Physical characterization and weathering of the basaltic rocks of the Paraná Basin, Brazil

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Abstract: This work presents the physical characterization and weathering assessment of samples of the tabular-columnar units of basalts located in the northern region of the Paraná Basin, Brazil. When used as construction materials, some basalts suffer degradation during storage, transport, and after construction. The changes in the characteristics of the rock materials are attributed to intrinsic factors, related to the nature of the rock. In this context, the methodology described in this work is based on the following:

a) Adoption of the concept of tabular-columnar basalts,

b) Evaluation and comparison of the physical and weathering characteristics of rock materials of the tabular-columnar units. This will enable traditional and alternative physical characterisation tests such as methylene blue adsorption, abrasive pH and abrasive conductivity to be performed. The results of some natural and artificial weathering tests are also described for quantitative comparison. The immersion fluids from the artificial alteration tests are monitored in respect to alkaline and earth alkaline chemical concentration, and the results used for material qualification and assessment of weathering. This enables a comparative analysis between the tabular and columnar types in respect to their use as aggregates for civil construction, and

c) Aproposal outlining the systematic evaluation of the physical quality of rocky materials. Instead of traditional descriptive worksheets, a computerised method can be adopted using digital forms.

Two main types of analysis and assessment of the rock material are used. The first looks at the composition of a qualitative analysis, the second uses the results of physical experiments to qualitatively assess the materials. Thus, the rock materials to be used as aggregates are classified in hierarchical levels of quality that help the user to choose the best material to be used for several purposes.

Résumé: Ce travail présente la caractérisation technologique et l´évaluation de alteration des échantillons provénant du compartimentage "entablature-colonnade" des roches basaltiques localisées dans la région nordique du bassin de Paraná, Brésil. Dans plusieurs cas, les roches basaltiques sont employées comme matériaux de construction, on l'a noté que certains d'entre eux ont souffis la dégradation pendant les processus de stockage et de transport, et beaucoup de périodes après la construction. Ces modifications dans les caractéristiques du matériel rocheux sont attribuées aux facteurs intrinsèques, reliés avec la nature de la roche. Dans ce contexte, la méthode utilisée dans ce travail est basée dans les procédures suivantes: a) utilisation du concept "entablature-colonnade" comme modèle de genèse des roches basaltiques, b) évaluation et comparaison des caractéristiques technologiques et alteration des matériaux rocheux des différent compartiments "entablature-colonnade". De cette façon, les essais de caractérisation technologiques traditionnels, c'était réalisés (bleu de méthylène, pH abrasif et conductivité abrasive) et les essais alternatifs. Pour evaluer l´alteration des materiaux ont été réalisés essais d´alteration naturelle et artificiels. Les fluides d'immersion des essais artificiels de changement ont été surveillés en ce qui concerne la concentration chimique de elements alkalines. Cette information a été employée pour la qualification matérielle et de l'évaluation de son alterabilitée, fournissant une analyse comparative entre les compartiments de "entablature-colonnade" en ce qui concerne a son utilisation pour la construction civile, et c) la proposition de l'évaluation systématique de la qualité technologique des matériaux rocheux. Pour analise de qualité, on a utilisé une méthode automatisée avec l´aide des formulaires életroniques au lieu des feuilles de travail descriptives traditionnelles. Deux procédures principales d'analyse et d'évaluation du matériel rocheux ont eté employés. Une d'eux a été visé la composition d'une analyse qualitative, l'autre a été basé sur les résultats des expériences technologiques. Ainsi, les matières rocheux qui puissent etre employés comme agrégats sont classifiées dans les plusieurs niveaux hiérarchiques de la qualité qui pussent aider, principalement, à l'utilisateur à choisir les meilleures matièrels avec leurs different finalités.

Keywords: Aggregate, Durability, Quarries, Igneous Rocks, Engineering Geology, Laboratory Tests

INTRODUCTION

In past decades the basalts of the Paraná Basin have been studied with the objective of evaluating their use as aggregate in civil construction. These studies supplied information about their geotechnical and physical characteristics, including changes in their mechanical properties in the long term. In several cases it was noticed that some basalts suffered degradation during storage, transport and after construction. The changes in characteristics of the rock material are attributed to intrinsic factors, related to the nature of the rock. From the point of view of civil engineering these alterations are reflected, mainly, in reduction of rock resistance. Inspite of the large amount of information on the use of basaltic rocks in civil construction, some aspects of these rocks remain poorly studied. One of these aspects refers to the use of the tabular-columnar characteristics as basic geological units of flood basalt. In this model the flood basalts present are divided into two distinct systems based on primary fracture type, refered to as columnar and tabular. This asks questions about these materials, such as: will the large amount of volcanic glass present in the tabular type compromise its use as aggregate in civil construction? How will this affect the alteration and weathering tests?

The first scientific works describing the characteristics and the nomenclature of the tabular and columnar basalt units were published by Tomkeieff (1940), Spry (1962) and Long & Wood (1986). Souza Jr. (1992) described the basaltic rocks in the Paraná Basin – Brazil.

METODOLOGY

The methodology used in this work is based in the following topics:

a) Adoption of the tabular-columnar concept as basic basaltic rock model,

b) Evaluation and comparison of the physical and weathering characteristics of the rock materials of the different tabular-columnar units, and

c) A proposal for the systematic evaluation of the physical quality of rock materials. Thus, the rock materials to be used as aggregates can be classified in hierarchical levels of quality to enable the user to select the best material to be used for several purposes.

Initially the methodology aims to recognise the different types of tabular-columnar units in several quarries in the São Paulo State, Brazil (Table 1). The field work defines the main types of flood basalts in accordance with the tabular-columnar concept (Figure 1). This classification is described in Gomes & Rodrigues (1999) and Gomes (2001). Twelve samples were collected, each from specific parts of the tabular and columnar units of the flood basalt profile and, in only case, a vesicular basalt. To enable comparison of the physical characteristics between flood basalts and intrusive basic rocks, a sample was also collected in a gabbro rock quarry.

Physical characterisation tests undertaken produced a primary description of these materials. These included: Physical index (NBR 6458), Uniaxial compressive strength (ISRM, 1978), Los Angeles abrasion value (NBR 6465), Soundness test by Ethylene glycol immersion (NBR 12697), Methylene Blue Adsorption test (Verhoef & Van de Wall, 1998), pH abrasion (Grant, 1969 and Malomo, 1980) and conductivity abrasion test (Gomes, 2001). Parallel to these tests, an X-ray difratometry was used for the detection and quantification of problematic minerals. The optic and Scanning Electron Microscope (SEM) analyses supplied information about the mineralogy, petrography and microstructures of the samples. The results of these tests are presented in detail in Gomes (2001). For evaluation of weathering, use was made of natural (field test exposure) and accelerated alteration tests. In the natural alteration test, the samples had been exposed in open for 360 days. For the accelerated alteration test, two cyclical methods were used: the wet and dry (NBR 12696) and the continuous leaching with the use of the Soxhlet extractor. For the quantification of mechanical resistance variation, after a determined numbers of cycles, the crushing test was used.

Figure 1. Tabular-columnar types in flood basalts (Inderp Quarry).

Table 1. Localization and type of sample.

Sample	Compartment	Localization
SCE	tabular	Quarry of the City - São Carlos/São Paulo State
SCC	columnar	Washington Luís High Way Quarry - São Carlos/ São Paulo State
PAV	columnar /gabro	Paviobras Quarry – Rio Claro/ São Paulo State
SAN	columnar	Santo Antônio Quarry – Araraquara/ São Paulo State
ANT	tabular	Santo Antônio Quarry – Araraquara/ São Paulo State
SAD	tabular	Said Quarry – Ribeirão Preto/ São Paulo State
VES	vesicular basalt	Said Quarry – Ribeirão Preto/ São Paulo State
IND	columnar	Inderp Quarry – Ribeirão Preto/ São Paulo State
BP	columnar	Bica de Pedra Quarry – Jaú/ São Paulo State
SM	columnar	Pedralite Quarry – São Manuel/ São Paulo State
SIQ	tabular	Siqueira Quarry – Assis/ São Paulo State
WS	columnar	Ws Quarry – Assis/ São Paulo State

PHYSICAL CHARACTERIZATION

The procedures used for testing are in accordance with national and international standards. Other methods or criteria developed during the present work, are described below. The results of these tests are presents in Table 2.

Petrographical Characteristics

Mineralogical and textural characteristics of the samples were determined using thin section studies. According to these studies, mineralogical composition, texture, pore structure, opaque and secondary mineral content and weathering rate of the basalt, in different units, were evaluated using the K1 and K2 Petrographical Indexes, proposed by Frazão & Paraguassu (1994) and Frascá (1998), and the R_{sm} Index "Secondary mineral rating" proposed by Cole & Sandy (1980). The X-ray difractometry detected the presence of plagioclase, pyroxene, metalic minerals and clay minerals, in all the samples. Deleterious minerals of the smectite group were identified in IND, VES, BP, SM and WS samples.

Physical Index

The dry unit weight ranges between 2,948kg/m^3 and 2,243kg/m^3. The dry unit weight of the BP sample is higher than that of the other basalts. The VES samples have the lowest dry unit weights. Already the wet unit weights show values that vary of 2,958kg/m^3 and 2,415kg/m^3, correspondents, respectively, WS and VES samples. The water absorption of the samplers ranges between 0.20% and 7.78%. The highest mean value of the water absorption belongs to VES sample and the lowest value belongs to IND sample. The total porosity varied between 17.27% and 0.60% values related, respectively, to samples VES and IND.

Resistance Values

The uniaxial compressive strength ranges between 60 and 290MPa. The SAD samples have the highest strength value among the basalts. The presence of vesicular structures and microfractures of the VES sample cause the lowest strength value. The Los Angeles abrasion values range between 13.09% and 31.58%. According to the results obtained, the maximum abrasion was observed for the VES sample, and the minimum abrasion was observed for the SCC sample.

Ethylene glycol Index

Ethylene glycol is one of the materials that reacts with swelling clays of the smectite group to form an Organo-clay complex having a larger basal spacing than that of the clay mineral itself. Hence a sample of basaltic rock containing swelling clay of the smectite group is expected to under-go expansive breakdown upon soaking in ethylene glycol, if the amount, distribution, state of expansion, and ability to take up glycol is such as to cause such breakdown to occur. If such breakdown does occur, a similar breakdown may occur if similar rock samples are exposed, for longer times, to wetting and drying or freezing and thawing in a water-soaked condition in service. The samples was immersed in the ethylene glycol solution for 21 days during which the amount of affected particles were evaluated at 3 day intervals. Table 2 presents the evaluation of the immersion in ethylene glycol of all the samples. The samples SCC, SCE, PAV, IND and SAD, were not been affected by this test.

Abrasion pH

Abrasion pH is determined after grinding a rock sample in distilled water. The resultant pH is dependent on the elemental and mineralogical composition of the rock material. In this way, Grant (1969) suggests that the reaction of the clay minerals present is dependant upon the pH value. In this concept, the clay minerals adsorb part of alkaline earths ions reducing its concentration in the solution, increasing the concentration of OH^-, and, consequently the value of Abrasion pH. The presence of clay minerals, mainly of 2:1 type, displays this action, for example in VES sample. The abrasion pH values range between 6.28 (PAV sample) and 9.49 (VES sample). The low pH values of PAV sample occurred due to presence of sulphites (pyrite) (Figure 2). The reaction of sulphite oxidation produces sulphate, free oxides and H^+ ions. During this reaction, the increase of H^+ concentration increases the acidity of the solution. The others samples had Abrasion pH values range between 8.45 (SIQ sample) and 9.09 (SAD sample).

Following the same procedure adopted for abrasion pH determination, the values of conductivity were measured. In this way, three groups of conductivity values were identified. Group one, represented by the PAV sample, presents the highest value of conductivity (203.4 mmohm), followed for Group 2, represented by the VES sample value (126.0 mmohm). The others samples of Group 3 display lower values of conductivity. These values range between 22.0 mmohm (SIQ sampler) and 36.0 mmohm (WS sample).

Methylene Blue Adsorption test

The results of the methylene blue adsorption test, expressed in values of Methylene Blue Adsorption (MBA) are presented in Table 2. The MBA values range between 0.22g/100g and 2.41g/100g. According to the results obtained, the highest MBA was observed for the VES sample, and the lowest MBA was observed for the PAV, IND, SAD and SCC samples.

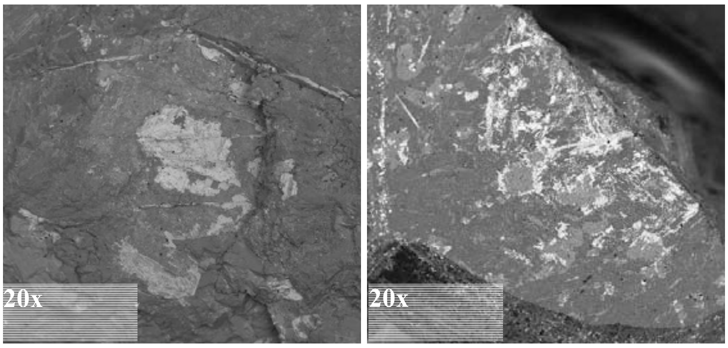

Figure 2. Images generated by the Scanning Electron Microscope (SEM) presenting, in clear tones, the occurrence of pyrite in PAV sample. The sulphite was identified using microprobe analyses.

ALTERATION AND WEATHERING

Exposure Field Tests

This test aims to evaluate the alteration of the rock materials when submitted to the natural weathered conditions. To evaluate the rate of the alteration, the loss of mass was measured together with a resistance of the sample. The loss of mass is the loss in weight of the aggregate after a specified number of cycles as a percentage of the original weight After these, the samples were submitted to X-ray difractometry and MBA test. For the weathering evaluation the KΔt index (Farjallat, 1971) and the Rf Index (Yoshida, 1972) were used. The KΔt index indicates the weathering of the rock material and range in the interval of 0 and 1. The larger the KΔt value, the greater the weathering of the rock. The R_f Index, suggested by Yoshida (1972), a range of 0 for the R_f. The smaller the R_f value, the greater is the weathering. For analysis of the MBA values variation were determined during 120 cycles, or over a period of 4 months.

Accelerate Alteration Tests

The accelerate alteration test aimed the determination of the alteration resistance of rock materials, when submitted a wet and dry cycles. For these, two methods were used: the wet and dry and the continuous leaching with the use of the Soxhlet extractor. The Soxhlet apparatus recirculates water or other fluids through a sample to simulate conditions of weathering. This work uses distilled water to leach a sample over a period of 100 cycles, each wet and dry cycle lasted approximately 6 hours. For the wet and dry test, the cycles were defined in daily intervals of 16 and 8 hours, respectively, for a total of 100 cycles. The amounts of loss of mass and mechanical resistance was similar to the Exposure Field Test. Afterwards, the samples were submitted to X-ray difractometry and MBA analysis. During the Accelerate Alteration Tests the immersion fluids are monitored in respect to alkaline and alkaline earths chemicals concentration. During this test, the immersion fluids samples were collected at intervals of 10 cycles. The concentration of the K^+, Na^+, Ca^{++} ions were determined using a Flame Photometer. The Mg^{++} ion concentration were detected using an Atomic Absorption Spectrometer. In this context, Parker (1970) considers the index of the ratio of alkaline and alkaline earths, in an attempt to quantify alteration of the rocky material through the measurement of these ions in the leaching solution. In this context, the increase in the value of the Parker index of sample PAV, see Table 2, relates to sulphites oxidation that occurs in PAV sample. This process promotes the appearance of sulphate in solution associated with a low pH conditions. Under these conditions an aggressive leaching solution is formed when in contact with the sample. The rate of aggressiveness of the leaching solution is dependent upon, the alkaline and alkaline earths elements present in the sample and, how much greater the leaching, the greater the removal of ions and consequently higher the concentration in solution. The elevated concentration of Ca^{++} ion promoted the calcium sulphate precipitation in the surface of the PAV sample (Figure 3).

Table 2. Summary of the results of Physical and Weathering tests.

Sample/ Test		PAV	SM	ANT	SAN	WS	SIQ	SAD	IND	SCE	SCC	VES	BP
Dry unit weight (kg/m^3)		2,862	2,921	2,889	2,910	2,942	2,945	2,916	2,923	2,893	2,912	2,243	2,948
Water absorption (%)		0.27	0.47	0. 54	0.29	0.54	0.39	0.29	0.20	0.30	0.27	7.78	0.33
Porosity (%)		0.77	1.38	1.57	0.84	1.58	1.15	0.83	0.60	0.87	0.77	17.27	0.97
Ethylene glycol immersion (%)		0	8	8	59	16	22	0	0	0	0	86	8
MBA (g/100g)		0.22	0.37	0.6	0.6	0.9	0.68	0.22	0.22	0.52	0.22	2.41	0.45
Uniaxial compressive strength (MPa)		191	124	230	160	155	86	290	175	242	265	60	180
Crushing test (%)		14.00	13.62	14.15	13.48	15.87	11.98	14.31	11.85	14.10	12.20	20.73	13.34
Los Angeles abrasion (%)		16.32	13.26	14.15	13.48	15.87	11.98	14.31	11.85	14.0	12.20	20.73	13.34
Petrographic Index K1		18.0	26.0	6.7	3.8	16.0	3.1	6.8	9.0	10.3	24.3	4.0	18.0
Petrographic Index K2		18.0	26.0	4.6	2.6	16.0	2.0	3.8	5.5	6.9	18.2	1.3	14.0
R_{sm} Index		40	34	53	110	40	145	72	49	55	23	175	31
Abrasion pH		6.28	8.70	8.83	8.51	8.71	8.45	9.09	8.87	8.48	8.61	9.49	8.72
Abrasion Conductivity (mmohm)		203.4	27.0	31.0	24.0	36.0	22.0	28.0	24.7	26.5	23.0	126.0	25.0
Parker's Index	Wd	0.44	1.50	0.25	0.36	0.37	0.34	0.19	0.28	1.70	0.34	0.27	0.37
	Sox	1.25	2.24	1.94	0.91	0.56	0.82	0.79	0.68	0.82	0.73	0.70	0.71
Loss of Mass (%)	Nat	3.06	2.43	2.14	8.27	3.29	5.67	3.46	3.35	3.50	3.23	11.30	2.92
	Wd	2.22	1.55	2.61	8.59	2.13	4.81	2.30	3.23	2.42	3.12	12.90	2.93
	Sox	0.63	3.08	1.18	3.02	1.36	1.40	1.10	2.28	4.47	2.31	6.17	1.83
$K\Delta t$ - Weathering index	Nat	0.021	0.016	0.020	0.054	0.025	0.036	0.026	0.029	0.022	0.026	0.071	0.018
	Wd	0.022	0.013	0.017	0.052	0.018	0.032	0.022	0.029	0.017	0.022	0.086	0.018
	Sox	0.005	0.022	0.007	0.020	0.008	0.012	0.008	0.022	0.025	0.021	0.048	0.012
Rf - Weathering index	Nat	82.56	83.81	82.39	77.65	80.07	81.91	81.48	83.24	82.29	83.40	69.06	83.77
	Wd	82.19	84.25	82.99	78.04	81.14	82.66	81.96	83.16	83.06	84.05	66.84	83.77
	Sox	85.16	82.78	84.63	83.21	82.83	85.97	84.30	84.32	81.81	84.17	72.10	84.72

QUALIFICATION OF THE MATERIALS

For use in civil construction, the Brazilian standards recommend the tests presented in Table 3. Looking at this table it is inferred that the great majority of the tests do not have limits of recommended values for appropriate characterization of the aggregate. Instead, the limits of values presented in Verhoef & Van De Wall (1998), IPT (1980) and in the tests carried through in this work were applied (Table 4).

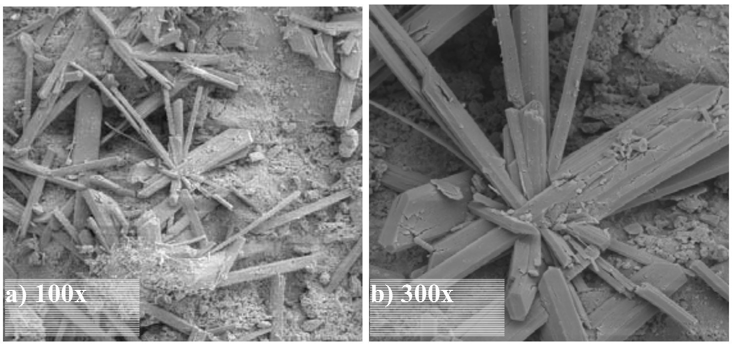

Figure 3. Images generated for the Scanning Electron Microscope (SEM) at the PAV sample in 70 wet and dry cycles: a) and b) Calcium sulphate precipitation in the surface of the PAV sample.

In Table 4 the results of the tests were subdivided in four classes of values. Each one of these classes possesses a different weight that varies from 0 to 3, with increase of the quality of the appraised attribute with size. In this way, the following relationships apply: weight = 0 (bad quality), weight = 1 (reasonable quality), weight = 2 (good quality) and weight = 3 (excellent quality). For evaluation of all information, an algorithm was created that represents the media of the weights. They have a total of 14 evaluated attributes, each one with its weight related to the results of tests. Below, The formula of the algorithm used is present below:

$$R = \sum_{j}^{i} Pa_{i,j} / P_{max} * N$$

where R is a Quality value, $Pa_{i,j}$ is a weight of each attribute, P_{max} is a maximum weight of attributes and N is a total number of attributes.

Table 5 presents the weights of each test in the range of samples analysed. In this way, if "R" value varies of 0 the 1, is possible then to define intervals of "R" associates to the different classes of quality. Thus, "R" values between 0 and 0.25 are "Bad"; "R" values between 0.26 and 0.50 are "Reasonable", "R" values between 0.51 and 0.75 are "Good" ; and "R" values between 0.76 and 1.00, are "Excellent" .

According to the classification results presented in Table 5, with the exception of the vesicular basalt sample (VES), all of the other samplers are classified as “excellent” or “good” quality. The sample PAV possesses excellent qualities of physical characteristics and resistance, but the sulphite present in the mineralogy cause a sulphate crystallisation on the surface and in the aggregate microfratures causing disaggregation. The samples SM, SAD, IND, SCE, SCC and BP are classified as of “excellent” quality. The sample SAD, presented low value of the K2 index, due to presence of interlinked smectites observed in the petrography microscope that could have negative influence on quality. However, the compact structure, low porosity and low water absorption, minimizes the influence of these deleterious minerals as shown in the results of the weathering tests.

The samples ANT, WS, SIQ and SAN, they are classified as a “good” quality. The sample ANT, due to the presence of approximately 28% of volcanic glass in the mineralogy, shows a reduced K2 index value. The presence of smectite, probably resultant of the volcanic glass alteration, is indicated by the high MBA value. This sample has weathering indexes compatible with the values of the samples classified as of “excellent” quality. In the sample WS the MBA test identified significant amounts of expandable minerals that, associated with larger values of porosity and water absorption, provided a significant loss in the ethylene glycol immersion test. This fact reflected in the result of the R_f weathering index. The samples SAN and SIQ presents excellent values of physical indexes and the X-ray difractometry did not detect expandable clay minerals but, they showed very bad ethylene glycol immersion, K1 and K2 index and R_{sm} index test results. They also produced poor weathering tests results. Therefore, in spite of the SAN and SIQ samples obtaining a good classification, their use as construction material requests some care.

Table 3. Some Aggregate Tests recommended by Brazilian Norms.

Test	Aggregate for Concrete	Aggregate for Roads	Aggregate for Roads train
Los Angeles abrasion	max. 50%	max. 40%; 50%	max. 40%
Crushing test	max. 30%	max. 30%	max. 30%
Dry unit weight	min. 2,500kg/m^3	min. 2,500kg/m^3	min. 2,400kg/m^3
Porosity	max. 2%	max. 2%	max. 1%
Water absorption	max. 1%	max. 1%	max. 1%
Uniaxial compressive strength	min. 100MPa	min. 140MPa	min. 140MPa

Table 4. Guide to rock durability from test results (after Verhoef & Van De Wall, 1998 and IPT,1980).

Test	Excellent (weight 3)	Good (weight 2)	Reasonable (weight 1)	Bad (weight 0)
Dry unit weight (kg/m^3)	> 2,900	2,600 – 2,900	2,300 – 2,600	< 2,300
Water absorption (%)	< 0.5	0.5 – 2.0	2.0 – 6.0	> 6.0
Porosity (%)	<2	2 - 3	3 - 4	>4
Ethylene glycol immersion (%)	< 2	2 - 12	12 - 30	> 30
Methylene blue adsorption test (g/100g)	< 0.4	0.4 – 0.7	0.7 – 1.0	> 1.0
Uniaxial compressive strength (MPa)	> 200	100 - 200	50 - 100	< 50
Crushing test (%)	< 20	20 - 25	25 - 30	>30
Los Angeles abrasion (%)	<40	40 - 45	45 - 50	>50
Petrographic Index K1	-	> 5	5 - 3	< 3
Petrographic Index K2	-	> 5	5 - 1	< 1
R_{sm} Index	< 60	60 - 110	110 - 140	> 140
Weathering – loss of mass (%)	-	< 3.50	3.50 – 11.00	> 11.00
KΔt - Weathering index	< 0.001	0.001 – 0.030	0.030 – 0.070	> 0.070
Rf - Weathering index	> 90.00	90.00 – 80.00	80.00 – 70.00	< 70.00

Table 5. Quality classification of each studied sample.

Sample / Test	PAV	SM	ANT	SAN	WS	SIQ	SAD	IND	SCE	SCC	VES	BP
Dry unit weight	2	3	2	3	3	3	3	3	2	3	0	3
Water absorption	3	3	2	3	2	3	3	3	3	3	0	3
Porosity	3	3	3	3	3	3	3	3	3	3	0	3
Ethylene glycol immersion	3	2	2	0	1	1	3	3	3	3	0	2
MBA	3	3	2	2	1	2	3	3	2	3	0	2
Uniaxial compressive strength	3	2	3	2	2	1	3	2	3	3	1	2
Crushing test	3	3	3	3	3	3	3	3	3	3	2	3
Los Angeles abrasion	3	3	3	3	3	3	3	3	3	3	3	3
Petrographic Index K1	2	2	2	1	2	1	2	2	2	2	1	2
Petrographic Index K2	2	2	1	1	2	1	1	2	2	2	1	2
R_{sm} Index	3	3	3	1	3	0	2	3	3	3	0	3
Weathering – loss of mass	3	3	3	1	3	1	3	3	2	3	0	3
KΔt - Weathering index	2	2	2	1	2	1	2	2	2	2	0	2
Rf - Weathering index	2	2	2	1	1	2	2	2	2	2	0	2
Addition of the weights of the attributes	37	36	33	25	31	25	36	37	35	38	8	35
Maximum weight of the attributes	3	3	3	3	3	3	3	3	3	3	3	3
Number of the attributes	14	14	14	14	14	14	14	14	14	14	14	14
“R” Value	0.88	0.86	0.79	0.60	0.74	0.60	0.86	0.88	0.83	0.90	0.19	0.83
Classification	Exc.	Exc.	Good	Good	Good	Good	Exc.	Exc.	Exc.	Exc.	Bad	Exc.

For the comparative analysis of the quality of the rock materials of the different units, the comparison of the “R” values calculated for the tabular and columnar samples fromthe same basaltic flood should be used. In this way, the classificatory values of the samples IND and SAD, SCC and SCE, and SAN and ANT were compared. The tabular (SAD) and columnar (IND) units presented have, approximately, the same values of “R”, respectively 0.86 and 0.88. These values indicate a better quality for the columnar unit. The same behaviour was detected for (SCE) and (SCC) samples, respectively, “R” = 0.83 for the tabular sample and “R”= 0.90 for the columnar sample. The samples SAN and ANT present one inverse situation. In this case, the “R”= 0.79 for the tabular unit (ANT) is larger than the value of columnar unit (“R” = 0.60) for the (SAN) sample.

SYSTEMATIZATION OF THE QUALITY EVALUATION

For the evaluation of the aggregate quality a computational system based in the “R” value was developed. For the quantitative analyse the knowledge of physical parameters is necessary. The interface with the user of the programme is sufficiently simple and is based on forms completed using a choice of items, in following order: “Physical Index form”, “Mechanics Resistance form”, “Soundness and Methylene Blue Adsorption form”, “Petrographics Characteristics form” and “Weathering form”. Each field is composed for four items. Each one of these possesses a different weight that varies between 0 and 3 with increase in the quality of the attribute evaluated. After completion of the forms, the system will be ready to make the quantitative analysis using the “R” algorithm. The results are represented in “Quality analysis form”.

CONCLUSION

The application of the tabular-columnar basis for the classification of the flood basalts is shown to be useful.

The study shows that the physical characterisation and weathering tests provide excellent information for the calculation of the quality indices, such as: K1 and K2 Petrographical Index, Rsm Index and Weathering indexes. Although the petrographical characteristics of the studied samples maybe very similar, the K1, K2 and R_{sm} indexes indicate clearly the poor the quality of samples SIQ, SAN and VES.

The X-ray difractometry identified the presence of clay minerals of the smectite group in different amounts in IND, VES, BP, SM and WS samples.

The values of physical index, uniaxial compressive strength, Los Angeles abrasion and crushing test, produce from the samples analysed failed to supply enough information to allow determination of sample aggregate quality, with exception of vesicular basalt sample (VES).

The results of ethylene glycol immersion proved to be efficient for discrimination of the disaggregation potential.

The $K_{\Delta t}$ and R_f Weathering indexes are useful in the evaluation of weathering rates for each sample.

The methylene blue adsorption test and abrasion pH were sufficiently appropriate. The methylene blue adsorption test proved useful in the evaluation of the presence and type of clay minerals. The Abrasion pH made possible the verification of the metallic mineral (sulphite) in a sample. These tests are useful for ease and rapidity in the attainment of results.

The “R” Quality Index proved to be a satisfactory form for the evaluation of information generated for the execution of the physical and weathering tests. It is concluded that significant differences between the quality of materials from the tabular and columnar units do not exist.

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