STRATIGRAPHIC INTERPLAYS BETWEEN IGNEOUS AND SEDIMENTARY EVENTS IN THE EARLY PALAEozoIC JAIBARAS TROUGH (NORTHWEST BRAZIL)

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ABSTRACT The Jaibaras Trough is an example of an intraplate province for which both origin of magmatic manifestations and basin generation mechanisms are coeval. The magmatic suites demonstrate close spatial and temporal relationships and, in turn, appear to be genetically associated. The simple distribution of igneous bodies occurrence constrains the spatial relationship between the whole magmatic activity during the basin infill. Sequential stratigraphic interplays between sediments and magmatic activities are perfectly constrained through thermal-structural features such as contact aureoles, faulted contacts/abutting and cross-cutting. The basin infill congregates continental immature siliciclastic sedimentary deposits. Deposition took place in areas of instable young shoulder relief and probably totals up to 3 km in thickness. Marked variations in thickness, rapid changes in depositional facies, interbedded thick conglomerates, local unconformities and disconformities of variable extent typify the overall sedimentary deposits making a regional palaeogeographic reconstruction difficult. Probably axial basin filling provided the sedimentation of shale and sandstone, whereas the rift flanks laterally sustained the alluvial fan conglomerates. The magmatic evolution of Jaibaras Trough comprises basically four temporal and spatially separated phases. The early phase involved the Vendian Coreau Dike Swarm, and represents the initial tectonic pulse of rift opening. With continued breakup, reactivation of deeper shear zones gave rise to the emplacement of the Mucambo Pluton during Early Cambrian times, which preceeded the main rift infill. The basin sedimentation was accompanied by a huge volume of volcanism, most of which is composed by flood basalts, dikes and sills. The Menouca Pluton is the last basin-related igneous manifestation during the Upper Cambrian.

Keywords: Jaibaras Trough, Borborema Province, Igneous-Sedimentary Sequence, Tectono-Stratigraphic Evolution, Basin Infill

INTRODUCTION The Jaibaras Trough (JT), the most important, prominent and extensive exposure of Early Palaeozoic sedimentary sequences in a wide Brasiliano-age area, including the Borborema Province and the Nigerian Shield, is an example of an intraplate province for which both origin of magmatic manifestations and basin generation mechanisms are coeval. Whether or not the magmatism is the result of basin formation mechanisms or vice-versa is difficult to constrain. Despite all uncertainties involved in the magmasedimentation system, the most obvious and reasonable seems to be an integrated process. The magmatic suites mainly constitute the exposed floor of a continental rift flank and thus, combined with sedimentary rocks, provides an opportunity to integrate igneous thermo-tectonic approaches within a geodynamic evolution of an extensional regime. It extends as a well-defined narrow depression (dimensions of 10-20 km in width x 120 km in length) overlying gneisses, migmatites and earlier metasedimentary terrains of the basement (Fig. 1). The main graben is bordered by mylonitic shear zones reactivated normally inside the continental-scale Transbrasiliano Lineament. This graben-like feature is the result of a strong and widespread continental breakup that took place during the separation of Laurentia and Baltica from Western Gondwana (Dalziel 1997). Resultant reactivation adjustments are observed globally along regional lithospheric anisotropies, in general generating rifts which did not evolve to a passive margin basin.

In this paper we integrate all geological observations in order to explain and establish a plausible stratigraphic model, where the role of magmatic expressions are primarily explored. The approach used to generate this framework was based on field studies and on a compilation of available data.

REGIONAL BASEMENT SETTING The so called Northwestern Ceará Domain, which encompasses the JT (Fig. 1), is a triangle-shaped, highly deformed and sheared wedge, lying at the extreme northwest of the Borborema Province. This domain configures a geometrical array of horsts and grabens aligned NE-SW and juxtaposed by deep subvertical shear zones, named the Transbrasiliano Lineament. The structural highs, called Migmatitic-Gneiss Complex, consists of Archean to Paleoproterozoic high-grade rocks (in general granulites and charnockites) strongly reworked during the Brasiliano Orogeny. The grabens are generally filled by conglomerates, sandstones, limestones and shales as well as by volcanogenic intrusions and extrusions, all metamorphosed in low-temperature facies. A detailed compilation concerning the geology of Northwestern Ceará domain is available in Torquato & Nogueira Neto (1996). Two kinds of graben fill, displaying contrasting tectonic evolution may be distinguished in the Northwestern Ceará domain (Jardim de Sa 1994, Torquato & Nogueira Neto 1996): the first corresponds to the polycyclic ones, which were affected by the Transamazónico tectono-thermal event (1.8/2.2 Ga) and were later reworked by the Brasiliano deformational event (0.5/0.7 Ga). Associated to these polycyclic sequences, docked onto basement highs, large thrust and ramps of
quartzites and schists also occur showing a highly complex tectono-metamorphic evolution (Oliveira 1992, Torquato & Nogueira Neto 1996). In contrast, the monoclinal belts were only structurally during the Brasiliano event. The Martinópole and Ubajara groups are the main representatives of this phase. Because of their excellent preservation within troughs, such units most likely correspond to an ancient preserved sedimentary basin, where the sediments of Martinópole Group characterize a typical rift infill whereas the Ubajara Group represents a possible continental margin composed of weakly metamorphosed assemblages of sandstones with subordinate shales, overlain by a carbonate sequence (Hackspacher et al. 1988).

A complex array of arcuate, anastomosing, transient shear zones play an important role in separating lithostructural blocks, in controlling the arrangement of supracrustal metasediments, and in the emplacement of granitic plutons.

JAIBARAS TECTONOSTRATIGRAPHIC FRAMEWORK

Basin Infill In general, it consists of continental immature siliciclastic sediments deposited in areas of unstable shoulder relief and probably totals up to 3 km in thickness. The complete sedimentary record indicates that the syn-tectonic activity decreases upwards. There is no clear evidence of regional metamorphism. However, anchimetamorphic mineralogy is widely recognized in the basin (Mello 1978, Novais et al. 1979). Despite the problematic reconnaissance of lithostratigraphic successions in the JT, Costa et al. (1979) proposed to divide the entire sedimentary column into three units named the Massapê, Pacujá and Aprazivel Formations, comprising the Jaibaras Group, as follows:

a) The Massapê Formation is the basal unit and is characterized by both fan polymict conglomerates and coarse-grained sandstone with debris and mud flows, locally restricted to faults edges, where accumulations of up to 2 km thick may occur. Conglomerates are generally clast-supported and consist of well-rounded to angular fragments of surrounding gneiss-migmatitic basement, including the Ubajara supracrustal sequences (Maisonneuve et al. 1971, Danni 1972, Costa et al. 1979, Mello 1978, among others);

b) The Pacujá Formation represents the distal portion of the Massapê Formation (Gorayeb et al. 1988, Quadros et al. 1994). The former consists of coarse- to fine-grained reddish brown sandstones, siltstones and shales. Pelitic facies appear to predominate within the basal center. Sedimentary structures identify the clastic assemblages as a fluvial system that graded to deltas and likely rift lakes (Mello 1978, Quadros et al. 1994). A Rh/Sr isochron using whole rock, fine and residual fractions indicated an age of 535±27 Ma. for this deposit, which possibly represents either the age of deposition or anchimetamorphism (Novais et al 1979);

c) The upper sequence of polymict conglomerates, named the Aprazivel Formation, differs from basal conglomerates by the presence of clasts of plutonic-volcanic rocks from Mucambo/ Meruoca plutons, Parapuí Suite and Massapê and Pacujá underlying sedimentary formations. Despite the change in clast composition, the Aprazivel Fm. presents a lot of similarities with the Massapê Formation in terms of sedimentary environments and tectonic controls.

Magmatic Activity Intrusives (Coreau Dike Swarm, Meruoca and Mucambo Plutons) and extrusives (sills and dikes of Parapuí Suite) demonstrate close temporal and spatial (Figs. 1 and 2) relationships with the JT, and hence, appear to be genetically related to its intrinsic tectonic evolution:

a) The Coreau Dike Swarm is characterized by a parallel and subvertical set of ENE-WSW trending dikes, which preferentially cross-cut metasediments of the Ubajara Group outcropping in the homonymous graben near the Meruoca Pluton, westward of the JT (Fig. 1). Petrographically, they comprise microgranite and rhyolite/ dacite with porphyritic textures. The combined ages give an average that fits well with the transition between the Proterozoic and the Phanerozoic, and clearly precede the JT infill (Fig. 3);

b) The Mucambo Pluton occupies an area of about 200 km² in the southwestern segment of the trough (Fig. 1). The pluton contact with surrounding host rocks is sharp and discordant. It is marked, to the west, by developed contact aureoles and chilled margins with metasediments of Ubajara Graben, reaching up to 2 km in width. In contrast, the contact to the east, with the Jaibaras Group, is faulted without evidence of contact metamorphism;

c) Meruoca is the northernmost pluton of the two intrusions (Fig. 1). It has a grossly square shape comprising an area of circa 400 km². Its contacts are mainly given by faults and shear zones, in places developing aureoles with host-rocks. Petrographic analysis reveals a coarse to fine-grained facies containing fayalite, K-feldspar, biotite and hornblende;

d) The volcanic rocks of the Parapuí Suite crop out as flood basalts, locally attaining 350 m in thickness, or as dikes with no preferential orientation and sills interbedded with siliciclastic sediments of the Massapê and Pacujá formations (Figs. 1 and 2), which locally comprise, in association with volcanioclastic rocks, a typical volcanic-sedimentary sequence (Quadros et al. 1994, Correa 1997). Based on

Figure 2 - Summarized schematic section showing the Jaibaras Trough tectonostratigraphic interactions between magmatism and sedimentary infill. Instead of displaying the configuration of igneous/sedimentary bodies, this sketch has solely the purpose of showing the stratigraphic interplay among the Jaibaras component units. All these schematic relationships are based on the compilation of available published data and as documented in surface exposures.
owing to the lack of deep wells and seismic surveys within the JT), a 

field mapping, Jardim de Sá et al. (1979) and Nascimento & Gava 

compatible relative stratigraphic hypothesis can be constructed, as 

Regionaly, one can easily observes the existence of metasediments 

stratigraphic approach considering interactions between magmatism 

is well-developed along the entire western Mucambo boundary with 

Figure 3 - Sketch illustrating all available radiometric ages for the igneous- 

natural (in Fig. 2). An interesting aspect 

there is no evidence that 

Geochronological evidences indicate that the first manifestation of 

Two points must be emphasized: (1) the lack of pervasive host rock 

extensional stresses along preexisting, deep NE-SW shear zones 

and cross-cutting relationships.

Figure 3 - Sketch illustrating all available radiometric ages for the igneous- 

sedimentary system in Jaibaras Trough. The full lines are considered as good 

dating results, whereas the dotted ones correspond to problematic and/or 
discutable ages. The dating range was squematized in average and its 

correspondent standard deviation. The geological time table is in accordance 

with Harland et al. (1990). Legend: The stippled band indicate the 

Proterozoic-Phanerozoic boundary according to Cowie (1981); (*) Rh-Sc 

ages; (**) K-Ar ages; (***) U-Pb ages. Bracketed numbers correspond to the 

cited references, (1) Brito Neves et al. (1975), (2) Noyais et al. (1979), (3) Sial 


Fetter et al., (1997), (11) Sial et al. (1981), (12) P. Vandoros (quoted in Brito 

Neves (quoted in Jardim de Sá et al. 1979), (9) Sial et al. (1981), (10) 

Mabesoone et al. (1971) and Sial (1989) reported the existence of dark 

sandstone xenoliths (possibly Ubajara Group) within the dikes. 

Hackspacher et al. (1988) recognized some ductile deformational features in localized dikes, such 

as a kind of mylonitic foliation, which could strongly favored the line 

of evidence that is the record of Jaibaras rift tectonism. 

Two points must be emphasized: (1) the lack of pervasive host rock 

deformational pattern within the Coreau dikes, reflecting a post- 

Brasiliano evolution; and, (2) the fact that dike intrusions show no 

evidence of affecting the Jaibaras sediments and/or the subsequent 

magmatic activity. These arguments together with geochronological data bear out the interpretation that these dikes represented the first 

pulse of the JT tectonic evolution. 

After dike swarm emplacement, the progressive increment of 

extensional stresses along preexisting, deep NE-SW shear zones 

created space at deep crustal levels that was passively filled by the 

Mucambo Pluton. At shallow levels, the pluton emplacement was 

accompanied by contact metamorphism and probably regional 

deformation within the Ubajara Graben (Fig. 2). Such emplacement 

level is in agreement with the abundant presence of compositionally 

varied xenoliths of horst rocks (Sial 1989). The more older 

stratigraphic linkage with JT can be interpreted from the contact with 

the sedimentary sequence, which is marked, along east side, by a 

strong normal-fault without thermal effects. The metamorphic contact 

is well-developed along the entire western Mucambo boundary with 

Ubajara Group, ranging between two and three kilometers in width. 

The mineral assemblage points to a pyroxene-hornfels facies in the 

internal zone, where thermal aureole that overprint bedding and 

foliation of Ubajara Group is truncated and/or is cross-cut, 

such as foliation, have affected the Jaibaras sequences. The slaty 
cleavage present in the Ubajara Group is truncated and/or is cross-cut, 
at high angle, by igneous bodies of the Coreau Dike Swarm. 

Mabesoone et al. (1971) and Sial (1989) reported the existence of dark 

foliated host rocks of the Ubajara Group. There is no evidence that 

these dikes truncated another JT igneous bodies anywhere else. Mafic 
xenoliths were described locally by Mabesoone et al. (1971) and Sial (1989) in some dikes, however the source of these xenoliths remains 

unknown. There is no evolved regional thermal event associated with 

the dike swarm, and then, as being essentially extensional in origin, 

the dike intrusion did not induce deformational or thermal effects when it 

segregated into shallow crustal level. Hackspacher et al. (1988) 

recognized some ductile deformational features in localized dikes, such 

as a kind of mylonitic foliation, which could strongly favored the line 

of evidence that is the record of Jaibaras rift tectonism. 

The fact that the Mucambo Pluton only presents thermal aureole 
along the contact with the Ubajara Group is particularly important 
because is a direct indication that the pluton is stratigraphically older 
than the JT sedimentary sequences and the Meruoca Pluton. This
Another additional important interpretation can be easily achieved: the lack of thermal effect resulting from the ascension and emplacement of the Mucambo Pluton along the boundary with the shear zone-fault indicates that the pluton was separated by a strong lateral and/or vertical fault offset which took place long time after its intrusion. In field mapping of the Ubajara Graben, Hackspecher et al. (1988) recognized thrust faults and associated, kilometric-scale, recurrent folds with westward vergence. The association of this pattern of thrusted structures with pluton space requirement is quite plausible during its emplacement processes. Nevertheless, the effective genetic relationship between these two factors remains to be better explained.

Another attractive tectono-stratigraphic relationship is shown between the country-rock and the Meruoca Pluton. The Pluton is almost entirely fault bounded. Contrary to the Mucambo Pluton, where the contact aureole found early along its boundary with the Ubajara Group, the Meruoca granite developed contact metamorphism along its whole boundary, including the sediments of the JT (Gorayeb et al. 1988). This metamorphism was able to produce high-temperature minerals such as garnet and diopside in the internal zone. Additionally at this area, Ubajara Group sandstone and limestone xenoliths occur highly metamorphosed (Sial et al. 1981, Nascimento et al. 1981, Gorayeb et al. 1988, Sial 1989), invoking an younger age for the pluton. Rh-Sr and K-Ar geochronological data indicate that the emplacement of the Mucambo Pluton took place about 20-30 Ma after Mucambo Pluton.

The existence of a thermal aureole of the Menaoca Pluton in both Ubajara and Jaibaras units and the seelative existence of the Mucambo Pluton aureole affecting only rocks of Ubajara Group are crucial indications of the age of the latter group, apparently an immediate age between the two plutons. This indirect stratigraphic relationship is partially corroborated by radiometric ages (Fig. 3). If the above stratigraphic interelationship is correct, the Jaibaras sediments were deposited during the Early-Middle Cambrian between the emplacement of Mucambo and Meruoca plutons (from 550-540 to 520-510 Ma). Novais et al. (1979) analysed non-thermally affected argillaceous rocks of the Jaibaras Group and obtained a Rh-Sr isochron of 535±27 Ma with seven samples, including whole rock, mudstones and residual fractions. This radiometric result, coupled with illite diffractometric data, were interpreted by the authors as anchimetamorphic age. This age seems to be well-constrained in terms of the stratigraphic interactions discussed previously.

Considering the basin infill, there is a complex stratigraphic relationship between the Parapuí Suite and the sediments. The Parapuí igneous bodies occur as dikes, sills and perhaps lava flows. Despite all the difficulties in recognizing cross-cutting relationships in the stratigraphic section, most studies consider the Parapuí Suite as completely post-basin infill (Danni 1972, Costa et al. 1981) or as several interbedded conglomerates. The tectonostratigraphic framework of the JT can be summarized as follows. Prior to basin nucleation, the first tectonic event was the emplacement of the Mucambo Pluton and rocks by volcaniclastic deposition. Next, the Meruoca Pluton intruded along the same crustal discontinuity as the preceding one. Finally, repeated reaction spasms in existing rock faults permitted the deposition of localized alluvial fans called the Aprazível Formation. Because of the existence of subordinant volcaniclastic rocks filling the basin (Quadros et al. 1994, Correa 1997) the syndepositional hypothesis seems to be more likely. Assuming that the Menaoca Pluton is younger than the Jaibaras Group, the Parapuí Suite could be considered older than that pluton. An important doubt is the stratigraphic position of the Jaibaras Group in this scenario. However, since it was considered coeval with the Parapuí Suite, one can assume the same age to the graben infill, which was also a question indirectly discussed early.

After emplacement of the Meruoca Pluton, faulting and erosion removed the upper part of volcanoclastic rocks of the cited pluton, depositing the eroded material along basin shoulders as the alluvial fans of the Aprazível Formation (Costa et al. 1979). This sequence represents the last tectonostratigraphic pulse in the basin development. A Late-Ordovician age for Aprazível Fm. can be easily achieved, since it is overlain by the Early-Silurian sediments of the Parnaíba Sag Basin. The existence of compositionally varied rocks as large fragments in this unit allows the inference of a regional unroofing erosional unconformity produced by hanging-wall uplift associated with faulting. The repeated stacking of alluvial fans with coarsening- and fining-upward megasequences and abrupt vertical facies changing from fan-conglomerates to lacustrine sediments provide strong evidence for recurrent vertical fault movements. After the basin infill, repeated motions of major delineating faults have been registered in adjoining sediments. These reactivation phases are variable in distribution, in throw magnitude and geological significance and are spectaculartly developed locally, but their timing is often imprecise. In outcrops, the structural pattern is characterized by meso faults and mesosolfs. This structural pattern rarely conforms to the conventionally accepted continuous Precambrian deformation (Jardim de Sa et al. 1979, Oliveira 1992).

OUTLOOK AND CONCLUSIONS Putting all the geological characteristics together, we attempted to assemble the graben and granitic rocks of the cited pluton, depositing the eroded material along basin shoulders as the alluvial fans of the Aprazível Formation (Costa et al. 1979). This sequence represents the last tectonostratigraphic pulse in the basin development. A Late-Ordovician age for Aprazível Fm. can be easily achieved, since it is overlain by the Early-Silurian sediments of the Parnaíba Sag Basin. The existence of compositionally varied rocks as large fragments in this unit allows the inference of a regional unroofing erosional unconformity produced by hanging-wall uplift associated with faulting. The repeated stacking of alluvial fans with coarsening- and fining-upward megasequences and abrupt vertical facies changing from fan-conglomerates to lacustrine sediments provide strong evidence for recurrent vertical fault movements. After the basin infill, repeated motions of major delineating faults have been registered in adjoining sediments. These reactivation phases are variable in distribution, in throw magnitude and geological significance and are spectaculartly developed locally, but their timing is often imprecise. In outcrops, the structural pattern is characterized by meso faults and mesosolfs. This structural pattern rarely conforms to the conventionally accepted continuous Precambrian deformation (Jardim de Sa et al. 1979, Oliveira 1992).

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