

ROȘIA MONTANĂ PROJECT REPORT

Prepared for

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HYDROGEOLOGY BASELINE REPORT

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1.0 INTRODUCTION

This document presents a summary of the baseline hydrogeology for the area where the Roşia Montană Project (the Project) is located. The document was prepared to support the Environmental Impact Assessment and to provide baseline information for the engineering designs for the project. 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 5.0) , data collected during the 2003 field investigations, and monitoring data from 2001 through 2006. More detail on individual topics may be located in the source documents listed in Section 5.0.

2.0 PHYSIOGRAPHY

The Project lies near the village of Roşia 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 Roşia Montană mining district, located immediately northeast of the town of Abrud within the Apuseni Mountains near the headwaters of the Corna, Saliste and Roşia Valleys.

The Corna, Saliste and Roşia 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 Roşia 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:

- Roşia 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 Roşia 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 Roşia 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 Dam (SCD).

3.0 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 un lithified 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 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, SCD and Cetate Water Catchment Dam embankments.
- Vent breccia - in the form of microconglomerates and tuffaceous grits, described as medium grained volcanoclastics (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 Roşia Valley and it can be a significant ore host. Some vent breccia is present in the upper portion of the Corna Valley where 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 Roşia 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 Roşia Valley is hosted in dacite that has been intruded into the vent breccia, and other phreatomagmatic breccias. Relatively minor areas of mineralised sedimentary rock are also present (see Section 3.4, below).

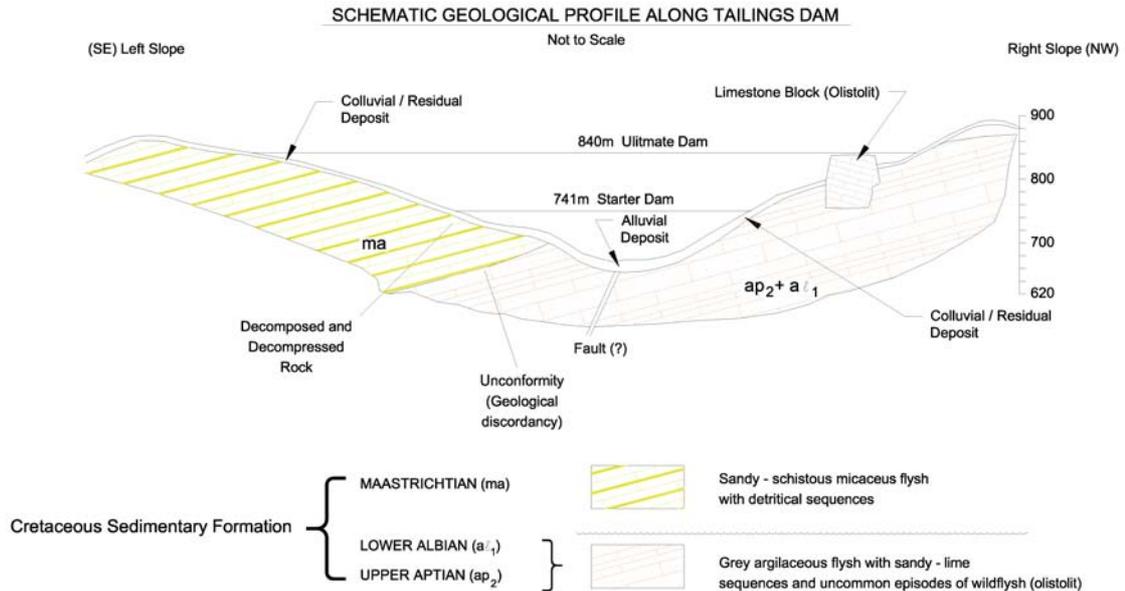
3.3 CORNA VALLEY AREA GEOLOGY

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. Enough is known about the rest of the valley to indicate that detailed information from the dam alignment is typical. The exception being the upper end of the valley where some vent breccia is present.

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. Figure 3-3, *Hydrogeologic Cross-Sections*, provides a geologic section across the TMF and SCD dam sites.

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.

FIGURE 3-2



Notes:

1. Geological Profile adapted from Marchidanu (2002a and 2002b).
2. Dip of bedding is schematic.
3. Maastrichtian formation is believed to be about 70 million years old.
4. Lower Albian and upper Aptian formations are about 100 million years old, with Aptian being recent.

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 olistolites. A large olistolite 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 Roşia 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.

Insert Figure 3-3, Hydrogeologic Cross-Sections, page 1

Insert Figure 3-3, Hydrogeologic Cross-Sections, page 2

3.4 ROŞIA MONTANĂ VALLEY AREA GEOLOGY

The lower portion of the Roşia Montană Valley is dominated by similar alluvium, colluvium, soils, and Cretaceous bedrock as found in the Corna Valley. This portion of the valley geology was investigated in detail at the Cetate Water Catchment Dam site and also at the plant site on the upper flank. 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 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 shallow bedrock is highly weathered and fractured within the upper four to eight meters and becomes more competent with depth.

The upper portion of the Roşia Montană Valley contains most of the altered and mineralised volcanic sequences that host the ore body. The Roşia Montană volcanic sequence is interpreted as a maar-diatreme complex emplaced into the Cretaceous sediments, predominantly black shales, with sandstone and conglomerate beds. The three dimensional geometry of the area is well established due to an extensive network of underground mines that have been developed since the Austro-Hungarian Empire period, and from the extensive drilling conducted from the surface and underground over the last 25 years.

Rock types within the maar-diatreme complex are dominated by breccias, including phreatomagmatic breccias, complexly re-worked and subaqueous breccias and volcanoclastics, intruded by a series of porphyritic dacitic sub-volcanic intrusions, dacitic dykes and later phreatomagmatic breccias (phreatomagmatic breccias form due to explosive eruptions steam and other gases). The dacitic intrusions are interpreted as Neogene age and are informally named the Cetate Dacite and Cârnic Dacite. The dacite complex is interpreted to have intruded vertically into the maar breccias, sediments and volcanoclastics and to have spread laterally at shallower levels. An alternative interpretation is that only one major dacite intrusion has occurred and that this has been split into the now separate Cârnic and Cetate dacite bodies by a northeast trending strike-slip fault.

The majority of the Roşia Montană volcanic deposit is made up of a lithology locally referred to as the “vent breccia”. This is a diatreme breccia created by numerous phreatomagmatic eruptions produced as hot rising dacitic magma interacted with groundwater. It is of variable composition with clasts of dacite, Cretaceous sediments and basement schist and gneiss.

Within the vent breccia a large (1 km by 1 km at the surface) body of breccia has been delineated as a separate phreatomagmatic event. This is composed of generally massive (some sedimentary reworking exists in the upper levels), poorly sorted, matrix-supported breccia, with sub-angular to sub-rounded clasts of dacite, Cretaceous sediments and basement metamorphic rocks. The breccia is distinct because it is the only breccia body at Roşia Montană that still contains significant magnetite.

A breccia, locally termed the ‘Black Breccia’, forms a sub-vertical pipe in the centre of the diatreme, between the Cetate and Cârnic dacites. The breccia is matrix supported, with clasts of dacite, Cretaceous sediment and basement garnet-bearing schist and gneiss in a matrix of pulverised (rock flour) Cretaceous shale, which gives the breccia its black, clay-rich character.

Andesitic extrusive rocks have been mapped as mantling the northern and eastern parts of the upper valley area, forming a thin to moderately thick cover over the maar complex. The andesitic units are post mineralisation in age and consist of unaltered agglomerates and flows.

4.0 HYDROGEOLOGIC SETTING

This section describes the hydrogeologic setting of the Roşia 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 5.0. 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 4.4, 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. Boring logs and piezometer completion logs are included in Appendix A

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 2001, 2002 and 2003.

In early 2001, a total of 12 drill holes were advanced within the Roşia, Corna, Salistei, and Abruzel Valleys (Agraro/KP, 2001). Drill hole logs are included in Appendix A, as is a tabular summary of all piezometers and monitoring wells at the site. Of these 12 drill holes, six were completed as groundwater monitoring wells (bores).

In 2002, three drill holes totalling 591.6m were advanced as part of the Open Pit Stability Design report field investigation (SNCL, 2003a) three in order to collect geotechnical information. The drill hole logs are included in Appendix A. The drill holes consisted of one in the proposed Cîrnic Pit area (180.5m deep), one in the proposed Cetate Pit area (266.6m deep), and a third in the proposed Orlea Pit area (145m deep).

Subsequent to the deep drilling at the head of Roşia Montană valley, a pump test was carried out on an orifice located on the 714 m gallery level of the mine (SNCL, 2003a). The tested orifice is believed to link the 714 m level with two lower galleries at -30 and -60 m with respect to the 714 m level. Details of the pump test and results are presented in Appendix B.

A second drilling program was conducted in 2002 (SNCL, 2003b) and consisted of 100 boreholes within the following areas:

- Plant site area;
- Open Pits area;
- Corna Valley (proposed TMF and SCD areas);
- Cârnic and Cetate Waste Rock Stockpile areas;
- Infrastructure areas; and
- 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.

Boring logs and piezometer completion logs are included in Appendix A.

During drilling, 39 packer tests were conducted for estimating hydraulic conductivities in the bedrock. Additionally, after completion of the piezometers, 45 in-situ permeability tests were conducted in the piezometers located in the Corna Valley, the Waste Rock Stockpile areas and the Infrastructure areas. Results of the aquifer testing are included in Appendix B.

An additional geotechnical investigation was conducted in 2003 (MWH, 2004a, 2004b). 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 SCD area (4), and the Cetate Dam area (4);
- 137 water pressure (packer) tests were conducted in bedrock beneath the TMF, SCD 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.

Boring logs and piezometer are included in Appendix A; packer test results are included in Appendix B.

Water levels were measured in the piezometers on a weekly basis starting in April 2002 and continuing through the present. These water level data were used to generate site-wide potentiometric surface maps of the unconfined (water table) using water level elevations measured in January 2004, July 2006, and October 2006. The water table contours are shown in the following figures:

- Figure 4-1, *Water Table Contours – January 2004*
- Figure 4-2, *Water Table Contours – July 2006*
- Figure 4-3, *Water Table Contours – October 2006*

The above measurement dates were selected to provide a range of high to low water level conditions. The changes in water levels can be seen on the hydrographs for the period April 2002 to October 2006, which are presented in Appendix C. An interpretation of the water table contours shown on the above maps is included in the following sections.

Additionally, seepage analyses through the proposed TMF dam and other water catchment dams were conducted. These analyses shed additional light on the nature of the hydrogeologic setting of the site Valley and augmented the information used to develop the conceptual hydrogeologic model presented in this report. The seepage analyses results are included in Appendix D.

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 HYDROLOGIC PROPERTIES¹		
Stratigraphic Unit	Description	Hydrogeologic Properties
Alluvium (Stream channels and floodplain)	Silty-clay and clayey-silt deposits with highly variable and localised amounts of gravel and cobbles. Includes layers of clean sand and gravel located in the stream beds, 10 to 80 meters wide and up to 12 meters deep, especially noted in Corna Valley.	Clean sand and gravel zones act as local aquifers. Average hydraulic conductivity is relatively high in the range of 2×10^{-4} to 3×10^{-2} cm/s.
Colluvium (Valley slopes)	Primarily clayey silt and silty clay with some sand and gravel, 3 to 10.5 meters thick.	Low water-bearing capacity. Average hydraulic conductivity of approximately 1×10^{-6} cm/s.
Upper (Shale) Bedrock	Highly weathered and fractured interbedded shale, sandstone, breccia and gouge in the upper 40 meters. Located directly beneath the alluvium within the flood plain and colluvium along the valley slopes.	Generally water bearing only through fracture network and has only low regional capacity. However, may be moderately water bearing through the joints and bedding planes. Hydraulic conductivity values range from 1×10^{-5} to 1×10^{-4} cm/s.
Lower (Shale) Bedrock	Increasingly competent with depth, the lower bedrock is interbedded shale and sandstone with minor gouge and breccia intervals.	Low capacity other than through localised joints, fracture network or shear zones. Hydraulic conductivity ranges from 6×10^{-7} to 1×10^{-5} cm/s.
Dacite and Andesite	Generally competent bedrock.	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 ($< 1 \times 10^{-5}$ cm/s).
Vent Breccia and Black Breccia	Typically soft rock.	Limited flow may occur through fractures or naturally formed zones of enhanced permeability. Low hydraulic conductivity ($< 1 \times 10^{-5}$ cm/s).
Notes: 1. This table is adapted from SNC-Lavalin (2003b) and is based on hydraulic conductivity data collected from 2001 through 2003.		

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, approximately 1×10^{-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 2×10^{-4} and 3×10^{-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 Cărnic 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 4×10^{-3} cm/s (silty-sand) and 4×10^{-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 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 1×10^{-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. Shale is by definition is composed of silt and clay.

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 6×10^{-7} cm/s to 4×10^{-4} cm/s. The hydraulic conductivity generally decreases with depth with values measured less than 1×10^{-5} cm/s deeper than approximately 25 meters below ground surface at Cetate and the SCD and 40 meters below ground surface at the TMF. The permeability of the shale bedrock is typically greatest where it has begun to decompose to soil, and it is also in this zone that fractures tend to open up due to the release of lithostatic pressure.

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 having intrinsic low permeability, and hence, have a low potential for groundwater supply.

However, the deep drilling conducted at the head of the Roşia Valley in 2001, did aid in evaluating these rock types. The hydrogeologic properties of the vent breccia are complex. The unit is extremely inhomogeneous and anisotropic so the properties will vary substantially over small distances with a possible minor contribution from primary permeability. Flow within the breccia is due mainly to secondary permeability. It is possible that acid mine drainage has resulted in the dissolution and subsequent permeability enhancement of the calcitic zones of the breccia. Calcite is found in the surrounding sedimentary units which constitute the vent breccia along with neogene volcanics.

The exact nature and value of breccia permeability is unknown but it is clear from the responses of observation points during the underground pumping test (Appendix B), the seepage and stalactites evident in the breccia of the 714 m level, that it is capable of transmitting water to some extent. Attempting to estimate the breccia's permeability from the observed water responses during the pump test would be meaningless due to deviation from pump test theory (which demands an infinite isotropic aquifer). The drill hole drilled at the top of Abruzel valley encountered Vent Breccia from 10 to 14 m. The breccia appeared to be the impermeable base supporting a perched aquifer within the colluvial overburden.

The dacite has very little water bearing capacity. Primary permeability is negligible and there is little evidence of much natural secondary permeability. The deep hydrogeology borehole drilled in Roşia Valley encountered Dacite from the surface down to 220 m. The bottom of the hole is at an elevation of 570 m ASL. No significant water was encountered despite the water level being at an elevation in excess of 700 m ASL in pump test observation boreholes in the 714 m ASL mine gallery. There was no evidence of water in the Dacite of the 714 m ASL gallery level during the 2002 pumping test.

By their nature, the volcanic rock should have low primary permeability, and the hydrogeology will be dictated by secondary features. The secondary permeability of the volcanic sequence is complex, and investigation of the hydrogeologic properties is difficult. This is in large part due to the extensive network of underground mine workings. These workings have drained large areas of the volcanic complex and have created open conduits for groundwater flow. However, an important consideration is that the volcanic rocks are emplaced in and surrounded by the low permeability Cretaceous shale units (Figure 3-1), and the underground mine working drain the volcanic units. Therefore, as discussed in following sections, the volcanic geology creates a local hydraulic sink.

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 Roşia Montană Valley, Corna Valley and Salistei Valley streams for the period 2001 to 2003 were 0.16, 0.07 and 0.16 m³/s, respectively, as measured using permanent weirs. The Roşia Montană Valley flow includes the 714 adit flow and Salistei Valley flow includes flow through the mine facilities. An extensive network of underground mine workings are all connected and act as a drain for the upper part of Roşia Montană Valley. This drain discharges to the 714 Adit and into the Roşia Montană Valley stream approximately 500 meters upstream of the planned 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 SCD Area (Corna Valley);
- Plant Area;
- Roşia Montană mine workings; and
- Cetate Water Catchment Dam Area (Roşia Montană 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 SCD has been characterised and designated as upper and lower (shale) 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 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 SCD 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 - 5×10^{-5} to 2×10^{-4} cm/s, lowest RQD and core recovery
- Upper bedrock - 2×10^{-5} to 1×10^{-4} cm/s, lowest RQD and core recovery
- Lower bedrock - 3×10^{-6} to 3×10^{-5} cm/s, highest RQD and core recovery

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 4.3×10^{-5} cm/s in the conglomerate and 1.0×10^{-3} cm/s in the colluvium near its contact with bedrock. It is important

to note that this variation in hydraulic conductivity values is localised, related to the presence of atypical lithologies, 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 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 SCD alignment, the water table was encountered at two to three meters below ground surface near the abutments 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 levels measured during January 2004, July 2006 and October 2006 (Appendix C) were used to construct water table contour maps of the area (Figures 4-1, 4-2 and 4-3). As shown in these figures, the predominant direction of groundwater flow is down the valley slopes and along the axis of the valley. In general, water levels are seasonally stable; although water levels in some piezometers did show seasonal variations of up to one to two meters. However, these changes were minor enough that they did not significantly change groundwater flow directions, as can be seen in Figures 4-1 through 4-3.

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 C). 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 $0.3 \text{ m}^3/\text{s}$. 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 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 TMF Dam

- -0.01 (upward) to 0.04 (downward) at the centerline of the TMF Dam
- -0.01 (upward) to 0.3 (downward) near the centerline of the SCD.

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.

Mine outflows in each of the valleys within the site range from 0.3 (Abruzel) to 9.5 L/s (Roşia Valley). Corna valley has significant mine outflow, at 4.5 L/s, from two sources, C122 and C123. These are close to each other and appear to be springs. Because of the iron stained appearance of the water, its low pH, and the proximity of the sources to existing mines, the springs are assumed to flow from collapsed mine adits.

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. This is notable because the plant site is located on the ridge between the Roşia Montană and Saliste Valleys. 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 on Figures 4-1, 4-2 and 4-3. 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 Montană Valley and then to the west down Roşia Montană 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 October 2006 (see Appendix C) indicate that, in general, water levels are seasonally stable, although some piezometers did show seasonal variations of up to one to two meters. However, these changes were minor enough that they did not significantly change groundwater flow directions, as can be seen in Figures 4-1 through 4-3.

4.4.3 Mine Workings – Roşia Montană Valley

Within the area of the existing mine workings, a single, continuous piezometric surface is considered unlikely. In highly impermeable areas, the piezometric surface exists only for widely spaced fracture flow. At shallow depths, a fairly continuous water table probably exists, where water infiltrates and flows in soils. With so many dry mine workings existing in the mined area, the vertical profile of pore pressure at any one point is very complex. Although water depths in wells and boreholes were measured during the inventory (SNCL, 2003c), they were not analysed because the above-mentioned complexities in the area would render such analysis not definitive.

As mentioned in Section 4.1, three deep drill holes were advanced in the area of the proposed pits. During drilling a negligible amount of groundwater was encountered. The negligible groundwater encountered was shallow in nature. The Dacite was dry at the drilled locations to a depth of 220 m bgs or 570 m above sea level (ASL). These findings indicate that there is not a

continuous phreatic surface at circa 700 m ASL in the volcanic sequences but rather limited conduits which can transmit groundwater.

The pump test that was conducted in the mine had a discharge rate of 21 L/s for 3 days and drawdown was measured at the tested orifice, the Rotunda lake and the mud room, all of which are located on the 714 m gallery level. Interpretation of drawdown data indicates that test discharge water came predominantly from void storage. The volume of void storage has been estimated by Gabriel Resources at 56,000 m³. Nothing conclusive could be determined as to aquifer transmissivity due to the nature of the pumped formation differing radically from conventional groundwater situations.

As presented in Section 4.4.2, mine outflows in each of the valleys within the site range from 0.3 (Abruzel) to 9.5 L/s (Roşia Valley). Roşia Valley has the highest flow from adits. Two main mine adit outflows contribute to the Roşia stream flow. One is from 714 level (R085) main mine entrance, and the flows here reportedly vary between 7.5 and 11 L/s (mean 9.3 L/s). This is the main drainage exit from the existing mine workings. The other adit flow (R086) is from the level above and is a much lower seepage, at 0.2 L/s.

4.4.4 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 Montană Valley, as shown on Figures 4-1, 4-2 and 4-3. The water table was generally encountered within the Roşia Montană 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) consistently towards the axis of the valley. These data suggest that the stream is a gaining stream (i.e., that groundwater flow towards the stream is contributing to base flow in the Corna Valley stream). At the Cetate Water Catchment Dam area, water levels indicated a horizontal gradient of about 0.02 to 0.14. Four nested piezometers were installed in the Roşia Montană 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 October 2006 (see Appendix C) indicate that, in general, water levels are seasonally stable, although some piezometers did show seasonal variations of up to one to two meters. However, these changes were minor enough that they did not significantly change groundwater flow directions, as can be seen in Figures 4-1 through 4-3. 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 (Appendix C) indicated that there was little to 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 of the site.

4.5 SUMMARY OF HYDROGEOLOGIC MODEL

The hydrogeologic model for the Corna Valley is schematically presented in Figure 4-4, *Conceptual Hydrogeologic Model*. The conditions are similar in the Roşia Montană 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 and ridges.

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 Corna and Roșia Montană Valleys.

Any significant groundwater flow between valleys within the shale bedrock is not considered likely and has never been indicated. 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 Roșia 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. In fact, such faults are more likely to act as barriers to flow.

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 (MWH, 2006) 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 Montană Valley is the extensive network of underground mine workings in the upper part of the Roşia Montană 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 Montană 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.

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APPENDIX A

**BORING LOGS AND PIEZOMETER/WELL CONSTRUCTION
DETAILS**

APPENDIX B
AQUIFER TESTING RESULTS

APPENDIX C

HYDROGRAPHS OF PIEZOMETERS AND MONITORING WELLS

APPENDIX D
RESULTS OF SEEPAGE ANALYSES