A Short Review on the Importance of Colonnades, Entablatures and "Fault Joints" for the Excavation of Basaltic Rocks

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Abstract. Entablatures, colonnades and "fault-joints" have been found in many excavations of dam foundations, tunnels and quarries in basaltic rocks of southern Brazil, but frequently they were not formally identified as such, and the two first, only rarely. This lack of recognition led many times to misunderstanding of their importance to slope stability and foundation problems. This short note reviews their basic definitions and stresses the influence of their properly consideration in the development of geotechnical projects.

Keywords: entablature, colonnade, basalt, jointing, columnar, dam.

1. Introduction

Entablatures, colonnades and "fault-joints" have been met during dam construction in Brazilian basalts but sometimes not identified as such. They may be frequently a concern in stability, excessive overbreak and seepage in dam foundations and also commonly in slope stability.

Entablatures and colonnades are widely known features in international scientific literature, but their description in Brazilian basalts has been done only after the studies of Souza Jr (1992). Even then, references were practically restricted to reports of quarry pit excavations, considerations about rock weathering susceptibility or concerns on the role they play in groundwater exploration (Fernandes *et al.*, 1998; Gomes & Rodrigues, 1999).

"Fault-joints" on the other hand were longer identified in Brazil but not described as such in international technical literature due probably to the preference in using the term "platy - joints".

This short note reviews their basic definitions and stresses the influence of their proper consideration in the development of geotechnical projects.

2. Definitions

There are several geological structures in basaltic flows that belong to the common geologists jargon: spiracles, lava tubes, breccias, volcanic glasses, columnar joints, etc. (Cetin *et al.*, 2000). Other terms are less popular, like "maars" (Araujo *et al.*, 1977), "fault joints" (Bjoernberg & Kutner, 1987) and entablatures Souza Jr. (1994a, b).

2.1. Colonnades and entablatures

Colonnades and entablatures are features or tiers of columnar cooling joints that may occur jointly in a single basalt flow (Fig. 1) giving sometimes "a false appearance of the existence of two flows" (Sherbon-Hills, 1976).

Colonnades are composed mainly by assemblages of relatively large diameter (0.3 to 2 m) and well-formed columns, frequently with pentagonal to hexagonal cross sections, that occur mainly in the lower or upper third of a flow. The columns are usually perpendicular to the base of the flow (presumably normal to the cooling isotherms).

Entablatures usually overlay the basal colonnade and show thinner and longer or slender columns, with a diameter of circa 0.2 to 0.5 m. They may be irregular to hackly, originating local radiating patterns, deviating from being perpendicular to the base of the flow (Fig. 1). Entablatures give frequently way to an upper colonnade, which, on its turn, is topped by vesicular basalt, but other recurrences are found in nature as described by Long & Wood (1986) (Fig. 2).

While colonnades are usually related by a somewhat slower cooling rate starting from the base to the top of the flow, entablatures have been related to faster downward cooling possibly related to quenching by flowing water from above (heavy rains or flooding). Entablatures usually show a larger (circa 40% more) percentage of fine matrix then colonnades.

In the field the separation between Entablatures and Colonnades is structurally sharp and, in certain cases, marked by a fault-joint. In what concerns the matrix of the rockmass the geomechanical differences, in our opinion, are still not clearly resolved (see, for example, Gomes & Rodrigues, 2008).

Since the matrix material from the entablatures is thinner and glassier it should be less porous then that from the colonnades and their texture therefore much more compact and the geomechanical properties of the rock masses

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should vary accordingly. In the entablatures domain, the uniaxial compression strength and the elasticity modules are expected to be higher.

Structurally, jointing is denser in the entablatures domain, but joints seem to be partially welded or cemented by thin films of minerals (Fig. 3). They are tightly closed in fresh rock and opened in weathered rock masses, where hackles turn to be more evident and help to induce fragmentation of the columns and thus, some raveling in open cuts (Fig. 4).

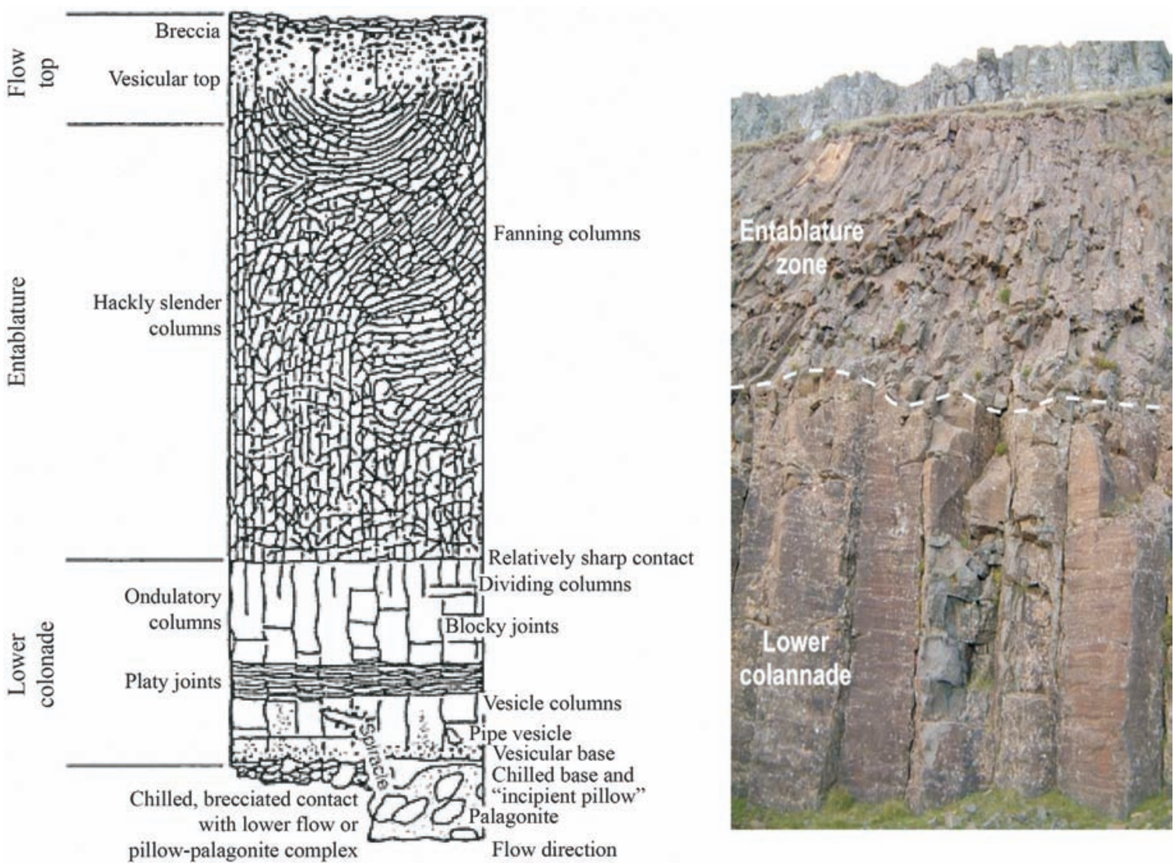

Figure 1 - Intraflow structure of a basalt flow. Scheme on the left according to Swanson & Wright (1981).

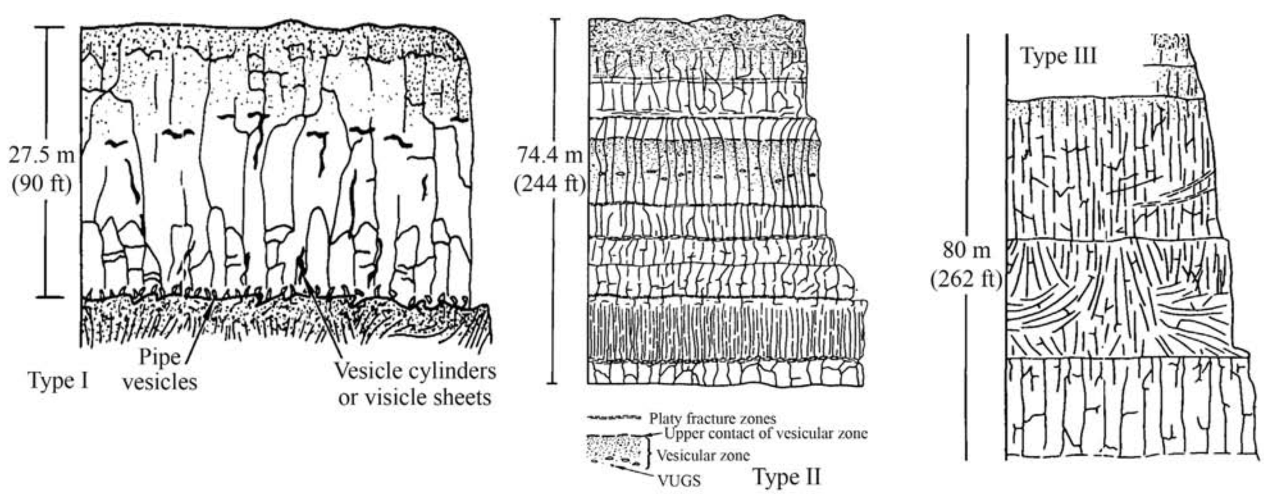

Figure 2 - Types of flows in terms of structural organization of cooling joints tiers (apud Long & Wood, 1986). Type I: flow - with no entablature, usually found in the Columbia River Basalts as related to relatively thin flows (10 to 20 m); Type II: flow: with alternating colonnades and entablatures, usually in flows with a thickness of 45 to 75 m; Type III: flow: with a lower colonnade and an upper entablature. Both, type I and II may have an upper colonnade.

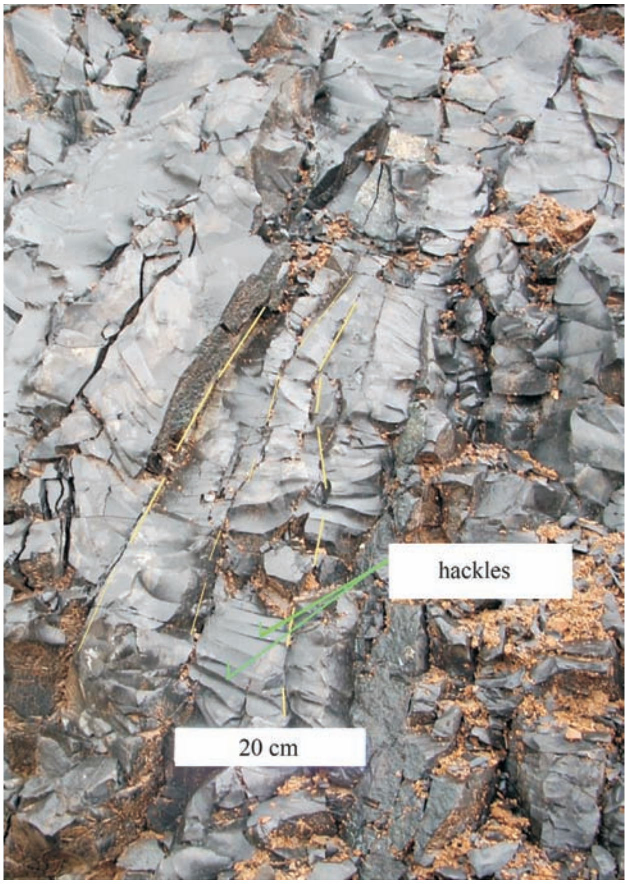

Figure 3 - Slender and partially welded columns.

Figure 4 - Slope cut raveling in loosened entablature basalt.

2.2. “Fault-Joints”

“Fault-Joints” were originally defined as such in Brazil by Guidiccini & Oliveira (1968) (Fig. 5) at the Ibitinga Dam construction site, and successively quoted in other dam constructions. such as Foz de Areia, São Simão, Volta Grande, Itaipu etc. in the basalt flows province of the Parana Basin (Bjoernberg & Kutner, op. cit., Souza Jr. & Oliveira Campos, 1987 and many others). One may probably relate them to the term “platy-joints” used in the anglo-saxon literature (Sherbon-Hills op. cit. and others).

These structures are usually represented by a planar sub-horizontal fracture or lamination surface which may gradually incline (dip) about 35° or more. It may be also braided or divided (moustache structure), sometimes ex-

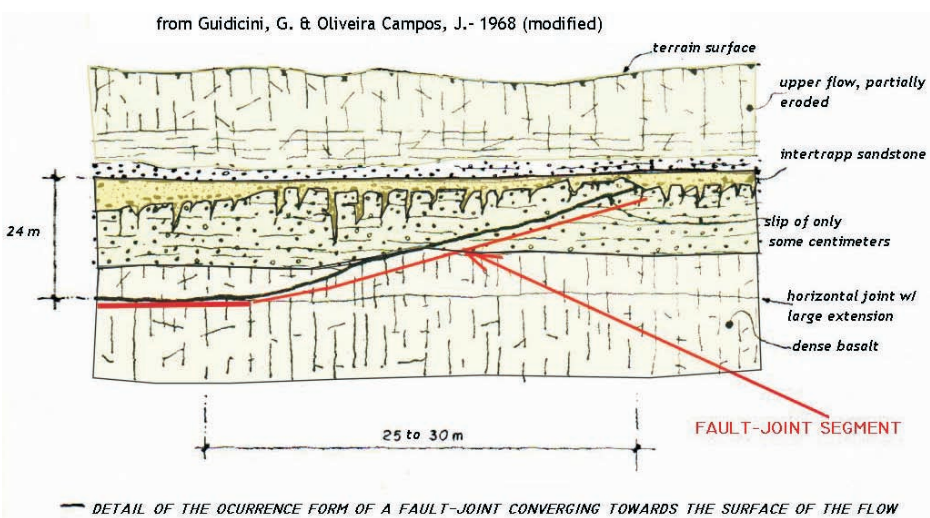

Figure 5 - Fault-joint as defined in Guidiccini & Campos (1968).

hibiting striations which allowed some tectonic speculations. Their origin has been related to different mechanism such as differential contractions during cooling, stress relief effects or even shallow tectonics. Being relatively permeable, they are frequently percolated and affected by differential weathering. Consequently, the laminated platy rock of the densely jointed zone may be totally or partially weathered. Shear strength properties are usually substantially lower then those of the rest of the rock mass. Mohr-Coulomb strength parameters have been determined, some with the help of "in situ" shear tests, to spread frequently around ~0.05 MPa for the cohesion and a phi of around 20 to 35° depending on the type of filling or the presence of evidences of pre-shearing (Marchi & Cury Jr., 1983) (Fig. 6). Figures 7 and 8 show their aspect in other dam construction sites.

3. Conclusive Remarks: The Influence of these Features in the Development of Geotechnical Projects

Depending on the joint orientation, one may conclude that the presence of entablatures may lead to a higher directional permeability in dam foundations and to a higher potential of rock raveling at high cuts (as in Fig. 4). The raveling and the ease of excavation or even risk of over-excavation in the more superficial horizons with the use of machines has been observed, particularly once one breaks the small cohesion between the partially welded columns (Fig. 9). However in what concerns permeability or bearing strength of the mass, no special problematic behavior has been determined. Both aspects ask for careful blasting in order to achieve the desired design profile.

Concerning the production of raw material, the differences between colonnade and entablature are also very important. Although favoring the fast production of hand-size blocks, the larger percentage of glass found in entablatures increases the percentage of splinters or lamellar particles and results in the need of special cements to diminish the reactivity with concrete.

In what concerns fault-joints, problems related to their lower shear strength and higher permeability have been of common concern amid Brazilian engineers and geologists. Reinforcements through anchoring or indentations of the concrete structures founded above these frac-

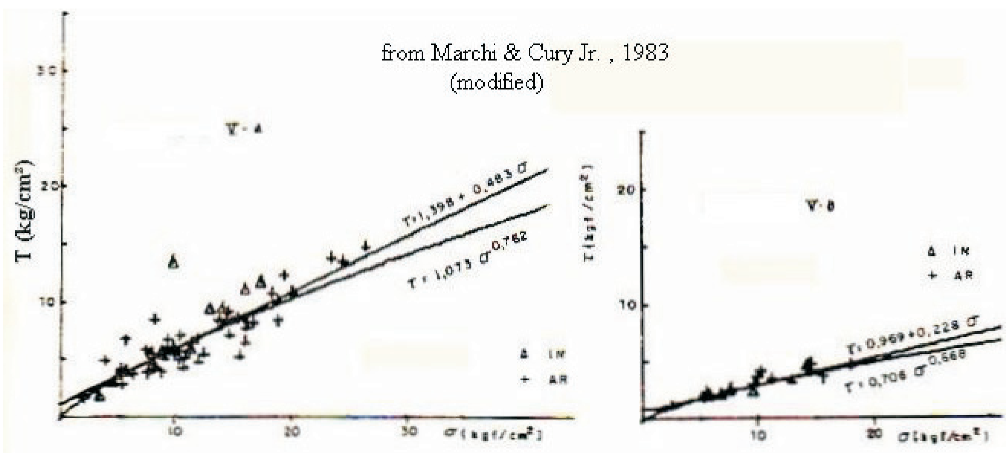

Figure 6 - Mohr Coulomb direct shear strength envelopes for sound and weathered fault joints (IN = intact, AR-after rupture) from Marchi & Cury Jr (1983).

Figure 7 - "Fault-joints" in basalts of Northern Brazil. Observe ramifications on the left end. The photo was taken during dam construction.

Figure 8 - Weathered “Fault-joint” between colonnade and entablature (upper realm) at a dam construction site in Parana Basin basalt flow in the São Paulo State.

Figure 9 - Machine excavation of blocky, partially weathered entablature. São Paulo State.

tures may be needed. Grouting or even removal of the soft filling followed by it substitution by concrete are also some of the preventive measures that have been implemented.

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