

Postcollisional magmatism of the Ross Orogeny (Victoria Land, Antarctica): a granite-lamprophyre genetic link

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Summary The central Victoria Land crustal sector of the early Paleozoic Ross Orogen is characterized by the widespread occurrence of pink granite plutons and dikes (Irizar unit) and lamprophyric dikes (Vegetation unit). Structural evidence indicates these intrusions were emplaced in a tensional regime during late stages of the Ross Orogeny. Geochronological U-Pb and ⁴⁰Ar-³⁹Ar data indicate emplacement age for both units within a restricted time interval around 490 Ma. This, coupled with emplacement style, imply a fast, block-like exhumation during this postcollisional stage. The Irizar granites-dikes and the Vegetation lamprophyres are both potassic, with overlapping initial Sr-Nd isotope ratios. The Vegetation melts derived from enriched subcontinental lithospheric mantle further metasomatised by a Ross subduction component, while the Irizar melts derived from remelting of Vegetation-like underplated material. Comparison with coeval postcollisional igneous activity in Australia-Tasmania suggests similar scenarios with slab roll-back in the Antarctic sector evolving to slab break-up in Australia-Tasmania.

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Introduction

During the post-collisional stage of the Ross Orogeny in Victoria Land (Antarctica) the latest products of the Ross-related igneous activity were emplaced as a variety of undeformed potassic granites and dikes and potassic lamprophyric dikes and sills. The magmas were intruded at different depths in a very short time interval during fast exhumation of the orogen. This tectonic setting has been defined on the basis of geological and geochronological data, that is independently from the geochemical features of igneous rocks: therefore the peculiar association of petrologically diverse, albeit coeval magmas, can be used to shed light on both the connection between potassic felsic and lamprophyric melts and the variable role of slab retreat along the margin at the end of the convergence process.

Geological setting - The late stages of the Ross Orogeny

The Ross Orogeny was the result of convergence between the East Antarctic Craton and the paleo-Pacific oceanic plate (Stump, 1995). The process of convergence started in the latest Neoproterozoic when the margin of East Antarctica underwent a conversion from passive to active convergent margin. Subduction along this margin probably initiated by ca. 560 Ma, the time when the first subduction-related magmas appeared (Goodge, 2002) in southern Victoria Land. The latest magmas emplaced in the Ross orogenic belt have ages not younger than about 480 Ma.

The present-day setting of Victoria Land is the result of early Paleozoic Ross convergence, and the subsequent Cenozoic activity of the West Antarctic rift. The Paleozoic margin is made up of the assembly of three main fault bounded lithotectonic units, from NE to SW (Fig. 1) the Robertson Bay, Bowers and Wilson terranes (Kleinschmidt and Tessensohn, 1987). The allochthonous nature of the Wilson terrane has recently been questioned, and it can be simply regarded as the margin/leading edge of the East Antarctic Craton (Roland et al., 2004), active during the latest Neoproterozoic-early Paleozoic.

The early Paleozoic active margin (Wilson margin, former Wilson terrane) of the East Antarctic Craton was multiply deformed during the convergence process and affected by igneous activity, whose traces are found today within the roots of the Transantarctic Mountains, uplifted during the Cenozoic. The trace of that active margin magmatism is a complex plutonic association gathering intrusive rocks of variable emplacement time and style and different chemical affinity, cropping out along the thousands of km of the Transantarctic Mountains stretch. Within the Wilson margin, the central Victoria Land zone, between Reeves Glacier to the north and the Fry Glacier to the south (Fig. 1) was affected by extensive intrusive activity resulting in the occurrence of deformed, undeformed and crosscutting intrusive bodies. The latter can be considered as postcollisional on the basis of geological-geochronological data: they are texturally isotropic, undeformed, emplaced in a permissive way during the exhumation of the orogen and cut across all the other, more or less deformed intrusive bodies. These internally homogeneous rock groups can be described as three main intrusive units: the Irizar granite, the Irizar felsic dike swarm and the Vegetation mafic dike swarm.

The Irizar granites and dikes and the Vegetation lamprophyres

The postcollisional units cropping out in central Victoria Land are a unique association of postcollisional intrusive products in the Ross Orogen. The pink Irizar granites of Victoria Land are a group of isolated plutons with roughly circular to oval outline. These are homogeneous pink, unfoliated, equigranular, medium- to coarse-grained syenomonzogranites. The Irizar granites consist of pink alkali feldspar, smoky quartz, whitish plagioclase, Fe-rich biotite \pm dark green ferro-edenitic amphibole. The rare xenoliths of igneous origin have small size, < 10 cm, and a cumulate texture with large brown amphibole crystals poikilitically including small euhedral crystals of plagioclase, clinopyroxene and cryptocrystalline pseudomorphs after olivine. The field relationships, the overall petrographic features and the mafic mineral composition give the Irizar granite an alkaline tendency, with some affinities with the broad category of A-type granites. The Irizar felsic dike swarm is an association of dikes with metre-thicknesses, found as both crosscutting the Irizar plutons and isolated dikes within older granites. The thickest dikes tend to follow a north-east strike. The dikes are commonly red-coated, and show a porphyritic texture with mm-sized euhedral phenocrysts of quartz, often smoky, pink alkali feldspar, Fe-rich biotite and scattered hastingsitic-pargasitic amphibole, set in a light grey to pink aphanitic groundmass. The dominant composition is syenogranitic. The Irizar granites and rhyolitic dikes have overlapping compositions, mostly syenogranitic with a few monzogranitic samples. K_2O variation shows a humped shape, with positive correlation with SiO_2 between 67 and 71 wt%, changing to negative for higher silica contents (Fig. 2). The whole association of Irizar granites and dikes has emplacement ages tightly clustered around 490 Ma (Di Vincenzo et al., 2003; Rocchi et al., submitted).

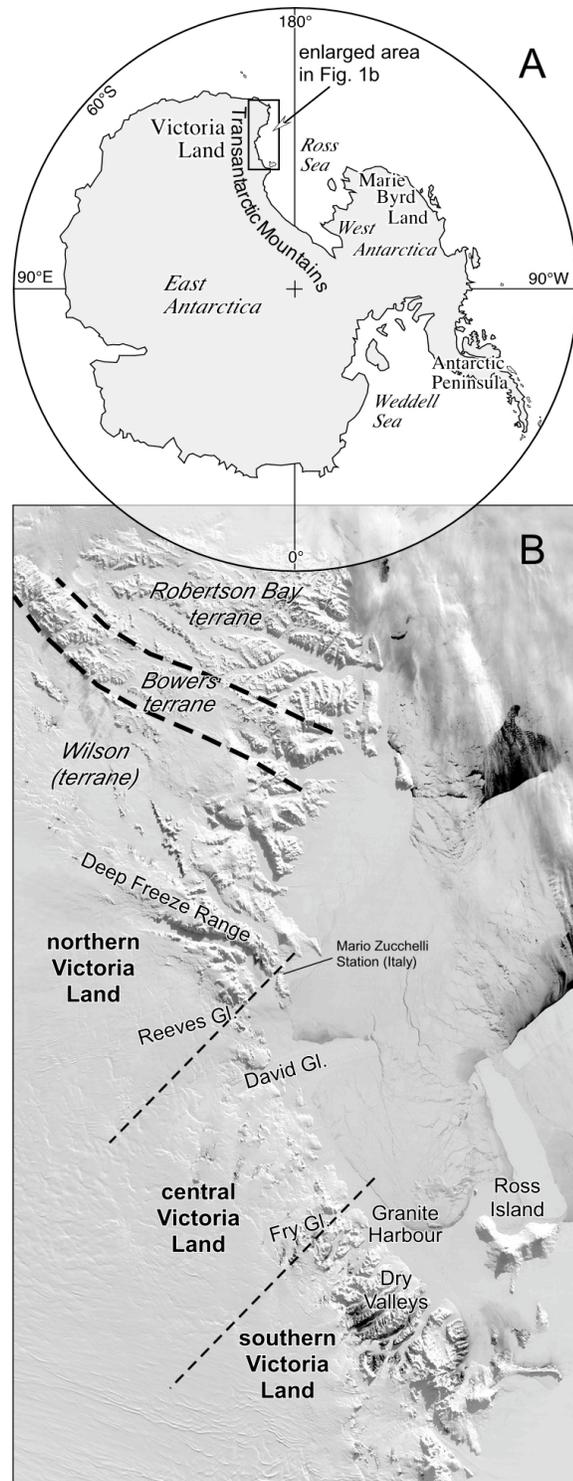


Figure 1. Location map. (a): Antarctica and location of Fig. 1B. (B): Satellite image of Victoria Land showing the study area.

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The Vegetation Dike Swarm is a widespread association of hypabissal tabular intrusions that crop out along 200 km of the Ross Sea coast of Victoria Land, between the Mario Zucchelli Italian Station and Fry Glacier-Tripp Island (Fig. 1). In the northernmost area, around the Nansen Ice Sheet, the tabular bodies are gently dipping sills, sometimes connected with underlying feeder dikes (Rocchi et al., 2004) and almost always show mingling-mixing relationships with coeval fine-grained peraluminous leucogranites of upper crustal origin (Di Vincenzo and Rocchi, 1999; Perugini et al., 2004). Geobarometric estimates on both mafic and felsic facies indicate $P \approx 0.2$ GPa (Di Vincenzo and Rocchi, 1999). Between Reeves and Fry glaciers, the Vegetation dike swarm is exclusively found as subvertical blades of metric thickness with overall strike clustering between NE and NNE, suggesting emplacement at a structural level slightly deeper with respect to sills north of the Reeves Glacier. All the dikes are texturally isotropic, and were emplaced under a tensional, brittle regime at around 490 Ma (Rocchi et al., submitted). This subset of the Vegetation dike swarm geographically overlap the outcrop area of the Irizar Granite and dike swarm, although they were found at the same outcrop. The Vegetation lamprophyric dikes commonly bear scarce phenocrysts of ubiquitous biotite along with minor amphibole sometimes surrounding clinopyroxene, which in turn rarely borders orthopyroxene. These phenocrysts are set in a groundmass of biotite, hornblende, plagioclase, minor interstitial potassic feldspar and sporadic quartz.

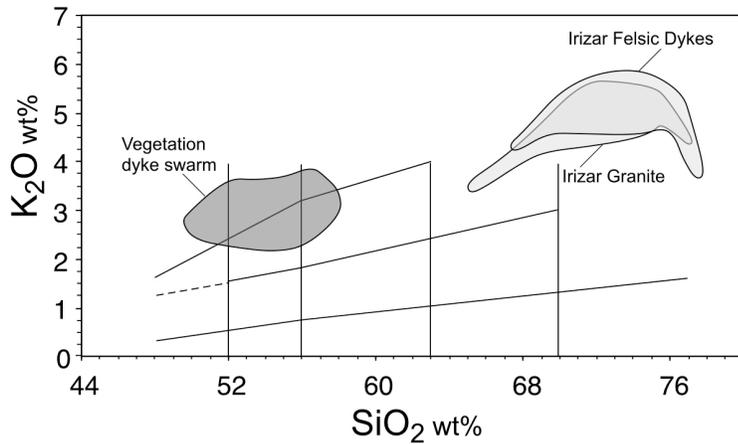


Figure 2. K₂O vs SiO₂ diagram.

has to be explained first, to assess the parental magma(s) of each unit, then discussion on magma genesis and inter-unit comparisons can be made.

Internal variability

The chemical variations observed for Irizar granites and dikes as a whole have no correlation with their geographical location. Chemical variations internal to the Irizar granites and dikes can be explained by differentiation related to crystal fractionation involving the observed mineral phases.

The variability of major and trace elements for Vegetation dikes cannot be defined as chemical trends, with some elements showing variable concentration at a fixed silica content. This distribution of concentrations makes it difficult to model chemical variations as related to closed system solid-liquid fractionation processes. The restricted isotopic variations internal to Vegetation mafic dikes from north of Reeves Glacier were explained as part of an assimilation-fractional crystallization-mixing trend with Vegetation crustal leucogranites (Di Vincenzo and Rocchi, 1999). On the other hand, the Nd isotopic variations shown by samples from south of Reeves Glacier are not compatible with reasonable mixing/assimilation processes. These observations and the occurrence as dikes lend support to the lack of a unique primitive melt for Vegetation magmas, that could rather represent small amounts of melts deriving from similar sources and undergoing very limited fractionation/assimilation during their ascent, if any.

Magma source(s)

The most mafic samples of the Vegetation dikes show high MgO, Cr and Ni contents coupled with enrichment in LILE with respect to HFSE and high initial $^{87}\text{Sr}/^{86}\text{Sr}$ and low initial ϵ_{Nd} . All these features indicate an origin from a mantle modified by subduction zone metasomatism. These geochemical data and the overall chemical similarities of the Vegetation mafic rocks with both late to post-orogenic shoshonites and lamprophyres, coupled to field occurrence, age, and extensional emplacement regime, suggest that Vegetation magmatism is linked to the local involvement in the melting zone of an old, previously enriched layer of subcontinental lithospheric mantle further metasomatised by a recent subduction component. The melting might have been related to heat supply by exposure of previously insulated portions of subcontinental mantle to asthenospheric heating during postcollisional slab roll-back, likely coupled with convective thinning/delamination of lithosphere overthickened during Ross convergence (Di Vincenzo and Rocchi, 1999).

For Irizar rocks, the major-trace element distribution and Sr-Nd isotope ratios lead to rule out upper or lower crustal melting, (assimilation and) crystal fractionation, and hybridism as viable genetic mechanisms. Experimental melting works on potassic basalts (Sisson et al., 2005) suggests that major element composition of Irizar potassic melts can be derived from such a source. Thus the overlapping Sr-Nd ratios of Irizar and Vegetation and trace element modelling lead to the formulation of the following two-stage model: (1) underplating of Vegetation shoshonitic melts at the base of the crust, and (2) high-degree partial melting of that Vegetation underplate, thermally assisted by replacement of thermal boundary layer by asthenosphere and late-orogenic extensional collapse.

Implications for the late evolution of the Ross-Delamerian Orogeny

Vegetation lamprophyres and Irizar granites have the same emplacement age and we infer that they are also genetically linked, yet emplaced at different levels. The difference in emplacement depth between Irizar Granite and Irizar dikes-Vegetation dikes could have been significant. Structural evidence on the emplacement setting (ductile for

Accessory phases are magnetite, ilmenite, apatite, allanite and titanite.

The Vegetation dike swarm is composed of lamprophyric rocks with SiO₂ varying between 48.1 and 57.6 wt%, and K₂O vs. SiO₂ relationships (Fig. 2) emphasizing the potassic nature of these rocks, that mostly belong to the shoshonitic association. The rather high silica content and potassic nature are coupled with features typical of primary mantle melts, like high MgO, Cr and Ni contents.

Discussion

The studied igneous units show internal, intra-unit geochemical variations along with similarities and differences among each other (inter-unit). The origin of intra-unit variations

the Irizar plutons, brittle for the two dike associations) and rough geobarometric estimates indicate a possible depth difference in the order of 5-10 km, pointing to an extremely fast exhumation rate of (some km per Ma).

Along the several thousand of km of the stretch of the Ross-Delamerian Orogenic belt, postcollisional igneous units are found only in some peculiar sectors where their emplacement occurred at the same age during rapid uplift, cooling and extension (Foden et al., 2006): the central Victoria Land-Dry Valleys along the Transantarctic Mountains and southeastern Australia. In SE Australia, postcollisional rocks are mantle-derived gabbros and potassic, A-type granites and volcanic rocks linked by extended fractional crystallization (Turner et al., 1992). Differently, in Victoria Land, the link between coeval bimodal postcollisional magmas is one of partial remelting. These similarities and differences between Ross and Delamerian postcollisional magmatism can be reconciled in a dual late-subduction scenario: (i) in Victoria Land, slab rollback allows asthenosphere flow over the retreating slab and generation of potassic melts with strong orogenic geochemical signature, while (ii) in SE Australia, the slab breakoff allows asthenosphere uprise from both above and below the slab: the asthenosphere from below the slab is not modified by Ross subduction and, when mixed with the supra-slab asthenosphere, became a suitable source for SE Australia alkaline gabbros and their differentiates.

Conclusions

The studied sector of the Ross Orogen in central Victoria Land is host to a unique coeval granite-lamprophyre igneous association. The Vegetation lamprophyres are inferred to derive from partial melting of metasomatised lithospheric mantle, and the Irizar granites from high-degree partial remelting of an underplate made of material compositionally akin to the Vegetation lamprophyre magma. Magmas were generated during strong uplift and erosion (=exhumation) around 490 Ma. This sequence of processes commonly occur in the late stage of a collisional event, when collision locked the subduction process and the slab loose its horizontal velocity component, start to sink in the mantle, rolls back (as inferred for Victoria Land) and sometimes breaks off (as suggested for SE Australia).

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