

Transition from continental to intracontinental subduction, south of São Francisco craton: terrane accretion, metamorphic paths and nappe kinematics.

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Mario C. Campos Neto* (IG-USP, camposnt@usp.br), Renaud Caby (ISTEEM, caby@dstu.univ-montp2.fr), Valdecir A. Janasi (IG-USP, janasi@usp.br), Miguel A. S. Basei (IG-USP, baseimas@usp.br), M. Glória M. Garcia (IG-USP) & Oswaldo Siga Jr. (IG-USP).

Introduction

The Neoproterozoic nappe system exposed south of the São Francisco craton (SFC) represents deep crustal equivalents to the Brasília belt (Fig. 1). The flat geometry of the nappes is that of spoon-like structures displaced eastward. These are separated by lateral ramps that were commonly reactivated as strike-slip faults after the main displacements. The nappe system represents a diachronic thick-skinned and frontal growing structure that underwent a minimum of 300 km in magnitude of aggregate displacement, accounting for deeper crustal levels progressively exposed in the western nappes. The uppermost tectonic unit derived from magmatic arc terrane (Socorro-Guaxupé nappe, SGN) displays high-pressure and high-temperature (HP-HT) basal granulites. High-pressure terranes underlain the SGN: the Ky-granulite unit (Três Pontas-Varginha nappe, TPVN and Carvalhos klippe) and the metapelite-metagreywacke unit below (Carmo da Cachoeira nappe, CCN and Aiuruoca-Andrelândia nappe, AAN). The lower allochthonous units are made up of quartzites (with medium-pressure metamorphism) and polymetamorphic orthogneisses (Luminárias-Carrancas nappe, LCN) and grade in trailing imbricate fan type thrusts to the parautochthonous units. Eastward these lower sheets (Lima Duarte nappe, LDN) with upper allochthonous migmatites are bounded by granulites (ca. 570 Ma) upon plutonic Paleoproterozoic protoliths^(1,2) of the Juiz de Fora terrane (JFT) framed in the transpressive Ribeira belt.

Tectonic units and nappe kinematics

The Socorro-Guaxupé nappe is a giant allochthon showing a right way up crustal section of hot and partially melted layered crust. It comprises a Basal Granulitic Unit (ca. 3-km thick) in which the green-coloured, banded Grt±Opx granulites of enderbite modal composition are the main rock types. It may be derived from a convergent magmatic arc protoliths and shows a preliminary Sm/Nd T(dm) age around 1290 Ma (eNd 0.640=-1.2). These granulites grade upward into a predominance of grey to pink, metaluminous migmatites of the Middle Diatexitic Unit (ca. 6-km thick) identifying at their top with pelitic to semi-pelitic migmatites (Upper Migmatitic Unit). From these migmatites longitudinal right-hand strike-slip shear zones control a major metamorphic jump to greenschist facies southwestward. Various deformed intrusives occur throughout the nappe pile: porphyritic-porphyclastic jotunitic-charnockitic suite [640 Ma⁽³⁾] at the base of the allochthon gives way upward to a mangeritic suite [625 Ma^(3, 4, 5)] and, at higher levels, to porphyritic Hbl-Bt granitoides forming large batholiths [630 Ma⁽⁶⁾]. Mesoproterozoic T(DM) ages were obtained for these granitoids whose chemical and isotopic signatures strongly suggest an origin in a subduction environment⁽⁷⁾. The SGN occurs as two major lobes in which the hanging wall of the main thrust, mainly composed of km-thick intermediate granulites, displays low plunging W/SW mineral and stretching lineations - and bearing top-E/NE shear sense indicator. A major detachment, locally accommodated by a NW-ori-

ented oblique left-hand strike-slip fault, accounts for the direct contact of the Upper Migmatitic Unit above the Basal Granulitic Unit showing SE-plunging syn-metamorphic linear fabric consistent with down-dip movement. In the northern lobe of the SGN the Middle Diatexitic Unit corresponds to a roof of the Upper Migmatitic Unit due to north-eastward late metamorphic out-of-sequence thrusting which cuts the 625 Ma old mangerites.

The Três Pontas-Varginha nappe (ca. 5-km thick) comprises mainly coarse-grained and grey to bluish Rut-Ky-Grt granulites, lesser impure quartzites, a few calc-silicate rocks, goudites, lenses of metabasic rocks and rare sills of mafic-ultramafic rocks. The Ky-granulites grade upward to Sil-bearing granulites as they approach the basal contact of the SGN. Anatectites also occur at the highest level. These granulites include both high K/Na pelites [Sm/Nd $T_{(DM)}=1.95$ Ma] and greywackes with higher Na/K and Ca [Sm/Nd $T_{(DM)}=1.26-1.55$ Ma]. The low $T_{(DM)}$ of the latter are incompatible with a derivation from the SFC arguing for an important contribution from a juvenile source, and also for a Neoproterozoic age for the sequence. The TPVN is a thick sheet of flat-lying footwall of the main thrust zone that emerges from below the SGN. It crops out for 170 km parallel to its E/NE displacement direction showing W.SW plunging linear fabrics developed during high-pressure granulite facies conditions.

The Aiuruoca-Andrelândia nappe is chiefly made up of a layered sequence of aluminous Rut-Ky-Grt-Ms schists and dark-grey, massive Grt-Bt-Pl gneisses and schists. The former have a pelitic source and show Sm/Nd $T_{(DM)}=1.92$ Ma, compatible with U-Pb ages of 1.87 Ma on detrital zircon⁽⁸⁾, whereas the second has a greywacke chemistry with Sm/Nd $T_{(DM)}$ between 1.16 and 1.26. The chemical and isotopic characteristics of these metasediments show therefore a good correlation with the Ky-granulites from the TPVN. Small lenses of metabasic rocks having Grt-clinopyroxenites in their cores and retrogressed Pl-rich amphibolites at the borders occur within the metasedimentary sequence. The AAN has a canoe-like shape and NE-directed transport as indicated by lineations present throughout the sequence. It comprises an inner re-

folded root zone detached over diatexites and Sil-bearing migmatites (overall up to 10-km thick) and a stretched and thinned front (ca. 2-km thick). The Ky-granulite rocks locally preserved as Carvalhos klippe override this nappe in an oblique E-direct transport. The CCN is the northern equivalent of AAN.

The quartzite nappe complex is a lower allochthon composed mainly of white and green mica quartzites grading upward into well bedded to laminated quartzite interlayered with graphitic and aluminous metapelites. The quartzite assemblage is normally allochthonous over the polymetamorphic orthogneisses and migmatites, which seem to constitute its basement. The whole package must correspond to the passive continental margin of SFC⁽⁹⁾. The major sheet shows eastward minimum transport of 140km (LCN, ca. 4.5 to 1.5-km thick). The easternmost preserved a-type fold nappes (LDN with ca. 4-km thick), with their upper portion merged with dextral strike-slip motion below the JFT, have a north-northeastward displacement up to 55-km.

The parautochthonous units made up of interbedded quartzite and grey phyllite also show, in their overall extension, a northward transport indicated by stretching lineation and composite S-C foliation. A thin-skinned structural style is a landscape scenario. This late thrusting behaviour predominates as a lamina of km-scale duplex of detached metasediments partially hiding the LDN.

An approach to metamorphic-time paths

The hanging wall granulites of the main thrust underwent $T=750-870^{\circ}\text{C}$ and $P=11.5-14.0$ kbar evidenced by the $\text{Opx}\pm\text{Cpx-Grt-Pl-Qtz}$ relict assemblage. The recrystallized matrix formed by late-kinematic annealing (Bt-Prg-Pl-Qtz-outermost Grt-rim assemblage) yields $730^{\circ}\text{C}-9.5$ kbar. An isobaric heating evolution may also be evidenced by high-Ti Bt-Opx-Grt-Pl-Qtz assemblage rising to $860-920^{\circ}\text{C}$ (fig.2), consistent with dry melting and generation of anhydrous charnockitic-mangeritic magmas. A Grt-Bt-whole rock Sm/Nd age of 630 Ma, sup-

ported by U-Pb zircon ages on syn-orogenic plutonic rocks, constrains the age on these granulites. A younger limit is given by the post-kinematic intrusion of a potassic syenite with zircon U-Pb age of 612 Ma ⁽⁶⁾.

A coherent inverted metamorphic pattern is supported by the underlying nappes. Lower temperatures (650°C) were attained under HP conditions (12-14 kbar) on Rt-Ky-Grt-Ms schist and metabasites of the AAN. This is related to the decompression stage of retroeclogitic ⁽¹⁰⁾ coronatype Grt-clinopyroxenite, in which Rt and Di-Omp with relict lamellae of Jd occurring as inclusions in a semi-radial cracked Grt-core argue for 660°C-17.5 kbar of minimum pressure. Upward, at the base of the TPVN, the granulites have an assemblage of Na-Pl clasts and strings from mesoperthite, Ky, Rt, Ms and rare Bt, in equilibrium with Prp-enriched Grt-rings that yield T=680°C and P=15 kbar. An early prograde assemblage preserved in Grt-core (Prp-Sd-Rt and Qtz-Ilm-Ky-Bt) suggests a fossilised LT-HP (470°C-7.5 kbar), whereas the syn-kinematic retrogression through the Ky-field varies from 600-690°C and 9-11 kbar. Towards the upper part of the TPVN, about 2.5-km below the SGN, syn-kinematic prismatic Sil appears with relics or newly grown Ky, Prp-rich Grt and Bt (Ms disappears), arguing for near-isobaric heating (830-950°C-12 kbar). Mylonitic texture which locally affects the main metamorphic foliation may be related to the hinterland out-of-sequence thrusting (S-shaped Prp-rich Grt, Phl-rich Bt, minute acicular Sil and Qtz+Pl) representing a near-isothermal decompression at 795°C and 8 kbar (Fig.2).

The HP mineral assemblages are not reported in the lower nappes. Displacement-parallel isogrades are sketched in LCN ⁽¹¹⁾ suggesting a *barrovian-type* metamorphism, for which no reliable age constraints are currently available. On the other hand, the eastern LDN was subjected to medium-pressure metamorphism within the Sil-stability field attaining granulite facies and late anatexis. Grt-Cpx amphibolites with IBC-type coronitic textures and Sil-bearing gneiss show the metamorphic peak under T_{max}=700°C and P_{max}=7 kbar developed at 570 Ma ⁽¹⁾, suggesting a relationship with the main metamorphic period recorded in the JFT (Fig.2).

In the parautochthonous units (south of Lavras), phengite, Fe-Cld phyllites with variable amounts of Mg and Fe-Chl, Zn-St, Ky, Rt and Ilm show a pressure around 7kbar for a T=500°C that may control the appearance of the Zn-St in the absence of Grt and Bt.

Conclusions

The southern extension of Brasília belt was juxtaposed in 3 major geodynamic environments. 1- a long-lived Neoproterozoic immature to mature magmatic arc terrane (SGN); 2- a metasedimentary assemblage with major contributions from an active margin environment (TPVN, AAN and CCN) representing a Neoproterozoic drift terrane or a external forearc thinned crust; 3- a metasedimentary passive continental margin assemblage related to the SFC (lower a nappes and parautochthons).

The HP conditions recorded by the Ky-granulites and eclogites of TPVN and AAN imply a low thermal gradient (ca. 11°C/km), which can only be achieved in an ocean closure through a W-dipping subduction setting. The continental metamorphic terrane conformed by these nappe was subducted to a minimum depth of 60±5 km. The age of this HP metamorphism is still poorly constrained and assumed at the onset of Neoproterozoic III. An inverted metamorphic field gradient is brought about by the perturbed paleogeotherm of the Ky-granulite to an upper steady state thermal gradient (20°C/km) toward the base of the arc terrane. This thermal pattern related to diachronic equilibration at different temperatures throughout the metamorphic prism requires the rapid emplacement of the upper hot allochthon onto the TPVN. It represents the collision at 630 Ma with the magmatic arc terrane (SGN) which displays similar dT/dP gradient.

The outward propagation of the nappe pile submitted to significant thinning was accompanied by T-decrease at each thrust rock-package. The preservation of an inverted metamorphic gradient equilibrated in the Ky-field requires rapid exhumation. This short-lived tectonic scenario beginning around 630 Ma and achieved shortly after 625

Ma. Thus, part of the lower crust was exhumed from subduction prism and driven horizontally and thinned above the medium-pressure SW-edge of SFC resulting a mean cooling rate of about 15°C/Ma. The eastward stacking propagation and thinning overrode the parautochthon at ca. 600Ma⁽¹²⁾.

The HT-MP metamorphism associated with extensive upper migmatization of the eastern nappes belonging to the south-edge of the SFC was reached after the thermal relaxation of the thickened continental crust. Such eastward evolution is related to a superimposed intracontinental subduction (at 570 Ma) due to arrival of the edge of Rio Doce orogen⁽¹³⁾.

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Figure 1: Simplified geological map

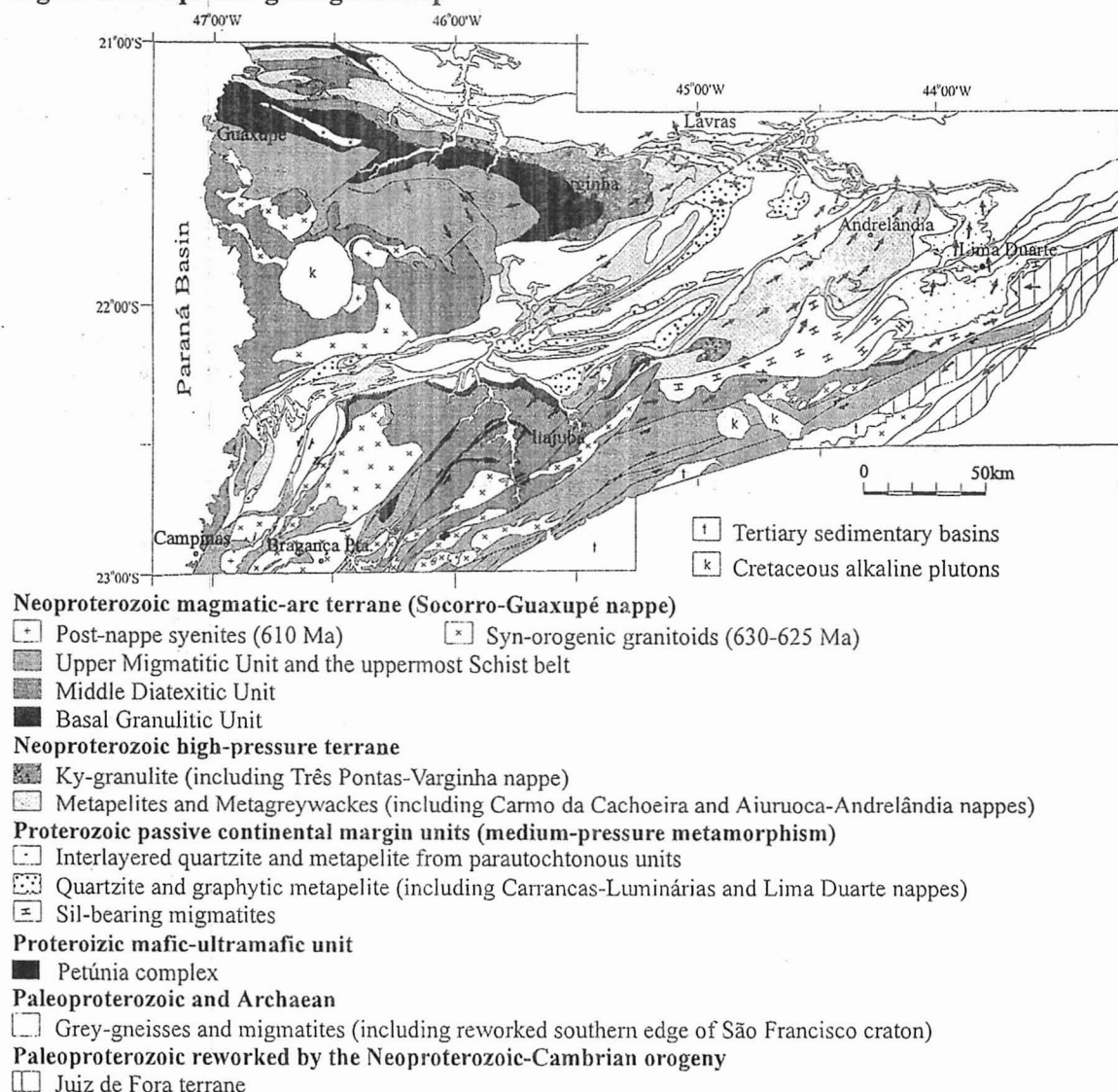


Figure 2: Metamorphic paths

