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Combining classical thermobarometry with simultaneous acquisition of trace element and isotopic compositions for U-Pb geochronology by laser ablation; an example from the Taureau shear zone, Central Grenville Province, Quebec

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GEOLOGICAL SETTING

The present study is located in the Mauricie area (Quebec) of the Grenville Province and is composed of three main lithotectonic domains (Fig. 1; Nadeau and Brouillette, 1995). The Mekinac-Taureau domain (MTD) is the structurally lowest domain and forms a dome that extends for more than 80 km from the St. Maurice River to the Taureau Reservoir. It is mostly composed of granulite-facies, migmatitic, felsic to intermediate orthogneiss with rare discontinuous layers of metapelite, quartzite, marble, calc-silicate and amphibolite. The MTD is in tectonic contact with the overlying Morin Terrane (MT) along the Taureau shear zone (TSZ) to the west, south and south-east. The MT is principally exposed on the western side of the MTD, but a thin slice of this terrane extends towards the east and is referred to as the Shawinigan domain (SD; e.g. Corrigan and van Breemen, 1997; Rivers, 2008). The MT is composed of orthogneiss, paragneiss and marbles metamorphosed at the granulite facies, except in the SD, where upper amphibolite facies rocks predominate. Finally, the SD is in tectonic contact with the overlying Portneuf-Mauricie domain (PMD) along the Tawachiche shear zone (TWSZ) to the east. The TWSZ is an oblique extensional shear zone that was active at ca. 1080-1040 Ma (Fig. 1; Corrigan and van Breemen, 1997).

On the western side of the MTD, the TSZ was interpreted as an oblique thrust active until ca. 1074 Ma (Fig. 1; Martignole and Friedman, 1998). However, the apparent decrease in metamorphism from the MTD towards the SD on the eastern side points to a normal sense of shear. The present study provides classical thermobarometric and geochronologic data essential to understand the kinematic history and the timing of shearing along the eastern TSZ.

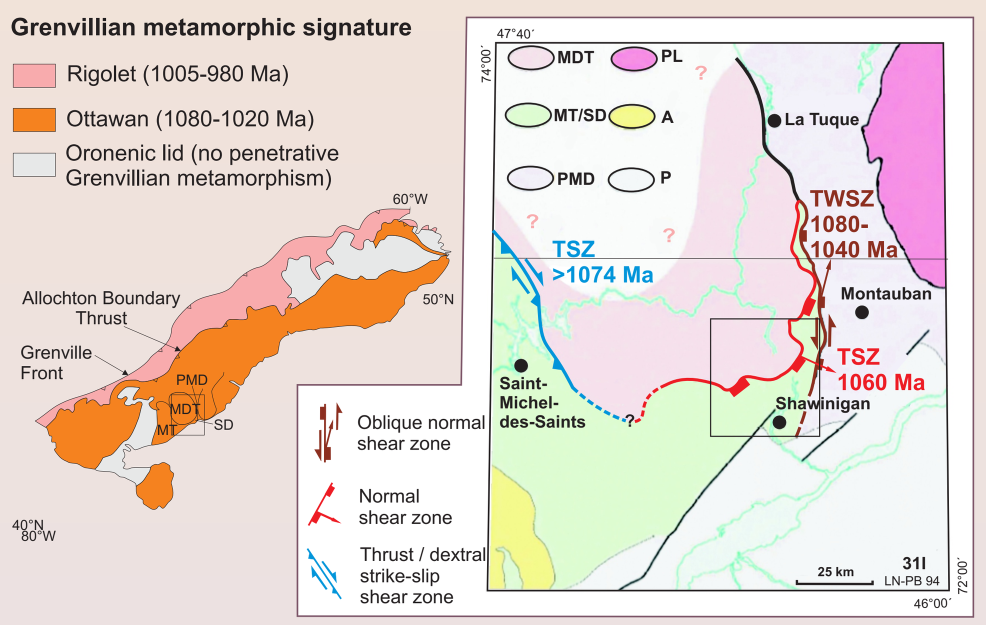


Fig. 1. Simplified tectonic subdivisions of the Grenville Province (modified from Rivers, 2008) and simplified geologic map of the Lanaudière-Mauricie area (modified from Nadeau and Brouillette, 1995). MT—Morin terrane, MDT—Mékinac–Taureau domain, SD—Shawinigan domain, PSD—Portneuf–Mauricie domain, PL—Parc des Laurentides domain, A—Anorthosite, P—Paleozoic cover, TWSZ—Tawachiche shear zone, TSZ—Taureau shear zone. Black rectangle represents area of Fig. 9.

THERMOBAROMETRY

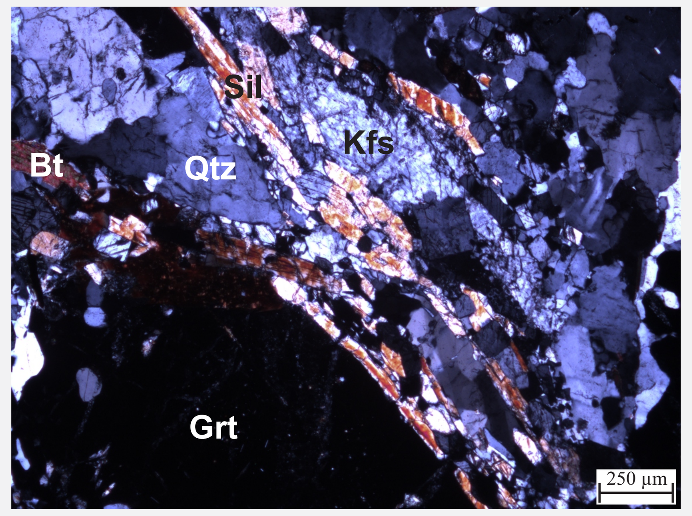


Fig. 2. RS12-015A. Typical metapelite containing Qtz–Kfs–Grt–Bt–Sil. Pl is missing from the photograph but was present in the assemblage.

Layers of paragneiss containing the peak metamorphic assemblage quartz (Qtz) – plagioclase (Pl) – K-feldspar (Kfs) – garnet (Grt) – biotite (Bt) – sillimanite (Sil) (Fig. 2) were analyzed for thermobarometry to determine if there is a metamorphic contrast across the TSZ. Metamorphic conditions were calculated with TWQ v. 2.32 (Berman, 2007) using Grt-Bt thermometer and Grt-Sil-Qtz-Pl (GASP) barometer.

Garnet zoning profiles in migmatitic pelitic schists generally show spikes in Fe/Fe+Mg ratio and Xspessartine (XSps) due to diffusional Fe-Mg exchange and retrograde net-transfer reaction with a melt phase during cooling (Spear et al. 1999). In the samples analyzed herein, however, garnet presents weak zoning (Fig. 3), indicating they were only weakly affected during the retrogression. Calculated conditions therefore represent the peak metamorphism, or conditions that were present for a time sufficiently long to completely re-equilibrate garnet. P-T conditions were calculated with the composition of homogeneous cores of Grt, Bt armoured by a non reacting phase (Qtz, Kfs or Pl) and matrix Pl found in the vicinity of Grt.

The core of the MTD was metamorphosed at 820-850°C and 1050-1120 MPa, whereas conditions of 750-780°C and 780-790 MPa were calculated close to the TSZ. Calculated P-T conditions are more variable in the Shawinigan domain. Conditions of 775 °C at 785 MPa were calculated in sample RS12-027b. In sample RS11-105, a first population characterized by ilmenite (Ilm) – Qtz inclusions-rich core and inclusion-free rim (Fig. 4) yielded temperatures of 700-750°C at pressures of 620 to 860 MPa, whereas a second type characterized by the absence of Qtz and Ilm inclusions (Fig. 5) yielded conditions of 680-710°C at 570-640 MPa.

A key sample from the Taureau shear zone is an amphibolite containing Grt surrounded by Pl – hornblende (Hbl) coronae in a groundmass of Hbl – Pl – Qtz. The sigmoidal shape of the coronas indicates a top-down-to-the-ESE sense of shear (Fig. 7). Metamorphic conditions were calculated with TWQ v. 1 (Berman, 2007) using Grt-Hbl-Pl thermobarometry.

Hbl in the groundmass has higher Fe/(Fe+Mg) values (0.430-0.448) than Hbl in the coronas (0.399 to 0.442). Pl is also chemically different in the groundmass (~An45) compared to the coronas (~An53). Peak conditions of 750-775°C at 1000-1100 MPa were calculated by combining chemical compositions of high-grossular Grt outer cores with plagioclase and hornblende from the groundmass. In contrast, retrograde conditions of 640-675°C at 640-760 MPa were calculated by combining chemical compositions of low-grossular Grt rims with Pl and Hbl from the coronas. The top-down-to-the-ESE sense of shear indicated by the sigmoidal shape of the coronas implies normal-sense shearing along the TSZ synchronous with, or postdating the development of the coronas. It is, therefore, likely that the MTD was exhumed from ca. 1000-1100 to ca. 700 MPa while normal shearing occurred along the TSZ.

The small decrease in metamorphism from the MTD to the SD may suggest that the TSZ accommodated only minor displacement during its top-down-to-the-ESE motion. However, the possible syn-kinematic nature of retrograde coronas may imply a re-equilibration of the metamorphic conditions during shearing, obscuring the real metamorphic offset between the domains. Otherwise, the timing of metamorphism may not be the same for both domains, which would also lead to a misinterpretation of the metamorphic contrast.

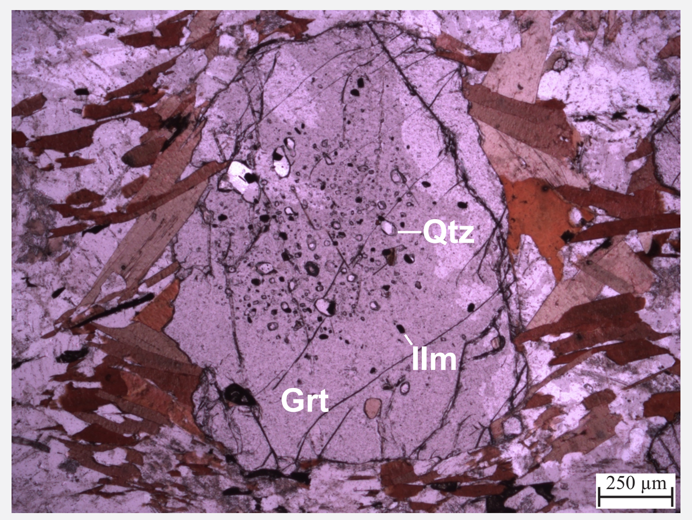


Fig. 4. RS11-105. Type 1 Grt with abundant Qtz and Ilm inclusions in the core. Odd color pattern in the garnet is due to carbon coating.

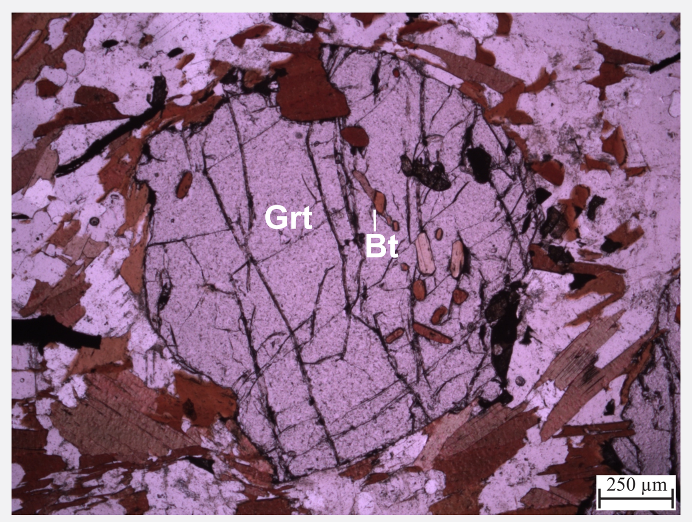
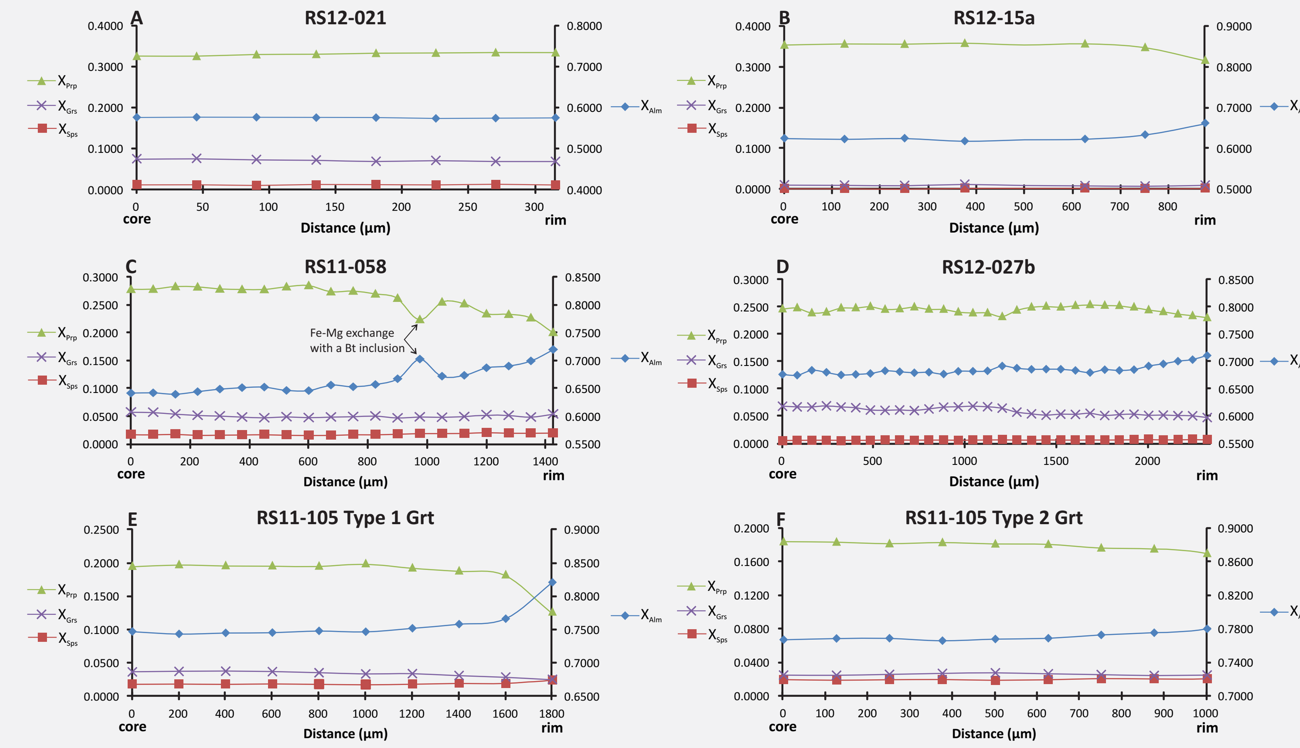


Fig. 5. RS11-105. Type 2 garnet that only contains Bt inclusions.



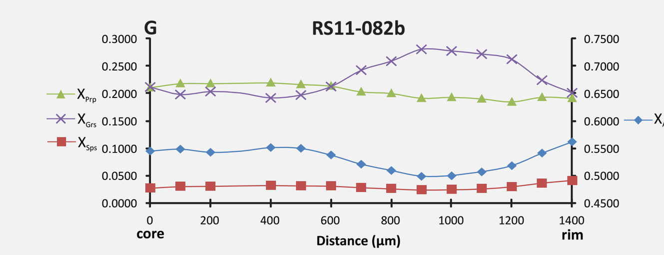


Fig 3. Grt chemical composition profiles from core to rim. X_{Alm}—almandine, X_{Prp}—pyrope, X_{Grs}—grossular and X_{Sps}—spessartine. A-F: metapelite; G: amphibolite.

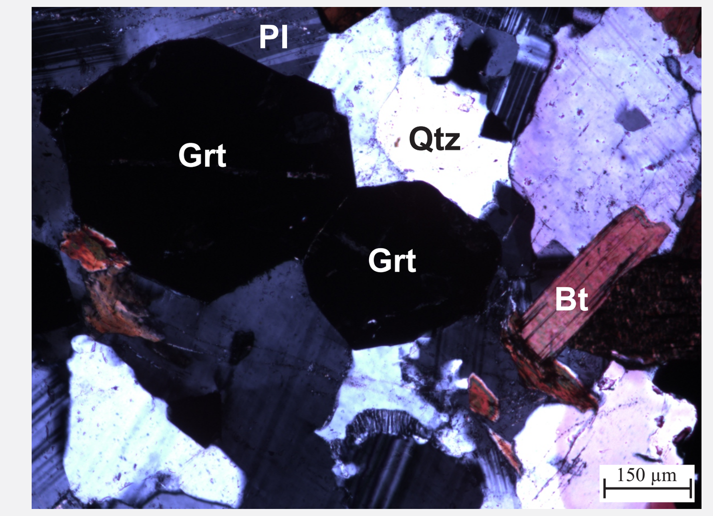


Fig. 6. RS12-021. Euhedral Grt in a matrix of Pl, Qtz and Bt. Sil and Kfs are absent from the microphotograph, but are present in the assemblage. Grt from this sample does not show any zoning at the edges.

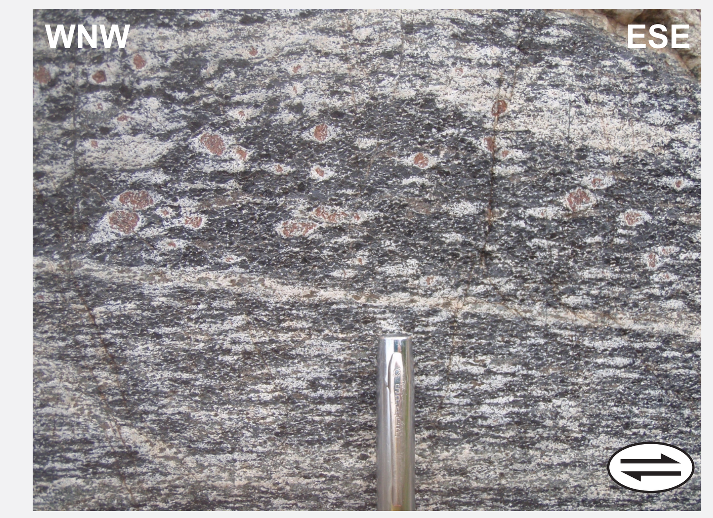


Fig. 7. Grt-amphibolite RS11-082b. View, parallel to the mineral lineation, showing σ-type coronas of Pl and Hbl around Grt indicating ESE-directed shearing.

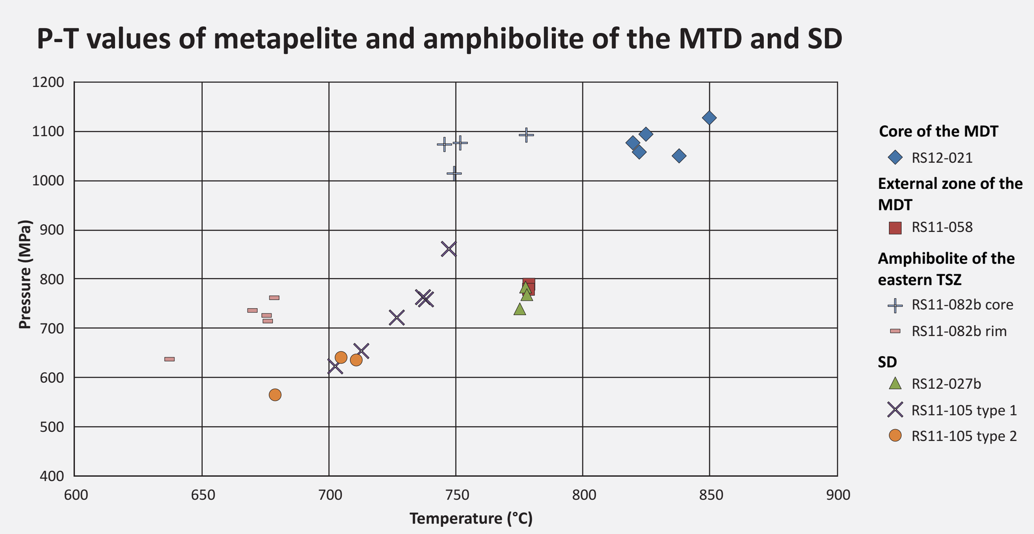
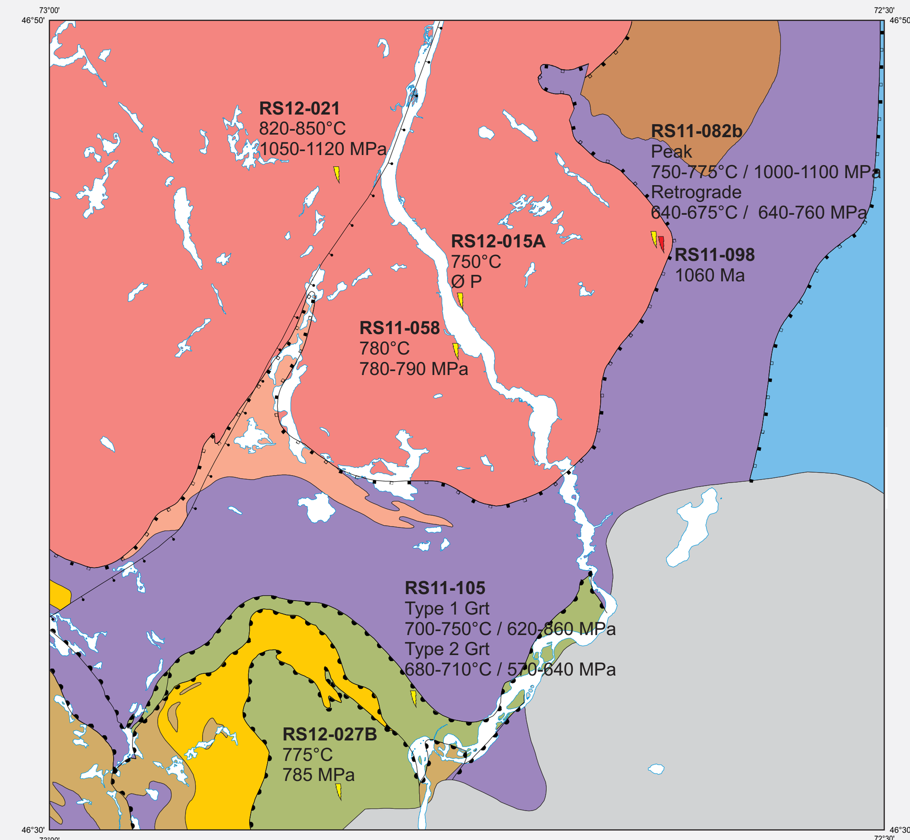


Fig. 8. Pressure and temperature obtained from the MDT and the SD.



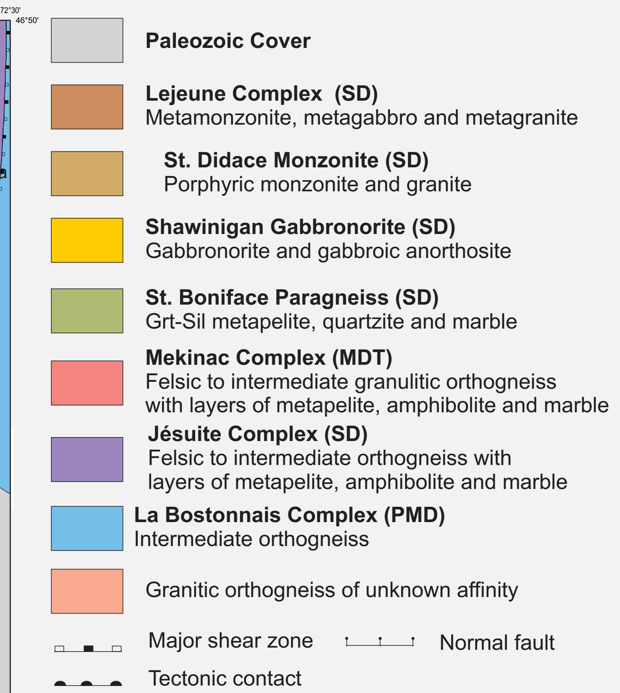


Fig. 9. Simplified geologic map of the Mauricie area With results of thermobarometry and U-Pb zircon geochronology.. Modified from Nadeau et al. 2009.

U-PB GEOCHRONOLOGY

Fig 10. Syn-kinematic granitic pegmatite cross-cutting the host rock foliation, but locally containing a weak internal foliation parallel to the external foliation. C-S fabric above the main pod, and folded external foliation close to a pegmatite dyke indicates top-down-to-the-ESE sense of shear.

A syn-kinematic granitic pegmatite was sampled to constrain the timing of extension along the eastern TSZ (Fig. 10). Zircon was classified according to morphology, zoning patterns in cathodoluminscence (CL) images, and trace element concentrations acquired by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) (Fig. 11 and 12). Three populations were identified. Group 1 is composed of homogeneous to oscillatory-zoned dark subequant zircon, characterized by high U and Th contents (120-420 and 90-330 ppm) and medium HREE contents. Group 2 is paler in CL and frequently sector or patchy zoned. It forms whole grains and rims on group 1. Their chemical composition partially overlaps group 1, but they have lower U and Th (90-210 and 70-190 ppm) and trace element concentrations. Group 3 is also characterized by pale zircon that is patchy or oscillatory zoned. It has low U (60-130 ppm), medium Th content (100-210 ppm) and higher HREE content.

Group 1 is interpreted as the primary igneous zircon formed during the crystallization of the pegmatite. Group 2 overgrows group 1 and probably formed by recrystallization or dissolution-precipitation because their chemical composition is similar. Finally, the distinct chemical composition of group 3 suggests it originated from a distinct fluid, but physical relationships between this group and the other groups have not been established yet.

Relatively large errors yielded by the LA-ICP-MS method preclude a clear distinction between these three Proterozoic groups. Future work includes additional LA-ICP-MS analysis to determine the relative timing of group 3. Also, isotope dilution - thermal-ionization mass spectrometry (ID-TIMS) dating of the groups is planned to better constrain the ages. Current results suggest extension along the eastern TSZ at ca. 1060 Ma.

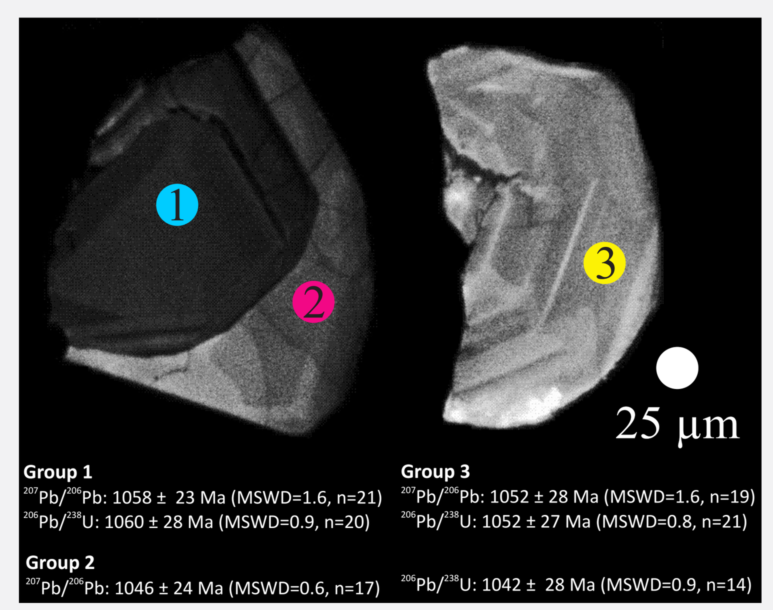


Fig. 11. CL images of representative zircons from group 1, 2 and 3. Errors are given at 2σ and include standard calibration uncertainties of 1.8% (2σ) for $^{207}Pb/^{206}Pb$ and 2.7% (2σ) for $^{206}Pb/^{238}U$.

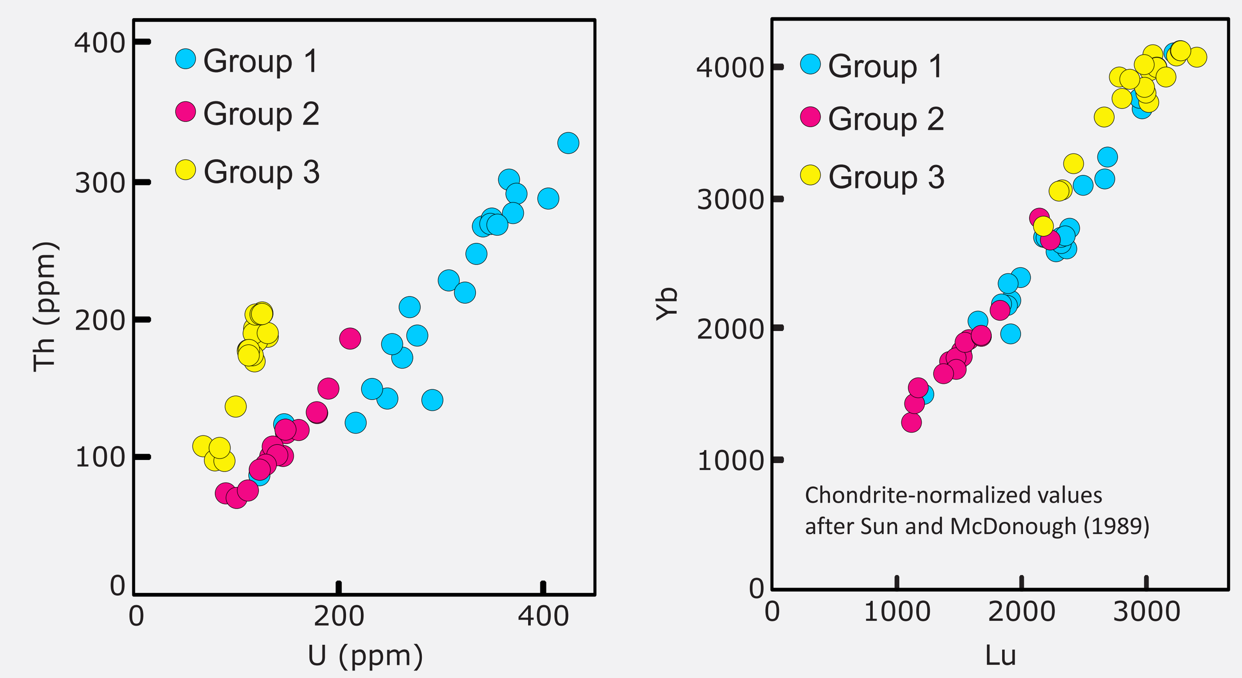


Fig. 12. Th vs. U and Yb vs. Lu plots showing a clear distinction between zircon groups.

CONCLUSIONS

The core of the MTD reached granulite facies conditions of ca. 850°C at ca. 1100 MPa and preserved the associated mineral assemblage and chemical compositions.

The external zone of the MTD was initially metamorphosed under granulite facies conditions that reached at least ca. 775 °C at 1100 MPa. Subsequently, it registered retrograde conditions of ca. 675-775°C at ca. 725-800MPa.

The SD attained granulite metamorphic conditions of at least 775°C at 800 MPa, but also registered upper amphibolite retrograde conditions as low as 680°C at 570 MPa.

Exhumation of the MTD, in the sense of England and Molnar (1990), probably started along the TWSZ at ca. 1080 Ma (Corrigan and van Breeman, 1997) and continued at ca. 1060 Ma (this study) along the eastern TSZ. Exhumation of 14 km of the MTD is most likely due to the combined action of both shear zones and other processes such as erosion and/or flattening.

Timing of extension along the eastern TSZ is compatible with the older thrust observed along its western section.

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