**BASEMENT OR INTRUSION? THE AMBROSIO DOME, RIO ITAPICURU GREENSTONE BELT, BAHIA, BRAZIL**

**ABSTRACT** The Rio Itapicuru greenstone belt is a synclinal keel of tholeiitic basalts, calc-alkaline volcanics, and volcanic-derived sediments of probable Lower Proterozoic age. The Ambrosio Dome is situated within this supracrustal sequence, and consists of a weakly foliated granite with highly deformed margins, containing large gneiss xenoliths. Previous authors have presented conflicting views of the dome as a basement to the greenstone supracrustals or as an intrusion. Structural and petrographic data indicate an intrusion, for the following reasons: an intense flattening fabric is developed parallel to the dome margin; late-stage tourmaline rich pegmatites are concentrated at the dome roof and intrude the greenstone supracrustals; contact metamorphism and partial melting of the supracrustals occurred at the dome margins. A banded iron formation occurs around the dome margin, which indicates that the intrusion was arrested at this level. Refolding of this originally shallow dipping contact produced the elongated dome shape, which has a half-wavelength of 7 km. The large-scale, steeply-dipping folds (70°W) suggest that the main mechanism of deformation in the greenstone belt was gravity influenced diapirism, coupled with E-W compression.

**RESUMO** O Greenstone Belt do Rio Itapicuru é uma calha sinclinal com basaltos toleíticos, vulcânicos calcio-alkalinos e sedimentos derivados de vulcânicos, de provável idade Proterozóica Inferior. O Domo de Ambrósio é colocado na seqüência supracrustal e corresponde a granito pouco foliado com margens altamente deformadas, contendo grandes xenólitos de gnaisses. Viços conflitantes têm sido apresentadas por diversos autores sobre a estrutura domólica, ora sendo considerada como embasamento das supracrustais, ora como uma intrusão. Dados estruturais e petrográficos indicam uma intrusão pelas seguintes razões: um intenso padrão de achatamento desenvolve-se paralelamente à margem do domo; pegmatitos ricos em turmalina de estágio tardio concentram-se no teto do domo e cortam as supracrustais; metamorfismo de contato e fusão parcial das supracrustais ocorrem nas margens do domo. A presença de uma formação ferrífera bandada ao longo da margem do domo sugere que a intrusão foi retida a este nível. Redobramento deste contato, originalmente de baixo mergulho, resultou na forma domólica alongada que possui meio comprimento de onda de 7 km. Macrodobras de mergulho acentuado (70°W) sugerem que o mecanismo principal de deformação no “greenstone belt” foi diapirismo colocado por gravidade, associado a compressão ao longo da direção E-W.

**INTRODUCTION** The Rio Itapicuru greenstone belt is situated in the São Francisco Craton in the northeast of Bahia State, Brazil (Almeida 1977, Mascarenhas 1973, 1976; Fig. 1(a)). It was the first greenstone to be described in Latin America and has subsequently been the subject of intense study by Brazilian mining companies because of its excellent potential for primary gold and massive sulphides. The belt consists of a greenschist grade vulcano-sedimentary sequence preserved in synclinal keels with intervening granite and gneiss terrains which are generally oriented N-S (Fig. 1b). Structural relations of these granite-gneiss terrains with the greenstone has been a controversial subject, with most attention focussed on the Ambrosio Dome (Fig. 2). This has been considered both as basement to the greenstone (Sá 1982) and as an intrusion (Silva 1983).

The aim of this paper is to take a closer look at the structural relations and petrographic textures of the Ambrosio Dome and its surroundings, to try and resolve this important controversy of whether the Ambrosio Dome constitutes a sialic basement to the greenstone.

**GREENSTONE BELT** The supracrustal sequence can be grouped into three principal lithological domains composed of mafic volcanics, felsic volcanics and sediments (Kishida & Riccio 1980). The mafic volcanic domain is believed to be the base of the sequence (Davison et al. in preparation). It occupies about 50% of the supracrustal surface area and is mainly composed of massive tholeiitic basalt flows with occasional pillow lava horizons and flow breccias. Thin finely laminated cherts, banded iron formation (BIF) and graphitic pelites occur throughout the domain indicating that most of the basalts were probably subaqueous eruptions.

The felsic volcanic domain is not laterally continuous and occupies about 10% of the surface area of the supracrustal sequence (Kishida & Riccio 1980). It consists of lavas, tuffs, agglomerates and epiclastic turbidites with andesitic to dacitic compositions, along with intercalated cherts and pelites. This domains grades laterally and vertically into the sedimentary domain. The sedimentary domain consists of pelites, silts, greywackes, epiclastic conglomerates, impure quartzites and arkoses with cherts, BIF, and rare tholeiitic basalts. The supracrustals host many small gold deposits with one
medium-sized deposit (Fazenda Brasileiro) now being mined in the south of the belt (Teixeira 1984).

The N-S trending part of the greenstone has a relatively simple structural evolution compared to the E-W trending arm situated to the south (Teixeira 1984). In the former, the main deformation phase produced asymmetric eastward verging large scale folds (up to 7 km half-wavelength) which refold localised bedding-parallel shear zones, perhaps produced by the same E-W compression which caused the folding. The Ambrosio and Pedra Alta Domes occupy anticlinal folds of this phase. Several late small crenulation phases have been recognised, but only in the less competent sediments. These structures are not considered important in the overall geometry of the greenstone belt. In the southern E-W trending arm of the greenstone the deformation is more intense and heterogeneous, but this area is not included in our study.

A poorly define isochron giving an age of 2.0 ± 0.2 Ga was obtained from the andesitic lavas in the felsic volcanic domain (Brito-Neves et al. 1980). Unpublished U/Pb zircon ages also give ages of approximately 2.0 - 2.2 Ga for the extrusion of lavas, intrusion of granites and the deformation (J.B. Teixeira pers. communication).

THE AMBROSIO DOME The Ambrosio Dome is situated in the central part of the greenstone (Fig. 1(b) and 2). It occupies a surficial area of 320 km². The structural and petrographic characteristics of this body are similar to those of the adjacent Pedra Alta Dome which is the other major granite-gneiss within the greenstone supracrustals. The Ambrosio Dome consists of a central core of weakly deformed granite with highly deformed margins of the same granite along with gneisses and pegmatites. The transition from gneiss can be progressive, caused by increasing strain at high temperatures, or abrupt where weakly deformed granites intrude the gneisses (Photo 1).

Gneisses The gneisses are situated around the northern borders of the dome (Fig. 2, Photo 2). They are
been identified, one of euhedral, zoned, dirty crystals and the other of rounded, clean crystals.

Small amphibolite sills (up to 1 m thick) were intruded sub-parallel to, but probably before, the gneissic banding. The sills are composed of 90% green hornblende and 10% quartz and plagioclase.

**Granite**

The granite occurs in the central part of the northern half and throughout the southern half of the dome (Fig. 2). The granite intrudes the gneisses and incorporates large elongate gneiss rafts which are elongated parallel to the gneissic banding, and any foliation observed in the granite. Some of these rafts are over 100 m long and up to 100 m wide. In the southern half of the dome the granite rocks lie in direct contact with the surrounding supracrustals. The contact is very highly deformed with mylonitic textures developed in the quartz crystals. The finite strain in the granite progressively increases towards the contact where the granite is transformed to a banded gneiss with millimetric scale banding of biotite rich and quartz-feldspar rich layers. Supracrustal xenoliths have been observed in the highly deformed granites near the contact.

In the central, less deformed zone, the granite matrix has a medium grain size with porphyritic feldspars. These phenocrysts have a weak orientation which was used to define the foliation (Fig. 2). Common small patches (~1 m²) of tonalitic and granodioritic material occur within the main granite, These patches have complex deformation patterns outlined by schlieren and leucocratic segregations and exhibit diffuse contacts with the granite. The significance of these patches requires further study.

Composition of the granite is fairly uniform, with

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**Fig. 2** - Geological map of the Ambrosio and Pedra Alta Domes

composed of continuous mafic and felsic bands. The major mineral phases are oligoclase, microcline, quartz and biotite, with quartz and microcline more concentrated in the felsic bands. Oligoclase and biotite and occasionally accessory hornblende are more concentrated in the mafic bands. The overall composition of the gneisses is primarily granodioritic but can vary to granitic.

Microcline generally shows recrystallized textures with porphyritic crystals, deformed at their edges into lenses and sigmoidal shapes and containing quartz and plagioclase inclusions. Quartz shows evidence of dynamic recrystallization with new small recrystallized grains and larger older grains exhibiting undulose extinction. These minerals produce a mineral shape fabric parallel to the gneissic banding. The oligoclase has an irregular granoblastic texture showing undulose extinction and deformed twins. Two distinct populations of zircons have
oligoclase (25-35%), microcline (25-42%), quartz (15-20%) and biotite (3-8%). Accessory minerals include apatite, unidentified opaque minerals and zircon. Biotite is often partially altered to chlorite. Oligoclase phenocrysts are euhedral and zoned with alteration to sericite and epidote. Interstitial microcline contains plagioclase, quartz and apatite inclusions, and interstitial quartz contains apatite and zircon inclusions, with strong undulose extinction and recrystallization of new grains occurring at the dome margins. Apatite is generally acicular and the zircon is euhedral and ‘dirty’ with inclusions.

**Pegmatites** Pegmatites can be separated into two distinct generations. Those of the first consists of K-feldspar, oligoclase and quartz with rare muscovite and magnetite. These pegmatites occur around all of the dome margins and also on the most elevated hilltops in the centre of the dome (topographic relief is about 200 metres). The pegmatites have been subsequently deformed (Photo 3). Recrystallized feldspar phenocrysts indicate that temperatures probably exceeded 500°C during this deformation.

The second generation are composed of K-feldspar, quartz, muscovite and tourmaline with accessory garnet and opaque minerals. They are coarser grained than the first generation, and a graphic texture is commonly developed. Zoned dark-green tourmaline forms three-dimensional rosettes which probably indicate a hydrostatic stress field during growth. These pegmatites were intruded into the supracrustals as well as the gneissic border along the eastern dome contact (Fig. 2). They cross cut the gneissic fabric and are less deformed than the first generations. Quartz deformation fabrics are developed, but no folding has been observed.

**CONTACT METAMORPHISM OF THE SUPRACRUSTALS** The supracrustals rocks circumscribing the Ambrosio Dome consist of pelites, tholeiitic basalts and BIF. These are generally in greenschist facies in all the greenstone pile except around the dome margins, where a 500 m thick zone shows a transition to upper amphibolite facies. Within the metapelites, the following mineral parageneses were observed outwards from the dome contact:

a) sillimanite + almandine garnet + biotite + quartz + partial melting;

b) andalusite + almandine garnet + staurolite + biotite + quartz;

c) andalusite + almandine garnet + biotite + quartz;

d) biotite + chlorite + muscovite + quartz.

The geothermal gradient must have been over 200°C/km to produce this zonation within a 500 m thick zone. Garnet and andalusite porphyroblasts show...
syn-tectonic and pre-tectonic textures, with pressure shadows filled by quartz, rotated helicitic inclusions of graphite and quartz, and warped schistosity surfaces wrapped around the porphyroblasts.

Within the basalts the typical paragenesis is green hornblende and andesine with a granoblastic texture. BIF consists of a grunerite-quartz-magnetite-hematite assemblage.

These mineral assemblages are characteristic of upper amphibolite facies (Miyashiro 1973). The pelitic assemblage containing sillimanite suggests temperatures of roughly 550°C to 650°C and 3-4 kbar pressure (Greenwood 1976).

**STRUCTURE** The main structural feature of the Ambrosio Dome is the highly sheared zone around its margins, which affects both the dome gneisses and granites and the surrounding supracrustals. The width of this sheared zone can be up to 500 m, perpendicular to the foliation, with most of the shear zone contained within the dome itself. The centre of the dome is only weakly deformed. Shearing imprinted a strong gneissic foliation on the granites which is always parallel to the contacts of the dome. This foliation was produced at high temperatures with dynamic recrystallization of K-feldspars (>500°C). The first generation of pegmatites were folded and boudinaged to varying degrees depending on the timing of their injection and original orientation indicating that injection accompanied deformation (Photo 3). The axial planes of folds affecting the pegmatites are parallel to the dome margins indicating flattening parallel to the margins. Fold axes are variable, depending on initial orientation of the pegmatite vein. The gneiss xenoliths were flattened parallel to the dome margins which produced boudinage, of the amphibolite sills contained within these xenoliths (Photo 4) and rotation of the xenolith long axes parallel to the dome margins. The recrystallization of the K-feldspar phenocrysts in the pegmatites and gneisses produced symmetric lenses, or asymmetric sigmoidal shaped feldspars, the former being the most common (Photo 5). The asymmetric feldspars indicate the sense of simple shear during recrystallization (Simpson & Schmidt 1983). Examination of more than one hundred asymmetric feldspars at both dome contacts within the Itapicuru River outcrops confirmed equal numbers of sinistral and dextral sheared feldspars. There is an absence of a mineral lineation upon the gneissic foliation planes, despite the presence of minerals capable of producing a linear fabric.

The gneissic foliation in the shear zone, was refolded by a large scale asymmetric periclinal fold which verges to the east and has a N-S trend (Fig. 2). Small folds with S, M, Z asymmetry also indicate an anticlinal hinge in the centre of the dome with an inverted or steeply-dipping normal eastern limb (Fig. 3). A stretched quartz and biotite lineation is produced parallel to the minor fold axes in the hinge zones. This style of folding is very similar to the major phase of folding observed in the greenstone supracrustals, which suggests that the shear zone was produced before, of early, during the folding phase. It is this folding phase which is responsible for the domal form of the Ambrosio granites and gneisses. The tourmaline pegmatites cross-cut the fold structures indicating that magmatism outlived the folding.

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Photo 4. Boudinaged amphibolite sill and pegmatite vein intruded into a large basement gneiss xenolith, the shape of the boudinage with rupture in the necks of amphibolite sills which have been filled by pegmatite material and pinch and swell structures in the pegmatites indicate the order of viscosity is amphibolite sill > pegmatite > granitic gneiss.

Photo 5. Highly deformed pegmatites with recrystallized K-feldspar phenocrysts. Most of the feldspars have symmetric tails but the asymmetric feldspar tails at A and B show dextral and sinistral shear respectively.
Within the supracrustal sequence a very strong foliation was developed with syntectonic upper amphibolite facies metamorphism. This foliation was probably parallel to the dome margins. Tight minor folds with axial planes parallel to the dome margins refold the earlier amphibolite facies foliation. These folds are probably the same as the major fold phase affecting the supracrustals.

**DISCUSSION**

The most important structural characteristic of the dome is the highly-deformed margin which usually has a width, perpendicular to the foliation, of 500 m. The intense foliation is always parallel to the dome margin (Fig. 2). There appears to be two possible explanations to produce the sheared contact of the dome.

1. **a) a simple shear zone between the basement and the greenstone cover sequence**, which produced frictional heating and partial melting in the shear; this model was used to explain field relations in the Arquean greenstone at Lake Dundas, Australia (Spray, 1985).

2. **b) a quasi-solid intrusion of granitic crystal mush with entrained xenoliths of possible gneissic basement fragments, which ballooned upwards and deformed the country rocks.**

Considerations of the structural and petrographic features listed below, helps to choose between these two contrasting models.

1. The finite strain fabric around the dome is believed to be an oblate flattening fabric. Evidence for this is the parallelism of the foliation with the shear zone, even in the weakly deformed margins, which would not be the case in a simple shear zone (Fig. 4(a) and 4(b)). Strong mineral lineations are absent from the shear zone, except in hinges of later folds folding the shear fabric, an LS fabric should be produced in a simple shear zone. There are equal proportions of sinistrally and dextrally sheared K-feldspar phenocrysts in the shear zone. This suggests a pure shear rather than a simple shear deformation where the majority of feldspars should show the same rotation sense (Fig. 4(c) and 4(d)). A pure shear zone should produce equal...
numbers of small scale sinistral and dextral shears where material is squeezed out laterally to accommodate the shortening perpendicular to the shear zone.

2. The tourmaline-rich pegmatites at the dome margins (upper contact) are typical of late-stage volatile enriched liquids in granitic intrusions. If the pegmatites were produced by partial melting due to shear heating of a previously eroded granitic basement, there would be no obvious reason for partial melts to be so rich in boron. Tourmaline was not identified in the granite or gneisses.

3. The thickness of the highly-deformed zone in the gneisses is the same as, or greater than, that in the supracrustal sequence. If these two lithologies were at the same temperature, or the sediments were at a higher temperature (which would be expected if they were up-thrust from greater depth) an equal distribution of finite strain between these two lithologies would be highly unlikely. It should be much easier to deform the sediments than an isotropic, initially cooler, coarse-grained granite. This implies the granite and gneisses were much hotter than the supracrustals when deformation took place.

4. The central core of granite is weakly deformed and preserves igneous textures, which indicates it was once liquid.

5. Xenoliths of country rocks are found within the deformed granite at the dome contacts.

6. Pegmatites in the contact zone were mylonitised, folded and boudinaged at high temperatures during their intrusion.

7. Contact metamorphism of the meta-sediments occurs near the dome and the metamorphic porphyroblasts show pre- and syn-tectonic textural relations.

These observations suggest that the Ambrosio Dome was intruded into the greenstone as a quasi-solid crystal mush, with entrained gneissic xenoliths which were collected from a lower crustal level; but kept in suspension near to the intrusion margin as there was little density or viscosity difference between the quasi-solid granite and the xenoliths. Soula (1982) states that the solid component must exceed 70% for stresses to be fully transmitted through a crystal liquid mush. The oblate strain fabric produced at the dome contact is not characteristic of a simple shear zone, where lineation and foliation should both be developed, and is more consistent with a pure shear fabric produced in the roof of a diapiric structure (Dixon 1975). Pegmatites are interpreted as being intruded during the later stages of diapiric upwelling, and they themselves were flattened against the diapir walls by further ballooning.

It is not clear whether the large gneiss xenoliths are basement or later under-plated material. However a U/Pb zircon (only clean and rounded crystals were used) age of 2.9 Ga on a gneiss from the eastern border of the dome indicates that they are probably basement remnants from lower crustal levels (Teixeira 1984). Thus the greenstone probably formed on a sialic basement which was subsequently remodelised and incorporated in the Ambrosio Dome.

A banded iron formation, which reaches about 25 m thickness, can be traced by outcrop mapping and geophysical methods around most of the circumference of the dome (Fig. 2). This highly viscous lithology is interpreted as the barrier which finally arrested the upward movement of the granite and gneisses.

The final elongated dome shape is a result of a synchronous E-W compression which also affected the greenstone belt. Minor folds which refold the foliation of the dome contacts, indicate this compression continued after the initial intrusion fabric was produced. Minor fold asymmetry (S M Z) defines the Ambrosio Dome as a westerly dipping asymmetrical pericline (Fig. 3). The Pedra Alta Dome is believed to be a similar type of anticlinal structure (Fig. 3). The large wavelength of these two anticlinal structures and the fact that intrusive rocks occupy the anticlines, suggests that the main deformation mechanisms of the greenstone were gravity influenced diapirism coupled with E-W compression.

CONCLUSIONS

1. The Ambrosio Dome is not thought to constitute an in-situ sialic basement to the Rio Itapicuru greenstone supracrustals.

2. The gneissic xenoliths which were entrained in the highly viscous granitic magma were brought up from lower crustal levels and probably represent partially fused and highly deformed remnants of a pre-existent sialic basement.

3. The Ambrosio Dome was intruded into the greenstone as a semi-solid diapirc structure which cut through most of the greenstone pile but was arrested against a highly viscous BIF barrier.

4. The latest magmatic liquids were injected into the country rocks, and contact metamorphism with a very high thermal gradient was produced in the supracrustals.

5. The intensely sheared zone bordering the dome is interpreted as a pure shear zone, characteristic of the flattening fabric produced in the roof of a diapir.

6. During and after intrusion an E–W compression accentuated the originally flatter lying dome into a large scale N–S trending periclinal structure. The intervening supracrustals were downfolded into mega-synclinal keels during this same event.

7. The Pedra Alta Dome shows very similar composition and structural field relations to those of the Ambrosio Dome and may be one and the same intrusion with a highly sheared syncline of supracrustals situated between the two (Fig. 3).

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REFERENCES


SCHOBENHAUS, C. (Gen. Coord.) – 1981 – Geologic map of Brazil and adjoining ocean floor including mineral deposits. Scale 1:2.500.000.DNPM/MME.


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Você está olhando com ironia, tudo o que vos digo parece ultrapassado e ridículo, mas quando eu passo perto de uma floresta que salvei do desflorestamento, ou quando ouço o murmúrio de um jovem bosque que plantei com minhas mãos, sinto que até o clima está um pouco em meu poder, e que, se dentro de mil anos o homem puder ser feliz, será também um pouco graças a mim.

Herói de Tchékov