Field-based kinetic testing of ARD potential of the waste rock from Roșia Montană ore deposit (Apuseni Mountains, Romania)

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Abstract ARD potential of the Roșia Montană ore deposit rocks is a key issue for the environmental impact of a new mining project. A field-based leaching test was initiated to monitor long term a series of future waste rock samples from this area, in order to determine the ARD potential under actual site climatic conditions. The number of samples adequately reflects the proportion of each waste rock type. Samples of the water that washed the waste rock were periodically collected and analysed. The chemistry of the water leachate generated by each sample over time was measured by performing complex physical-chemical analyses.

Key Words Roșia Montană, kinetic test, ARD, lithology, rock waste

Introduction

An increasing demand of mineral resources in present-day human society is the stimulus of the new mining projects developing. In the evaluation of a mine development project, a very important element is the environmental impact, especially the metal and other elements leaching, often caused by the acid rock drainage (ARD) of sulphide bearing geologic materials (Bowell et al. 2000). Projected mine waste must be characterized and their drainage quality predicted before the starting of the mining activity in order to apply the efficient management solutions capable to avoid the adverse impacts on natural waters. An accurate prediction of future drainage chemistry is a key factor in choosing the successful cost-effective, proactive measures (Price 2009). Predictive analyses and tests can be classified as either static or kinetic. Inexpensive and short-term static tests (like Acid Base Accounting – ABA) are designed to determine the balance between the acid generation potential and acid neutralization potential of the rock. More expensive, long-term kinetic tests are intended to subject the sample in a controlled environment in the laboratory or at the mine site. The aim of this paper is to present drainage chemistry data based on the first results of the field-based kinetic test performed on waste rock from Roșia Montană area, Romania.

Study area

Roșia Montană is located in west-central Romania (Transylvania region), in the northern part of the South Apuseni Mountains (Metaliferi Mountains), about 65 km southwest of the major city of Cluj-Napoca. In this area, a world-class gold-silver deposit is well known since pre-Roman times (Cauuet et al. 2003) for its very rich ores. This deposit occurs in the historical gold mining region known as the "Golden Quadrilateral", where a number of precious and/or base metals deposit are located. The mining activity (underground and/or open-pit methods) in this area continued until 2006, when the state mining company, Minvest, stopped any mining operation due to the elevated exploitation and processing costs. Starting 1998, Gabriel Resources Ltd. (Toronto, Canada), through its Romanian subsidiary Roșia Montană Gold Corporation (RMGC) commenced exploration of the deposit with state of the art techniques and is currently developing and permitting a new modern mining project which includes four open pits, waste rock stockpiles and a tailings dam. The exploration data revealed a resource of 400.4 Mt of ore at an average grade of 1.3 g/tAu and 6.0 g/t Ag, for a total contained resource (measured, indicated, and inferred) of 16.1 Moz Au and 73.3 Moz Ag, making Roșia Montană the largest gold deposit in Europe. The current proven and probable reserves contain 218 Mt of ore at a grade of 1.52 g/t Au and 7.5 g/t Ag, for total contained metal of 10.6 Moz Au and 52.3 Moz Ag (Manske et al. 2006).

Roșia Montană Au-Ag deposit is hosted by a Neogene maar-diatreme complex (Leary et al. 2004) emplaced within flysch-type Cretaceous sedimentary rocks overlaying the Paleozoic basement. Two types of volcanic units are present in the area: dacite domes and related volcanoclastics, and andesite rooted body and lava flows with associated volcanoclastics (fig. 1). This geologic structure was created by the multiple phreatomagmatic eruptions due to the shallow emplacement of the Montana dacite, generating volcaniclastic breccias (vent breccia) and other breccia bodies like black breccia (Wallier et al. 2006). The hydrothermal processes associated to magmatic activity have led to pervasive alteration. Adularia alteration with a phyllic overprint is widespread, whereas silicification and argillic alteration occur locally. Roșia Montană is an epithermal deposit characterized by various types of ore bodies:

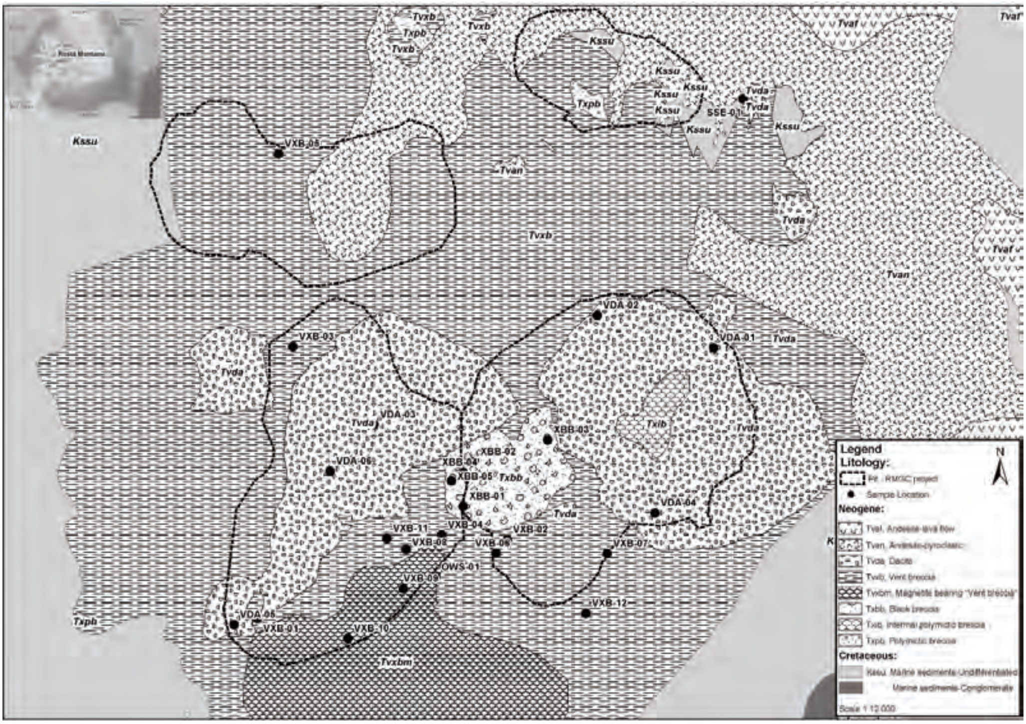

__Figure 1__ Location of the waste rock sample on the geological map of Roșia Montană area. Source: Roșia Montană Gold Corporation.

veins, breccia structures (breccia pipes and breccia dykes), stockworks, and impregnations. The main precious metals minerals are electrum and free gold. Smaller amounts of common sulphides (pyrite, chalcopyrite, sphalerite, galena, marcasite, arsenopyrite, etc.), Ag-minerals (argentite, proustite, pearceite, polybasite, etc.) and tellurides (hessite, sylvanite, petzite, altaite) are present in mineralization (Tămaş, 2007).

Historically mining activities in the Roşia Montană area and other mining districts from Metaliferi Mountains had led to a major environmental impact, especially in terms of heavy metal pollution of the watercourses. Acid waters occurring in mining works and waste piles are collected by small tributaries of Arieş River which is the main local stream. Elevated concentrations of heavy metals (Cd, Cu, Pb and Zn) have been determined by chemical analysis of the surface water and river channel sediment samples (Bird et al. 2005). In Roşia Montană area, the heavy metals concentrations in water had exceed by over 1,000 times the maximum contaminant level from Romanian standards (Florea et al. 2005).

Methodology

Different procedures were used to characterize the ARD potential of the waste rock from the Project area. In the initial stage, Acid-Base Accounting (ABA) method was applied in order to evaluate the quantities of acid generating and acid-neutralising materials hosted by the waste rock. Such a static testing typically addresses the absolute potential for ARD generation, but it is not always a precise procedure for the characterization of the ARD potential. Therefore, the waste rock characterization program was completed by conducting three forms of kinetic testing: Synthetic Precipitation Leaching Procedure, laboratory column testing, and field column testing (RMGC 2006).

Lithologic distribution of the future waste rock represented the main criteria for ARD characterization. The geologic and resource model based on exploration data was used to identify the lithologies to be sampled and their relative percentages. Based on a combination of rock and hydrothermal alteration type, several types of waste rock were separated (MWH 2005, RMGC 2006). The main rock types are: dacite, vent breccia, black breccia, andesite, and Cretaceous sedimentary rocks. The first three types are subsequently classified by silicified/potassic alteration type (abbreviated as SIK), and non-silicified/non-potassic (NSIK), which is generally argillic but may include unaltered rock or other less intense alteration types (like propylitic).

Using the geologic model, for each rock/alteration type was identified a percentage of the total waste rock volume. These data was used for weighting the number of samples collected for running the field column testing, considering also the spatial coverage in the Project area boundaries (fig. 1; tab. 1).

Field-based leaching tests at the Roşia Montană site was conducted on 26 plastic barrels containing representative waste rock and it has started in August 2003 (MWH 2005). Each sample has a weight of approximately 300 kilograms and a sufficient volume to fill a 200-litre barrel (fig. 2). Extracting of fresh rock required by the sampling protocol was made by using an excavator which removed unrepresentative material. Prior to manually filling of the drums, screening of the rocks was applied to remove the plus 10-cm fragments. The containers were filled to a level approximately 10 cm below the top. These plastic barrels are open at the top so that the material is exposed to atmospheric conditions. In order to allow air circulation through the barrels, approximately eight 10-millimeter holes were drilled in the sides. Elevated emplacement of the barrels allows the access to a sampling port at the base. The inlet to the sampling port has a screening which prevents the plugging with the waste rock material.

The sampling port on the barrels remains open between collections the leachate, allowing precipitation to drain through the waste rock in the barrel. Leachate from the field testing is collected in a container placed below each barrel. Different field parameter measurements and laboratory analysis are performed on approximately quarterly basis: pH and electrical conductivity (on field), sulphate, bicarbonate and various metals (in laboratory). The gathered data are compared to previous results from static and other kinetic tests.

Mineralogical features of the waste rocks were determined using X-Ray Diffraction (XRD) method and optical microscopy (MWH 2005). Quartz was the main mineral identified in XRD spectra, whiles feldspars, mica, clinochlore, pyrite, clays, gypsum and calcite were identified as minor and trace constituents in various samples. Microscopic observations revealed the presence of the pyrite as free grains or encapsulated in quartz or feldspar. Potassium feldspar, mica and clays were observed in abundance, and calcite was identified only sporadically. This mineralogical composition denotes a limited neutralization capacity of the waste rock samples, but then the full acid generating potential may not be realized due to the encapsulation of some pyrite grains by other minerals. However, the dissolution of some minerals possibly occurring during the development of ARD process could create new pathways for solutions to react with pyrite and other sulphides.

Results and discussions

Previous static ABA testing indicates that waste rock has a range of potentials to generate ARD: from rock without appreciable potential for ARD generation, to rock that is likely to generate ARD (RMGC 2006). These initial data suggest that ARD production from waste rock which will be generated during the ore extraction in the new open-pits is possible and even likely. Further field based test leaching was intended to generate a more realistic view of ARD generation potential. Until the first round of sampling (November 2003), 5 of the 26 columns did not generate sufficient leachate for sampling. In August 2007, the first testing phase was ended by collecting the last sample. The second phase of the kinetic testing is conducting on the same samples started in October 2008

Table 1 *Sample type and number of field column samples.*

Lithology	Alteration	No. of samples
Vent Breccia (VXB)	NSIK	10
Vent Breccia (VXB)	SIK	2
Dacite (VDA)	NSIK	4
Dacite (VDA)	SIK	2
Black Breccia (XBB)	NSIK	3
Black Breccia (XBB)	SIK	2
Cretaceous sediments (SSE)	NSIK	1
Andesite (VAN)	NSIK	1
Existing Waste Rock (OWS)	NSIK	1
Total		**26**

Figure 2 *Emplacement of the barrels used in field-based leaching test.*

until present-day.

Except one sample, all of the field columns containing rocks that had ABA classifications of none, low and possible show pH values above 5.8. Except one sample, all of the barrels with the rocks that have an ABA classification of likely generated leachate with 1.6 to 4.7 pH. ARD was observed in 9 barrels from 26, representing approximately 35% of the total. The vent and black breccia samples yielded more acidic waters (tab. 2) comparing to dacite samples. Acidic solutions were generated in 50% from dacite-filled barrels, only 25% of vent breccia samples generated ARD, and 60% of black breccia samples yielded acidic leachate. The old waste rock sample was acidic, while andesite and sediment sample were non-acid producing.

Sulphate is the most concentrated ion from the leachate, therefore TDS value are highly influenced by sulphate concentrations. The highest sulphate concentrations in the leachate were recorded for the likely category of rock samples while those in none category have the lowest. Moderate sulphate concentrations characterizing the samples classified in the low and possible categories are due to the neutralization reactions offsetting the acid generation. ARD producing samples are characterized by high values of iron and manganese in percolated water. Solutions associated to vent and black breccia are more concentrated in these two elements comparative to dacite leachate. Samples that yield acidic solutions have the highest values of various elements concentration. The most elevated concentrations of Zn and Se were recorded in percolated dacite water. Vent breccia weathering generated the solutions characterized by the highest concentration of Cu, Pb, Sb and Hg. The highest values of As, Cd, Ni, Cr, Co, Ba and Mo was determined in black breccia leachate (tab. 2).

Generally, the black breccia produces some of the highest ARD concentrations. All the silicified samples of the waste rocks generated acidic solutions suggesting that the alteration process created chemically and physically favourable conditions to initiate the ARD. The other acid producing samples are characterized by various stages of argillic alteration, but only 4 of 13 samples from this alterated type rocks generated acidic leachate. Solutions resulted from leaching of the old waste rock sample had lower element concentration relatively to leachate collected from the barrels hosting the acid generation rock types, probably due to the more intense weathering prior to beginging of the kinetic test. Andesite and sediment leachate were much diluted, similarly to non-acid producing samples of the main three wastes rock types.

Time variation of the pH values recorded for the most acidic samples of the main three waste rock types indicates a general descending trend for the dacite and black breccia, and a slight increasing trend for the vent breccia (fig. 3). TDS values variation of the dacite sample is not very high indicating a very slight increasing trend over time. A very slight decreasing trend can be observed for TDS values of the vent breccia sample. The most obvious increasing trend characterized the TDS values obtained for black breccia sample (fig. 3).

Conclusions

This type of kinetic test is more realistic in terms of actual site conditions comparing to the static tests. However, the chemical reactions in the barrels probably are not the same like those developing in the waste rock piles characterized by greater mass and volume. Additional reactions with other waste rock and secondary mineral precipitation may occur in the piles along the leachate flow path to the surface. Prior to leachate sample collection, some concentration in this solution may results due to the evaporation. The kinetic results indicate that almost all the acid generating waste rocks will become active shortly after exposure. There are no significant data suggesting that non acid-generating waste rocks could become acidic in time.

Despite the small differences observed between ABA test and field-based leaching test, the

Table 2 *Maximum value of chemical parameters (minimum value for pH) analysed on generated leachate from weathering of the main type's waste rock*

Chemical parameter (measurement unit)	Dacite	Vent Breccia	Black Breccia	Chemical parameter (measurement unit)	Dacite	Vent Breccia	Black Breccia
pH	1.8	1.6	1.6	Cd (µg/L)	2386	414	23100
TDS (mg/L)	17660	42152	59356	Ni (µg/L)	3150	11560	24980
Sulphate (mg/L)	12268	33954	42531	Cr (µg/L)	6380	7025	75210
Fe (mg/L)	6622	15643	19956	Co (µg/L)	6180	3035	30800
Mn (mg/L)	85.1	9619	11363	Sb (µg/L)	582	5278	1608
Cu (µg/L)	37510	151250	145780	Ba (µg/L)	161	158.8	266
Pb (µg/L)	615	134000	298	Hg (µg/L)	0.96	13.2	4.3
Zn (µg/L)	5214600	22030	370000	Mo (µg/L)	254	2000	3480
As (µg/L)	91210	21200	210000	Se (µg/L)	3162	516.2	2670

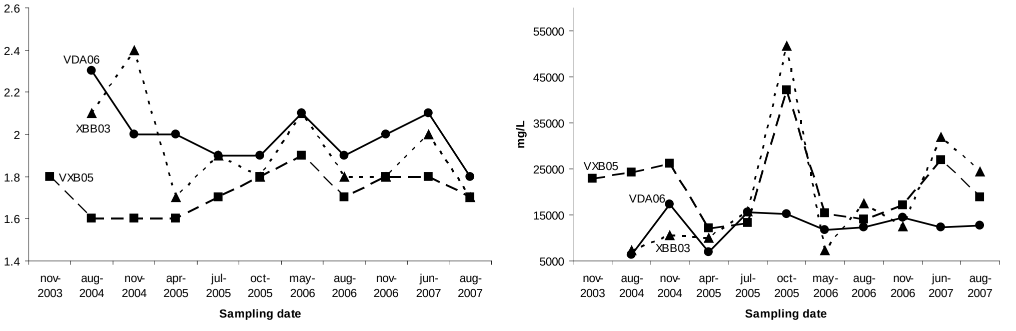

Figure 3 *Time variations of pH and TDS values recorded for the most acidic samples of the waste rock type: VDA06-dacite, VXB05-vent breccia and XBB03-black breccia.*

kinetic testing has confirmed the conclusions of the static test. Based on these data, the volume of non-ARD generating waste rock will be larger than the volume of ARD generation waste rock. Most of the time, the seepage from the waste rock piles will be near neutral, but probably having increased TDS values. Due to the heterogeneity of the waste rock, in some areas of the piles, acidic waters are possible to be generated in some periods. Therefore, in order to prevent the negative impact on water quality of the acidic runoff and seepage, these solutions will be handled as ARD during the project and mitigation measures will be applied. The conclusions of field-based kinetic test will be used in order to choose the best treating method of the seepage from the waste rock piles.

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