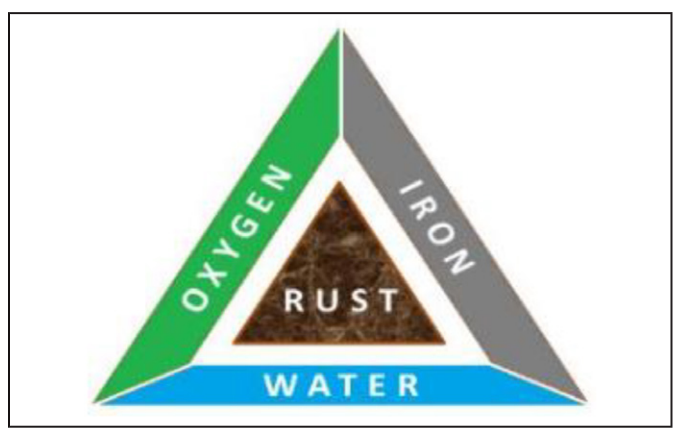

Figure 17. Corrosion triangle showing how any of the sides can be minimized or eliminated, this will prevent damage to ground support

Table 5. Corrosion mitigation optimization and action items for future research

Corrosion; Identified Factors for Optimization	Action Items for Future Study and Action Research
Minimize Oxygen exposure	Thin spray on liner (TSL)for entire drift exposure to rust or sealing shotcrete. Spray-on liners for small spaces with modest and portable spraying equipment.
Minimize Blast Damage	Blast study for overbreak optimization: Low density explosives; proper drill hole spacing, perimeter blasting. Bring in consultants to optimize mechanized excavation: minimize affected zone. Most likely using contractors: monitor initial blasting.
Hydrology (source of water)	Seal off water by grouting around long-term openings especially 9 and 10 shaft of high pH and identified wet zones. Potential to test around #9 shaft on 68L Potential use on 58L 10 shaft excavation if needed.
Overcoring of bolts for testing of over coring drills	"New bolts" not previously tested need to be placed for future over-coreing and his includes sending to the lab for metallurgy and tensile testing. Need to find bolter or vendor specializing in overcoring entire 8–10 depth for bolts.
Cost studies trade-offs	Main concern is availability and increased cost of corrosion resistant coatings for ground support elements.
Rehab based on corrosion and damage	Develop standards for rehab: Use coated bolts, mesh, fibercrete

SUMMARY AND CONCLUSIONS

The recipe for corrosion on underground support(bolts) and other support elements (mesh, hangers) is the oxidation of sulfides (dominantly pyrite) in an aqueous solution (water) or high-humidity environment that produces high pH acids and paste particulates that attack the exposed metal (usually iron and steel components). Areas of high pyrite are potentially more susceptible, but without water, the processes is halted. Corrosion is considered a very rapid process once the rock is exposed to oxygen when the drift is excavated. The depth of saturation is thought to be accentuated by blasting for the first 1–2 meters, which is also in the zone of the primary support for bolts. The surface of the drifts are covered with a thin shotcrete shell that helps to neutralize the acids, but may deteriorate the shotcrete in the process. A potential partial solution is the application of a thin spray on layer (TSL) and/or shotcrete the entire drift to the floor.

Practical mitigation strategies are to isolate the steel components from the corrosive acids or electrolysis fluids by fully encapsulating or limiting the steel exposure or dewatering with drilling. Bolts may still corrode, as movement and cracks form between the bolt and rock by ground movement or by gaps in final installation process. Other alternatives include adding protective plastic or other coatings to the bolts, but this is usually expensive, and may be limited to availability or cost. Pumpable resin is the preferred system to replace manual cartridge system to insure QA/QC in addition to full encapsulation. Another way is to seal off the areas of known high pyrite and water such as around the #9 and #10 shaft. Bolt pull testing is the preferred proof of support capability, but limited overcoring may be needed to explain results. Extra bolts should be earmarked for testing based on corrosion hazard mapping in conjunction with water pH, conductivity and salinity measurements. This should be a part of damage mapping system to insure ground support capability.

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Critical Minerals and Acid Mine Drainage in Black Hawk Mine Waste, Grant County, New Mexico

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ABSTRACT

There are more than 15,000 abandoned mine features in New Mexico. A considerable number of these mines have not been cataloged or assessed for prioritized reclamation efforts. These mine wastes can be examined as a resource of critical minerals. Many of legacy mine waste deposits have undiscovered commodities and critical minerals, due to low recovery processes during past production. In this project, Black Hawk mine wastes in Grant County, New Mexico are examined by thorough mineralogical and geochemical characterization. This project seeks to characterize and estimate the critical minerals in mine wastes of Black Hawk mine, and determine the acid generating potential of mine waste. Identifying and producing critical minerals in New Mexico may directly benefit the U.S economy and national security.

INTRODUCTION

Critical minerals are nonfuel minerals that are essential to the economical and national well-being of a country whose sources are vulnerable to disruption. Examples of this include the production of renewable energy, electronics, agricultural production, and common household items (McLemore, 2020). Critical mineral resources in New Mexico must be recognized before government authorities withdraw land from mineral entry, or make other decisions regarding land use. Moreover, identification of these minerals may directly enhance the overall economic well-being of the United States. Figure 1 illustrates the critical minerals known to occur in New Mexico. Advancements in mining and processing technologies, as well as improved analytical techniques, have made it more feasible to extract critical minerals from waste materials. The U.S. Department of Defense, Department of the Interior, and Department of Energy established a preliminary list of critical minerals in 2019 and revised that list in 2022 (Fig. 1). Currently, 53 minerals are listed as critical for the United States. Copper is not considered a critical mineral by the USGS because the nation currently produces enough copper for domestic use. Copper is also imported from countries with which there are secure trade agreements, so the current supply of copper for domestic use is not in jeopardy. Recently, the DOE has noted copper as a critical mineral. Uranium was listed as a critical mineral in 2019 because of its use in Navy nuclear reactors. However, because uranium is used as a fuel, it was removed from the list in 2022. The critical minerals list is reviewed by the government agencies every 2 to 3 years (McLemore and Gysi, 2023).

Mine wastes are important potential resources of critical minerals, particularly because in the original mine production, base and precious metals and not the critical minerals were produced. Consequently, mine wastes would