Petrochronology of UHT garnet-free granulites: Linking zircon geochemistry to metamorphic reactions

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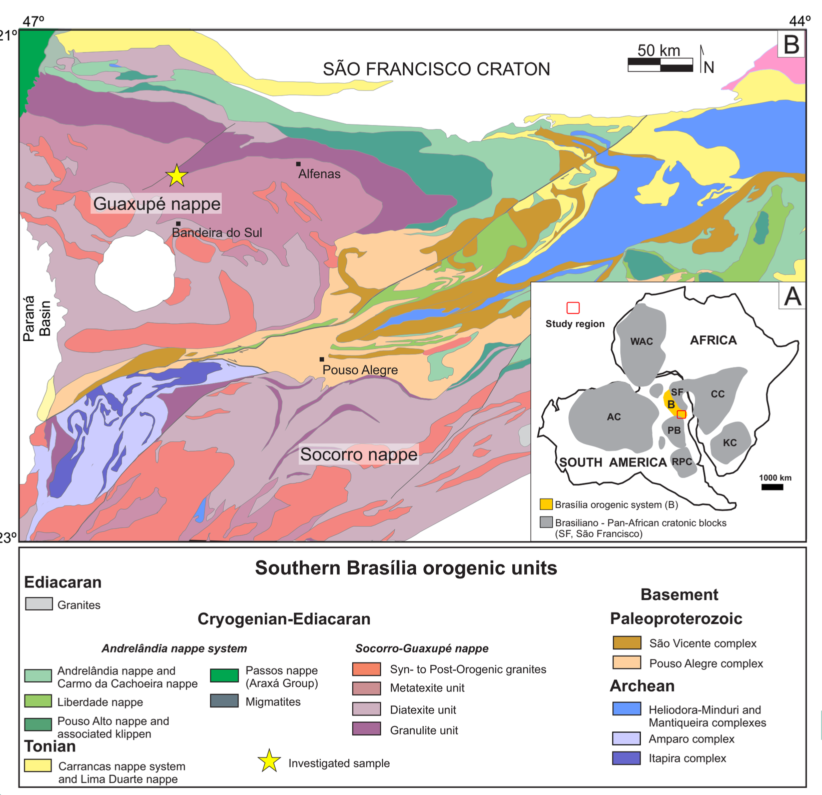
Introduction

Partial melting plays an important role in the redistribution of elements within the lower continental crust in space and time. Ultimately, these processes affect the crust's chemical and mechanical properties, transport and enrich metals, and locally result in (hazardous) volcanism.

Petrochronological investigations (i.e., linking time and duration to specific rock-forming processes and their physical conditions; Engi et al., 2017) may provide insights into crustal reworking throughout the evolution of the Earth. The high temperatures to which migmatites are subjected to often overprint prograde mineral assemblages and produce protracted zircon geochronological records, rendering pressure-temperature-time reconstructions a challenging task. In addition, garnet-free rocks lack the possibility of linking petrological information recorded in garnet with geochronological constraints obtained from zircon or monazite, the most wide-spread petrochronological mineral pairs.

Can trace element compositions of amphibole, orthopyroxene and clinopyroxene combined to zircon be used to link timing data to petrological processes?

Geological Context



Southern Brasília orogen (SE-Brazil)

A complex framework of east-verging nappe systems developed during the collisional stage in the Neoproterozoic (670-590 Ma);

The *Socorro-Guaxupé nappe*: metamorphic remains of a pre-collisional magmatic arc formed at 790-640 Ma and metamorphosed at 660-600 Ma;

Migmatites record ultra-high temperature metamorphism:
T = 800-1050 °C and P = 8-14 kbar

Fig. 1: (A) Distribution of cratonic blocks and orogens in Western Gondwana (red rectangle: location of the studied region illustrated in B): WAC, West African craton; AC, Amazonian craton; SF, São Francisco craton; CC, Congo craton; PB, Paranapanema block; KC, Kalahari craton; RPC, Rio de la Plata craton. (B) Sketch map of the southernmost Brasília orogen (modified from Campos Neto et al., 2011; Cioffi et al., 2016; Westin et al., 2016).

Field relationship

From north to south transitional migmatitic granulite with stromatic metatexites to schollen diatexites passes to schollen to nebulitic diatexites.

Banded opx-cpx granulites occur mainly as enclaves within opdalitic leucosome (★).

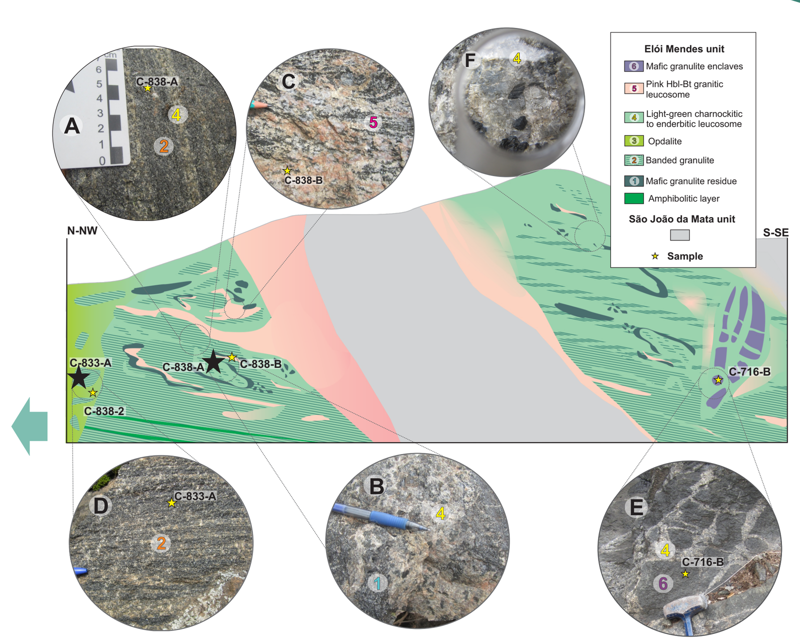
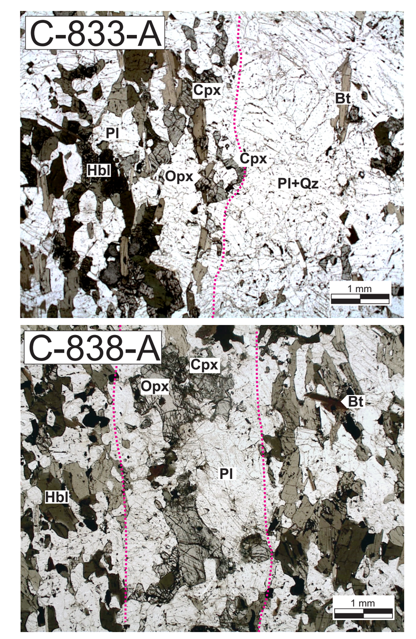


Fig. 2: Sketch cross-section showing the field relationships of the studied rocks of the granulitic – Elói Mendes unit: (1) mafic granulite (residue), (2) banded granulite, (3) opdalite, (4) light-green charnockitic to enderbitic leucosome, and (5) pink hornblende-biotite-bearing granitic leucosome, and (6) mafic granulite enclave. Mesoscopic aspects of each sample: (A) Banded granulite with concordant light green charnockitic leucosome in stromatic structure (C-838-A); (B) mafic schollen (residue) in charnockitic leucosome with peritectic orthopyroxene and clinopyroxene (C-838-2); (C) schlieren of biotite and schollen of stromatic metatexite in the pink hornblende-biotitebearing granitic leucosome (C-838-B); (D) banded granulite (C-833-A); (E) Agmatic structure formed by the mafic granulite enclaves (sample C-716-B) in the diatexite; and (F) euhedral peritectic hornblende in the nebulitic diatexite. Detailed samples on this study correspond to the black stars.

Petrography and mineral chemistry



Banded Opx-Cpx granulites

Mafic layers:
Hbl+Pl+Bt+Cpx+Opx+Qz
Leucocratic layers:
Kfs+Pl+Qz±Cpx±Opx±Hbl

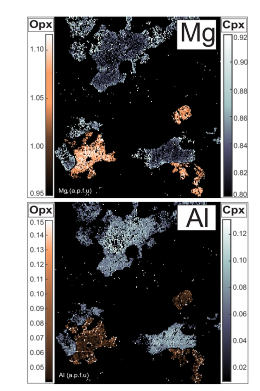
Hbl replaces Opx and Cpx in the residue (selvedge). The only difference is that C-833-A has only few Opx and Cpx in the leucosome (<10 vol.%) when compared to C-838-A (~25 vol.%).

Fig. 3: Transmitted light, non-polarized photomicrographs from the studied rocks. Dotted pink lines outline faded domanial boundaries between leucosome and residue. (A) Relation between thin bands of residue and leucosome in the banded granulite (C-833-A), showing a leucosome depleted in mafic minerals (mostly orthopyroxene and clinopyroxene); (B) peritectic orthopyroxene and clinopyroxene in a band of leucosome relatively enriched in mafic minerals (C-838-A).

Opx and Cpx are zoned in the leucosome
$En_{56-48}Fs_{40-46}MgTs_{4-6}$
$Di_{60-70}Hd_{36-27}Jd_{5-4}$

Hornblende (Al in the site M2=0.6 apfu; Na=0.59 apfu; Ca=1.8 apfu; and XMg=0.11)

Zoned Kfs in the leucosome: $(Ab_{23-10}Mc_{77-90})$



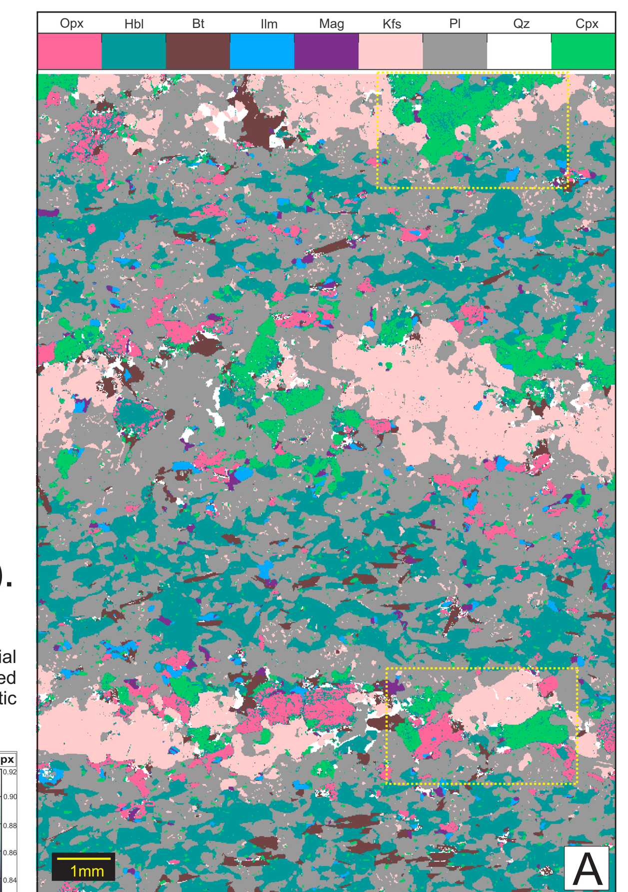


Fig. 4: Compositional maps from EPMA imaging: (A) Phase map showing the texture of the banded granulite (C-838-A) with assigned phases based on quantified compositional maps. Dotted yellow rectangles indicate the position of compositional maps for clinopyroxene and orthopyroxene.

Petrochronology

C-833-A

C-838-A

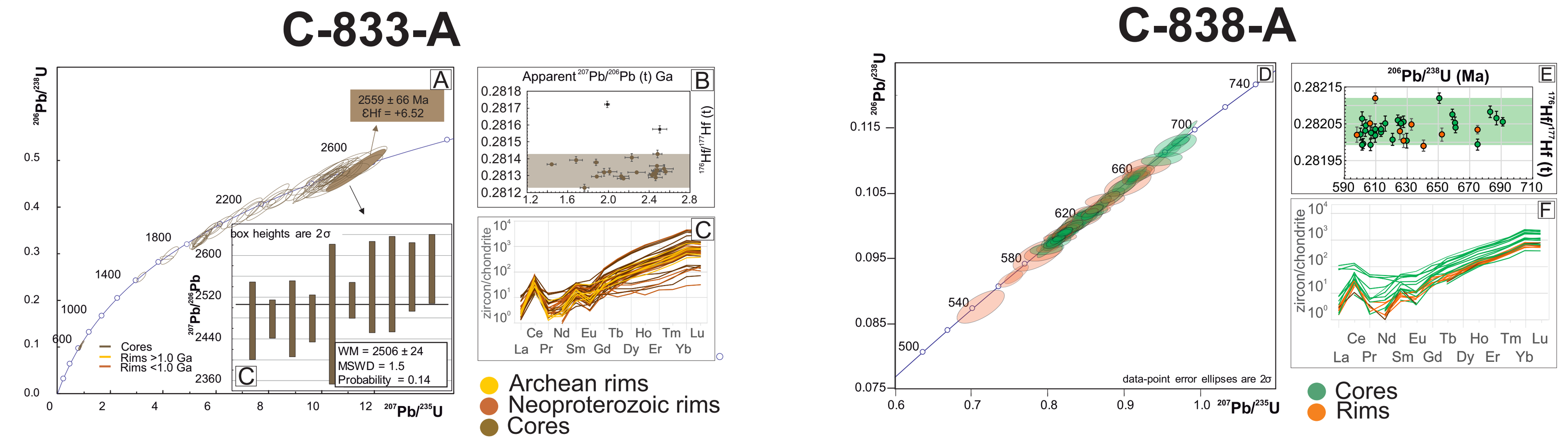


Fig. 5: U-Pb LA-ICP-MS data(Concordia and probability density diagrams), $^{176}Hf/^{177}Hf(t)$ ratio vs age (using $^{206}Pb/^{238}U$ dates), and chondrite-normalized REE diagrams for: banded granulite C-833-A (A-C) and banded granulite C-838-A (D-F). Ellipses in the Concordia diagrams are 2σ errors.

Protracted U-Pb zircon geochronological records prevent the determination of "ages". However, different samples record same age peaks distribution.

$^{176}Hf/^{177}Hf_{(t)}$ allowed to constrain the crystallization age of the protolith.

Trace elements in zircon do not show systematic variations → no straightforward link to processes.

$^{176}Hf/^{177}Hf_{(t)}$ in the rims are different than in the cores in C-833-A suggesting contribution of a Hf-enriched melt/fluid. In sample C-838-A, $^{176}Hf/^{177}Hf_{(t)}$ suggests that the fluid/melt that interacted with the rock had no significant contribution from breakdown of Lu-sink.

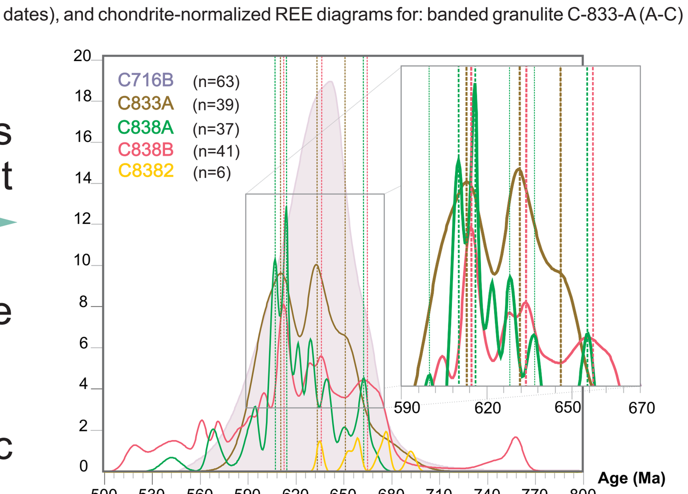


Fig. 6: Probability density diagram for the zircon U/Pb dates of the rims and single phases from the banded granulites (C-833-A and C-838-A) with other zircon rims from rocks in the same geological section.

Are the protracted records related to multiple metamorphic events? Different stages? or domain-related reactions?

Trace elements in Opx, Cpx and Amp

C-833-A
Archean banded granulite

C-838-A
Neoproterozoic banded granulite

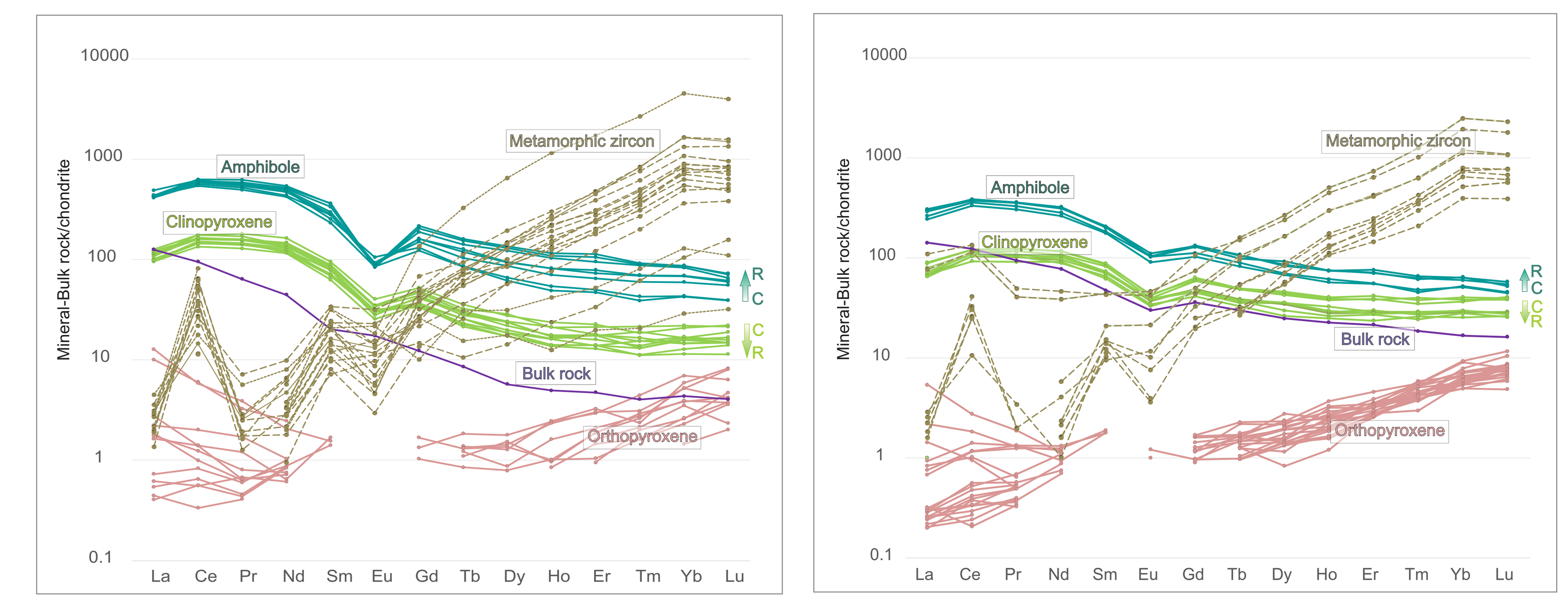


Fig. 7: Chondrite-normalized (McDonough and Sun, 1995) REE diagrams for amphibole, clinopyroxene, orthopyroxene, zircon and the bulk rock composition.

Opx-Cpx-Amp observations:

C-833-A (no peritectic Opx and Cpx in the leucosome) REE signature when compared to C-838-A:
- Stronger negative Eu anomalies for Amp and Cpx;
- Higher variations in LREE and HREE contents;
- Opx is REE depleted and has more diffuse HREE pattern;
- Enrichment of HREEs in the Amp is incompatible with HREE release by Cpx breakdown.

Zrn observations:

- Variable Eu anomalies in both samples suggest growth in associations with different amounts and/or compositions of feldspar;
- Some zircon grains from C-833-A record low HREEs comparable with values from Cpx and Amp;
- LREE enrichment in some grains from C-838-A.

Discussion

Metamorphic zircon grains (620-680 Ma) that crystallized in the residue, where the transition from Cpx to Amp proceeded in the absence or presence of few melt, are depleted in HREEs. This suggests that HREEs from Cpx were directly incorporated by Amp and is supported by the light Eu anomalies of these Zrn grains when compared to the HREE-rich Zrn.

Eu negative anomalies in Zrn increase where Kfs crystallizes, in volumes without Cpx. In C-838-A, Amp is less enriched in HREEs because in the presence of melt, HREE likely enters the structure of Zrn. The absence of external fluid/melt as demonstrated by Hf isotopes for some Zrn reduces the mobility of REEs. For C-833-A the absence of fluids corroborates a subsolidus crystallization for part of the grains that indeed record higher temperatures (Tedeschi et al., 2018). Alternatively, the variation of trace elements in zircon could be caused by external melt/fluid components!?

At least partially, the protracted geochronological records potentially reflect domanial reactions in different stages of a prolonged metamorphic event.

Aknowledgments

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irap
CODEMIG

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