USDA Forest Service
Tonto National Forest
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# Process Memorandum to File

## Gila Conglomerate and Cover Material Summary



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## Purpose of Process Memorandum

Gila Conglomerate has been identified as the primary cover material for the tailings storage facility proposed for the Resolution Copper Project and Land Exchange (herein called the project) (Resolution Copper Mining, LLC [Resolution Copper] 2016). The goals of the tailings closure cover and associated reclamation include the following:

- Create a stable surface, where vegetation is established that limits infiltration and protects quality of surface water runoff
- Prevent ponding of water on surface of tailings
- Facilitate potentially acid generating (PAG) tailings saturation to prevent exposure to oxidation
- Protect tailings and closure cover from wind and water erosion
- Create a growth medium that supports establishment of long-term, sustainable vegetation cover.

Gila Conglomerate, which has been successfully applied as a cover material in other tailings storage facility reclamation projects, is the preferred cover material to create a store-and-release (evapotranspiration) cover at the project's Near West tailings storage facility. Gila Conglomerate has been recommended for the following reasons: (1) its borrow source is available near the Near West tailings storage facility; (2) it is relatively easy to extract; (3) it is relatively unreactive; (4) it has measurable acid neutralization potential; and (5) it weathers readily into finer-grained material for plant growth media (Klohn Crippen Berger Ltd. [KCB] 2016).

A number of studies examined Gila Conglomerate's effectiveness as a cover material for tailings storage facilities. The purpose of this process memorandum is to summarize information for the U.S. Department of Agriculture Forest Service regarding the following:

- Physical and chemical characteristics of Gila Conglomerate, particularly its characteristics within proposed borrow areas of the project's proposed Near West tailings storage facility;
- The hydrologic performance of Gila Conglomerate as a store-and-release (evapotranspiration) cover material; and
- Past studies demonstrating the suitability and effectiveness of Gila Conglomerate as a plant growth medium for revegetation efforts along tailings storage facility surfaces.

## Key Process Steps

A literature review was completed to summarize current information regarding the characteristics and potential performance of Gila Conglomerate as a capping material and plant growth medium. Gila Conglomerate has been applied widely as a cover and plant growth material in Arizona mining operations (KCB 2016), and many studies and projects have documented its performance (KCB 2016;

Lawson 2011, 2012; Milczarek et al. 2011; Romig et al. 2006; Vinson et al. 1999). While the characteristics of Gila Conglomerate vary widely, some studies have characterized the nature, extent, and properties of Gila Conglomerate within or near the footprint and proposed borrow sites of the Near West tailings storage facility (KCB 2014, 2016, 2017).

# Key Findings

## Physical and Chemical Characteristics of Gila Conglomerate

### General Characteristics and Distribution

The Gila Conglomerate proposed for tailings cover material is expected to be extracted from Borrow Areas 5 and 6, just east of the Near West tailings storage facility (Resolution Copper 2016), which have been calculated to be sufficient to meet the closure cover needs of the tailings storage facility (KCB 2014). The Gila Conglomerate and associated Gila Sandstone in this area were derived from a series of coalescing alluvial fans deposited during the middle Tertiary along the northern and eastern flanks of the Superstition Mountains (KCB 2017). The Gila Conglomerate underlies 55% of the proposed Near West tailings storage facility footprint, where it reaches thicknesses up to 410 feet (KCB 2017). The Gila Conglomerate is regionally variable in composition and texture, but in general, it is a massive to subhorizontally bedded, well-graded conglomerate with particle sizes ranging from fines to boulders that may be clast- or matrix-supported (KCB 2014). At the proposed Near West tailings storage facility, crushed Gila Conglomerate has a composition of 0 to 11% fines, 18% to 45% sand, and 58% to 86% gravel, and most commonly has less than 30% matrix composed of fine to coarse sand with trace silt (KCB 2017). The strength of Gila Conglomerate decreases significantly with weathering or soaking in water (i.e., slaking) (KCB 2017). Therefore, fragments of the Gila Conglomerate's sandy matrix are likely to break down into finer-grained material as natural weathering occurs.

### Physical and Chemical Characteristics

A closure cover study for the proposed Near West tailings storage facility was completed in 2016, which characterized the physical and chemical properties of Gila Conglomerate and assessed its hydrologic performance as a closure material for the proposed store-and-release tailings cover material (KCB 2016). Sampling and laboratory characterization included analyses of Gila Conglomerate collected from surface exposures and stockpiles from the nearby Superior Mine nearby the Near West tailings storage facility. Characterization included: particle size distribution, moisture content, specific gravity, Atterberg limits, and modified proctor, acid base accounting, total elemental analysis, static leach tests, total organic carbon, organic matter, and available nutrients, saturated hydraulic conductivity, and moisture retention curves (KCB 2016).

Physical and chemical characteristics of the Gila Conglomerate (relevant to its hydrologic and plant-growth supporting performance) are provided in Table 1 below (data from KCB 2016). Laboratory data indicate that Gila Conglomerate is a neutral to slightly alkaline material (pH 7 to 8.2), not potentially acid generating (NPAG), and has a high net neutralization potential (NNP) (NNP in excess of 2) (KCB 2016). Gila Conglomerate has both high saturated hydraulic conductivity (up to 8.2 ×

$10^{-1}$ cm/cm) and low water-holding capacity (0.06 to 0.11 cm/cm) (KCB 2016). Salt concentrations are generally low (most conductivity measurements ranging from 270 to 500 µS/cm) but may be as high as 4,340 µS/cm. Organic matter ranged from 1.6% to 3.2%, which is on scale with organic matter measured in natural surface soils in the area (KCB 2016; Natural Resources Conservation Service [NRCS] 2017). Total Nitrogen ranged from <0.02% to 0.028%, and organic carbon ranged from 1.6% to 3.2% (KCB 2016; NRCS 2017).

**Table 1. Laboratory Analysis Results for Gila Conglomerate**

| Analyte | Unit | Minimum Value | Maximum Value |
|---|---|---|---|
| Net Neutralization Potential | g/$CaCO_3$/kg | 11 | 296 |
| Neutralization Potential Ratio | ratio | 11 | 752 |
| Paste pH | | 7.0 | 8.2 |
| Acid Generating Potential (AGP) | g $CaCO_3$/kg | <0.5 | 1.6 |
| Paste Conductivity | µS/cm | 240† | 4,340† |
| Organic Carbon | % | 1.5 | 3.2 |
| Organic Matter | % | 1.6 | 3.2 |
| Total Nitrogen | % | <0.02 | 0.028 |
| Phosphorus* | ppm | 234 | 1,220 |
| Potassium* | ppm | 2,010 | 4,720 |
| Sulfur* | ppm | <500 | <500 |
| Available Water Holding Capacity | cm/cm | 0.06 | 0.11 |
| Saturated Hydraulic Conductivity | cm/s | $1.7 \times 10^{-1}$ | $8.2 \times 10^{-1}$ |
| Bulk Density | g/$cm^3$ | 1.66 | 1.83 |

Source: KCB (2016)

*Phosphorus, potassium, and sulfur analyses were strong acid extracts, which are not standard methods used for agronomic (or plant available) interpretations.

† KCB (2016) indicates that most conductivity values range from 270 to 500 µS/cm.

### Hydrologic Performance

As part of the project's *Near West Tailings Storage Facility Closure Cover Study*, the hydrologic performance of closure materials was assessed through a water balance analysis (KCB 2016). The study concluded that the climate of the proposed Near West tailings storage facility is conducive to an earthen store-and-release cover, as precipitation is low relative to the potential evapotranspiration.

The water balance analysis included assessment of physical and hydraulic properties of the Gila Conglomerate, PAG tailings, and NPAG tailings. The coarser-grained Gila Conglomerate had high hydraulic conductivity ($1.7 \times 10^{-1}$ to $8.2 \times 10^{-1}$ cm/s) and rates of infiltration as compared with the hydraulic conductivity of the finer-grained PAG tailings ($7.5 \times 10^{-8}$ cm/s) and the NPAG tailings ($2.3 \times 10^{-4}$ to $6.3 \times 10^{-7}$ cm/s) (see Table 1) (KCB 2016).

The water balance analysis and associated modeling suggests the combination of Gila Conglomerate and NPAG tailings (whether layered or blended) are expected to meet the needs and objectives of reclamation. Specifically, the analysis indicates that the saturation of PAG tailings is predicted to remain high (85% or greater, as required to prevent oxidation of pyrite minerals) if covered by either 1) NPAG tailings with vegetated Gila Conglomerate cover, or 2) blended NPAG tailings with Gila Conglomerate (KCB 2016). The modeling also suggests that this design of store-and-release cover, if successfully planted with native vegetation, will reduce net infiltration to less than 3% of annual precipitation (KCB 2016).

## Gila Conglomerate as a Plant Growth Medium

Several studies have examined the efficacy of Gila Conglomerate capping material and soils derived from Gila Conglomerate as a plant growth material, specifically for reclamation efforts (Lawson 2011, 2012; Milczarek et al. 2011; Romig et al. 2006; Vinson et al. 1999). Gila Conglomerate as a bedrock and soil parent material can be highly variable in composition and degree of weathering, so interpretation of these findings should consider the characteristics of the material used in each study.

### Studies of Soils Derived from Gila Conglomerate Bedrock

In a complementary set of studies, Lawson (2011, 2012) investigated two sandy loam soils derived from two bedrock sources—Arkose bedrock (a complex rock unit including siltstone, sandstone, and conglomerate containing quartz, feldspar, kaolinitic clay, and some iron oxides) and Gila Conglomerate bedrock (containing cemented quartz sandstone, carbonates, argillite, hornfels, granite, and quartz-feldspar). The studies were completed to support a proposed copper mine located in southeast Arizona, where the desired climax community was a semi-desert grassland with well-dispersed shrubs. Greenhouse studies showed that soils derived from Gila Conglomerate yielded greater biomass, plant densities, and diversity than soils derived from Arkose bedrock. The seed mix applied in the field trials was based on outcomes of greenhouse studies and included a mixture of warm- and cool-season perennial grasses, annual forbs, and perennial forbs. The field studies showed that Gila Conglomerate-derived soils retained 12.9% more soil moisture and supported 2.8 times the vegetation cover than Arkose-derived soils (Lawson 2011, 2012). Six months after field revegetation treatments, vegetation cover for Gila Conglomerate-derived soils ranged from 2.8% to 26% (Lawson 2011, 2012). While Gila Conglomerate-derived soils do have favorable characteristics for plant growth, this material is finer-grained than Arkose-derived soils and is, therefore, more susceptible to wind and water erosion.

In a study of historic mine tailings in southwestern New Mexico, Romig et al. (2006) examined the success of revegetation efforts 20 years after reclamation. The reclamation methods are not detailed, but the authors describe the soils (or capping material) applied along the tailings surface to be derived from Gila Conglomerate. At the time of survey (20 years after reclamation), vegetation cover of the reclaimed semi-arid, shrub-grassland community ranged from 18% to 78%.

#### Studies of Gila Conglomerate Bedrock Capping Material

In their study of a monolayer evapotranspiration cover at a tailings facility in southeast Arizona, Vinson et al. (1999) and later Milczarek et al. (2011) reported revegetation success within areas where Gila Conglomerate was used as a capping material, ranging from 30 cm to 60 cm thick. The Gila Conglomerate applied was classified as a cobbly, gravelling sandy loam, and the seed mix applied included native grasses, shrubs, and trees, and select non-native grasses. Less than 1 year after reclamation treatment there were some signs of success: biomass ranged from 12 to 97 lb/acre; and germination rates varied from 3% to 9% (Vinson et al. 1999). Within these initial time frames, Gila Conglomerate amended with biosolids and areas where cattle were allowed graze had more productive vegetation growth than areas of unamended capping material. However, biosolids treatments increased salinity (Vinson et al. 1999). Soil amendments appeared to increase restoration success in later stages of the study, as both organic amendments and mulch treatments enhanced vegetation cover (Milczarek et al. 2011). One year after treatments, vegetation cover ranged from 11% to 71%, and by year 12 vegetation cover ranged from 23% to 77% (results for all treatments combined) (Milczarek et al. 2011). Thickness of the Gila Conglomerate cap did not impact vegetation cover, and both thicknesses of Gila Conglomerate tested effectively limited infiltration at a depth of 180 cm (Milczarek et al. 2011).

These findings seem to support the conclusions of KCB (2016) that additional processing of the very coarse-grained Gila Conglomerate may be required to increase its suitability as a plant growth medium, specifically to improve its water-holding capacity at the beginning of reclamation before the conglomerate has weathered into finer-grained material. These findings further may also indicate that organic amendments can enhance restoration success by increasing soil fertility (Milczarek et al. 2011; Vinson et al. 1999).

## Summary and Conclusions

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

- Gila Conglomerate occurs in sufficient qualities (on- or near-site) to be the closure material for the proposed Near West tailings storage facility (KCB 2014).
- Laboratory data indicate that Gila Conglomerate is a neutral to slightly alkaline material (pH 7 to 8.2), is not potentially acid generating, and has a high net neutralization potential (KCB 2016). Gila Conglomerate has both high saturated hydraulic conductivity and low water-holding capacity. Salt concentrations are generally low (most conductivity measurements ranging from 270 to 500 µS/cm). Organic matter ranged from 1.6% to 3.2%, which is on scale with organic matter measured in natural surface soils in the area (KCB 2016; NRCS 2017). Total Nitrogen ranged from <0.02% to 0.028%, and organic carbon ranged from 1.6% to 3.2% (KCB 2016).
- Revegetation efforts using Gila Conglomerate bedrock as a capping material or revegetating surface soils derived from Gila Conglomerate have been generally successful in mining reclamation projects. These successes have been demonstrated in southwestern New

Mexico and southeast Arizona, where revegetation efforts have been aimed at reestablishing native and warm- and cool-season perennial grasses, annual forbs, and perennial forbs, some shrubs, and trees (Lawson 2011, 2012; Milczarek et al. 2011; Romig et al. 2006; Vinson et al. 1999).

- The degree of revegetation success varies depending on the nature of the Gila Conglomerate-derived material, reclamation and revegetation treatments, and time since revegetation/reclamation treatment. For Gila Conglomerate-derived soils, vegetation cover has been shown to range from 2.8% to 26%, less than 1 year after treatments were applied (Lawson 2011, 2012). For surfaces capped by crushed Gila Conglomerate, vegetation cover varied from 11% to 71% one year after treatment, and by year 12, vegetation cover ranged from 23% to 77% (Milczarek et al. 2011).
- Areas with steep slopes or drainages may require some surface mulch or rip-rap to prevent erosional losses of Gila Conglomerate (Lawson 2011). For example, material such as Pinal schist has been identified as a potential erosion control cover material for the Near West tailings storage facility (Resolution Copper 2016).
- Soil amendments, such as organic amendments and mulch treatments, may help increase the success of revegetation, particularly when crushed Gila Conglomerate bedrock is the primary plant growth medium. Amendments may increase soil water-holding capacity of the Gila Conglomerate, increase soil fertility, and decrease erosion susceptibility (KCB 2016; Lawson 2011; Milczarek et al. 2011; Vinson et al. 1999).

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