

Chronologic-dynamic zoning of the Ross Orogen – a current research program of the PNRA (Italy)

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Summary In the frame of the Antarctic Research Program of Italy (PNRA), the studies on the Early Paleozoic Ross Orogeny are coordinated in a mainframe project named "Chronologic-dynamic zoning of the Ross Orogen", including seven research units. The research work is focused on two main geographical-conceptual themes: (A) the reconstruction of the igneous-metamorphic history of the margin active in Victoria Land, carrying evidence for long-lasting igneous activity of variable chemical affinity and emplacement style, and (B) the role of the transition between fault-bounded lithotectonic units, which have been the reference frame for the interpretation of the Ross Orogeny in northern Victoria Land for two decades. At ISAES X, several preliminary and mature products of this research program are presented.

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Introduction

The Transantarctic Mountains expose the uplifted roots of the Ross-Delamerian orogenic system, that was active on the East Antarctic-Australia craton margin during Cambrian-Ordovician time. Granitoid magmas extensively intruded the Antarctic sector of the orogen, that results segmented in crustal sectors, structurally, chronologically and geochemically diverse. The Cenozoic reactivation of the sector discontinuities rules the Cenozoic tectonic and volcanic activity of the area. The Ross orogen offers the opportunity to investigate phenomena that are basic in understanding the consequences of plate convergence processes, such as lithospheric segmentation, widespread invasion of the crust by granites, mechanisms of magma emplacement, and exploitation of fossil lithospheric architecture by the following tectonic events.

The models put forward to explain the Ross structures in Victoria Land emphasize the role of juxtaposition of the main terranes (Robertson Bay, Bowers e Wilson) bounded by regional faults, in a transcurrent context or during convergence, which was likely oblique with significant longitudinal movements with respect to the margin. The crustal sectors stuck together could represent exotic terranes, different portions of the same margin, or intermediate setting.

Overall research plan and objectives

The research project is designed to gather and focus different methods and skills on selected, significant case studies. The overall project is based on two main lines of research: (A) study of the emplacement mechanisms for selected intrusions and their relations to the tectonometamorphic evolution in some key-areas of the Ross Orogen within the Wilson margin, and (B) study of the tectonic, metamorphic, and igneous evolution of the Wilson-Bowers-Robertson Bay terrane transitions.

A. The field work has been carried out in selected key-areas (1) the Morozumi Range, close to the outer portion of the margin, (2) the central Deep Freeze Range, a peculiar area associated to the transition of metamorphic grade from low through medium to high in few km (Palmeri, 1997), up to granulite facies (Talarico et al., 1995; Talarico and Castelli, 1995), (3) the Eisenhower Range, (4) the Terra Nova Intrusive Complex: the 1:50.000 geopetrographic map (Rocchi et al., 2004) and a detailed petrological study (Di Vincenzo and Rocchi, 1999) put in evidence the long lasting building time (c. 60 Ma), coupled with a significant decline of the stress regime, with emplacement of magmas of variable compositions always characterized by mingling-mixing phenomena between mantle-derived mafic magmas and crust-derived felsic melts.

B. The exotic nature of the Bowers terrane became matter of debate in recent models based on aeromagnetic (Ferraccioli et al., 2002; Finn et al., 1999) and geochemical data (Rocchi et al., 2003). This research project includes geological-petrological transects across the Wilson-Bowers terrane junction, to work out the link between deformation events, magma emplacement, HP-UHP metamorphism (Di Vincenzo et al., 2001; Palmeri et al., 2003a; Palmeri et al., 2003b), sediment production and deposition in the Bowers basins. As regards the intrusive igneous rocks, a geochemical study will be performed both for samples from intrusive (often cumulate) rocks from the outer belt bordering Wilson terrane (Niagara Icefalls and Tiger Gabbro), and for pebbles from Husky Conglomerates at the Wilson-Bowers terrane junction (Capponi et al., 1999). The chronological characterization of these igneous rocks is a crucial point: the volcanic-volcaniclastic rocks from the Bowers terrane can be ascribed to the middle Cambrian on the basis of indirect

paleontological evidence; for all the igneous rock units, weak Sm-Nd isotopic evidence exists for a likely Ross-related magma generation. The Bowers-Robertson Bay transition could have different natures at different crustal levels. For the upper crustal levels, the possible provenance of Robertson Bay sediments from Wilson continental material will be investigated. The study of the Bowers-Robertson Bay transition at a deep crustal level will be performed by petrochemical and geochronological studies on crustal xenoliths collected from Cenozoic scoria cones in the Robertson Bay terrane.

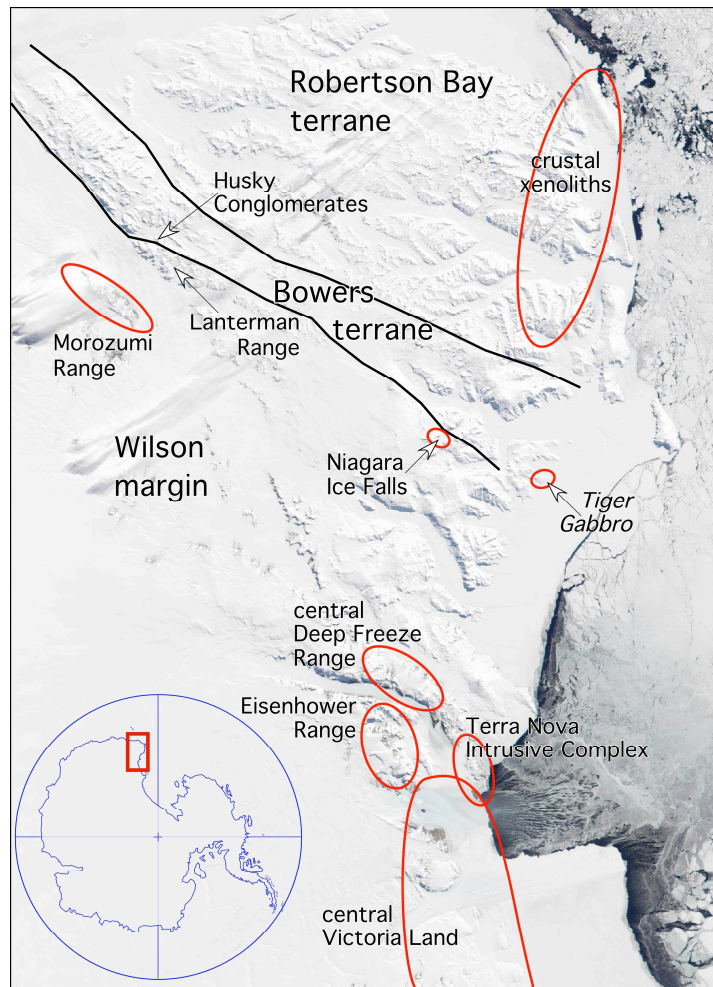


Figure 1. Location map of the studied areas.

LA-ICP-MS, (3) collection of petrological data for metamorphic host rocks to reconstruct the metamorphic processes linked to the magma intrusion and those possibly occurred before that, (4) laser extraction ^{40}Ar - ^{39}Ar and U-Th-Pb geochronology, (5) study of the chemical-physical processes (mingling-mixing) during emplacement: dynamic models and numerical simulations of the interaction processes (image analyses, theory of chaotic dynamic systems); fractal analysis techniques (SEM-EDS maps and minerals transects by LA-ICP-MS); comparison with field observations; (6) thermomechanical models analogue for magma emplacement, (7) analysis of the anisotropy of magnetic susceptibility (AMS) in the igneous intrusions and their country rocks.

Internal zones of the margin

Inside Granite Harbour Intrusives of northern Victoria Land: timing and origin of the intrusive sequence

In-situ U-Pb dating of zircons constrains the timing of individual magmatic pulses between Prince Albert Mountains and Mountaineer Range in the time interval 520-480 Ma. This part of the program is carried out mainly by researchers of the University of Siena. Some papers have been published in the frame of this program (Bomparola et al., 2007; Giacomini et al., 2007) and a summary of the state of art will be presented at ISAES X in the C2 session.

The understanding of the structure of the continental margin in Victoria Land will greatly benefit of comparisons with both modern and ancient analogues. The project will therefore include an in-depth comparison with early Paleozoic geological history of Tasmania, New Zealand and south-eastern Australia, where the Ross-Delamerian event involved terranes that were similar and likely contiguous with Victoria Land terranes.

The aim of this research is the reconstruction of the working mechanisms of the active margin of the East Antarctic craton during the Early Paleozoic. This research is also aimed to improve the knowledge of magma emplacement processes in orogenic belts, to evaluate the role of magmatism in growth and structuration of the crust in convergent through collisional to postcollisional settings.

Methods and logistics

The field work has been mostly accomplished during the field seasons 2004-2005 and 2005-2006, based on both the Mario Zucchelli Station (Italy) and a remote camp (Litell Rocks, Rennick Glacier-Morozumi Range).

The overall methodology of the research proposal is based on a multidisciplinary approach, integrating (1) field structural data, (2) petrographic data (SEM-EDS and/or EPMA-WDS microanalysis) and geochemical characterization (major elements via XRF, trace elements via ICP-MS, Sr and Nd isotopes via TIMS) of igneous whole-rocks; for cumulate mafic-ultramafic rocks: reconstruction of the liquids in equilibrium with cumulus phases, analysed for trace elements by

Magma interaction in the Terra Nova Intrusive Complex

The spectacular magma interaction evidence are used to investigate the process timescales during its evolution via morphological fractal analysis of mafic/felsic interfaces and plagioclase transects by and EPMA + LA-ICP-MS. This part of the program is carried out by researchers of the University of Perugia. Some papers have been published in the frame of this program (Perugini and Poli, 2005; Perugini et al., 2005).

Granite-lamprophyre connection in the postcollisional stage of the Ross Orogeny

In central Victoria Land, a unique coeval association of granites and lamprophyres has been investigated, highlighting the genetic link between them in a scenario of fast postcollisional exhumation and slab roll-back. This part of the program is carried out by researchers of the University of Pisa and Siena and IGG-CNR-Pisa and will be presented at ISAES X in the C2 session.

Shear zones in the Ross granites (Deep Freeze Range)

A systematic study of the spatial distribution and the kinematic-petrological characteristics of the major ductile shear zones that cross-cut the granitoid rocks and show overprinting relationships with late leucocratic dykes is in progress to define the significance of these shear zones in the framework of the Ross orogenic cycle. This part of the program is carried out by researchers of the University of Roma Tre and will be presented at ISAES X in the C2 session.

Post-Ross localized reworking in the inner Wilson terrane

Structural evidence and U–Th–Pb (zircon and monazite) and ^{40}Ar – ^{39}Ar (muscovite and biotite) data on shear zones from the Deep Freeze Range suggest that local ductile deformational features overprinting Ross granitoids occurred at ca. 440–450 Ma. These shear zones formed synchronously with the early stages of deformation in the Lachlan Fold Belt (SE Australia). This part of the program is carried out by researchers of the IGG-CNR-Pisa, University of Pisa, MNA-Siena and University of Pavia. In the frame of this program a paper is in press (Di Vincenzo et al., 2007).

Thermomechanical models of igneous intrusions

Thermomechanical models of pluton emplacement were undertaken, with temperature used to achieve rheological similarity between model and nature, to define the influence of the magma filling rate on the pluton shapes assuming magma transport through dykes. This part of the program is carried out by researchers of the University of Roma Tre.

Outer zones of the margin

Age and nature of the Robertson Bay crust

This is a crucial point underpinning any model for the Ross collision/accretion in Victoria Land. Geochemical and geochronological studies on granulitic xenoliths from Cenozoic scoria cones are carried out by researchers of the University of Pisa, IGG-CNR-Pisa and University of Perugia. The results will be presented at ISAES X in the C2 session.

Boninite-type melts in the Wilson margin

Analyses of trace element mineral compositions and zircon U–Pb data by LA-ICP-MS on mafic-ultramafic cumulates from Niagara Icefalls and Husky Ridge indicate derivation from boninite-type melts at around 500 Ma in an embryonic back-arc basin. This part of the program is carried out by researchers of the University of Pavia and two papers have been submitted.

The Tiger Gabbro

This mafic cumulate intrusion shows geochemical features typical of an origin in immature arc setting during the Ross convergence at the border of the Wilson margin. This part of the program is carried out by researchers of the University of Pisa and IGG-CNR-Pisa, and a paper is in preparation in the frame of this program.

The Cambrian Ross Orogeny in northern Victoria Land and New Zealand: a synthesis

Comparison of the type and timing of sedimentary, magmatic and metamorphic events Victoria Land and New Zealand suggests for both areas the occurrence of arc/back-arc assemblages produced by west-directed subduction. This part of the program is carried out by researchers of the University of Genova and will be presented at ISAES X in the C2 session.

Gold-bearing veins in the Transantarctic Mountains

The occurrence of gold-bearing quartz veins in northern Victoria Land is reported for the first time and framed in the regional tectonic evolution. This part of the program is carried out by researchers of the Universities of Genova and Siena and will be presented at ISAES X in the C1 session.

Tectonics at the Bowers - Robertson Bay Terrane boundary, northern Victoria Land

Structural analysis on large scale structures of Millen Range indicate a top to NE and to E movement, in the regional framework of oblique-slip tectonics that characterizes the amalgamation and docking of terranes during the Ross Orogeny. This part of the program is carried out by researchers of the Universities of Genova and will be presented at ISAES X in the C1 session.

The Morozumi Range Intrusive Complex

This composite intrusion close to the Wilson-Bowers margin is constituted by a main granite mass along with minor peraluminous bodies and a mafic stock, with variable intrusive relationships with complex tabular intrusions. This part of the program is carried out by researchers of the University of Pisa and IGG-CNR-Pisa and will be presented at ISAES X in the C2 session.

Conclusions

Since ISAES IX, this program has been submitted, approved and partly funded. At ISAES X, both preliminary and mature results are presented.

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References

- Bomparola, R.M., Ghezzi, C., Belousova, E., Griffin, W.L., and O'Reilly, S.Y., 2007, Resetting of the U-Pb zircon system in Cambro-Ordovician intrusives of the Deep Freeze Range, northern Victoria Land, Antarctica: *Journal of Petrology*, v. 48, p. 327-364, doi:10.1093/petrology/egl064.
- Capponi, G., Crispini, L., and Meccheri, M., 1999, The metaconglomerates of the eastern Lanterman Range (northern Victoria Land, Antarctica): new constraints for their interpretation: *Antarctic Science*, v. 11, p. 217-227.
- Di Vincenzo, G., Carosi, R., Palmeri, R., and Tiepolo, M., 2007, A comparative U-Th-Pb (zircon-monzonite) and ⁴⁰Ar-³⁹Ar (muscovite-biotite) study of shear zones in northern Victoria Land (Antarctica): implications for geochronology and localized reworking of the Ross Orogen: *Journal of Metamorphic Geology*, in press.
- Di Vincenzo, G., Ghiribelli, B., Giorgetti, G., and Palmeri, R., 2001, Evidence of a close link between petrology and isotope records: constraints from SEM, EMP, TEM and in situ ⁴⁰Ar/³⁹Ar laser analyses on multiple generations of white micas (Lanterman Range, Antarctica): *Earth and Planetary Science Letters*.
- Di Vincenzo, G., and Rocchi, S., 1999, Origin and interaction of mafic and felsic magmas in an evolving late orogenic setting: the early Paleozoic Terra Nova Intrusive Complex, Antarctica: *Contributions to Mineralogy and Petrology*, v. 137, p. 15-35.
- Ferraccioli, F., Bozzo, E., and Capponi, G., 2002, Aeromagnetic and gravity anomaly constraints for an early Paleozoic subduction system of Victoria Land, Antarctica: *Geophysical Research Letters*, v. 29, p. 10.1029/2001GL014138.
- Finn, C., Moore, D., Damaske, D., and Mackey, T., 1999, Aeromagnetic legacy of early subduction along the Pacific margin of Gondwana: *Geology*, v. 27, p. 1087-1090.
- Giacomini, F., Tiepolo, M., Dallai, L., and Ghezzi, C., 2007, On the onset and evolution of the Ross-orogeny magmatism in North Victoria Land - Antarctica: *Chemical Geology*, v. 240, p. 103-128, doi:10.1016/j.chemgeo.2007.02.005.
- Palmeri, R., 1997, P-T paths and migmatite formation: An example from Deep Freeze range, northern Victoria Land, Antarctica: *Lithos*, v. 42, p. 47-66.
- Palmeri, R., Ghiribelli, B., Talarico, F., and Ricci, C.A., 2003a, Ultra-high-pressure metamorphism in felsic rocks: the garnet-phengite gneisses and quartzites from the Lanterman Range, Antarctica: *European Journal of Mineralogy*, v. 15, p. 513-525.
- Palmeri, R., Talarico, F., and Ricci, C.A., 2003b, Ultra-high pressure metamorphism at the palaeo-Pacific margin of Gondwana: the Lanterman Range in Antarctica, 9th International Symposium on Antarctic Earth Sciences, Potsdam (Germany), 8-12 September 2003, p. 249-250.
- Perugini, D., and Poli, G., 2005, Viscous fingering during replenishment of felsic magma chambers by continuous inputs of mafic magmas: Field evidence and fluid-mechanics experiments: *Geology*, v. 33, p. 5-8, doi: 10.1130/G21075.1.
- Perugini, D., Poli, G., and Rocchi, S., 2005, Development of viscous fingering between mafic and felsic magmas: evidence from the Terra Nova Intrusive Complex (Antarctica): *Mineralogy and Petrology*, v. 83, p. 151-166, doi: 10.1007/s00710-004-0064-2.
- Rocchi, S., Capponi, G., Crispini, L., Di Vincenzo, G., Ghezzi, C., Meccheri, M., and Palmeri, R., 2003, Mafic rocks at the Wilson-Bowers terrane boundary and within the Bowers terrane: clues to the Ross geodynamics in northern Victoria Land, Antarctica., 9th International Symposium on Antarctic Earth Sciences, Potsdam (Germany), 8-12 September 2003.
- Rocchi, S., Di Vincenzo, G., and Ghezzi, C., 2004, The Terra Nova Intrusive Complex (Victoria Land, Antarctica), with 1:50,000 Geopetrographic Map: *Terra Antarctica Reports*, v. 10, p. 51.
- Rocchi, S., Di Vincenzo, G., Tonarini, S., and Ghezzi, C., 1999, The Tiger Gabbro of northern Victoria Land: age, affinity and tectonic implications, in Skinner, D.N.B., ed., 8th International Symposium on Antarctic Earth Sciences: Wellington, New Zealand, p. 270.
- Talarico, F., Borsi, L., and Lombardo, B., 1995, Relict granulites of the Ross Orogen of northern Victoria Land (Antarctica). II - Geochemistry and paleo-tectonic implications: *Precambrian Research*, v. 75, p. 157-174.
- Talarico, F., and Castelli, D., 1995, Relict granulites of the Ross Orogen of northern Victoria Land (Antarctica). I - Field occurrence, petrography and metamorphic evolution: *Precambrian Research*, v. 75, p. 141-156.