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Process Memorandum to File

Gila Conglomerate and Cover Material Summary for the Skunk Camp Tailings Storage Facility

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Revision History

Date	Personnel	Revisions Made

Purpose of Process Memorandum

Gila conglomerate has been identified as the primary cover material for the proposed Skunk Camp tailings storage facility (TSF) at the Resolution Copper Project and Land Exchange (project).[1] The goals of the tailings closure cover and associated reclamation include developing a stable and long-lasting landform with features that minimize and manage erosion, ponding, runoff, oxidation of tailings, and seepage from the TSF and with growth medium that supports a self-sustaining vegetation community.

Gila conglomerate has been used successfully as a cover material in other mine reclamation projects and is the preferred cover material for creating an evaporative store-and-release cover at the TSF. This cover material has been recommended for the following reasons: 1) its borrow source is available near the TSF and does not require reclamation, which allows for concurrent reclamation of other facilities during the life of mining; 2) it is relatively easy to extract; 3) it is relatively unreactive and has measurable acid neutralization potential; and 4) it readily weathers into finer grained material suitable for plant growth media.[2]

Various studies have examined the effectiveness of Gila conglomerate as a tailings cover material. The purpose of this process memorandum is to summarize the physical, chemical, and hydrologic characteristics of the Gila conglomerate from the project's proposed borrow area and to demonstrate its suitability to perform as a plant growth medium and store-and-release cover material.

Available Literature and Data

A literature review of current information was completed to detail the characteristics and potential performance of Gila conglomerate as a capping material and plant growth medium. Several studies have documented Gila conglomerate's performance as a cover and plant growth medium in southern

[1] Resolution Copper Mining, LLC. 2016. *General Plan of Operations Resolution Copper Mining.* Superior, Arizona. May 9.

[2] Klohn Crippen Berger Ltd (Klohn Crippen Berger). 2020. *Resolution Copper Project: Skunk Camp TSF Reclamation Plan.* Doc. # CCC.03-81600-EX-REP-00023 – Rev. 0. Phoenix, Arizona: Klohn Crippen Berger Ltd. June 10.

Arizona and southwestern New Mexico.[3,4,5,6,7] Although the characteristics of Gila conglomerate vary regionally, Klohn Crippen Berger[8,9] has characterized the nature of the material within both the TSF and at other proposed project facilities.

Key Findings

Physical and Chemical Characteristics

General Characteristics and Distribution

Shallow (< 1-foot) and gravelly soils overlying bedrock occur within the TSF footprint, which would not provide a sufficient amount of cover material for reclamation; therefore, cover material will be sourced from Gila conglomerate excavated during construction of the Closure Diversion Channel just east of the TSF. A sufficient volume (approximately 14.0 million cubic yards [MCY]) of cover material is expected to be available from the closure diversion channel excavation, which will satisfy the 12.0 MCY of material needed to cover the TSF to around 1 to 2 feet thick. Additional material may be sourced from excavating ridges around the Closure Diversion Channel and from material stockpiled during clearing and grubbing the TSF footprint. Within the TSF footprint, Gila conglomerate is derived from tertiary alluvial deposits composed of cobbles, gravels, and fines with soil-like characteristics at the surface and coarse materials beneath. Variable cementation and carbonate concentrations occur throughout its distribution within the site. To meet the closure objectives, salvaged material may need to be processed by crushing to break down cementation and reduce particle size to create a soil-like substrate. Crushed Gila conglomerate had a composition of 4.8% to 38.2% fines (below #200 sieve) and 1% to 46% coarse (> ¾-inch) particles.[10] Additionally, natural weathering will reduce the conglomerate into finer grained material over time.

Physical and Chemical Characteristics

A closure cover study for the proposed TSF was completed in 2020 that characterized the physical, chemical, and hydrologic properties of Gila conglomerate in relation to its performance as a plant growth medium and store-and-release cover material.[9] Eleven samples (8 surface and 3 deep core) of Gila conglomerate from within the TSF footprint were collected for a laboratory characterization. It should be noted that no soil samples were collected from within the closure diversion channel. However, it is close to the TSF footprint, and the Gila conglomerate occurring there likely has similar

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[3] Lawson, H.M. 2011. Grassland Revegetation for Mine Reclamation in Southeast Arizona. M.S. thesis, School of Natural Resources and the Environment, University of Arizona, Tucson.

[4] Lawson, H.M. 2012. *Rosemont Reclamation Treatments.* Memorandum to File. Document No. 069/12. Rosemont Copper. July 18, 2012.

[5] Milczarek, M.A., F.M. Steward, W.B. Word, M.M. Buchanan, and J.M. Keller. 2011. Final results for the Morenci tailings experimental reclamation plots. Paper presented at the Conference: VI International Seminar on Mine Closure, Lake Louise, Canada.

[6] Romig, D., L. Munk, and T. Stein. 2006. Leaf area and root density measurements for use in cover performance evaluations on semi-arid reclaimed mine lands. Paper presented at Seventh International Conference on Acid Rock Drainage. March 26–30, 2006, St. Louis, Missouri.

[7] Vinson, J., B. Jones, M. Milczarek, D. Hammermeister, and J. Ward. 1999. Vegetation success, seepage, and erosion on tailings sites reclaimed with cattle and biosolids. Paper presented at 16th National Meeting of the American Society for Surface Mining and Reclamation, August 13–19, 1999, Scottsdale, Arizona.

[8] Klohn Crippen Berger Ltd. (Klohn Crippen Berger). 2016. *Resolution Copper Project: Near West Tailings Storage Facility Closure Cover Study.* Vancouver, Canada: Klohn Crippen Berger Ltd. March.

[9] Klohn Crippen Berger, 2020.

[10] Klohn Crippen Berger, 2020.

characteristics. Characterization included physical index testing, standard Proctor test, saturated and unsaturated material testing, acid-base accounting, chemical and total elemental analyses, static leach tests, and soil nutrient testing.[11]

Results from the laboratory analysis relevant to Gila conglomerate's performance as a plant growth medium are presented in Table 1.[12] Analyses show that Gila conglomerate is slightly acidic to slightly alkaline (pH 6.7 to 8.2), is not potentially acid generating, and has a high (>2) net neutralization potential.[13] Total nitrogen and organic carbon ranged from <0.1% to 0.2% and 0.03% to 1.3%, respectively.[14] Salt concentrations are low (248 to 528 microsiemens per centimeter [µS/cm]), and organic matter is low (0.1% to 2.2%).[15] However, this range of organic matter is comparable to what naturally occurs in soils in the area.[16] The hydrologic characteristics of Gila conglomerate include high saturated hydraulic conductivity (1.03×10^{-3} centimeters per second [cm/s]), low water-holding capacity (0.13 centimeters per centimeter [cm/cm]), and a bulk density of 1.65 grams per cubic centimeter (g/cm^3).[17]

Table 1. Laboratory Analysis Results for Gila Conglomerate Sampled at the Skunk Camp TSF

Analyte	Unit	Minimum Value	Maximum Value
Net Neutralization Potential	Grams of calcium carbonate per kilogram ($g\text{-}CaCO_3/kg$)	17	376
Neutralization Potential Ratio	Ratio	36	804
Paste pH	Standard units	6.7	8.2
Acid-Generating Potential	$g\text{-}CaCO_3/kg$	0.47	0.94
Paste Conductivity	µS/cm	248	528
Organic Carbon	%	0.03	1.3
Organic Matter	%	0.1	2.2
Total Nitrogen	%	<0.1	0.2
Phosphorus*	Parts per million (ppm)	590	2,030
Potassium*	Ppm	10,600	23,400
Sulfur*	Ppm	50	300

Source: Klohn Crippen Berger[18]

*Phosphorus, potassium, and sulfur were analyzed using ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) extractant, which is an applicable method for agronomic (or plant available) interpretations.

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[11] Klohn Crippen Berger, 2020.

[12] Klohn Crippen Berger, 2020.

[13] Klohn Crippen Berger, 2020.

[14] Klohn Crippen Berger, 2020.

[15] Klohn Crippen Berger, 2020.

[16] Klohn Crippen Berger Ltd. (Klohn Crippen Berger). 2019. *Resolution Copper Project: Skunk Camp Site Investigation.* Doc. # CCC.03-81600-EX-REP-00012 - Rev.0. Phoenix, Arizona: Klohn Crippen Berger Ltd. November 1.

[17] Klohn Crippen Berger, 2020.

[18] Klohn Crippen Berger, 2020.

Hydrologic Performance

The TSF cover design will be evaporative store-and-release due to the arid climate conditions at the project and the hydrologic properties of Gila conglomerate. Evaporative store-and-release cover types provide a "storage layer" that collects precipitation which will be released by runoff or evaporation and evapotranspiration. The laboratory soils analysis concluded that Gila conglomerate has high saturated hydraulic connectivity (1.03×10^{-3} cm/s) which will facilitate the store-and-release process.[19] A water balance model found that cover thicknesses of 1 to 3 feet of soil-like Gila conglomerate effectively limit infiltration; however, revegetation combined with approximately 2 feet of soil-like Gila conglomerate produced the lowest net infiltration of all the factors that were examined for TSF cover material.[20]

Gila Conglomerate as a Plant Growth Medium

The studies detailed below analyzed the success of Gila conglomerate–derived soils and capping material as plant growth material for reclamation efforts. Gila conglomerate varies in composition based on regional factors, so interpretations of these findings should consider the unique characteristics of the material presented in each study.

Studies of Soils Derived from Gila Conglomerate Bedrock

Lawson[21,22] performed a complementary pair of studies comparing two sandy loam soils: one derived from Arkose bedrock (composed of siltstone, sandstone, and conglomerate containing quartz, feldspar, kaolinitic clay, and iron oxides) and one derived from Gila conglomerate bedrock (composed of cemented quartz sandstone, carbonates, argillite, hornfels, granite, and quartz-feldspar). The studies were intended to support a proposed copper mine in southeast Arizona where the desired climax community was semi-desert grassland with well dispersed shrubs. The Gila conglomerate–derived soils produced greater biomass, plant density, and diversity than Arkose-derived soils in greenhouse studies that examined a seed mix of warm- and cool-season perennial grasses and annual and perennial forbs. Additionally, the Gila conglomerate–derived soils retained 12.9% more soil moisture and supported 2.8 times more vegetation cover than the Arkose-derived soils in field studies.[23,24] Field revegetation studies showed that the Gila conglomerate–derived soils produced 2.8% to 26% vegetation cover 6 months after treatments.[25,26] Although Gila conglomerate–derived soils were favorable to plant growth, they are composed of fine-grained materials, which are more susceptible to wind and water erosion than Arkose-derived soils.

Romig et al.[27] studied historic mine tailings in southwestern New Mexico to examine revegetation 20 years after reclamation. Specific reclamation methods were not included, but the soils and capping

[19] Klohn Crippen Berger, 2020.

[20] Klohn Crippen Berger, 2020.

[21] Lawson, 2011.

[22] Lawson, 2012.

[23] Lawson, 2011.

[24] Lawson, 2012.

[25] Lawson, 2011.

[26] Lawson, 2012.

[27] Romig et al., 2006.

materials were specified as derived from Gila conglomerate. Semi-arid shrub-grassland communities had 18% to 78% vegetation cover 20 years after reclamation with Gila conglomerate–derived cover materials.[28]

Studies of Gila Conglomerate Bedrock Capping Material

Vinson et al.[29] and Milczarek et al.[30] examined revegetation success in areas where Gila Conglomerate was used as a monolayer evapotranspiration cover at a tailings facility in southeast Arizona. The material was cobbly, gravelly sandy loam and spread between 30 and 60 cm thick. The applied seed mix included native and non-native grasses, shrubs, and trees. Less than 1 year after reclamation treatment, biomass ranged from 12 to 97 pounds per acre, and germination rates ranged from 3% to 9%.[31] The areas of Gila conglomerate that were amended with biosolids and areas with cattle grazing had more productive vegetation growth than where the material was not amended; however, the biosolids increased soil salinity.[32] Organic amendments and mulch treatments allowed vegetation cover to increase to 11% to 71% in the first year and to 23% to 77% by year 12.[33] The amount of capping material (30 to 60 cm) did not impact vegetation cover and infiltration was limited to a depth of 180 cm, regardless of cover thickness.[34]

These findings support Klohn Crippen Berger's[35] conclusions that processing coarse-grained Gila conglomerate into finer materials may increase its suitability as a plant growth medium, especially to improve its water-holding capacity at the beginning of reclamation before weathering affects the material. Additionally, these findings further indicate that adding organic amendments to increase soil fertility will enhance restoration success over time.[36,37]

Summary and Conclusions

The outcomes of the literature and studies reviewed in this technical memorandum indicate the following:

- Gila conglomerate at or near the project occurs in sufficient quantity and quality to be the closure material for the proposed TSF.[38]
- Laboratory data indicate that Gila conglomerate is a slightly acidic to slightly alkaline material (pH 6.7 to 8.2), is not potentially acid generating, and has a high net neutralization potential.[39] Total nitrogen and organic carbon concentrations are low (<0.1% to 0.2% and 0.03% to 1.3%,

[28] Romig et al., 2006.

[29] Vinson et al., 1999.

[30] Milczarek et al., 2011.

[31] Vinson et al., 1999.

[32] Vinson et al., 1999.

[33] Milczarek et al., 2011.

[34] Milczarek et al., 2011.

[35] Klohn Crippen Berger, 2020.

[36] Vinson et al., 1999.

[37] Milczarek et al., 2011.

[38] Klohn Crippen Berger, 2020.

[39] Klohn Crippen Berger, 2020.

respectively).[40] Salt concentrations ranged from 248 to 528 µS/cm and organic matter ranged from 0.1% to 2.2%, which is on scale with organic matter measured in natural surface soils in the area.[41,42] Additionally, the material has both high saturated hydraulic conductivity (1.03×10^{-3} cm/s) and low water-holding capacity (0.13 cm/cm].[43]

- Revegetation efforts using Gila conglomerate as a capping material or growth medium have been generally successful in mining reclamation projects. These successes have been documented in southwestern New Mexico and southern Arizona where revegetation efforts have been focused on reestablishing native and non-native perennial grasses, perennial and annual forbs, shrubs, and trees.[44,45,46,47,48]
- The degree of revegetation success varies on the qualities of the Gila conglomerate–derived material, reclamation and revegetation treatments, and elapsed time between treatments. For Gila conglomerate–derived soils, vegetation cover has been documented ranging from 2.8% to 26% less than 1 year after applying treatments.[49,50] For surfaces using crushed Gila conglomerate as a capping material, vegetation cover ranged from 11% to 71% 1 year after treatment and 23% to 77% by year 12.[51]
- To prevent erosional losses of soil-like Gila conglomerate, some areas (e.g., surface channels) within the TSF will be covered with approximately 3 feet of coarse Gila conglomerate, which will allow the material to self-armor and minimize erosion throughout the facility.[52]
- Organic amendments, mulch, and other soil treatments may increase revegetation success, especially when crushed Gila conglomerate is the primary plant growth medium. Soil amendments and treatments may increase the soil water-holding capacity and soil fertility and decrease the erosional susceptibility of Gila conglomerate.[53,54,55,56]

[40] Klohn Crippen Berger, 2020.
[41] Klohn Crippen Berger, 2020.
[42] Klohn Crippen Berger, 2019.
[43] Klohn Crippen Berger, 2020.
[44] Vinson et al., 1999.
[45] Milczarek et al., 2011.
[46] Lawson, 2011.
[47] Lawson, 2012.
[48] Romig et al., 2006.
[49] Lawson, 2011.
[50] Lawson, 2012.
[51] Milczarek et al., 2011.
[52] Klohn Crippen Berger, 2020.
[53] Lawson, 2011.
[54] Milczarek et al., 2011.
[55] Klohn Crippern Berger, 2020.
[56] Vinson et al., 1999.