PETROLOGY AND U-PB GEOCHRONOLOGY OF THE MAFIC-ULTRAMAFIC SEQUENCE AND ASSOCIATED QUARTZ-FELDSPATHIC ROCKS FROM NIAGARA ICEFALLS (NORTHERN VICTORIA LAND, ANTARCTICA)

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INTRODUCTION AND GEOLOGICAL SETTING

The Transantarctic Mountains are the elevated roots of the Ross orogenic system, which is broadly related to the Cambro-Ordovician subduction of the palaeo-Pacific ocean under Gondwana supercontinent (Encarnaciòn & Grunow, 1996; Allibone & Wysoczansky, 2002; Foden *et al*., 2006). The Northern Victoria Land, at the Pacific end of the Transantarctic Mountains, consists of three crustal terranes, namely the Wilson, Bowers and Robertson Bay terranes. The Niagara Icefalls mafic-ultramafic sequence crops out along the southern portion of the tectonic boundary between the Wilson and Bowers terranes. In this area, the mid-crustal rocks of the Wilson Terrane and the upper crustal rocks of the Bowers Terrane were tectonically juxtaposed through a transpressive structure during the latest stages of the Ross Orogeny (Musumeci, 1999; Meccheri *et al*., 2003; Federico *et al*., 2006). The Niagara Icefalls mafic-ultramafic sequence is attributed to the Wilson Terrane (see also Capponi *et al*., 1998, 2003) and its petrological, geochemical and geochronological features are poorly known.

The Niagara Icefalls sequence is bounded to southwest and northeast by the Retreat Schist and Tonalite Belt, respectively, with contacts marked by low-temperature mylonites or covered by ice. The Retreat Schist rocks consist of fine-grained biotite-bearing quartz-feldspathic gneisses recording pressure and temperature equilibration conditions of 0.3-0.4 GPa and 520°C and are attributed to the metamorphic basement of the Wilson Terrane (Castelli *et al*., 2003). Two Retreat Schist samples gave K-Ar biotite ages of 488±6 Ma and 489±6 Ma (Vita-Scaillet & Lombardo, 2003). The Tonalite Belt is a suite of intrusions consisting of hornblende-bearing foliated granitoids that commonly record a polyphase retrograde tectono-metamorphic evolution (Musumeci, 1999). A Pb-Pb titanite age of 480±13 Ma was interpreted to date the high-temperature deformation recorded by the Tonalite Belt (Musumeci *et al*., 2000).

The aim of this work is the petrological and geochronological characterisation of the Niagara Icefalls mafic-ultramafic sequence. In particular, we wish to determine: i) nature and composition of parental melts; ii) age of emplacement; and iii) geochronological and petrogenetic relationships between the Niagara Icefalls sequence and adjacent Tonalite Belt and Retreat Schist.

METHODS

Representative rocks samples of Niagara Icefalls mafic-ultramafic sequence, and adjacent Tonalite Belt and Retreat Schist bodies were selected for chemical analyses on the basis of a petrographic study at the optical microscope. Major element mineral compositions were determined by electron microprobe. In addition, clinopyroxenes were analysed for trace elements by laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS). Whole-rock major and trace element compositions of Tonalite Belt and Retreat Schist samples were obtained by ICP-MS at Activation Laboratories (Ancaster, Ontario). *In-situ*

U-Pb zircon geochronology was performed at CNR - Istituto di Geoscienze e Georisorse, U.O. di Pavia. The instrument used couples an ArF excimer laser microprobe at 193 nm (Geolas200Q-Microlas) with ICPMS Element I (ThermoFinnigan). Zircons as free from cracks as possible were selected, mounted in epoxy resin and polished down using a 0.25 µm diamond paste. Prior to U-Pb dating, zircon structures were characterised by cathodoluminescence imaging. In addition, the trace element compositions of zircons were determined by LA-ICP-MS.

RESULTS

The Niagara Icefalls sequence consists of dunites, harzburgites, orthopyroxenites, melagabbronorites and gabbronorites of cumulus origin (Tribuzio *et al.*, 2008). The Mg# value of spinel, orthopyroxene and clinopyroxene from these rocks yields positive correlations, thus indicating a formation by melts that mainly evolved through fractional crystallisation. The following fractionation sequence was recognised: olivine (up to 94 mol.% of forsterite component) + Cr-rich spinel → olivine + orthopyroxene ± spinel → orthopyroxene → orthopyroxene + anorthite-rich plagioclase ± clinopyroxene. The clinopyroxenes retain the peculiar trace element signature of boninite melts, which is extremely low concentrations of HREE and HFSE, and LILE enrichment over REE and HFSE. The significant changes in the LREE fractionation of the most primitive clinopyroxenes may be related to primary melts with slightly different geochemical signatures, or reflect a process of crustal contamination. Indeed, the occurrence of inherited zircons in the gabbronorite and orthopyroxenite selected for U-Pb zircon geochronology indicates that the boninitic melts were at least locally subjected to crustal contamination.

Whole-rock major and trace element analyses show that selected Tonalite Belt and Retreat Schist rocks (*i.e.* from the Niagara Icefalls area) are chemically similar. The Tonalite Belt consists of high-K calc-alkaline granitoids with geochemical signature typical of volcanic-arc granites (Pearce *et al*., 1984). The Retreat Schist may derive from the Tonalite Belt in response to a tectono-metamorphic event under amphibolite facies conditions.

Zircons from Niagara Icefalls mafic-ultramafic rocks are characterised by complex internal structures. They have locally small subrounded cores, rimmed by a thin bright zone (up to a few microns thick) indicating a resorption process (Vavra *et al*., 1996). These inherited cores are commonly characterised by low to moderate luminescence. The zircon portions enclosing the inherited cores commonly show oscillatory or sector zoning. There is frequently also a structureless zircon overgrowth, generally with high to moderate luminescence, which truncates the internal structures of zircon fragments with oscillatory or sector zoning. These structureless zircon portions are commonly found in the outermost position of the zircon grains and are volumetrically subordinate relative to those with oscillatory or sector zoning. The contact surfaces between these different zircon portions are sinuous in places, thus indicating resorption.

Most inherited zircons from the mafic-ultramafic rocks commonly yielded U-Pb ages of ~ 538 Ma; a few inherited grains with Proterozoic to Precambrian age are also preserved. The zircon portions with oscillatory or sector zoning gave ages of ~ 514 Ma, interpreted to date the emplacement of the Niagara Icefalls sequence. The analyses carried out on structureless zircon portions furnished an age of ~ 490 Ma, which is most likely related to growth or re-equilibration under subsolidus conditions. Trace element analyses did not provide significant chemical variations among the zircon portions with different cathodoluminescence structures; the chondrite normalised REE pattern is invariably characterised by marked HREE enrichment over MREE and LREE, and negative Eu anomaly.

The geochronological history inferred from the mafic-ultramafic rocks is supported by the U-Pb isotope data from a biotite-leucotonalite showing mingling relationship with gabbronorites, *i.e.* these two rock-types are coeval on the basis of field relations. The biotite-leucotonalite has inherited zircons with Precambrian to Proterozoic ages and zircons with oscillatory zoning, inferred to date the crystallisation of the biotite-leucotonalite. These zircons yielded an age that is within error the U-Pb zircon age of ~ 514 Ma determined for the mafic-ultramafic sequence. In one zircon from the biotite-leucotonalite, we carried out an analysis of the thin overgrowth with high luminescence, which furnished an age of ~ 494 Ma, interpreted to result from growth or re-equilibration under subsolidus conditions.

Mafic-ultramafic complexes with petrological features similar to those of the Niagara Icefalls sequence, correlated with boninite-type parental melts, are exposed in other sectors of the eastern margin of the Gondwana supercontinent. In particular, the age proposed for the intrusion of the Niagara Icefalls sequence is within error of the U-Pb zircon ages of granitoids related to the mafic-ultramafic complexes from both Delamerian (515±7 Ma; Turner *et al*., 1998) and Takaka Terrane (515±7 Ma; Münker & Crawford, 2000). Therefore, the Niagara Icefalls mafic-ultramafic sequence can be related to a regional scale igneous event that affected the eastern margin of the Gondwana supercontinent in the Middle Cambrian.

The U-Pb geochronological data for two Tonalite Belt samples from the Niagara Icefalls area suggest an age of emplacement of ~ 534 Ma. These data pertain to zircons with oscillatory zoning and trace element patterns indicating an igneous origin. Inherited zircons, with low luminescence and/or sector zoning, gave Proterozoic and Precambrian ages. The Tonalite Belt samples allowed us to perform also a few analyses of structureless zircon portions, which yielded ages of ~ 500 Ma. Similar to the Niagara Icefalls mafic-ultramafic sequence, we suggest that these ages may represent a perturbation of the U-Pb system.

Zircons from one Retreat Schist sample collected in the Niagara Icefalls area furnished a wide range of U-Pb ages. There are many Proterozoic and Precambrian ages and two zircons yielded ages of ~ 532 Ma, which may date the formation of the protolith.

CONCLUSIONS

The following succession of events is proposed for the mafic-ultramafic sequence and associated quartz-feldspathic rocks from the Niagara Icefalls area:

1. Early Cambrian (530-540 Ma): presumable emplacement of the Tonalite Belt in an active continental margin. Similar U-Pb zircon ages were found for the calc-alkaline and “adakite” plutons from the Wilson Terrane (Black & Sheraton, 1990; Goodge *et al*., 1993; Encarnaciòn & Grunow, 1996; Allibone & Wysoczansky, 2002).

2. Middle Cambrian (~ 514 Ma): emplacement of subduction-related boninite-type melts that gave rise to the Niagara Icefalls mafic-ultramafic sequence. The local presence of inherited zircons pre-dating the Ross Orogeny, together with the occurrence of mingling relationship between gabbronorites and biotite-granitoids, suggest that the emplacement was in a continental setting.

3. Late Cambrian-Early Ordovician (490-500 Ma): retrograde tectono-metamorphic evolution related to the tectonic event that affected both mafic-ultramafic sequence and Tonalite Belt, in conjunction to the juxtaposition of the Wilson and Bowers terranes (Castelli *et al.*, 2003, Vita-Scaillet & Lombardo, 2003).

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