The application of oxygen isotopes of zircon in regional mapping: an example from Paleoproterozoic granites in the Gascoyne Province

by

SP Johnson, FJ Korhonen, CL Kirkland, JB Cliff[1], EA Belousova[2], S Sheppard[3], R Murphy[2], and MTD Wingate

The timing and style of crust formation or reworking are important factors in understanding regional-scale crustal evolution and architecture, which in turn provide important constraints on mineral systems (e.g. McCuaig et al., 2010; Joly et al., 2012). Since 2008, GSWA has routinely collected high-precision, Lu–Hf isotopic data (by Laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS)) in situ from dated zircon crystals. With the installation of the Cameca IMS 1280 multi-collector ion microprobe at the Centre for Microscopy, Characterisation and Analysis (CMCA) at The University of Western Australia, the measurement of oxygen isotopes from the same dated and isotopically characterized zircon crystals is now possible. The high-spatial resolutions (typically <25 µm diameter and 2 µm depth (SIMS) to 50 µm diameter and depth (LA-ICPMS)) of each of the analysis techniques allows the measurement of U–Pb, $\delta^{18}O$ and Lu–Hf from the same discrete zircon domain in a single crystal.

The ratio of measured ^{18}O to ^{16}O (reported in $\delta^{18}O$ notation, in per mil variations relative to Vienna standard mean ocean water [VSMOW]) in a zircon crystal can be used to determine whether the parental magma from which the zircon crystallized contained a contribution from near-surface rocks, since zircons in equilibrium with mantle-derived melts have specific $\delta^{18}O$ values in the range of 5.3 ± 0.6 ‰ (Valley, 2003). Incorporation of rocks or minerals altered by low-temperature near-surface processes into the magma (e.g. assimilation of country rocks, or generation of the melt from a sedimentary precursor) may dramatically increase the $\delta^{18}O$ values of the melt and thus the crystallizing zircon (Peck et al., 2001). Combined with corresponding Hf data, these data may provide information on a) magma sources, b) physio-chemical conditions, and, c) when combined with age information, processes operating during magma generation and pluton construction (e.g. Kemp et al., 2007). These time-integrated isotopic datasets provide an increasingly complete record of crustal evolution at a variety of scales, greatly increasing our ability to resolve the regional-scale crustal architecture.

Pluton and batholith construction

Irrespective of tectonic setting, the construction of individual plutons and batholiths has been shown to be a continual and cyclical process that operates at all scales (de Saint Blanquat et al., 2011). A hand specimen sample of a plutonic rock can be considered representative of an individual magma batch, formed during the incremental process of pulsed injection into a magma chamber. Thus routine whole-rock analytical techniques — such as major and trace element and isotope chemistry — provide only an average ‘snapshot’ of all the individual components within that magma batch. Depending on the time scales of crystallization, individual major rock-forming mineral phases such as feldspar or amphibole, or accessory phases such as zircon, may record information related to processes that operate on much smaller time divisions, including those of magmatic pulsation. Thus, chemical or isotopic zonation of these crystals may reveal:

- temporal variations in the source(s) of the magma (e.g. variability of asthenospheric or lithospheric components)
- variable contamination via emplacement-related processes including pluton–wallrock interaction
- mixing of distinct magma batches
- various magma chamber processes, including fractional crystallization and crystal settling.

Additionally, the isotopic composition of any xenocrystic zircon can provide information on the country rocks which the magmas interacted with or were intruded. Data from many different magma batches (individual rocks) can yield important information on physio-chemical processes at time scales associated with pluton and batholith construction, which are vital for understanding the interplay between magmatism and regional-scale tectonism.

[1] Centre for Microscopy, Characterisation and Analysis, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009

[2] Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC), Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW 2109

[3] Brockman Mining Australia Pty Ltd, 1/117 Stirling Highway, Nedlands WA 6009

Paleoproterozoic batholiths in the Gascoyne Province

Following assembly of the West Australian Craton (the suturing of the Pilbara and Yilgarn Cratons with the Glenburgh Terrane of the Gascoyne Province) during the 2005–1950 Ma Glenburgh Orogeny, the Gascoyne Province has been subject to more than one billion years of intracratonic reworking (Sheppard et al., 2010). Voluminous felsic magmatism took place during two spatially and temporally distinct orogenic episodes, the 1820–1770 Ma Capricorn Orogeny and the 1680–1620 Ma Mangaroon Orogeny. During the Capricorn Orogeny, the Moorarie Supersuite was emplaced across the entire province, forming isolated plutons in the north — the Northern Gascoyne plutons — and two batholiths — the Minnie Creek and Landor batholiths — in the central and southern parts (Fig. 1a). During the Mangaroon Orogeny, the Durlacher Supersuite was emplaced into structurally bound corridors, the largest of which contains the Davey Well batholith in the central part of the province (Fig. 1a).

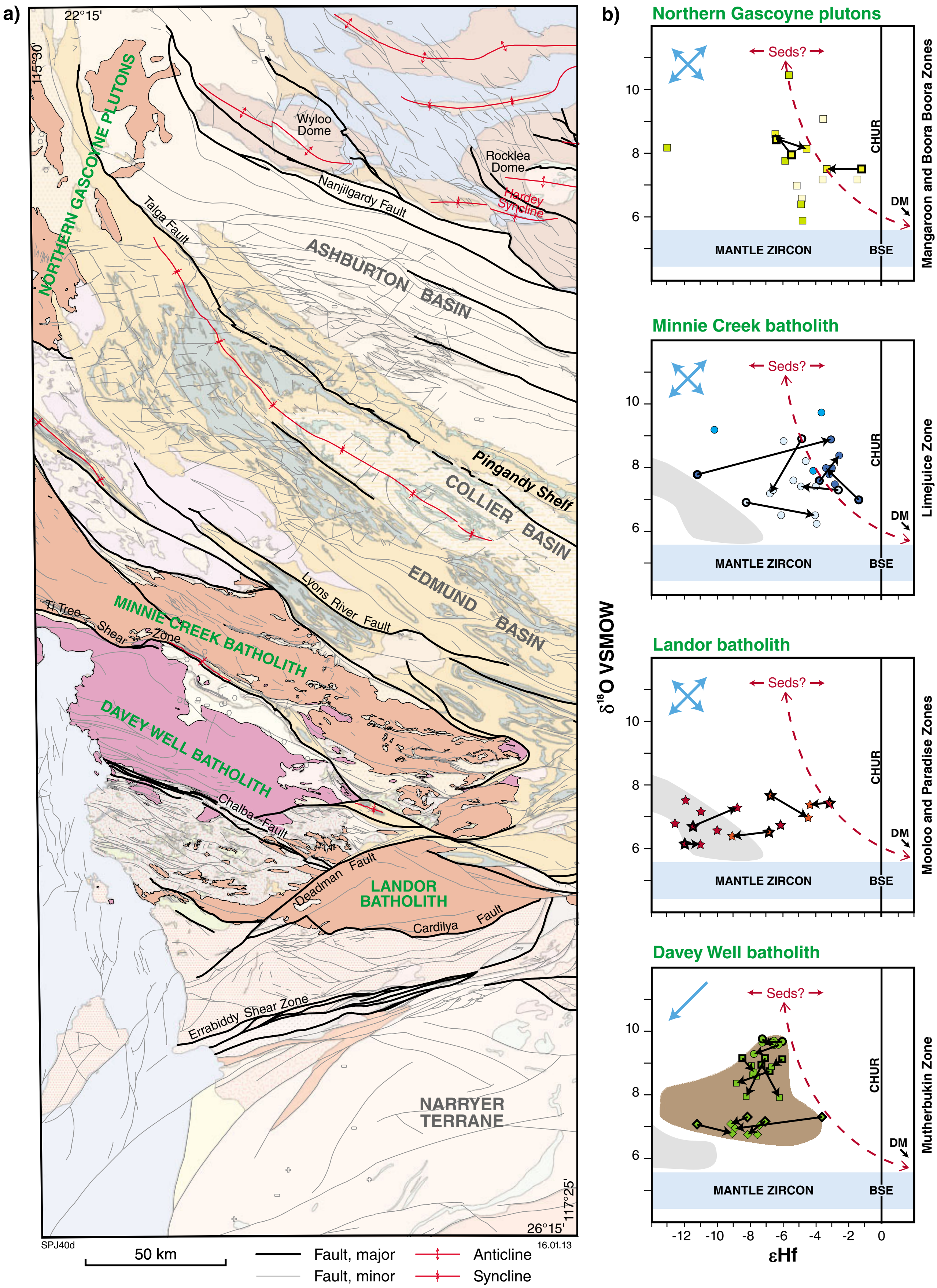
The whole-rock geochemical compositions of granites from both supersuites are remarkably similar, lacking any distinct features that might distinguish their tectonic setting or any physio-chemical processes that might have accompanied intrusion. However, the Lu–Hf and $\delta^{18}O$ isotopic compositions of the magmatic zircon crystals have revealed significant differences in the processes which operated during the formation and emplacement of the Moorarie and Durlacher Supersuites.

Magmatic zircon from the Moorarie Supersuite shows highly variable Lu–Hf and $\delta^{18}O$ compositions which indicate interaction between three distinct isotopic components — depleted mantle, surficial sediments and an old (c. 2700 Ma) radiogenic basement (Fig. 1b) — in a highly dynamic magmatic system dominated by mixing of magma pulses of different composition, and significant pluton–wallrock interaction. Depleted mantle appears to be the major source component for all the granites (Fig. 1b), although the isotopic composition of the Landor batholith is dominated by c. 2700 Ma radiogenic basement of the Glenburgh Terrane, which is not evident north of the Lyons River Fault in the Northern Gascoyne plutons (Fig. 1b). The Minnie Creek batholith and Northern Gascoyne plutons show evidence for mixing and assimilation of low-grade metasedimentary rocks, presumably by pluton–wallrock processes, indicating that the magmas were emplaced into the upper crust. This isotopic feature is not evident in the Landor batholith, implying that it was emplaced within the mid-crust.

The Davey Well batholith of the Durlacher Supersuite shows more uniform inter- and intragrain Lu–Hf and $\delta^{18}O$ isotopic compositions, indicating a source similar in isotopic composition to the Minnie Creek batholith of the Moorarie Supersuite (tan-coloured field in Fig. 1b), and may have lacked a significant depleted mantle component. Minor intragrain isotopic variations consistently suggest melting and mixing of c. 2700 Ma radiogenic basement into the main magma. The absence of a major upper crustal component also suggests emplacement of the batholith into the mid-crust.

In situ zircon isotopic data from these temporally and spatially distinct plutons and batholiths highlight important differences in the sources of the melt, melt evolution and emplacement mechanisms that are not evident at the magma batch – hand specimen scale, and which provide critical constraints on regional-scale crustal evolution and architecture. The 1820–1775 Ma Moorarie Supersuite is dominated by both mantle and upper crustal components, having been emplaced within the mid- to upper crust. The depleted mantle source, highly dynamic physio-chemical magmatic processes and high level of emplacement, particularly of the Northern Gascoyne plutons and Minnie Creek batholith, make these intrusions more prospective as they provide a pathway, and enrichment mechanism, for mantle-derived metals to be transported to the upper crust. These intrusions host known mineralization, including tungsten-bearing skarns in the northern Gascoyne Province (Davies, 1988) and disseminated and vein-hosted molybdenum at Minnie Springs (Pirajno et al., 2008). In contrast, the 1680–1620 Ma Durlacher Supersuite appears to have been generated without a significant mantle component by the melting and recycling of pre-existing crust, making this intrusion less prospective for base metals, gold and rare earth elements.

Figure 1. (facing page) a) Simplified gological map of the western Capricorn Orogen showing the distribution of batholiths and plutons associated with the 1820–1775 Moorarie Supersuite (pale pink) and 1680–1620 Ma Durlacher Supersuite (pale purple) in the Gascoyne Province (after Johnson et al., 2011); b) Hf and $\delta^{18}O$ isotope compositions of magmatic zircon from the Gascoyne Province plutons and batholiths. Black arrows show the change in isotopic composition from the centre to the edges of magmatic grains, representing the evolution of magma batches. The light grey shaded fields represent the isotopic composition of c. 2700 Ma radiogenic basement of the Glenburgh Terrane, calculated from inherited zircon xenocrysts within the plutonic rocks. The tan field in the Davey Well batholith plot represents the isotopic composition of the Minnie Creek batholith at c. 1650 Ma. Light blue arrows in all plots show the trend in isotopic evolution for the batholith or pluton. The dotted red line shows a theoretical contamination line between depleted mantle-derived melts and surficial sediments.


a)
22°15'
115°30'
NORTHERN GASCOYNE PLUTONS
Wyloo Dome
Rocklea Dome
Hardey Syncline
Nanjilgardy Fault
Talga Fault
ASHBURTON BASIN
Pingandy Shelf
COLLIER BASIN
EDMUND BASIN
Lyons River Fault
Ti Tree Shear Zone
MINNIE CREEK BATHOLITH
DAVEY WELL BATHOLITH
Chalba Fault
Deadman Fault
LANDOR BATHOLITH
Cardilya Fault
Errabiddy Shear Zone
NARRYER TERRANE
26°15'
117°25'
SPJ40d
16.01.13
50 km
Fault, major
Fault, minor
Anticline
Syncline
b)
Northern Gascoyne plutons
Minnie Creek batholith
Landor batholith
Davey Well batholith
Seds?
CHUR
DM
MANTLE ZIRCON
BSE
Mangaroon and Boora Boora Zones
Limejuice Zone
Mooloo and Paradise Zones
Mutherbukin Zone
δ18O VSMOW
εHf
10
8
6
-12
-10
-8
-6
-4
-2
0

References

Davies, BM 1998, Proterozoic zoned tungsten-bearing skarns and associated intrusives of the northwest Gascoyne Complex, Western Australia: Geological Survey of Western Australia, Report 53, 54p.

de Saint Blanquat, M, Hosman, E, Habert, G, Morgan, S, Vanderhaeghe, O, Law, R and Tikoff, B 2011, Multiscale magmatic cyclicity, duration of pluton construction, and the paradoxical relationship between tectonism and plutonism in continental arcs: Tectonophysics, v. 500, p. 20–33.

Johnson, SP, Thorne, AM and Tyler, IM (eds) 2011, Capricorn Orogen seismic and magnetotelluric (MT) workshop 2011: extended abstracts: Geological Survey of Western Australia, Record 2011/25, 120p.

Joly, A, Aitken, ARA, Dentith, M, Porwal, AK and Smithies, RH 2012, Mineral prospectivity analysis of the West Musgrave Province: GSWA Report, Geological Survey of Western Australia, Perth.

Kemp, AIS, Hawkesworth, CJ, Foster, GL, Paterson, BA, Woodhead, JD, Hergt, JM, Gray, CM and Whitehouse, MJ 2007, Magmatic and crustal differentiation history of granitic rocks from Hf-O isotopes in zircon: Science, v. 315, p. 980–983.

McCuaig, TC, Beresford, S and Hronsky, J 2010, Translating the mineral systems approach into an effective exploration targeting system: Ore Geology Reviews, v. 38, p. 128–138.

Peck WH, Valley JW, Wilde SA and Graham CM 2001, Oxygen isotope ratios and rare earth elements in 3.3 to 4.4 Ga zircons: ion microprobe evidence for high $\delta^{18}O$ continental crust and oceans in the Early Archean: Geochimica et Cosmochimica Acta, v. 64, p. 4215–4229.

Pirajno, F, Sheppard, S, Groenewald, PB and Johnson, SP 2008, Mineral systems in the Gascoyne Complex, Western Australia, in GSWA 2008 extended abstracts: promoting the prospectivity of Western Australia: Geological Survey of Western Australia, Record 2008/2, p. 4–7.

Sheppard, S, Johnson, SP, Wingate, MTD, Kirkland, CL and Pirajno, F 2010, Explanatory Notes for the Gascoyne Province: Geological Survey of Western Australia, Perth, Western Australia, 336p.

Valley, JW 2003, Oxygen isotopes in zircon: Reviews in Mineralogy and Geochemistry, v. 53, p. 343–385.