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Methodology to evaluate the ARD potential in some Brazilian gold mines

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ABSTRACT: *This paper proposes a methodology to evaluates the potential of acid rock drainage (ARD) in some gold mines of Brazilian ferriferous quadrangle. A program of sampling was developed to characterize geochemically the ores and wastes in minesites and quantify the potential of acid mine drainage and metal solubility. Were performed analyses by the following static tests: - saturated paste pH , ABA, NAG, MABA and total and soluble metal analysis. To compare the results is suggested a tabulation considering a relative weight for each performed test. In this methodology each test (ABA, MABA or NAG) was evaluated in a graduated scale from zero to 100 points totalizing a maximum of 300 points.*

KEYWORDS: *acid drainage; gold mines, methodology*

I. INTRODUCTION

In the centre of the Brazilian State of Minas Gerais a region denominated Ferriferous Quadrangle concentrates the largest mineral output of the country, including several iron ore and gold mines (Mello, 2006). This paper evaluates the potential of acid rock drainage (ARD) in some gold mines of this traditional mineral district (Capanema et al., 2003) (Pereira, 2004). In these mines a collection of representative samples of the minesite was done. These samples was obtained in the open pits, waste dumps and tailings. Petrographic, mineralogical and geochemical characterizations of the samples were done, relating these characterizations with the potential of acid water production (Borma et. al., 2002, Zumaran et.al., 2004) . It was evaluated the presence of sulfide minerals, comparing the results of potential acid mine drainage in the samples and the correlation between these values and the different gold ores, oxidized or sulfide. With the development and deepening of the mines, a program of extensive sampling was developed to characterize geochemically the ores in minesites and quantify the potential of acid mine drainage and metal solubility. Were performed analyses by the following static tests: -saturated paste pH, Standard Acid Base Accounting Procedure for Neutralization Potential- ABA, Net Acid Generation – NAG, Modified Acid Base Accounting Procedure for Neutralization Potential-MABA and total and soluble metal analysis (Price, 2003) (Esper et. al, 2002) (Mello et. Al., 2004) (Comarmond, 1996).

To interpret the results the research suggests an original methodology that proportionally, ponders the several results obtained through the several static (ABA, MABA, NAG) and kinetic chemical tests and the petrographic, mineralogical and geochemical characterizations specifying a relative weight for each accomplished test (Price, 2003). Thus, it can be evaluated the relative potential of acid mine drainage in each minesite considering the samples representativity according to this specified methodology..

II. DEFINITION OF TEST METHODOLOGY

The statics tests are normally performed in bench tests in laboratory and the basic proposal is to examine the balance between the components that generates the acid and the components that consume the acid. These tests are denominated in this way because they do not consider the proportionality between the production and consume of the acid. Among the several available tests we can cite (Esper et. Al., 2002, Mello et. al, 2004 Comarmond, 1996): - saturated paste pH , Standard Acid Base Accounting Procedure for Neutralization Potential- ABA, Net Acid Generation – NAG, Modified Acid Base Accounting Procedure for Neutralization Potential-MABA and total and soluble metal analysis. These tests have as finality provide the first Idea about the potential of acid generation of the material in study. It is advisable to perform tests in several methodologies and the results must be compared with chemical, mineralogical and petrographical data.

In spite of the existence of numerous methods for the execution of statics tests for the determination of the acid base balance the fundamentals or principles of the same ones is identical. The capacity of a sample to consume acid is named neutralization potential or PN and the potential do generate acid is named acid potential or PA, and these quantities are expressed in units comparable and consistents. The difference between these two values is defined as the liquid neutralization potential or PNL and **PNL = PN – PA.**

The material classification is normally made considering the liquid neutralization potential or PNL . In this case, according to the balance, if the PNL is positive the sample has capacity to consume acid or neutralization potential. However, some researchers assume that the simple comparison between the values of PN and PA is not the most suitable criterion to confirm the acid generation potential. That being so, were proposed some criterions to evaluate the results being the most recommendable that ones presented in the table 1.

Table 1 - Criterion to evaluate static tests

Acid generation	Ferguson & Robertson	Ferguson	B.C.MD Taske Force	Smith & Barton-Bridges
don't generate	PN/PA > 2	-	PN – PA > 20	PN/PA > 3
Can generate	1 < PN/PA < 2	-	-20 < PN – PA < 20	PN/PA < 3
Don't generate	PN/PA < 1	PN – PA < 5	PN – PA < -20	-

For the test of liquid acid generation (NAG TEST) the Ph at the final of the oxidation process (pH_{NAG}) and the liquid potential of acid generation (NAG) are the parameters used to classify the material according to the table 2.

Table 2 – Criterion to classify the material following NAG Test

Acid generation Capacity	
$pH_{NAG} > 4$	Don't generate
1 < NAG < 10	Low capacity
NAG > 10, $pH_{NAG} < 4$	High capacity
Acid generation risk	
$3 < pH_{NAG} < 4$	Low risk
$pH_{NAG} < 3$	High risk

III. SAMPLES PREPARATION AND CHARACTERIZATION

3.1 Samples definition

In this study were used samples to represent the different ore types, wastes and tailings present in open pits, underground mines and lixiviation piles. The samples were selectively collected in piles and deposition places, defining the sampling denomination according to some local characteristic or a typology of the ore, waste or rejects. The table 3 presents the nomenclature adopted.

Table 3 - Samples nomenclature

1- Sabará oxidized ore – (MINOXSAB)	Sample collected at the ore deposit of the lixiviation pile.
2- Sabará transition ore – (MINTRSAB)	Sample collected at the mine ore deposit
3 – Sabará Waste - (ESTSAB)	Sample collected at the mine waste pile
4 -Sabará rejects - (REJSAB)	Sample collected at the reject pile
5- Caeté sulfite ore – (MINRG)	Sample collected at the ore stockpile in the mine
6 - Caeté Waste (ESTRG)	Amostra coletada na pilha de estéril
7 – Caeté rejects – (REJCTE)	Amostra coletada na pilha de rejeito
8-Santa Barbara sulfite ore - (MINPIL)	Sample collected at the ore stockpile in the mine
9- Santa Barbara waste – (ESTPIL)	Sample collected at the waste pile

3.2 Samples preparation

The samples were sent to laboratory to preparation and characterization. The phases of samples preparation were: - sample quartering, breaking in stone crusher, powdering and granulometric classification according to the tests. The samples were prepared according the required granulometry for each test following the table 4.

Table 4 – Test granulometry for the static tests

Test	Granulometry
pH de pasta	< 60# tyler
ABA	< 60# tyler
MABA	80% < 200 # tyler
NAG Test	80% < 200 # tyler

3.3 Chemical characterization

The samples were chemically analyzed by the methodology of X rays fluorescence to determinate the chemical elements sulfur, arsenic, chromium, ferrous, cupper, calcium, magnesium, zinc and nickel. The results are presented in table 5.

Table 5 - Chemical analyses of the samples

Sample	S (%)	As (%)	Ca (%)	Fe (%)	Mg (%)	Cu	Cr
MINOXSAB	0.05	1423	0.03	9.2	0.01	188	53
MINTRSAB	0.68	3776	0.03	9.9	0.5	61	169
REJSAB	0.05	1228	0.21	9.1	0.04	18	91
ESTSAB	0.02	1106	0.03	10.8	0.11	201	176
MINRG	2.05	1072	1.2	15.0	1.7	26	93
ESTRG	0.84	149	2.8	11.6	1.9	75	84
REJCTE	0.11	2084	0.46	15.0	0.31	178	225
MINPIL	1.74	46	3.3	10.2	2.00	106	213
ESTPIL	0.83	31	3.3	13.6	2.10	79	202

3.4 Mineralogical characterization

Were performed the mineralogical characterization of the three ore types belonged to the mines in operation, following the nomenclature below:

1 - MINOXSAB – Sabará oxidized ore
2 – MINRG –Caeté sulfite ore
3 – MINPIL - Santa Barbara sulfide ore

To each sample were prepared thin sections and these ones were described using a petrographical microscope with scattered light. .

3.4.1 Sabará oxidized ore (MINOXSAB)

The minerals were essentially free in the milling process and the majority of the particles were in the size between 20 and 300 microns. Only 2% of the minerals were in the form of small fragments. The sulfite minerals were very oxidized, and linked to the goethite. The percentage of the identified minerals were quartz 80 %, sericite 2 %, goethite 17 % and others minerals 1 %, being the sub-total of gangue equal to 82 %.

3.4.2 Caeté sulfite ore (MINRG)

The minerals were essentially free in the milling process and the majority of the particles were in the size between 30 and 200 microns. Only 2% of the minerals were in the form of small fragments. The sulfite minerals were essentially free. The percentage of the identified minerals were quartz 40 %, arsenopyrite 3 %, chlorite 5 %, goethite 1 %, sericite 3 % , pyrite 7 %, carbonate 41 % and others minerals 1 % , being the sub-total of gangue equal to 89 %.

3.4.3 Santa Barbara sulfide ore (MINPIL)

The minerals were essentially free in the milling process and the majority of the particles were in the size between 20 and 500 microns. Only 5% of the minerals were in the form of small fragments. The sulfite minerals were essentially free. The percentage of the identified minerals were quartz 34 %, biotite1 %, chlorite 5 %, plagioclase 1 %, sericite 5 %, carbonate 34 %, tourmaline 2 %, arsenopyrite 1 %, pyrrhotite 13 %, pyrite 1 %, carbonatic material 2 % and others minerals 1 %, being the sub-total of gangue equal to 82 %.

IV. RESULTS

In this case study were collected samples to predict acid mine drainage in the places listed in table 3, before. Were performed tests of paste pH, ABA (Acid Base Acouting) , MABA (Acid Base Acounting Modified) and NAG Test. The results of paste pH indicates if a sample is acidic or not. All the samples tested presented a paste pH value upper than 7, except the samples of Sabará ore. The results of these tests are presented in the following tables 6, 7, 8, 9, 10 and 11.

Table 6 - Paste pH results

Sample	Paste pH	Interpretation
MINOXSAB	6,78	
MINTRSAB	6,11	
REJSAB	8,06	Presence of reactive carbonate
ESTSAB	7,73	Presence of reactive carbonate
MINRG	8,17	Presence of reactive carbonate
ESTRG	8,58	Presence of reactive carbonate
REJCTE	8,48	Presence of reactive carbonate
MINPIL	8,73	Presence of reactive carbonate
ESTPIL	9,14	Presence of reactive carbonate

Table 7 - ABA (Acid Base Acounting) Standart test results

Sample		norm. HCl	norm. NaOH	weight sample (g)	vol. HCl .	vol. NaOH	potential neutralization (PN)	% S	potential acid (PA)	potential Liquid neutralization (PLN)
Sabará Oxidized ore	MINAOXSAB	0,	0,	2,	4	39,	1,0	0,0	1,5	-0,56
Sabara transition ore	MINATRSAB	0,	0,	2,	4	40,	-	0,6	21,2	-
Sabara	REJSAB	0,	0,	2,	2	17,	5,5	0,0	1,5	3,9
Sabará waste	ESTSAB	0,	0,	2,	2	20,	-	0,0	0,6	-2,63
Caete sulfite ore	MINRG	0,	0,	2,	4	18,	53,75	2,0	64,0	-
Caete waste	ESTRG	0,	0,	2,	4	6,	84,00	0,8	26,2	57,7
Caete rejects	REJCT	0,	0,	2,	2	15,	11,75	0,1	3,4	8,3
Santa Barbara	MINPIL	0,	0,	2,	4	4,	88,50	1,7	54,3	34,1
Santa Barbara waste	ESTPIL	0,	0,	2,	4	8,	79,00	0,8	25,9	53,0

Table 8 - Results considering criterion to evaluate ABA static tests according Table 1 and the results of table 7.

Amostra	Criterion of evaluation according:			
	Ferguson & Robertson	**Ferguson**	**B.C.MD Taske Force**	**Smith & Barton-Bridges**
Sabara oxidized ore	generate	generate	Can generate	Can generate
Sabará transition ore	generate	generate	generate	Can generate
Sabará rejects	Don't generate	generate	Can generate	Don't generate
Sabará waste	generate	generate	Can generate	Can generate
Caete sulfite ore	generate	generate	Can generate	Can generate
Caete waste	Don't generate	-	Don't generate	Don't generate
Caete rejects	Don't generate	-	Don't generate	Don't generate
Santa Barbara ore	Can generate	-	Don't generate	Can generate
Santa Barbara waste	Don't generate	-	Don't generate	Don't generate

Table 9 – MABA (Acid Base Accounting Modified) test results

sample	HCl (N)	NaOH (N)	Weight (g)	HCl (Vol.)	NaOH (Vol.)	PN	%S	PA	PLN
MINAOXSAB	0,1	0,1	2,0	20	20,1	-0,25	0,05	1,56	-1,81
MINATRSAB	0,1	0,1	2,0	40	41,4	-3,50	0,68	21,25	-24,75
REJSAB	0,1	0,1	2,0	20	19,2	2,00	0,05	1,56	0,44
ESTSAB	0,1	0,1	2,0	20	20,1	-0,25	0,02	0,63	-0,88
MINRG	0,1	0,1	2,0	40	62,0	-55,00	2,05	64,06	-119,06
ESTRG	0,1	0,1	2,0	40	51,6	-29,00	0,84	26,25	-55,25
REJCTE	0,1	0,1	2,0	20	16,0	10,00	0,11	3,44	6,56
MINPIL	0,1	0,1	2,0	40	53,0	-32,50	1,74	54,38	-86,88
ESTPIL	0,1	0,1	2,0	40	75,3	-88,25	0,83	25,94	-114,19

Table 10 – Results considering criterion to evaluate MABA static tests according Table 1 and the results of table 9.

sample	PN - PA (MABA)	PN/PA (MABA)	Ferguson & Robertson	Ferguson	B.C.MD Taske Force	Smith & Barton-Bridges
Sabará oxidized ore	-1,81	-0,16	generate	generate	Can generate	Can generate
Sabará transition ore	-24,75	-0,16	generate	generate	generate	Can generate
Sabará rejects	0,44	1,28	Can generate	generate	Can generate	Can generate
Sabará wastes	-0,88	-0,40	generate	generate	Can generate	Can generate
Caeté sulfide ore	-119,06	-0,86	generate	generate	generate	Can generate
Caeté waste	-55,25	-1,10	generate	generate	generate	Can generate
Caeté oxidized rejects	6,56	2,91	Can generate	Can generate	Can generate	Can generate
S. Barbara sulfide ore	-86,88	-0,60	generate	generate	generate	Can generate
S.Barbara waste	-114,19	-3,40	generate	generate	generate	Can generate

Table 11 – NAG Test results considering table 2

Sample	pH NAG	Vol NaOH	Norm. NaOH	Sample weight	NAG	Generation capacity	Generation risk
Sabará oxidized ore	3,32	3	0,1	2,5	6	low	low
Sabará transition ore	2,5	112,1	0,1	2,5	24	high	high
Sabará rejects	5,87					Don't generate	
Sabará wastes	5,40					Don't generate	
Caeté sulfide ore	3,06	7,7	0,1	2,5	15	high	low
Caeté waste	7,62					Don't generate	
Caeté oxidized rejects	6,42					Don't generate	
S. Barbara sulfide ore	8,53					Don't generate	
S.Barbara waste	8,85					Don't generate	

V. DISCUSSION OF THE RESULTS

To align the results is suggested a tabulation off the results considering a relative weight for each performed test. Each test (ABA, MABA or NAG) is evaluated in a graduated scale from zero to 100 points for each test totalizing a maximum of 300 points considering the three tests (ABA, MABA and NAG). The punctuation for each sample is presented in table 13 and was obtained consulting the tables 8, 9 and 10 and 11 respecting the points stipulated in the table 12, below:

Table 12- criterions for comparison between tests ABA, MABA and NAG

criterions	ABA	MABA	NAG
Generate	25	25	-
Can generate	12,5	12,5	-
Don't generate	0	0	-
High	-	-	50
Low	-	-	25
	-	-	

Table 13 – Relative potential to generate acid mine drainage

Sample	ABA	MABA	NAG	Total	%
Sabará oxidized ore	75,00	75,00	50,00	200,0	66,74
Sabará transition ore	89,50	89,50	100,0	279,0	93,00
Sabará rejects	37,50	62,50	0	100,0	33,30
Sabará waste	75,00	75,00	0	150,0	50,00
Caeté sulfide ore	75,00	89,50	75	239,5	79,80
Caeté waste	0	89,50	0	89,5	29,80
Caeté reject	12,50	25,00	0	37,5	12,50
Santa Barbara sulfide ore	25,00	89,50	0	114,5	38,20
Santa Barbara waste	0	89,50	0	89,5	29,80

Considering the table 12 and the percentage of 75 % as a limit in terms of capacity off acid generation is concluded that two samples have potential to generate acid mine drainage being these ones a sample of **Sabará transition ore** with a total percentage in the three tests of 93 % and the sample of **Caeté sulfide ore** with the total percentage the three tests off 79,80 %. These results confirm the evidence demonstrated in mineralogical characterization and chemical analysis. The **Sabará transition ore** presented the biggest grade in arsenic indicating the presence of arsenopyrite as the probable cause of acid generation. The **Caeté sulfide ore** presented the biggest grade in sulphur indicating the pyrite as the probable cause of acid generation.

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