Hydrogeology Baseline Report

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1 Introduction

This document presents a summary of the baseline hydrogeology for the area where the Roşia Montană Project (the Project) is located. The objectives of this document are as follows:

- Provide a summary of the physiography and geology of the Project and associated area that relates to the hydrogeology; and,

- Present the hydrogeologic framework for the Project, including a summary of field activities and resulting data and a conceptual level hydrogeological model.

The information included in this document was summarised from existing documents (see Section 5) and data collected during the field investigations conducted in 2003. More detail on individual topics may be located in the source documents listed in Section 5.
2 Physiography

The Project lies near the village of Roșia Montană in Alba County, Romania, approximately 80 kilometers (km) northwest of the regional capital of Alba Iulia, and 85 km north-northeast of the City of Deva in west-central Romania. This general region in the Apuseni and Metaliferi Mountains of Transylvania is known as the “Golden Quadrilateral”. Specifically, the Project is located within the Roșia Montană mining district, located immediately northeast of the town of Abrud within the Apuseni Mountains near the headwaters of the Corna, Saliste and Roșia Valleys.

The Corna, Saliste and Roșia Valley watersheds all flow towards the Abrud River. The Corna Valley watershed drains southwest to the Abrud River just upstream of the town of Abrud, and the Saliste and Roșia Montană Valley watersheds flow west to the Abrud River further downstream. The area is marked by moderately steep mountainous terrain with the upper portions of the mining district at an elevation of just over 1,000 meters and the lower portions of the district below 700 meters. An overview of the Project area under 2004 conditions along with watershed areas is shown on Figure 2-1, Existing Conditions with Watershed Areas. The site development plan at Year-07 is presented in Figure 2-2, Conditions at Year 7 with Watershed Areas.

As presented in these figures, the following Project features are currently contained, or will exist, in each of the valleys:

- Roșia Valley - This valley currently contains the Cârnic and Cetate pits and associated waste rock stockpiles. Following Project development, this watershed will contain the four proposed pits (Cetate, Cârnic, Orlea and Jig pits), Cetate Waste Rock Stockpile, Cetate Water Catchment Pond and Dam, and the northeast portion of the plant site area. As a result of the planned grading activities, the entire Plant site will eventually drain to the Roșia Valley.

- Saliste Valley - This valley currently contains the Saliste Tailings Impoundment, which is used for tailings disposal by the current mining operation. This facility is not a feature of the proposed Project. This valley will also contain the southwest portion of the Plant site area and possibly the proposed topsoil pile located adjacent to the Low Grade Ore Stockpile. However, after grading the Plant site area, drainage will be to the Roșia Valley.

- Corna Valley - This valley will contain the Cârnic Waste Rock Stockpile, Cârnic Seepage Collection Ponds, and the Tailings Management Facility (TMF), consisting of the tailings impoundment, tailings dam, and Secondary Containment System (SCS).
Figura 2.1. Existing Conditions with Watershed Areas
Figura 2.2. Conditions at Years 7 whit Watershed Areas
3 Geologic Setting

The geologic setting as it is generally relevant to the groundwater conditions in the Project area is presented here. Additional geologic information is presented within the text of the EIA in Sections 4.4, Soil and 4.5, Geology.

3.1 Surficial Geology

The undisturbed surficial geology in the Project area consists predominately of alluvium, colluvium, and rock outcrop. The unconsolidated deposits may be up to 12 meters thick along the valley bottoms and 3 to 10 meters thick on the valley slopes. These unconsolidated materials within the Project area consist dominantly of Quaternary alluvial deposits along the valley floors and colluvial soils along the valley slopes. The alluvial deposits along the valley bottoms contain a variety of sediment types ranging from silty clay to limited intervals of clean sand, gravel and cobbles in a fine-grained matrix mostly along the stream channels.

The material generally classified as colluvium is a mixture of true colluvium (a mass of soil and rock fragments derived from mass wasting and down-slope movement) and deep soil residuum derived from in-place weathering of the bedrock resulting in soil or unlithified silty clay. The colluvial and residual soils on the valley slopes are up to 10 meters thick. The predominant soil types in these deposits are fine grained clayey and cohesive in nature. The colluvial deposits dominate the surficial exposure of the Corna Valley. There are also deposits of mine waste rock in the upstream portions of the Corna Valley generated from historic mining activities. The surficial geology in the Roşia Valley is similar to Corna Valley. However, the surficial materials are more disturbed and variable because of the existing mining activities, increased habitation and greater variability in bedrock geology.

Rock outcrops, typically consisting of the shale and/or sandstone units, occur in locations along the ridgelines associated with both valleys. In addition, the higher elevations along ridgeline are often capped by volcanic andesite. Outcrops of volcanic rocks are more common in the Roşia Valley.

3.2 Bedrock Geology

The bedrock geology in the Project area influences groundwater flow due to its properties of water transmission, and also because it acts as the source material for the shallow water bearing soils and colluvial units. As such, a general geologic description of the project area bedrock geology is presented here. Figure 3-1, Project Site Geologic Map, presents a simplified geologic map of the Project Area. A detailed discussion on Project area geology is presented in Section 4.5, Geology, of the EIA Report. The geologic features that have the most significance for water flow in the Project area are briefly discussed below.

Bedrock in the Project area, outside of the mine area and beneath the key ancillary Project facilities, largely consists of Cretaceous sedimentary deposits that are predominantly black shale with interbedded sandstone with some conglomerate which are interpreted as a flysch rock sequence. Bodies of volcanic rocks and phreatomagmatic breccias from the late Tertiary (Neogene) period intruded and overlay the sedimentary units in the Project area. Mineralisation is strongly associated with phreatomagmatic breccias pipes and dacitic intrusives.
The main unmineralised rock types within the Project area are described below.

- **Black shales** - this Cretaceous-aged sedimentary sequence, also described as flysch or argillaceous marl schist, typically consists of interbedded shale and fine to medium grain sandstone. Local thin conglomerate beds are also present. The unit is characterised by calcite veins within the sandstone, variable bedding orientation and occasional weak and/or brecciated zones. This unit comprises the bedrock typical of much of the Project area outside of the mine area and forms the foundation of the proposed TMF, SCS and Cetate Water Catchment Dam embankments.

- **Vent breccia** - in the form of microconglomerates and tuffaceous grits, described as medium grain volcaniclastics (i.e., sedimentary rock composed mainly of particles of volcanic origin) from the late Tertiary period (Neogene). The vent breccias are generally massive. The vent breccia may be mineralised in portions of the Rosia Valley and it can be a significant ore host. Some vent breccia is present in the upper portion of the Corna Valley were it borders the ore body.

- **Andesitic agglomerate** - this rock type has been mapped in several locations near the head of the Corna Valley and on the ridge between the Corna and Salistei Valleys, but lies outside the planned TMF. Extensive outcrops of the andesite occur on the east and north ridges bordering the upper Rosia Valley. (The term agglomerate denotes a chaotic assemblage of coarse angular pyroclastic material.)

While not considered a primary rock type, there are local blocks of limestone outliers (olistolites) that were observed just upstream of the TMF embankment centerline and near the right abutment. Based on drilling and site-specific mapping, the limestone blocks are not considered to be rooted and no karst formation is expected.

Mineralisation in the Rosia Valley is hosted in dacite that has been intruded in to the vent breccia, vent breccia, and other phreatomagmatic breccias. Relatively minor areas of mineralised sedimentary rock are also present (see Section 4.5, *Geology*, for more detail).

### 3.3 Corna Valley Area Geology

The primary Project feature in the Corna Valley will be the TMF. Much of the geologic characterisation has, therefore, focused on the key features associated with this facility. In particular, the TMF dam area has been evaluated in detail. Subsequent to much of the evaluation, the planned alignment was moved approximately 150 metres up-valley. Much of the following discussion is focused on the results for the investigations of the old alignment, but geology is not expected to be significantly different at the new location. Detailed assessment of the new location will be conducted as part of final design studies.

Bedrock beneath the TMF dam is a sequence of foliated shale (black shale) with interbedded sandstone and shale breccia. Fresh, unconsolidated clay, typically 15 to 30 centimetres (cm) in thickness and mixed with granular material (fault gouge, breccia and/or weathered bedrock), was observed within the shale unit. Figure 3.2, *Schematic Geological Profile along Tailings Dam*, provides a generalised geologic section across Corna Valley.

Investigation of the geology of the Corna Valley found that the bedrock on the east and west slopes and in the flood plain near the proposed TMF Dam, consist mainly of Cretaceous cleavable schistose shale interbedded with fine gritstone (coarse sandstone) with calcareous cement. The shale and more often the gritstones contain narrow fractures and cleavage surfaces, with millimetre and sub-millimetre openings, most of them cemented with calcite. The shale unit dips 30 to 55 degrees in a southerly direction.
Figura 3.1. Project Site Geologic Map
Within this unit, intensely micro-folded layers with random structure and, sometimes, with breccia-like rock debris were observed, typical of a tectonic flysch sequence. Figure 3.3, **Hydrogeologic Cross-Sections**, presents typical cross sections through the Corna Valley illustrating the depth to bedrock and other features. It has also been found that black shale units of two different Cretaceous subdivisions are present in the valley. Upper Cretaceous (Maastrichtian) and Lower Cretaceous (Albian) units located on the southeast and northwest sides of the valley, respectively (see Figure 3.2).

Limestone blocks of various sizes are present regionally in this rock complex. In the geological literature, these exotic blocks, are known as olistoliths. A large olistolith is present on the right slope near the proposed TMF dam alignment at an elevation of approximately 800 meters, as indicated by two distinct limestone outcrops in this area. The limestone block is not rooted and no karst features (e.g., sinkholes, caves and underground drainage) were observed.

An airborne magnetic survey was conducted over the Roșia Montană – Bucium survey block (RSG, 2001). An interpretation of the survey results revealed numerous linear features that were interpreted to be faults. The survey results revealed two dominant conjugate sets of faults trending north-northwest and east-northeast. An older, north-south trending set of faults can also be traced and appeared to be associated with mineralisation. An inclined borehole was advanced across one of the north-northeast interpreted faults in the lower part of the valley to a depth of 90 meters (along the incline) with the objective of defining the presence and condition of this potential fault. A shear zone consisting of coarse-grain breccia (different from the rock above and below) was encountered and was identified as likely being a minor fault. Good core recovery was obtained from this borehole and the brecciated zone was packer tested to evaluate its hydrogeologic properties, as described in Section 4.1 of this report.
3.4 Roşia Valley Area Geology

The Roşia Valley contains most of the altered and mineralised volcanic sequences that host the ore body. These include dacite and volcanic breccias of various types. Overburden within the Cetate Water Catchment Dam area is predominantly residual and/or colluvial soils, approximately two to seven meters thick. The alluvium within the valley consists mainly of clayey-silt/silty-clay either as a main constituent or as a matrix within a coarser fraction including gravel and some cobbles and boulders. Figure 3-3, Hydrogeologic Cross-Sections, provides a geologic section across the Cetate Dam site. Bedrock beneath the Cetate Dam area consists mainly of black shale with interbedded sandstone. The rock core recovered from boreholes advanced at the Cetate Water Catchment Dam alignment have been identified as predominantly sandstone with interbeds of shale grading to shale with interbeds of sandstone. The bedrock is highly weathered and fractured within the upper four to eight meters and becomes more competent with depth.
Figure 3.3. Hydrogeologic Cross-Sections
4 Hydrogeologic Setting

This section describes the hydrogeologic setting of the Roșia Montană Project. First described are the physical data sources that were used to develop the characterisation of the hydrogeological conditions (Section 4.1, Data Sources). Reports that contributed to this database are summarised in Section 5. A general description of the principal hydrogeologic units is then provided (Section 4.2, General Hydrogeologic Units). This is followed by a presentation of data on groundwater recharge and discharge, which provides an indication of the hydrogeological flow conditions (Section 4.3, Groundwater Recharge and Discharge). Section 4.5, Summary Hydrogeologic Model, presents a generalised hydrogeological model for the Project area. This model provides a visualisation of how groundwater moves in the general hydrogeological framework of the site.

4.1 Data Sources

The hydrogeology of the Project area has primarily been evaluated through extensive drilling programs that were conducted at the site in 2000 and 2003.

The 2000 drilling program consisted of 100 boreholes within the following areas:

- Plant site area;
- Open Pits area;
- Corna Valley (proposed TMF and SCS areas);
- Cârnic and Cetate Waste Rock Stockpile areas;
- Infrastructure area, including the water management dams (Cetate Dam), site access roads and future by-pass roads;
- Quarry borrow areas.

Forty-seven of these boreholes were completed as piezometers for monitoring groundwater levels. These piezometers were installed in the overburden and the bedrock as follows:

- 14 piezometers in the Plant area;
- 15 piezometers in the TMF area;
- 7 piezometers in the Infrastructure areas; and
- 11 piezometers in the Waste Rock Stockpile areas.

During drilling, 39 packer tests were conducted for estimating hydraulic conductivities in the bedrock. Additionally, after completion of the piezometers, 45 slug or pump tests were conducted in the piezometers located in the Corna Valley, the Waste Rock Stockpile areas and the Infrastructure areas.

An additional geotechnical investigation was conducted in 2003. During this investigation, the following work was performed:

- 15 drill holes were completed and sampled (standard penetration testing and continuous coring) in the TMF Dam area (7), the SCS area (4), and the Cetate Dam area (4);
- 137 water pressure tests were conducted in bedrock beneath the TMF, SCS and Cetate Dam centerlines;
- Soil and rock samples were submitted for laboratory geotechnical testing, including triaxial, consolidation and index properties testing;
• 17 piezometers were installed in the Plant area; and
• 4 piezometers were installed in the TMF area.

Water levels were measured in the piezometers on a biweekly basis since April 2002. These water level data were used to generate a potentiometric surface map of the unconfined (water table) using water level elevations measured on January 7 and 8, 2004. These data have been used to construct a potentiometric surface map to illustrate the shallow groundwater flow conditions. This map is presented as Figure 4-1, Water Table Contours – Site-Wide. Hydrographs for the period April 2002 to May 2004 were also generated using these data, and are presented in Appendix A.

4.2 General Hydrogeologic Units

The primary stratigraphic units and their typical hydrogeologic properties are summarised in Table 4.1, Summary of Primary Stratigraphic Units and their Hydrologic Properties, below, and further described in this section.

Table 4.1 Summary of primary stratigraphic units and their hydrological properties

<table>
<thead>
<tr>
<th>Stratigraphic Unit</th>
<th>Description</th>
<th>Hydrogeologic Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium (Stream channels</td>
<td>Silty-clay and clayey-silt deposits with highly variable and localised</td>
<td>Clean sand and gravel zones act as local aquifers. Average hydraulic</td>
</tr>
<tr>
<td>and floodplain)</td>
<td>amounts of gravel and cobbles. Includes layers of clean sand and</td>
<td>conductivity is relatively high in the range of $2 \times 10^{-4}$ to $3 \times 10^{-2}$ cm/s.</td>
</tr>
<tr>
<td></td>
<td>gravel located in the stream beds, 10 to 80 meters wide and up to 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>meters deep, especially noted in Corna Valley.</td>
<td></td>
</tr>
<tr>
<td>Colluvium (with soil)</td>
<td>Primarily clayey silt and silty clay with some sand and gravel, 3 to</td>
<td>Low water-bearing capacity. Average hydraulic conductivity of approximately $1 \times 10^{-6}$ cm/s.</td>
</tr>
<tr>
<td>(Valley slopes)</td>
<td>10.5 meters thick.</td>
<td></td>
</tr>
<tr>
<td>Upper (Shale) Bedrock</td>
<td>Highly weathered and fractured interbedded shale, sandstone, breccia and</td>
<td>Generally water bearing only through fracture network and has only low regional capacity.</td>
</tr>
<tr>
<td></td>
<td>gouge in the upper 40 meters. Located directly beneath the alluvium within the flood plain and colluvium along the valley slopes.</td>
<td>However, may be moderately water bearing through the joints and bedding planes. Hydraulic conductivity values range from $1 \times 10^{-5}$ to $1 \times 10^{-4}$ cm/s.</td>
</tr>
<tr>
<td>Lower (Shale) Bedrock</td>
<td>Increasingly competent with depth, the lower bedrock is interbedded shale and sandstone with minor gouge and breccia intervals.</td>
<td>Low capacity other than through localised joints, fracture network or shear zones. Hydraulic conductivity ranges from $6 \times 10^{-7}$ to $1 \times 10^{-5}$ cm/s.</td>
</tr>
<tr>
<td>Dacite and Andesite</td>
<td>Generally competent bedrock.</td>
<td>Low capacity other than localised through fracture network or fault zones. No piezometers were installed in this rock type. Characterised as a low hydraulic conductivity unit ($&lt; 1 \times 10^{-5}$ cm/s).</td>
</tr>
<tr>
<td>Vent Breccia and Black Breccia</td>
<td>Typically soft rock.</td>
<td>Limited flow may occur through fractures or naturally formed zones of enhanced permeability. Low hydraulic conductivity ($&lt; 1 \times 10^{-5}$ cm/s).</td>
</tr>
</tbody>
</table>
Figura 4.1. Water Table Contours – Site – Wide
Alluvium

Alluvium occurs along the valley bottoms within the extent of the current stream channels. These surface deposits of alluvium in the stream valleys are up to a maximum of 12 meters thick, and may act as local aquifers with locally high hydraulic conductivity. The hydraulic conductivity of the alluvial deposits was estimated to be relatively high, up to $1 \times 10^{-2}$ cm/s. Pumping tests were conducted in five piezometers within the TMF basin. Two piezometers were slug tested in the Waste Rock Stockpile Areas to estimate hydraulic conductivities. Within the original TMF dam alignment, all five piezometers were located near the centerline of either the main or secondary containment dams. Within each piezometer, several tests were conducted. Based on these tests, hydraulic conductivities were estimated to be between $2 \times 10^{-4}$ and $3 \times 10^{-2}$ cm/s. The cut off trench in the starter dam will be excavated through this material and will tie-in to the shale bedrock. This will provide a seepage cutoff for the TMF dam.

Within the Cârnic waste rock stockpile area, one pumping test and one slug test were conducted. Within the Cetate waste rock stockpile, three constant head and two rising head tests were performed. The mean hydraulic conductivities of these wells were $4 \times 10^{-3}$ cm/s (silty-sand) and $4 \times 10^{-5}$ cm/s (clayey-silt/sandy-silt).

Colluvium

Colluvium is generally present in the valleys, except where there are bedrock outcrops or where alluvium is the predominant surface material (e.g., within the valley bottoms/streams). The colluvium observed at the site is a combination of formal colluvium (i.e., soil and rock deposited by water action and/or downslope mass creep) and bedrock residuum or soil (i.e., bedrock completely weathered to a soil or unlithified residuum). The colluvium was observed to be between 3.0 and 10.5 meters thick.

The upper 10 to 40 centimetres (average 15 centimetres) typically consist of organic-rich top soil with rootlets underlain by silty clay to clayey silt as a matrix within variable amounts of sand and gravel sized rock fragments. The fine-grained clayey character of the colluvium is derived from the shale bedrock that is pervasive in the area outside of the ore body and proposed mining. The rock fragments contained in the clayey matrix typically consist of sandstone and/or shale.

The colluvium is the preferred material within the footprint of the TMF as determined by hydraulic testing, because of its low permeability on the order of $1 \times 10^{-6}$ cm/s. This low permeability is the result of the clayey fine-grain content of the material. This fine grained character is inherited from the black shale, which is the dominant bedrock beneath much of the site.

Black Shale

The Cretaceous black shale is found throughout much of the site. Interbedded, cemented sandstone and conglomerate layers occur in the shale, but are laterally and vertically discontinuous and are not considered significant water-bearing units, except in the upper weathered zones. Hydraulic conductivity values of the shale unit were estimated to be $6 \times 10^{-7}$ cm/s to $4 \times 10^{-4}$ cm/s. The hydraulic conductivity generally decreases with depth with values measured less than $1 \times 10^{-5}$ cm/s deeper than approximately 25 meters below ground surface at Cetate and the SCS and 40 meters below ground surface at the TMF.

Dacite/Andesite/Breccia

The bedrock near the Cetate and Cârnic Pits is drained (to an elevation of about 714 meters) because of existing underground workings. No piezometers were installed within the area of the current mining area, since the historical underground mine workings have substantially altered the natural groundwater conditions. However, these rock types (dacite, andesite, breccia) are described as being of low permeability, and hence, have a low potential for groundwater supply.
4.3 Groundwater Recharge and Discharge

Recharge

The main source of groundwater recharge at the mine site is precipitation. The site is in a climatic region classified as continental temperate with strong topographic influences. Winters are cold with snowfalls during four to six months of the year. On average, 76 percent of the precipitation occurs as rain and 24 percent as snow. Snowfall occurs during the winter months and does not contribute to runoff until April and May. Rainfall peaks occur in the summer months. The average precipitation for the period 1965 to 2003 was approximately 700 to 780 mm (National Institute of Meteorology and Hydrology (INMH), 2002).

Discharge

Groundwater discharge occurs primarily through spring flow and stream baseflow within the two primary watersheds. As discussed further in the following section the streams gain groundwater as the result of the low-permeability geologic units and convergent groundwater flow. The average flow rates for the Roșia Valley, Corna Valley and Salistei Valley streams for the period 2001 to 2003 were 0.16, 0.07 and 0.16 m³/s, as measured using permanent weirs. An extensive network of historic underground mine workings are all connected and act as a drain for the upper part of Roșia Valley. This drain discharges to the 714 Adit and into the Roșia Valley stream approximately 500 meters upstream of the Cetate Water Catchment Dam, as shown on Figure 2-2. These underground mine workings will hydraulically connect all of the proposed mine pits with the possible exception of the Jig pit.

High yield water supply wells are not present at the mine site or in the immediate vicinity. The current mining operation acquires its water from surface water supplies.

4.4 Site-Specific Hydrogeologic Conditions

The data collected during the drilling program were used to evaluate hydrogeologic conditions in three specific areas:

- TMF and SCS Area (Corna Valley);
- Plant Area; and
- Cetate Water Catchment Dam Area (Roșia Valley).

The results of the data collected in these areas are described in the following sections.

4.4.1 Tailings Management Facility Area

The shale bedrock present beneath the TMF and SCS has been characterised and designated as upper and lower bedrock. These intervals were characterised based on differences in measured hydraulic conductivity, as well as rock quality designation (RQD) and core recovery. Based on drillholes advanced in the initial dam alignments, the upper bedrock is typically between 8 and 40 meters thick. Additionally, a third division, weathered bedrock, has been identified within the upper bedrock on the northwest abutments only. The weathered bedrock was observed on the northwest abutments of both the starter/TMF dam and the SCS alignments and is between 3 and 20 meters thick. The hydraulic conductivities estimated from water pressure tests and relative RQDs and core recovery for each of the units are as follows:

- Weathered bedrock - 5 x 10⁻⁵ to 2 x 10⁻⁴ cm/s, lowest RQD and core recovery
- Upper bedrock - 2 x 10⁻⁵ to 1 x 10⁻⁴ cm/s, lowest RQD and core recovery
- Lower bedrock - 3 x 10⁻⁶ to 3 x 10⁻⁵ cm/s, highest RQD and core recovery
The hydraulic conductivity of the lower bedrock was previously measured to be as low as $10^{-7}$ cm/s. Additional data will be developed at the revised dam alignment, approximately 150 meters upstream.

An angled borehole was advanced near the large limestone outlier coincident with the northwest abutment of the proposed TMF Dam. The stratigraphic log from this borehole indicates the lithology at this location consists of colluvium, conglomerate, limestone, and breccia. Packer test results in this borehole indicated a hydraulic conductivity of about $4.3 \times 10^{-5}$ cm/s in the conglomerate and $1.0 \times 10^{-3}$ cm/s in the lower colluvium. It is important to note that this variation in hydraulic conductivity values is localized and likely does not significantly affect groundwater flow in the TMF.

One borehole was advanced specifically to intercept one of the inferred faults, located along or near the axis of the Corna Valley. The borehole was packer tested along three intervals. The results of the packer testing indicated that the brecciated fault zone has a hydraulic conductivity on the order of $10^{-6}$ cm/s. This suggests that the fault is a low permeability feature with a hydraulic conductivity similar to the surrounding bedrock. The fault zone is narrow without significant dilation and does not create a significant discontinuity.

The water table within the alluvium/colluvium generally occurs within one meter below ground surface within the valley bottom and up to 20 meters below ground surface along the ridges. The water table at the planned TMF Dam was encountered at 11 to 18 meters below ground surface on the abutments, and one to three meters below ground surface at the centerline. At the proposed SCS alignment, the water table was encountered at two to three meters below ground surface near the southeast abutment and the centerline locations. Along the valley slopes, numerous seeps and springs occur at the contact between geologic units (e.g., the contact between colluvium and upper bedrock).

Water level data collected from April 2002 to January 2004 in the piezometers installed in the Corna Valley (Appendix A) indicate that, in general, water levels are seasonally stable; although water levels in some piezometers did show some seasonal variation. Water level data are continuing to be collected at the site, and these data will be useful to further evaluate seasonal changes in the water table. Water levels measured during January 2004 were used to construct a water table contour map of the area (Figure 4-1). As shown in this figure, the predominant direction of groundwater flow is down the valley slopes and along the axis of the valley. Hydraulic gradients within Corna Valley (within and near the TMF) range from 0.08 to 0.40. The shallower gradients are along the axis of the valley (e.g., near the proposed dam), whereas the steeper gradients are along the valley slopes (i.e., near the abutments). The water table map also indicates that the stream flowing down the Corna Valley is a gaining stream (i.e., receives water from the zone of saturation/groundwater) throughout the year during normal and wet precipitation years. This pattern is typical in mountainous valleys underlain by low permeability bedrock.

A comparison of water levels in the piezometers to flow rates in the stream indicated that there is generally a response (up to one meter) in some of the piezometers to short-term precipitation events (see Appendix A). For example, a rise in water level of up to one meter was observed in piezometer 02DH-C2-06/5 during an increase in flow of up to 0.3 m$^3$/s. Conversely, piezometers 02DH-C2-12/12 and 02DH-C2-12/29 apparently showed no response to the same precipitation events. However, the lack of response in some piezometers may be a function of the time lag between the precipitation event and when the water level was measured in the piezometer (i.e., the response in the well had occurred and dissipated by the time the water level was measured). It may also be that short-term precipitation events occur as runoff and are not of sufficient duration to influence groundwater levels locally. These data also indicate that the stream and alluvial groundwater are generally in direct connection with each other.

A feature of the groundwater flow system is the presence of a downward vertical hydraulic gradient in the vicinity of the initial TMF Dam alignment. These gradients were measured by comparing water levels in 22 pairs of nested piezometers located in this area. The
downward vertical hydraulic gradient is somewhat higher below the right abutment (0.6, downward), compared to the left abutment (0.4, downward), possibly due to the different bedrock formations at these locations. The vertical gradients along the axis of the Corna Valley were as follows:

- 0.17 (downward) upstream of the proposed initial TMF Dam
- -0.01 (upward) to 0.04 (downward) at the centerline of the initial TMF Dam
- -0.01 (upward) to 0.3 (downward) near the centerline of the SCS.

The significance of the gradients is uncertain, but may simply be due to the relative differences in hydraulic conductivity with lower conductivity colluvium maintaining a high (perched) head in response to precipitation, for example. Additional data will be generated to confirm this information at the revised dam alignment.

4.4.2 **Plant Area**

The water table at the Plant area was generally encountered between less than one to seven meters below ground surface, with an average depth of approximately four meters below ground surface. January 2004 water level readings from piezometers located in the Plant area as well as the water levels recorded for the existing pond were used to interpret the unconfined groundwater contours for the Plant area. The water table beneath the Plant area is shown in Figure 4-1. The interpreted contours indicate that, with the exception of a ridge at the western edge of the Plant area, groundwater flows northerly towards the axis of the Roşia Valley. The hydraulic gradient was estimated in January 2004 to generally be from 0.1 to 0.2, except along the watershed divide where it is on the order of 0.03.

As indicated by the water table contours, groundwater on the southwestern side of the Plant area flows to the southwest down the axis of the Saliste Valley. The dividing line between groundwater flowing northerly and groundwater flowing southwest corresponds to the watershed divide between the Roşia Valley and the Saliste Valley. This groundwater divide will likely shift to the southwest, similar to the watershed divide, as a result of grading activities planned for the Plant area.

Hydrographs of the water levels collected from April 2002 to January 2004 (see Appendix A) indicate that, in general, water levels are seasonally stable, although some piezometers did appear to indicate some seasonal variation. However, the period of record for these piezometers is relatively short and may not be representative of long-term changes. Water level data are continuing to be collected at the site, and these data will be useful in more fully evaluating seasonal changes in the piezometric surface or in the response of the water levels to long-term changes in precipitation.

4.4.3 **Cetate Water Catchment Dam Area**

A total of eight piezometers located near the Cetate Water Catchment Dam and the Cetate Waste Rock Stockpile areas were used to interpret the groundwater flow pattern in the Roşia Valley, as shown in Figure 4-1. The water table was generally encountered within the Roşia Valley between one and five meters below ground surface.

The interpreted contours indicate that the direction of groundwater flow is variable (northerly, southerly and westerly) towards the axis of the valley. These data indicate that the stream is a gaining stream. At the Cetate Water Catchment Dam area, January 2004 water levels indicated a horizontal gradient of about 0.02 to 0.14. Four nested piezometers were installed in the Roşia Valley and the vertical gradient ranged from -1.0 (upward) to 0.74 (downward). Near the planned dam, the vertical gradient was downward at 0.2.

Hydrographs of the water levels collected from April 2002 to January 2004 (see Appendix A) indicate that, in general, water levels are seasonally stable, although some piezometers did appear to indicate seasonal variation. Additionally, a comparison of water levels in the
piezometers located in the streams that drain from the Plant site and Cetate Pit to flow rates in the streams indicated that there was no response in the piezometers to short-term precipitation events, even in piezometers as shallow as four meters, such as WD-06/4 (see Appendix A). This suggests that the stream water and groundwater screened by the piezometers are not in direct hydraulic connection in this area.

The period of record for water levels measured in the piezometers is relatively short and may not represent longer-term changes that may occur during drought or wet years. Water level data are continuing to be collected at the site, and these data will be useful in more fully evaluating seasonal changes in the piezometric surface or the response of the water levels in the piezometers to longer-term changes in precipitation.

4.5 Summary of Hydrogeologic Model

The hydrogeologic model for the Coma Valley is schematically presented in Figure 4-2, Hydrologic Model. The conditions are similar in the Roşia Valley at the Cetate Water Catchment Dam site, and the model equally applies there, as well as at other valley sites underlain by the shale units. The key, basic characteristics of the area discussed above are considered in this model, and include the following:

- Geologic deposits in the Project area predominantly consist of moderately permeable alluvial deposits primarily along stream channels, lower permeability colluvial deposits on the valley flanks and floor, and moderately permeable (weathered) shale underlain by low permeability (unweathered) shale.
- Groundwater potentiometric measurements indicate groundwater flow is toward the valley axis and down-valley.
- Groundwater is generally encountered at approximately one meter below ground surface along the valley bottoms, and up to 10 - 20 meters below ground surface along the valley slopes.

The shale bedrock is a key component of the conceptual hydrogeological model. Shale by definition is dominated by clay- and silt-sized particles, and in its in-situ, unweathered conditions is typified by low permeability. Because it is dominated by clay and silt particles it also tends to be structurally less competent and is a slope-former as opposed to a cliff-former.

Structural features (faults) are also more likely to be filled with clay gouge that can limit their ability to transmit water. At depth with greater lithostatic pressure, fractures are less likely to remain open than with more competent rocks. The greatest permeability in shale sequences is often seen in the weathered portions of the unit. In the zone where the rock is in the early stages of the soil forming process (Zone C soil horizon), fractures tend to open and weathering occurs along bedding planes breaking apart the rock. Under lower lithostatic pressure, fractures are more likely to remain open and transmit water. However, as the shale material completely weathers and breaks down it forms low-permeability clay-rich soils or bedrock residuum. This model of the hydrogeologic properties of a shale unit fits well with the observed conditions in the Coma and Roşia Valleys.

Any significant groundwater flow between valleys within the shale bedrock is not considered likely. This is because hydraulic conductivities in the cores of shale-dominated ridges are expected to be orders of magnitude less than those measured in the shallow borings advanced during the investigatory projects in the Roşia Montană area ($10^5$ to $10^7$ cm/s). Large fault systems are unlikely to provide continuous flow conduits due to gouge zones in the incompetent shale.

Recharge to the groundwater system is also more limited in areas where colluvial soils are present. The low permeability soils limit the amount of water that can infiltrate deeply, and thus water is retained in the shallow organic-rich layers. The infiltration rate is slow, so during large storms rapid runoff can occur. The high moisture retention capacity of these
soils promotes plant transpiration. Relatively more groundwater recharge to the weathered shale is near the ridge tops where the clayey colluvium is thinner and slopes are shallower. Because the occurrence of the weathered horizon mirrors surface topography, the groundwater that enters the weathered horizon will flow downhill towards the valley bottom.

The groundwater will occasionally be forced to the surface as spring flow as a result of discontinuities in the overlying colluvial cover or in the weathered horizon. At locations where the degree of weathering is less, due to changes in lithology for example, groundwater may be forced to the surface due to a lower capacity for the rock to transmit water. Another possibility is in areas where the low-permeability colluvial cover confines the groundwater flow and creates artesian pressures, a discontinuity in the colluvium could result in surfacing of groundwater as a spring.

Water that does not surface as spring water will flow to the valley bottom where it will likely discharge to the creek alluvium or to the creek bed. The alluvium has high permeability and can transmit proportionally more water per unit area. However, water flow converging from both valley flanks should result in some water discharging to the creek as baseflow. This discharge helps maintain some perennial flow in the creek even through the dry season. The observed dilution of conservative chemical tracers (i.e., sulphate) flowing from discharging mine adits in Corna Valley during baseflow conditions also indicate groundwater gaining stream conditions.

Two types of barriers, physical and hydraulic, will be present to prevent lateral and vertical flow from the valleys once the TMF and Cetate Dams are constructed. The first physical barrier will be the low-permeability colluvial layer. Where this layer does not exist in the footprint of the TMF, compacted colluvial material from outside the footprint will be used to replace excavated, higher permeability material (i.e., alluvium or bedrock outcrop). The second physical barrier will be the low-permeability bedrock at depth. This material will restrict deep migration of TMF water, or the lateral migration to adjacent valleys.

Hydraulic containment will result because of the water table conditions that closely mirror the surface topography. Water table levels along the ridgeline in the Corna Valley area are significantly above the final predicted TMF water level of 834 m-ASL. Measured water levels range from 844 m-ASL near the dam alignment, where water levels in the TMF will be lowest because of the pervious dam, to 954 m-ASL further up the Corna Valley (Figure 4-1). To escape this hydraulic containment, the water levels in the TMF would need to exceed the natural water table elevation. The only place that this may occur is down the Corna Valley and to the dewatering system associated with the open pit mining on the north end of the TMF. In both cases, the water will be contained on site.

An important component of the groundwater model in the Roşia Valley is the extensive network of underground mine workings in the upper part of the Roşia Valley. Portions of these workings are flooded with groundwater, which discharges via the 714 Adit. These underground mine workings will hydraulically connect all of the proposed mine pits, except possibly the Jig pit, and act as a drain in the upper part of Roşia Valley. Because of this underground network, extensive pit dewatering is not likely to be needed until the mine levels extend below 720 to 715 m-ASL. Some flooded mine galleries may be encountered at higher levels, but this water will likely flow to the 714 Adit system.
Figura 4.2. Conceptual Hydrologic Model
5 References


Marchidanu, 2002b. Sketch of Geological Section in the Dam Site.


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