



Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2009/16

AGE AND GEOCHEMISTRY OF THE ALCURRA SUITE IN THE WEST MUSGRAVE PROVINCE AND IMPLICATIONS FOR ORTHOMAGMATIC NI-CU-PGE MINERALIZATION DURING THE GILES EVENT

by
HM Howard, RH Smithies, CL Kirkland, PM Evins,
and MTD Wingate



Geological Survey of
Western Australia



Government of Western Australia
Department of Mines and Petroleum

Record 2009/16

AGE AND GEOCHEMISTRY OF THE ALCURRA SUITE IN THE WEST MUSGRAVE PROVINCE AND IMPLICATIONS FOR ORTHOMAGMATIC NI–CU–PGE MINERALIZATION DURING THE GILES EVENT

by

HM Howard, RH Smithies, CL Kirkland, PM Evins, and MTD Wingate



Geological Survey of
Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon. Norman Moore MLC

DIRECTOR GENERAL, DEPARTMENT OF MINES AND PETROLEUM
Richard Sellers

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Tim Griffin

REFERENCE

The recommended reference for this publication is:

Howard, HM, Smithies, RH, Kirkland, CL, Evins, PM and Wingate, MTD 2009, Age and geochemistry of the Alcurra suite in the west Musgrave Province and implications for orthomagmatic Ni–Cu–PGE mineralization during the Giles Event: Geological Survey of Western Australia, Record 2009/16, 16p.

National Library of Australia Card Number and ISBN 978-1-74168-272-4

Published 2009 by Geological Survey of Western Australia

This Record is published in digital format (PDF) and is available online at www.dmp.wa.gov.au/GSWApublications. Laser-printed copies can be ordered from the Information Centre for the cost of printing and binding.

Further details of geological publications and maps produced by the Geological Survey of Western Australia are available from:

Information Centre
Department of Mines and Petroleum
100 Plain Street
EAST PERTH, WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Facsimile: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications

Contents

Abstract	1
Introduction	1
The Warakurna Supersuite (Giles Event)	3
The Jameson Range Cu-mineralized gabbros	4
SIMS (SHRIMP) zircon geochronology of the gabbro.....	5
Geochemistry of the mineralized gabbro suite and comparisons with coeval mafic units	7
Geochemical comparisons between the Alcurra suite and other mafic units of the Warakurna Supersuite	8
Comparisons with gabbro-norite of the Nebo–Babel intrusion.....	12
Implications for orthomagmatic Ni–Cu–PGE exploration in the west Musgrave Province	14
References	15

Figures

1. Interpreted bedrock geology map of the project area.....	2,3
2. Ophitic and dual textures of gabbro from the Alcurra suite.....	4
3. Cathodoluminescence image of representative zircons from sample GSWA 194354	5
4. U–Pb analytical data for sample GSWA 194354	7
5. Primitive mantle-normalized trace element plot for the Alcurra Dolerite, dual-textured intrusions and the dated mineralized dyke	8
6. Nb vs La for the layered Giles intrusions and Alcurra suite	10
7. Major element variation diagrams for the Alcurra Dolerite, dual-textured intrusions, and massive gabbro	10
8. Incompatible trace element plots for the Alcurra Dolerite, dual-textured intrusions, and massive gabbro	11
9. Primitive mantle-normalized trace element variation diagram for the Alcurra Dolerite, dual-textured intrusions, and Tollu Volcanics.....	11
10. Incompatible trace element plots for the Alcurra Dolerite, dual-textured intrusions, and Tollu Volcanics	12
11. Major element variation diagrams for the Alcurra Dolerite and other mafic dyke units.....	13
12. Incompatible trace element plots for the Alcurra Dolerite and other mafic dyke units	13
13. Incompatible trace element plots for the Alcurra suite, Nebo–Babel intrusion, and Kullal Dyke Suite....	14

Tables

1. Ion microprobe analytical results for zircons from sample 194354: gabbro, north of Jameson Range.....	6
2. Whole-rock analyses of Alcurra suite and Kullal Dyke Suite gabbros	9

Age and geochemistry of the Alcurra suite in the west Musgrave Province and implications for orthomagmatic Ni–Cu–PGE mineralization during the Giles Event

by

HM Howard, RH Smithies, CL Kirkland, PM Evins, and MTD Wingate

Abstract

Intrusive rocks of the late Mesoproterozoic (c. 1075 Ma) Giles Event host significant orthomagmatic Ni–Cu–PGE mineralization in the Musgrave Province of central Australia, of which the most notable is the recently discovered Nebo–Babel deposit. Recent mapping of the west Musgrave Province, however, shows that the magmatic history of the Giles Event is complicated and lasted as long as 60 million years. A new sensitive high resolution ion microprobe (SHRIMP) U–Pb zircon date of 1067 ± 8 Ma for a copper-mineralized dyke provides constraints on the age of one magmatic event related to mineralization. This age is identical to that of the 1068 ± 4 Ma Nebo–Babel intrusion (Seat, 2008). Both intrusions are geochemically similar to the Alcurra suite, a late phase of the Giles Event, which forms dolerite, gabbro, olivine gabbro, ferromylonite and ferrodiorite sills. The Saturn pluton and smaller gabbroic bodies immediately north of the Cavenagh Range (an area that includes the Halleys and Voyager copper–nickel–platinum group element–gold prospects) also show geochemical similarities with the Alcurra suite.

In the west Musgrave Province the Alcurra suite is generally an evolved, Fe-rich, and incompatible trace element-rich suite of tholeiitic intrusions which extends from the Walpa Pulka Zone, across the Tjuni Purlka Tectonic Zone, and into the Mamutjarra Zone. Rocks of the Kullal Dyke Suite cover a similar geographical extent and most likely crystallized from magmas derived from the same mantle source as the Alcurra suite. The rocks of the Alcurra suite (including Kullal dykes) are geochemically distinct from other mafic rocks of the Giles Event, and from other dyke suites in the region.

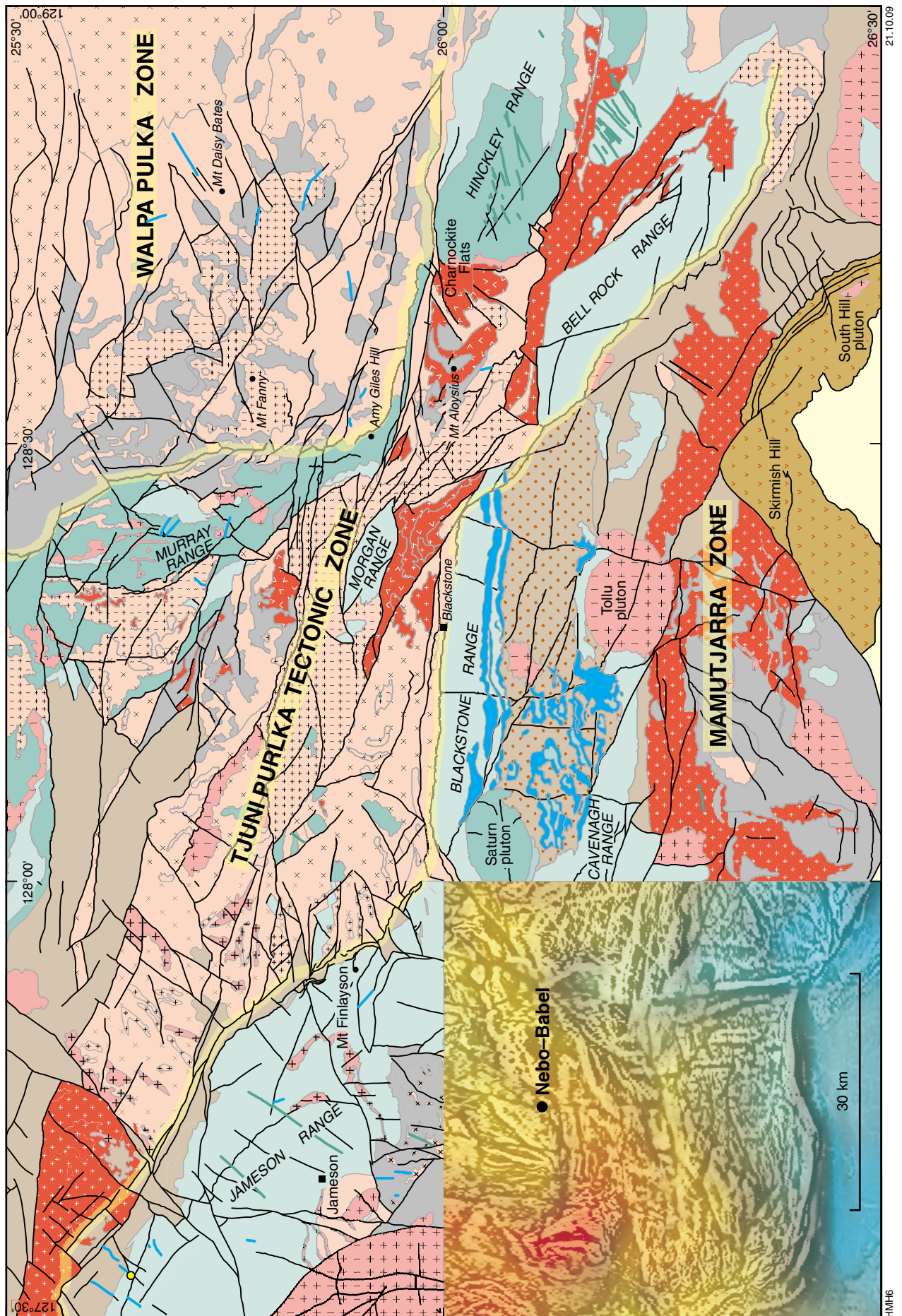
Dykes and intrusions of the Alcurra suite post-date the more voluminous layered mafic–ultramafic intrusions and massive gabbro of the Giles Event. The dykes were emplaced both along the west- to northwest-trending margins of the layered mafic–ultramafic intrusions, and along northeast-trending extensional fractures resulting from northeast–southwest compression. The northeast conduits and their intersection with west to northwest-trending lithological boundaries or structures are potential sites for magma mixing and may be realistic targets for orthomagmatic mineralization.

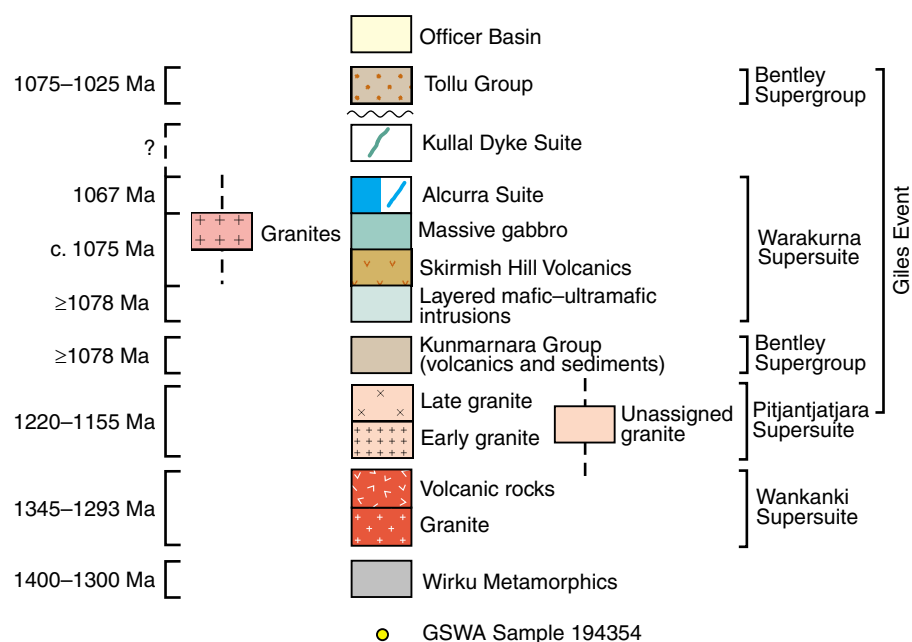
KEYWORDS: Alcurra suite, Giles Event, Warakurna large igneous province, Musgrave Province, Mesoproterozoic, Ni–Cu–PGE mineralization

Introduction

Mafic rocks of the Mesoproterozoic Giles Event, in the Musgrave Province of central Australia, host a world class orthomagmatic Ni–Cu–PGE deposit at Nebo–Babel, south of Jameson (Fig. 1). The discovery of this deposit has directed considerable exploration interest towards the range of voluminous and widespread mafic and ultramafic intrusions that have traditionally been grouped into the Giles intrusions. These intrusions form part of the Warakurna Supersuite (the magmatic expression of the Giles Event), which outcrops over 1.5 million km² of central and western Australia and which, in turn, forms the c. 1075 Ma Warakurna large igneous province (Wingate et al., 2004; Morris and Pirajno, 2005).

Recent mapping by the Geological Survey of Western Australia (GSWA) in the western part of the Musgrave Province (Howard et al., 2009a,b; Evins et al., 2009; Smithies et al., 2009b) has shown that the Giles Event in this region was not a simple, short-lived event, but rather a complicated series of events (Evins et al., in press; Smithies et al., 2009a). Within this region, the many phases of both mafic and felsic magmatism belonging to the Warakurna Supersuite were accompanied by extensive shearing and large-scale folding which took place as a series of punctuated events over a period as long as 60 m.y. (Evins et al., in press; Smithies et al., 2009a). At least five generations of mafic magmatism have been recorded, including emplacement of major layered mafic–ultramafic intrusions, various intrusions of massive gabbro and





HMH6a

28.10.09

Figure 1. Interpreted bedrock geology map showing the distribution of Alcurra Dolerite in the eastern portion of the west Musgrave Province. Where recent GSWA mapping is not available, a combined gravity and RTP 1vd magnetic image is shown.

leucogranite, compositionally evolved ferrogabbro and ferronorite sills, as well as several distinct generations of dolerite and gabbro dykes.

If the style of orthomagmatic Ni–Cu–PGE mineralization developed at Nebo–Babel relates to a specific type or episode of mafic magma, then the geological complexity now apparent in the west Musgrave Province makes the identification of potential exploration targets a difficult task. The identification of Cu-mineralized gabbro bodies to the northwest of Jameson (Evins et al., in prep.) during the 2008 GSWA field season, provided an ideal opportunity to constrain the age and composition of at least one magmatic event associated with mineralization, and to examine these constraints in the context of the regional geological framework established by the GSWA mapping program. In this report, we present geochronological and geochemical data on this mineralized suite of rocks and then compare these rocks with our regional geochronological and geochemical database of Warakurna Supersuite mafic rocks, and with data on the mineralized body that hosts the Nebo–Babel Ni–Cu–PGE deposit itself (Seat, 2008).

The Warakurna Supersuite (Giles Event)

Mapping of the BELL ROCK (Howard et al., 2009b), BLACKSTONE (Smithies et al., 2009b), and HOLT (Evins et al., 2009) 1:100 000 map sheets, in particular, has highlighted the complex geological and geochronological relationships between rocks historically regarded as belonging to the Warakurna Supersuite or the Giles

Event (collectively referred to by Daniels (1974) as the Giles Complex). These complexities have recently been documented by Evins et al. (in press) and Smithies et al. (2009a) and the major lithological components are summarized below, from oldest to youngest.

The most conspicuous components of the Warakurna Supersuite in the west Musgrave Province are the layered mafic-ultramafic intrusions (shown on GSWA 1:100 000 mapsheets as G1) which form the west to northwest-trending spine of the province. These can be broadly subdivided into troctolitic (e.g. Bell Rock intrusion, Blackstone intrusion), peridotitic (e.g. Wingellina Hills) and gabbroic (e.g. Michael Hills) bodies (Daniels, 1974; Glikson et al., 1996). Sun et al. (1996) obtained a U–Pb zircon age of 1078 ± 3 Ma from a granophyric leucogranite thought to form a comagmatic layer of the Bell Rock intrusion, but Smithies et al. (2009a) suggest that this granite is more likely a localized sill that is part of a separate intrusive event and that the 1078 ± 3 Ma date represents only a minimum age for the layered intrusion. The layered intrusions were emplaced into the Mummawarrawarra Basalt, thought by Daniels (1974) to be a volcanic equivalent of the ‘Giles Complex’ but now known to pre-date the G1 gabbro intrusions (Smithies et al., 2009a).

Abundant bodies of unlayered gabbro (referred to on GSWA 1:100 000 mapsheets as G2) intrude the layered mafic-ultramafic bodies, particularly along their margins. The larger of the massive gabbro bodies are found in the Murray Range and western part of the Hinckley Range (Fig. 1). Leucogranite shows mingling relationships with the gabbro and intrudes as dykes and larger plutons. In

the west Hinckley Range, syn-deformational leucogranite showing co-mingling textures with gabbro was dated at 1075 ± 7 Ma (Kirkland et al., 2008). This and several other ages determined from various dykes and plutons within the region (including the granophyric leucogranite from the Bell Rock intrusion) constrain the intrusion of the massive gabbro and coeval leucogranite to a narrow period at c. 1075 Ma (Smithies et al., 2009a). An unnamed suite of plagioclase-rich dolerite dykes which cross-cut the layering of the Bell Rock intrusion are geochemically similar to the more primitive end-members of the massive gabbros (Howard et al., 2007) and may be co-genetic.

Dykes of the Alcurra Dolerite have been dated by $^{40}\text{Ar}/^{39}\text{Ar}$ at 1068 ± 2 Ma to 1085 ± 2 Ma (Schmidt et al., 2006) and the contemporaneous Stuart Pass Dolerite of the Northern Territory yielded a Sm–Nd isochron age of 1076 ± 33 Ma (Zhao and McCulloch 1993). Field relationships in the west Musgrave Province show that dykes of dolerite that are geochemically similar to the Alcurra Dolerite cross-cut and post-date the layered intrusions and massive gabbro. We correlate these with the Alcurra Dolerites and assign all of these dolerite dykes to the Alcurra suite. In the Walpa Pulka Zone many dykes of ophitic Alcurra Dolerite (Fig. 2a) are oriented east-southeast and dip 40 to 60° to the south. However, in the Tjuni Purlka Tectonic Zone and the Mamutjarra Zone (Fig. 1), they are more commonly oriented east-northeast.

Immediately to the south of the Blackstone Range (which is in large part formed by the layered Blackstone intrusion (G1)), felsic volcanic and volcanoclastic rocks of the c. 1026 Ma Tollar Volcanics (Smithies et al., 2009a) unconformably overlie small, high-level intrusions of olivine gabbro, ferromylonite, and ferrodiorite. These intrusions are commonly characterized by a ‘dual texture’ composed of a framework of coarse-grained crystals (mainly euhedral plagioclase) enclosing a mineralogically identical (except for the presence of accessory quartz in granophyric intergrowths) and locally granophyric-textured, fine-grained assemblage forming interstitial pockets filled with anhedral orthopyroxene, lesser magnetite, and fibrous aggregates of blue-green amphibole after clinopyroxene (Fig. 2b,c). Locally occurring, fine-grained rocks containing euhedral plagioclase phenocrysts represent the interstitial component of the ‘dual-textured’ rock freed of the coarse-grained crystal framework. Similar rocks have also been found as late intrusions along the northern margin of the Jameson layered mafic intrusion and are referred to on GSWA 1:100 000 mapsheets as G3.

Several other mafic dyke suites have been identified in the region based on a combination of their field relationships, petrography, major, trace and isotope chemistry (Gliksun et al., 1996; Howard et al., 2007). These include c. 1149 Ma mafic dykes of the Pitjantjatjarra Supersuite, Kullal dykes (c. 1000 Ma), Gairdner Dolerite dykes (825 Ma) and a suite of LREE-depleted dykes (c. 750 Ma). Of these, the Kullal dykes are of particular interest because their Sm–Nd isochron age (Sun, unpublished data; Gliksun et al., 1996) places them broadly within the age range of the Giles Event, both Kullal dykes and rocks of the Alcurra suite show a similar geographical range (and dykes of both intrusive units commonly follow similar structural trends), and they are relatively common within the area of the dated mineralized gabbro and the Nebo–Babel region.

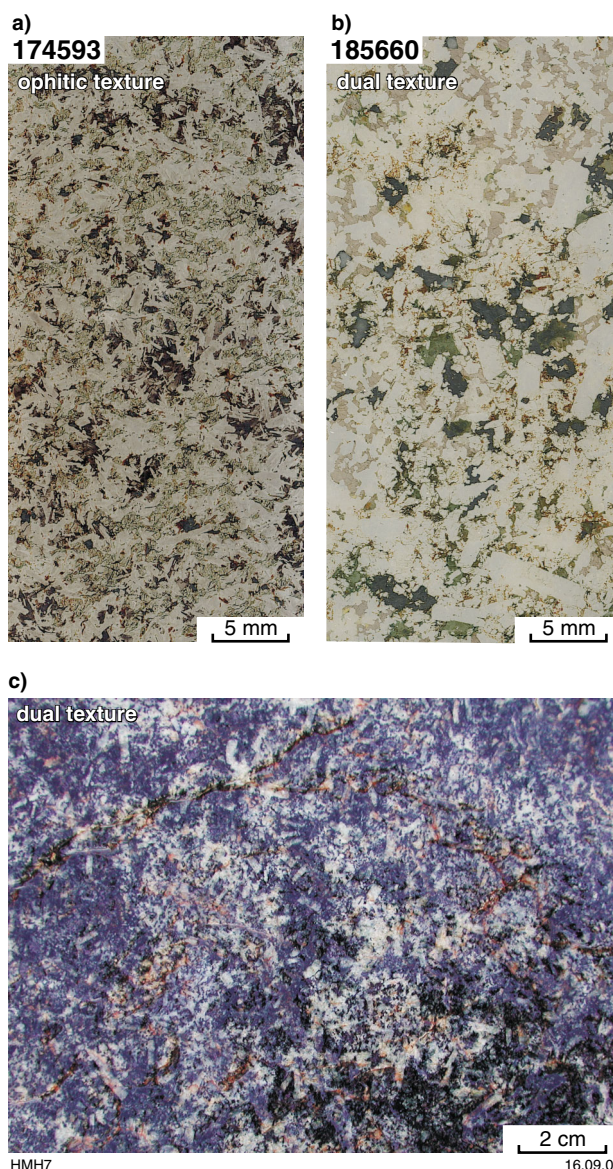


Figure 2. a) photomicrograph (ppl) of ophitic gabbro of the Alcurra suite from the Walpa Pulka Zone; b) photomicrograph (ppl) of dual-textured olivine gabbro from the Alcurra suite from the Mamutjarra Zone; c) field photo of dual-textured olivine gabbro of the Alcurra suite from the Mamutjarra Zone.

The Jameson Range Cu-mineralized gabbros

A northeast-trending dyke of coarse-grained, dual-textured gabbro, cross-cutting the northwest part of the layered Jameson intrusion (Fig. 1), has locally developed malachite and chrysocolla. A sample (GSWA 194354) lacking this Cu-mineralization was taken for geochronology and geochemistry. The gabbro has an ophitic texture with interstitial pyroxene, trace orthopyroxene, olivine, and magnetite (1%). Pyroxene is partially to completely replaced by actinolite (characteristically blue-green sodic amphibole). Plagioclase is sericitized and chrysocolla (Cu alteration) is associated with the dyke. A mineralized

dyke that is otherwise geochemically and mineralogically identical to the dated dyke was sampled from elsewhere in the northwest area of the Jameson intrusion (GSWA 194405) and contained 0.4 wt% Cu, 133 ppb Pd, and 116 ppb Pt.

SIMS (SHRIMP) zircon geochronology of the gabbro

The operating procedures for SIMS U–Th–Pb isotopic measurements on zircon from the gabbro sample follow that summarized in Wingate and Kirkland (2009). Details of the analytical uncertainty from replicate analyses of the standard are given in Kirkland et al. (2009).

Zircons separated from sample GSWA 194354 are broken fragments of equant and bladed euhedral grains up to 200 μm long, although many were originally larger (Kirkland et al., 2009). Cathodoluminescence images (Fig. 3) reveal concentric growth zoning in many grains with a minor population of homogeneous fragments of originally larger zoned grains.

The results of 20 analyses of 20 zircons are shown in a concordia diagram (Fig. 4) and are listed in Table 1. All analyses are within uncertainty of concordia and define one coherent population from both idiomorphically zoned grains and fragments of larger crystals. All analyses have high Th/U between 0.99 and 2.56 and together yield a concordia age of 1067 ± 8 Ma (MSWD = 1.8; Kirkland et al., 2009).

Owing to the low volume of zircon crystallized from mafic magmas compared to granitic magmas, there is frequently debate over which grains grew during crystallization of

the mafic melt, and which are inherited (e.g. Black et al., 1991). Thus there could be some question as to which of the 1067 Ma zircons (described above) record the igneous crystallization of the dyke. U–Pb zircon data for granitic rocks of the west Musgrave Province (Smithies et al., 2009a) indicate that the youngest potential host rocks to the sampled dyke are c. 1075 Ma rocks of the Warakurna Supersuite, which places an upper age limit on the dyke compatible with the zircon age. Furthermore, the zircons have equant, prismatic, bladed, and jagged-anhedral habits, which are rare in granitic rocks, but commonly observed for igneous zircons in gabbros and norites.

Poldervaart (1956) suggested that such grains were restricted to trapped melt pockets and impinged on by previously crystallized plagioclase and pyroxene. The zircons in the dykes have generally higher Th/U ratios than in igneous zircons from granites of the Warakurna Supersuite. Because the La/Nb ratio of the sample is c. 1.5 (similar to NMORB), there is little evidence to support crustal contamination of the dyke (Thompson et al., 1984).

These data suggest that the zircons in the dyke are igneous in origin and are not inherited from the country rock. Hence, the date of 1067 ± 8 Ma for the 20 analyses (Fig. 4; Table 1) is interpreted as the age of magmatic crystallization of the gabbro dyke. This age is within analytical uncertainty of the 1068 ± 4 Ma result obtained by Seat (2008) for a gabbro-norite that was coeval with orthomagmatic Ni–Cu–PGE mineralization at Nebo–Babel. Both ages are significantly younger than the c. 1078 Ma maximum age of the major layered intrusions (G1; Smithies et al., 2009a) and younger than the c. 1075 Ma age of the syntectonic massive gabbros and locally co-mingled granites (G2).

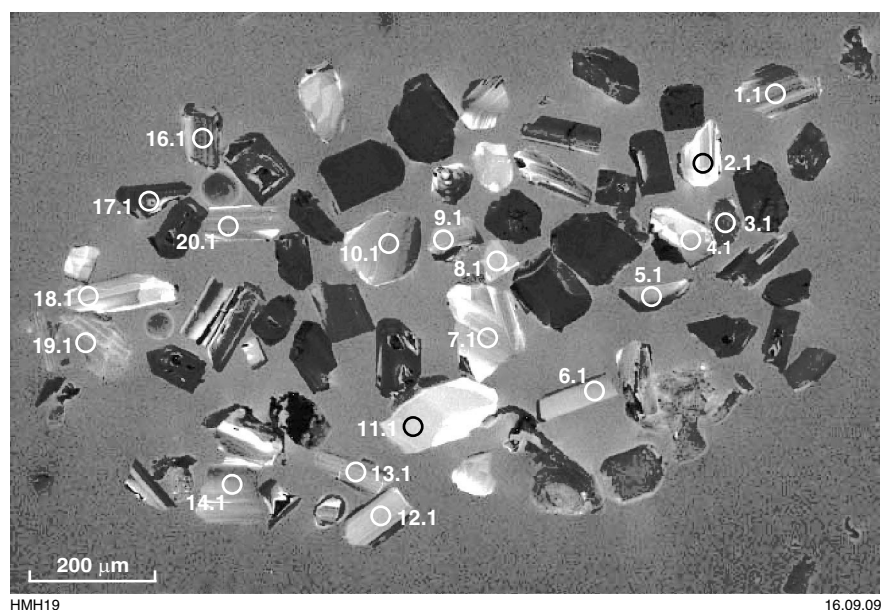


Figure 3. Cathodoluminescence image of representative zircons from sample GSWA 194354: gabbro north of Jameson Range. Numbered circles indicate the position of analysis sites.

Table 1. Ion microprobe analytical results for zircons from sample 194354: Gabbro, Jameson Range

Group ID	Spot no.	Grain. spot	^{238}U (ppm)	^{232}Th (ppm)	$\frac{^{232}\text{Th}}{^{238}\text{U}}$	$\delta^{204}\text{Pb}$ (‰)	$^{238}\text{U}/^{206}\text{Pb} \pm 1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb} \pm 1\sigma$	$^{238}\text{U}/^{206}\text{Pb}^* \pm 1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}^* \pm 1\sigma$	$^{238}\text{U}/^{206}\text{Pb}^*$ date (Ma) $\pm 1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}^*$ date (Ma) $\pm 1\sigma$	Disc. (%)
I	4	4.1	157	263	1.73	0.025	5.733	0.103	5.734	0.106	0.07651	0.00119	6.5
I	8	8.1	116	134	1.19	0.000	5.535	0.100	5.535	0.103	0.07545	0.00086	0.9
I	2	2.1	80	93	1.21	0.000	5.239	0.098	5.239	0.101	0.07544	0.00106	-4.3
I	16	16.1	381	366	0.99	-0.021	5.369	0.080	5.368	0.088	0.07492	0.00050	-2.8
I	6	6.1	143	201	1.45	0.075	5.484	0.099	5.488	0.103	0.07544	0.00088	-1.5
I	12	12.1	136	192	1.46	-0.170	5.509	0.098	5.499	0.101	0.07324	0.00078	-1.6
I	14	14.1	158	227	1.48	0.133	5.511	0.098	5.519	0.101	0.07551	0.00077	-2.0
I	1	1.1	262	383	1.51	0.086	5.481	0.097	5.485	0.100	0.07499	0.00058	-2.9
I	7	7.1	138	188	1.41	0.109	5.390	0.096	5.396	0.099	0.07515	0.00079	-4.6
I	19	19.1	210	294	1.45	0.069	5.475	0.083	5.479	0.092	0.07480	0.00101	-3.2
I	15	15.1	93	118	1.31	0.096	5.483	0.089	5.488	0.097	0.07495	0.00096	-3.2
I	17	17.1	658	1630	2.56	0.019	5.505	0.080	5.506	0.089	0.07429	0.00037	-2.9
I	5	5.1	216	303	1.45	-0.018	5.623	0.099	5.622	0.102	0.07396	0.00075	-1.0
I	9	9.1	157	206	1.35	0.157	5.412	0.096	5.421	0.099	0.07514	0.00073	-5.3
I	18	18.1	137	179	1.35	0.156	5.384	0.084	5.392	0.093	0.07496	0.00082	-6.3
I	10	10.1	225	295	1.35	0.062	5.350	0.093	5.353	0.097	0.07412	0.00062	-7.1
I	20	20.1	202	286	1.46	0.095	5.533	0.086	5.538	0.094	0.07419	0.00066	-4.4
I	13	13.1	103	133	1.33	0.128	5.450	0.099	5.457	0.102	0.07445	0.00091	-5.9
I	3	3.1	382	663	1.79	0.067	5.672	0.097	5.676	0.101	0.07376	0.00055	-2.6
I	11	11.1	91	125	1.42	0.373	5.486	0.101	5.506	0.105	0.07553	0.00098	-7.9

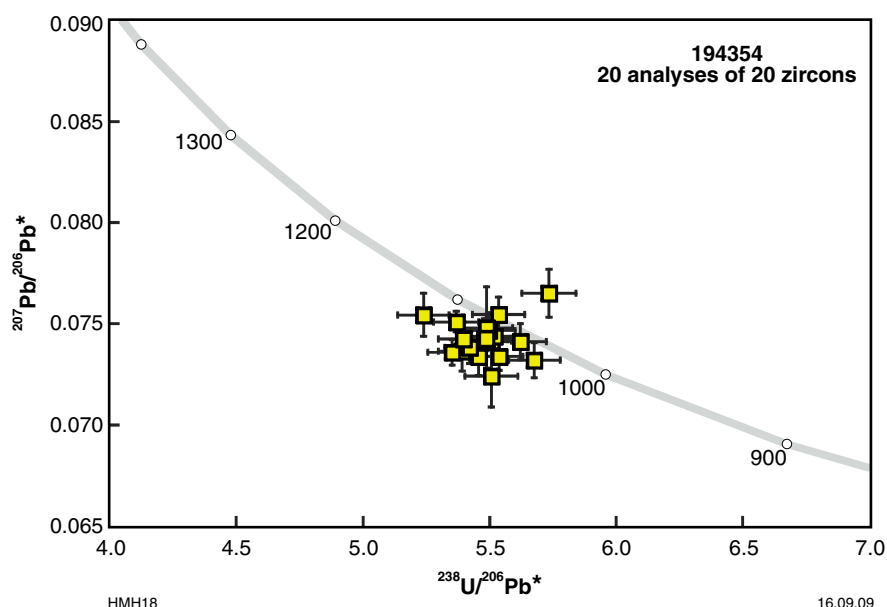


Figure 4. U–Pb analytical data for sample GSWA 194354: gabbro north of Jameson Range. Yellow squares denote Group I (magmatic zircons).

Where exposed, field relationships show relative age differences that are consistent with our measured geochronological differences. The Saturn pluton, a concentrically zoned, elliptical body dominated by magnetite-rich olivine gabbro, appears in aeromagnetic images to cross-cut layering in the >1078 Ma Blackstone intrusion, in the northwest corner of BLACKSTONE, and has an age within analytical uncertainty (1072 ± 8 Ma; Redstone Resources Ltd, written comm., 2008) of the dated, mineralized gabbro dyke. The Saturn pluton, along with several other similar-age plutons, postdates macroscopic folding associated with G2. Details of these plutons are presented in Evins et al. (in press). There is some overlap in the individual ages of intrusions within G1 to G3 but cross-cutting field relationships (Smithies et al., 2009a; Evins et al., in press) indicate a chronology of events which is beyond the resolution of the U–Pb geochronology.

Geochemistry of the mineralized gabbro suite and comparisons with coeval mafic units

A significant problem in drawing meaningful comparisons between the whole-rock geochemistry of mafic rocks in datasets that include fine-grained and coarse-grained rocks, and layered (including cryptically) and non-layered (including dyke) rocks, is eliminating the effects that cumulate processes may have had on major and compatible trace element compositions. In addition, migration in magmatic mush columns, as suggested for many mafic magmas (e.g. Marsh, 2004), and processes of in situ differentiation may significantly, but variably, decouple major element and incompatible trace element compositions. The ‘dual textures’ seen in the small, high-level intrusions of olivine gabbro, ferromylonite, and

ferrodiorite immediately to the south of the Blackstone Range and to the northwest of the Jameson Range, provide direct evidence that late-stage and chemically evolved interstitial liquids might be free to migrate through a porous framework of early-crystallized minerals, within a dynamic plumbing system. One way to minimize the effects of such processes for mafic systems is to concentrate mainly on incompatible trace elements (i.e. those that do not partition into early-crystallized minerals). Ratios of such trace elements (e.g. Th/Nb, La/Nb, La/Sm, Gd/Yb and La/Yb) more closely reflect the compositions of parental magmas, particularly in mafic magmas that do not crystallize garnet, or significant amounts of hornblende or clinopyroxene, and are relatively insensitive to fractional crystallization or accumulation.

The dated gabbro dyke GSWA 194354 is dual textured and is geochemically similar to other nearby gabbroic intrusions (e.g. GSWA 194349), as well as to olivine gabbro, ferromylonite, and ferrodiorite intrusions immediately to the south of the Blackstone Range. All of these are interpreted as small bodies emplaced at a high structural level. Mantle-normalized trace element patterns (Fig. 5) show strong enrichments in incompatible trace elements such as Th, U, and the LREE (La, Ce), with small to moderate negative Nb anomalies (La/Nb between 1.35 and 1.93). Rare earth element patterns are moderately enriched with La/Sm = 3.12–3.54 and La/Yb = 6.11–8.35.

Notably, these compositional ranges closely match those of the regional Alcurra Dolerites (Fig. 5; Table 2), and the 1068 ± 2 to 1085 ± 2 Ma age range of the Alcurra Dolerites (Schmidt et al., 2006) allows a temporal link between the two rock types. Both groups of rocks also share a similar, albeit rather wide, range in Nd-isotopic compositions (with ϵ_{Nd} from -3.03 to $+1.23$) that reflect a depleted mantle source with minimal crustal contamination. Accordingly, we have grouped all of these rocks into the Alcurra suite.

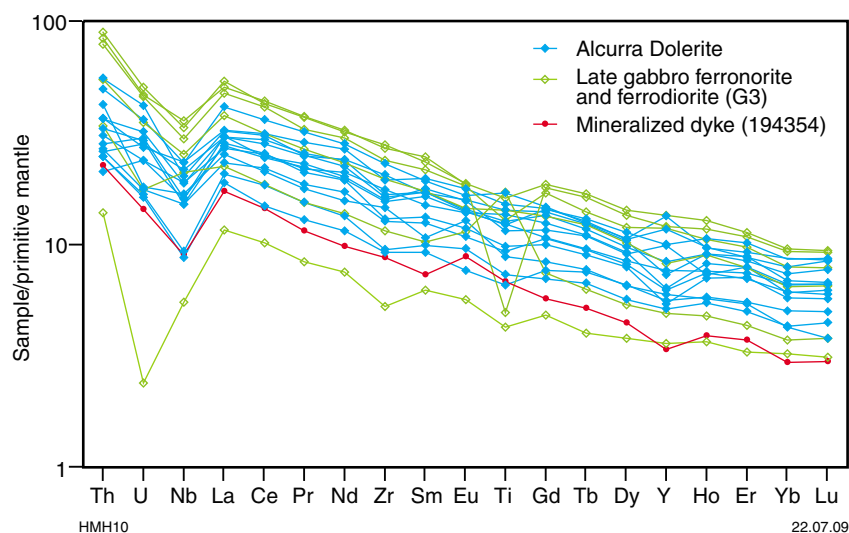


Figure 5. Primitive mantle-normalized trace element plot for the Alcurra Dolerite, dual-textured intrusions of (G3) olivine gabbro, ferronorite and ferrodiorite, and the dated mineralized dyke. Normalization values from the Geochemical Earth Reference Model database <<http://earthref.org/GERM>>.

Geochemical comparisons between the Alcurra suite and other mafic units of the Warakurna Supersuite

Preliminary comparisons with geochemical data from other regional components of the Warakurna large igneous province (e.g. studies of Morris and Pirajno (2005) on the sill complexes of the Bangemall Supergroup approximately 800 km west of the Musgrave Province) show different trace element ratios (e.g. La/Yb and Th/Tb), suggesting that, although the Warakurna Supersuite extends over central and western Australia, the Alcurra suite appears to be confined to the Musgrave Province.

It is also important to note that the Alcurra suite is compositionally distinct from other mafic units of the Warakurna Supersuite within the Musgrave Province. The Alcurra suite clearly cross-cuts many of the (G1) layered intrusions, such as the broadly troctolitic Bell Rock, Blackstone, Jameson, and Finlay intrusions, and the gabbroic layered intrusions are geochemically distinct from the Alcurra suite. Layered gabbroic intrusions such as the Hinckley Range, Michael Hills, Cavanagh Range, Murray Range, and Morgan Range have higher La/Nb ratios of ~3 (compared with ~1.5 for the Alcurra suite) and the broadly troctolitic layered intrusions such as Bell Rock, Blackstone, Jameson and Finlay (Fig. 6). This separation in terms of La/Nb provides additional evidence that Alcurra suite dykes are unlikely to have been the feeders to any of these layered intrusions.

The dykes of the Alcurra suite are tholeiitic, and most have magnesium numbers ($100[\text{Mg}^{2+}/(\text{Mg}^{2+} + \text{Fe}^{2+})]$) between 25 and 50 compared with 47 to 80 for the (G2) massive gabbro (Fig. 7a). They also have higher TiO_2 and total Fe, and lower SiO_2 and CaO, than the massive gabbros (Fig. 7a–d). These differences in major element geochemistry alone do not discount evolution of the

Alcurra suite from the massive gabbro by fractional crystallization but their age difference does not support such a relationship. The more evolved members of the Alcurra suite have higher concentrations of many trace elements than the massive gabbros but there are significant differences in some incompatible trace element ratios (Fig. 8a–d). The most significant differences are in the higher La/Nb (~2 to 4.5) ratios and lower Nb/Y ratios (<0.3) of the massive gabbros (cf. ~1–2.2 and 0.25–0.5, respectively, for the Alcurra suite). The higher La/Nb ratio suggests the involvement of a crustal component in the petrogenesis of the massive gabbros which is absent in the Alcurra suite. These differences in incompatible trace element ratios and age suggest that the two are not related via any simple igneous process.

Although the Alcurra suite shows broadly similar but more evolved multi-element profiles compared with the Tollu Volcanics (Fig. 9), which outcrop immediately to the south of the Blackstone Range, there are some geochemical differences. The volcanic rocks can be subdivided into two groups on the basis of their incompatible trace element ratios, such as La/Sm, La/Nb, Th/Ta and Th/Yb (Fig. 10a–d). One group (TV2) can be clearly distinguished from the Alcurra suite because of its distinctly higher La/Nb, La/Sm, Th/Tb and Th/Ta, and the average of these ratios for the other group (TV1) is slightly higher than for the Alcurra suite. Both groups (TV1 and TV2) have considerably higher Zr content of 500–1100 ppm compared with <400 ppm Zr for the Alcurra suite. In addition to these geochemical differences, preliminary data from a vitric dacite (TV2) of the Tollu Volcanics yielded a U/Pb SHRIMP age of 1026 ± 26 Ma (GSWA 187177; preliminary data) that is significantly younger than the 1068 Ma age of the Alcurra suite reported here. Thus geochemical and geochronological data preclude a genetic relationship between the Alcurra suite and both groups of the Tollu Volcanics.

Table 2. Whole-rock analyses of Alcurra suite and Kullal Dyke Suite gabbros

Sample ID Mafic suite	174547 Alcurra Dolerite	174593 Alcurra Dolerite	180885 Alcurra Dolerite	189416 Dual textured G3	189418 Dual textured G3	174568 Kullal Dyke Suite	174570 Kullal Dyke Suite	194354 Mineralized dyke
Weight percentage								
SiO ₂	48.33	46.12	48.36	46.20	50.29	51.73	49.05	49.12
TiO ₂	2.11	2.50	2.76	3.07	2.77	1.25	1.33	1.48
Al ₂ O ₃	15.45	16.15	14.86	15.62	18.25	15.75	16.71	20.51
Fe ₂ O ₃	1.97	1.81	2.17	2.24	3.48	1.04	2.10	3.05
FeO	11.47	12.27	12.14	12.47	8.11	9.02	8.59	5.63
MnO	0.20	0.21	0.21	0.19	0.16	0.16	0.17	0.11
MgO	6.07	6.81	5.99	4.44	2.14	7.33	8.06	2.39
CaO	8.32	8.96	8.50	8.06	9.33	9.06	9.90	10.54
Na ₂ O	2.79	3.01	3.04	2.68	3.28	2.94	2.66	3.22
K ₂ O	1.09	0.92	1.10	0.93	1.21	0.49	0.66	0.42
P ₂ O ₅	0.42	0.49	0.47	0.30	0.42	0.22	0.32	0.12
LOI	0.21	-1.08	-1.30	2.23	-0.57	-0.41	-0.94	2.68
SO ₃	0.10	0.28	0.19	0.03	0.05	0.23	0.24	0.02
Total	98.54	98.45	98.46	98.44	98.90	98.80	98.85	99.27
Parts per million								
Ag	0.2	0.2	0	0	0	0.1	0.1	0.0
As	4.9	0	0.6	0	0	1.8	1.9	3.2
Ba	420	402	527	284	355	216	324	222
Be	1.4	1.4	1.6	2.0	0.6	0.4	0.4	0.0
Cr	60	118	97	103	6	347	288	9
Cs	0.68	0.57	0.91	0.37	0.44	0.04	0.07	0.17
Cu	76	46	72	171	256	70	68	100
Ga	20.9	20.0	27.5	28.3	30.3	18.6	18.2	28.7
Ge	1.4	1.6	0	1.4	0	1.3	1.1	1.3
Hf	4.1	4.3	5.1	6.0	6.9	2.1	2.5	2.7
Mo	1.2	2.3	0.4	1.2	1.5	0.5	1.1	0.0
Nb	10.8	11.4	13.3	18.0	21.1	3.7	6.3	6.4
Ni	108	129	119	89	20	176	132	46
Pb	6.6	5.5	7.4	6.9	7.9	3.1	3.5	4.0
Rb	30.3	23.2	25.8	29.2	37.5	7.8	13.4	9.8
Sb	0.1	1.3	1.5	0.0	0.0	3.7	5.4	0.9
Sc	22	22	28	21	0	19	22	17
Sn	1.8	1.4	1.6	1.8	2.4	1.0	0.9	0.6
Sr	362.2	310.7	303.2	293.6	337.9	410.3	336.7	354.7
Ta	0.7	0.4	0.7	1.1	1.3	0.0	0.3	0.4
Th	2.8	2.6	3.1	4.7	6.7	1.0	1.8	1.9
Ti	12 664	14 966	16 512	18 424	16 596	7 462	7 959	8 872
U	0.6	0.5	0.7	0.7	1.0	0.1	0.2	0.3
V	234	208	301	464	254	176	204	249
Y	24.5	44.9	38.1	37.2	53.6	21.9	29.3	15.3
Zn	128	129	139	130	106	89	87	74
Zr	146	177	186	219	265	88	111	98
La	19.47	20.96	20.65	25.99	32.47	11.50	15.84	11.85
Ce	45.16	43.85	52.02	55.64	73.17	23.56	32.39	25.69
Pr	5.81	6.33	7.01	7.35	8.99	3.11	4.23	3.16
Nd	26.29	27.21	32.07	31.30	40.54	14.03	19.08	13.26
Sm	5.87	7.89	7.61	7.66	9.53	3.89	4.13	3.24
Eu	1.971	2.628	2.405	2.418	3.053	1.506	1.541	1.480
Gd	5.95	6.90	7.99	7.93	10.12	3.86	4.31	3.38
Tb	0.97	1.18	1.26	1.32	1.50	0.65	0.75	0.56
Dy	5.85	6.68	7.16	7.46	8.73	3.52	4.38	3.28
Ho	1.16	1.20	1.48	1.47	1.72	0.72	0.86	0.64
Er	3.42	3.79	4.03	3.77	4.67	2.02	2.52	1.78
Yb	2.83	3.26	3.63	3.17	3.89	1.63	2.21	1.46
Lu	0.42	0.49	0.57	0.48	0.58	0.23	0.34	0.22

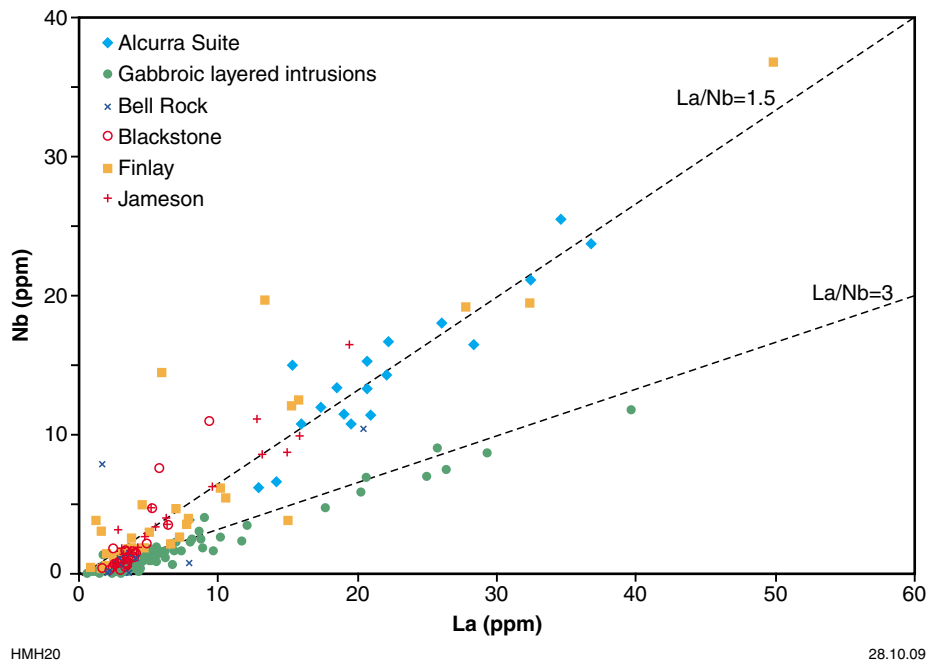


Figure 6. Nb vs La for the layered gabbroic Giles intrusions, troctolitic (Bell Rock, Blackstone, Finlay and Jameson) intrusions, and Alcurra Dolerite of the Warakurna Supersuite.

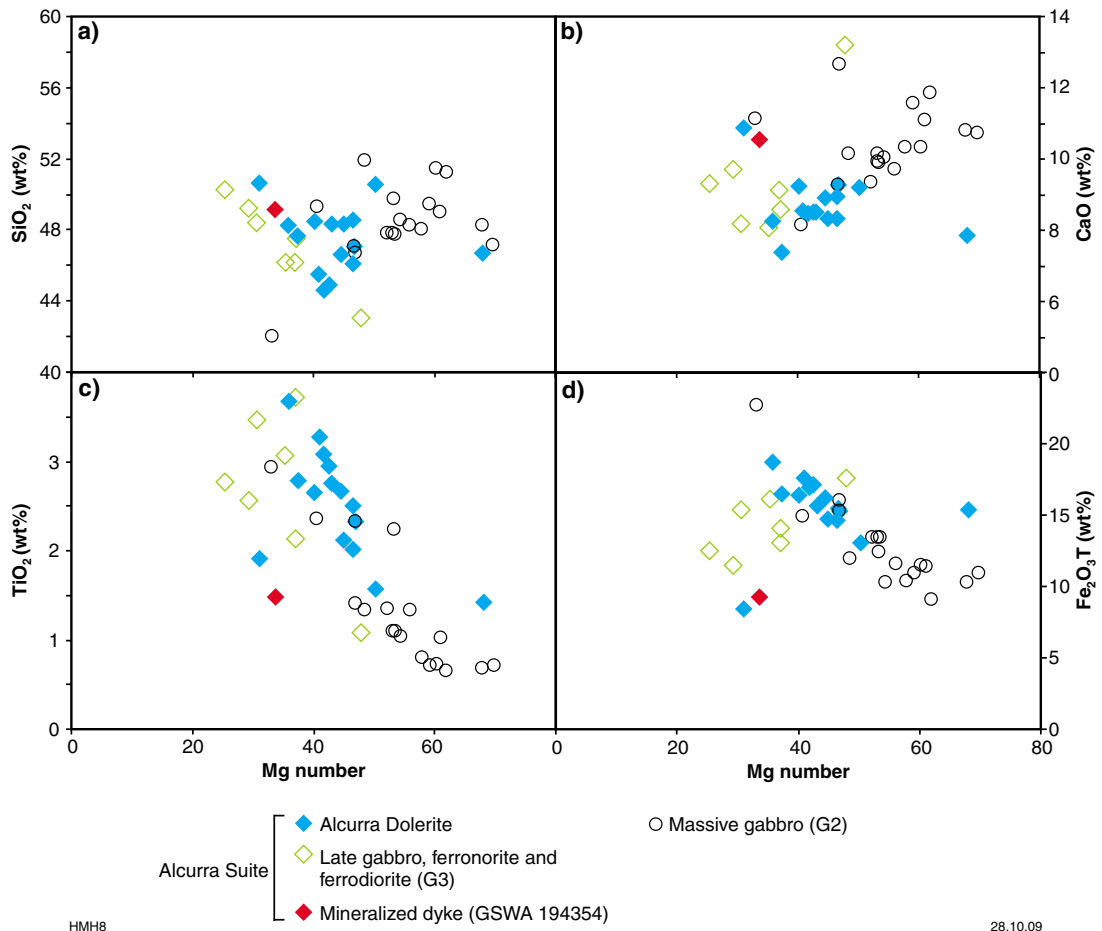


Figure 7. Major element variation diagrams: a) SiO₂; b) CaO; c) TiO₂; and d) Fe₂O₃ total, showing the Alcurra Dolerite, olivine gabbro, ferrorite, and ferrodiorite (G3), and massive gabbro (G2).

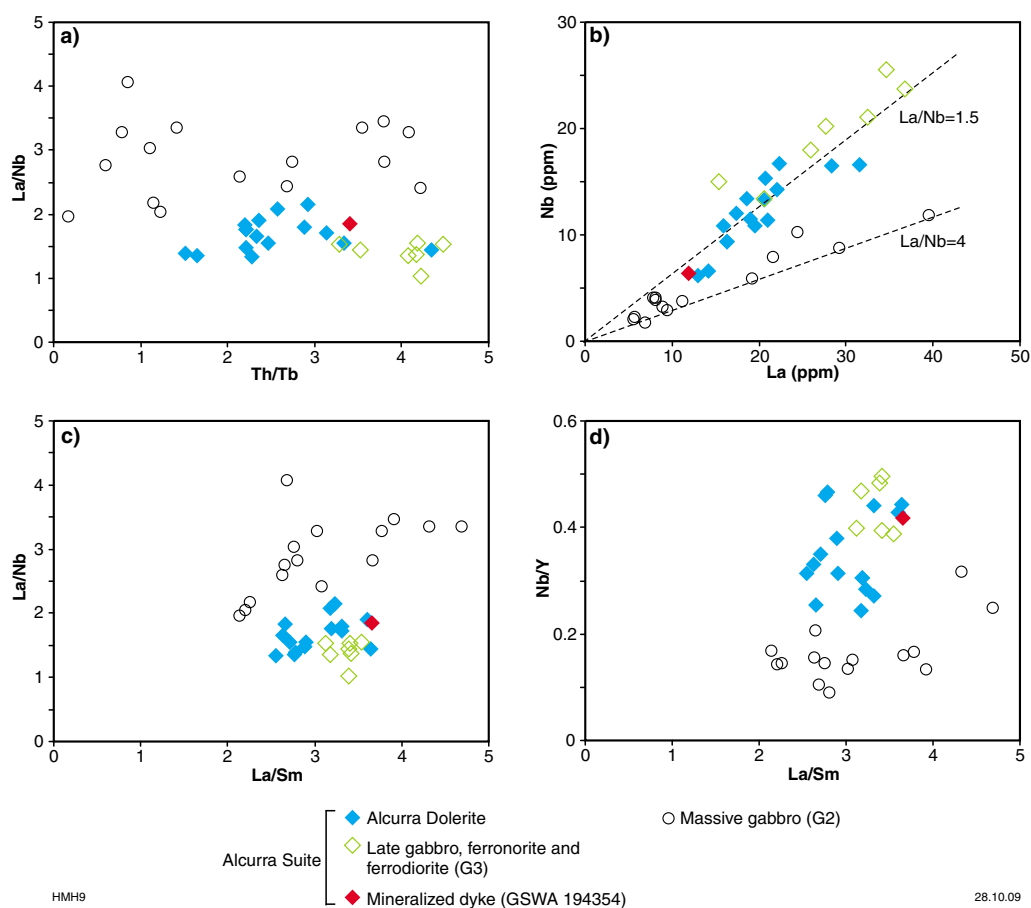


Figure 8. Incompatible trace element diagrams: a) Th/Tb vs La/Nb; b) La vs Nb; c) La/Sm vs La/Nb; and d) La/Sm vs Nb/Y, showing the Alcurra Dolerite, olivine gabbro, ferromylonite, and ferrodiorite (G3), and massive gabbro (G2).

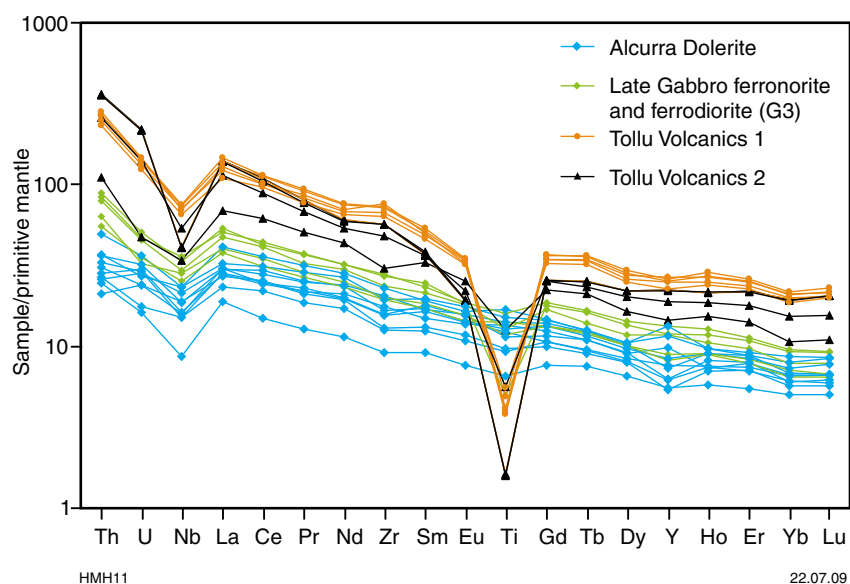


Figure 9. Primitive mantle-normalized trace element variation diagram for the Alcurra Dolerite, dual-textured intrusions of olivine gabbro, ferromylonite, and ferrodiorite (G3), and the Tollu Volcanics (TV1 and TV2). Normalization values from the Geochemical Earth Reference Model database <<http://earthref.org/GERM>>.

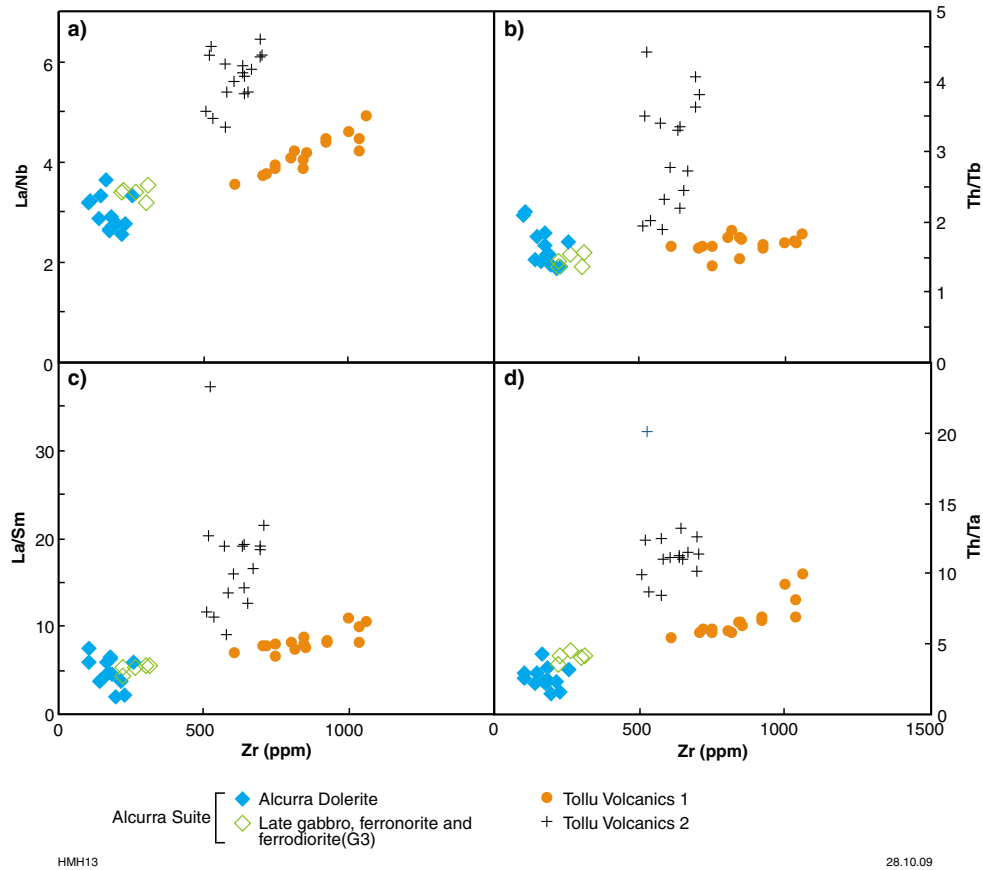


Figure 10. Incompatible trace element diagrams: a) Zr vs La/Nb; b) Zr vs Th/Tb; c) Zr vs La/Sm; and d) Zr vs Th/Ta, comparing the Alcurra Dolerite, olivine gabbro, ferrornorite, and ferrodiorite (G3) with the Tollu Volcanics (TV1 and TV2).

The Alcurra suite can also be distinguished from many of the other mafic dyke suites by their major element chemistry (Fig. 11a–d) and by their La/Nb of 1.5 compared with the dykes of the 1149 Ma Pitjantjatjarra Supersuite and the c. 1075 Ma unnamed plagioclase-rich dykes whose La/Nb is approximately 4 (Fig. 12a,b). Whilst the 825 Ma Gairdner dykes have La/Nb ratios of 1.5, they can be distinguished from the Alcurra suite by their lower La/Sm ratios (Fig. 12b).

The Kullal dykes, however, prove more difficult to confidently distinguish from the Alcurra suite. Initial distinctions made in the east, based on their different distribution and orientations, have now been found to be less significant in the west where they have a similar geographical range and orientation. In addition, it is now found that they have the same broad isotopic range (with ϵ_{Nd} from -2.84 to $+0.65$) and their major element geochemistry is transitional, with trends that permit a relationship through simple fractional crystallization (Fig. 11a–d). Some trace element ratios, such as La/Nb and Nb/Y, reveal subtle differences between the two groups and this can be explained in part by, for example, plagioclase and pyroxene fractionation (Fig. 13a–c) or differing degrees of crustal contamination. The age of the Kullal dykes is poorly constrained, but is either contemporaneous with or younger than the Alcurra suite. Thus, while it might be plausible that the Kullal

dykes simply represent a less evolved equivalent of the magma batch(s) that formed the Alcurra Dolerites, it is more likely that they were generated from a similar magma source but experienced slightly different evolutionary histories.

The geochemistry and Nd isotopic signatures of the Alcurra suite in the west are consistent with the same suite in the east Musgrave Province. For example, ϵ_{Nd} values of -1.05 to $+1.23$ (calculated at $t = 1067$ Ma) for the Alcurra suite from the west Musgrave Province are similar to the range of -1.3 to $+0.1$ for Alcurra dykes of the Northern Territory (Scrimgeour and Close, 1999).

Comparisons with gabbro of the Nebo–Babel intrusion

Seat et al. (2007) provide geochemical data on a range of gabbro from the Nebo–Babel intrusion which host orthomagmatic Cu–Ni–PGE mineralization. Gabbroic rocks geochemically similar to the Nebo–Babel intrusion are also found to the east, notably forming the Saturn pluton, as well as smaller gabbroic bodies immediately to the north of the Cavenagh Range. Within this region, significant Cu(–Ni–PGE–Au) mineralization is found at the Halleys and Voyager Prospects (Redstone Resources and Traka Resources detailed in the Traka Resources Quarterly

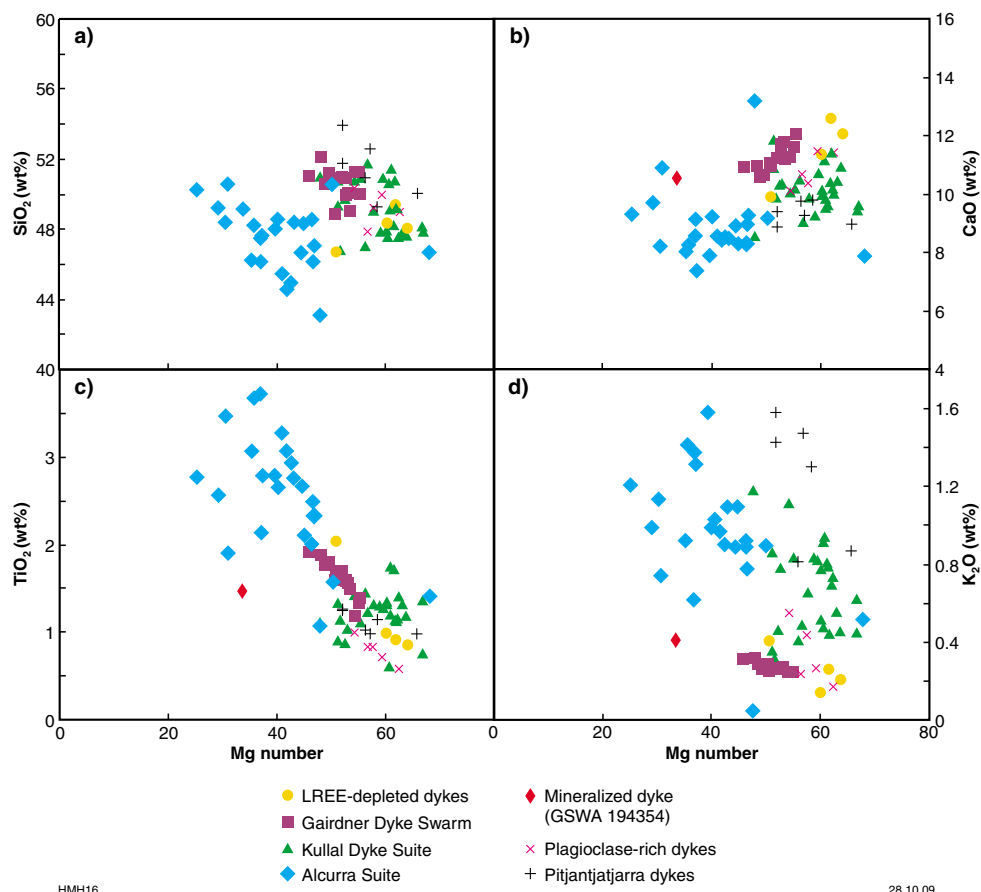


Figure 11. Major element variation diagrams: a) SiO_2 ; b) CaO ; c) TiO_2 ; and d) K_2O , showing the Alcurra suite and other mafic dyke suites of the west Musgrave Province.

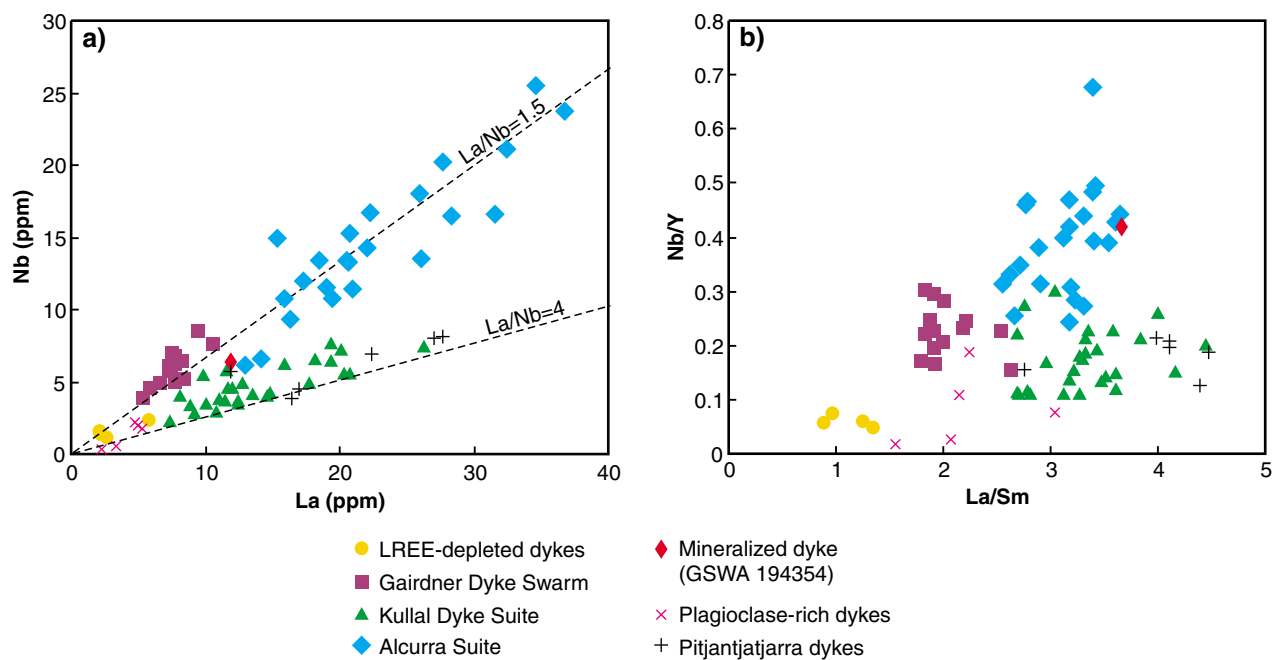
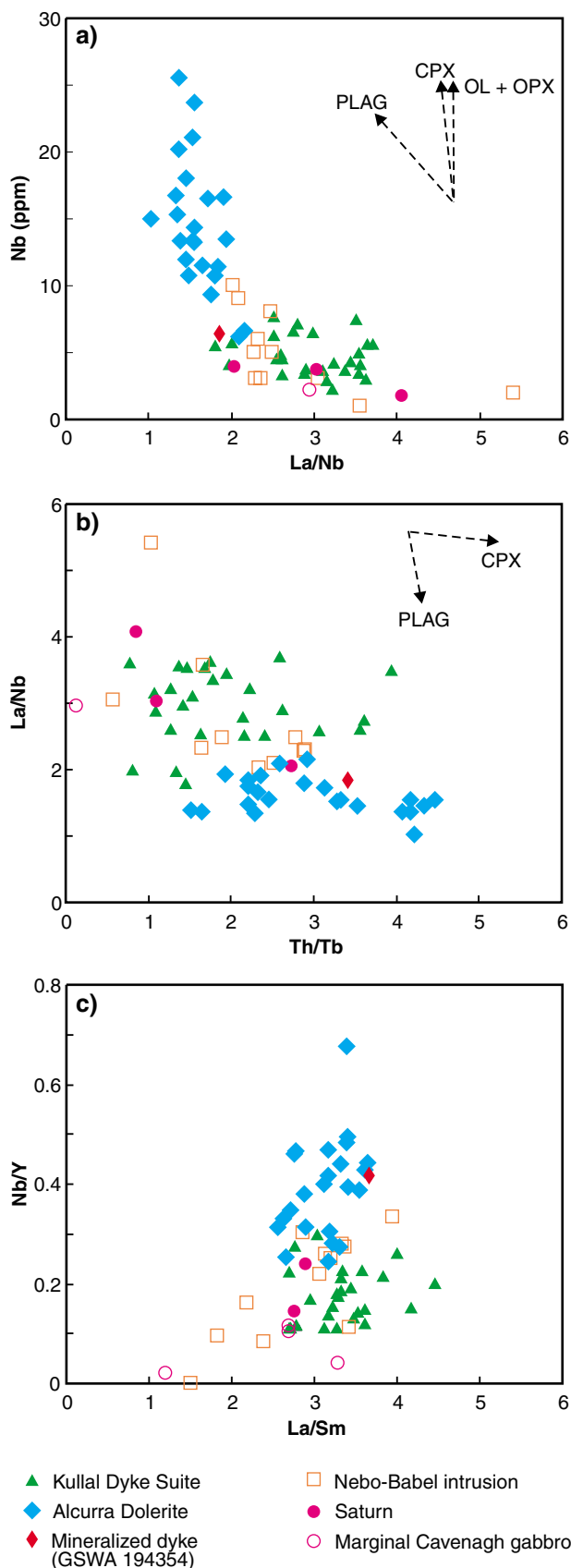


Figure 12. Incompatible trace element diagrams: a) La vs Nb and b) La/Sm vs Nb/Y showing the Alcurra suite and other mafic dyke suites of the west Musgrave Province.



HMH14

28.10.09

Activity Report Dec 2008 <<http://www.trakaresources.com.au/quaterly.asp>>, respectively). Importantly, all of these intrusions show close compositional similarities to the Alcurra suite. They have slightly higher La/Nb and lower Nb/Y ratios than the Alcurra Dolerites and show very similar trace element patterns to the Kullal dykes (Fig. 13a–c). Their compositional range overlaps extensively with the more evolved end of the range for the Kullal dykes, where the compositions of these dykes becomes difficult to distinguish from that of the more primitive members of the Alcurra suite.

It was suggested above that the geochemistry and age of the Alcurra suite and the Kullal dykes allows for a close, or even genetic, relationship between the two groups, most likely as separate magma batches derived from a common mantle source, but each subsequently following slightly different evolutionary trends. If this is the case, then the wide, but similar, geographical range of the Alcurra suite and the Kullal dykes, and the contrastingly small geographical range of the Nebo–Babel-type rocks, suggests that the latter are not a result of fractionation of Kullal-type compositions (i.e. are not an evolutionary link between the Alcurra suite and the Kullal dykes), but are perhaps more likely physical mixes of the two magma types. Either way, the Nebo–Babel-type rocks can be included within the Alcurra suite.

Implications for orthomagmatic Ni–Cu–PGE exploration in the west Musgrave Province

The results of this study have at least two major implications in terms of regional exploration for orthomagmatic Ni–Cu–PGE mineralization related to the Giles Event in the west Musgrave Province.

Firstly, some (and possibly all) known orthomagmatic Ni–Cu–PGE mineralization is directly linked to Alcurra suite gabbroic intrusions that are both distinctly younger (c. 1068 Ma) and compositionally and texturally distinct from all other major mafic intrusions (c. 1075 Ma or older) in the Musgrave Province. Overall, the Alcurra suite can be characterized as a relatively evolved, Fe-rich, and incompatible trace element-rich suite of tholeiitic intrusions.

Figure 13. Incompatible trace element diagrams: a) La/Nb vs Nb; b) Th/Tb vs La/Nb; and c) La/Sm vs Nb/Y showing the Alcurra Dolerite, Nebo–Babel intrusion, Kullal Dyke Suite, Saturn gabbro and marginal Cavenagh gabbro. Partition coefficients (K_d) values from the Geochemical Earth Reference Model database <<http://earthref.org/GERM>>.

Secondly, the emplacement of rocks of the Alcurra suite appears to have a distinct, structural control. The older (>1078 Ma) layered Giles intrusions likely follow a northwest basement structural trend established before or during the c. 1220–1150 Ma Musgravian Orogeny. A structural analysis of events throughout the Giles Event (Evins et al., in press) indicates that shortly after emplacement of the older layered intrusions, the region underwent a period of northeast–southwest compression or transpression at c. 1075 Ma that folded the layered intrusions about moderate to upright northwest-trending axial planes. Figure 1 shows that the larger intrusions of the Alcurra suite appear to be emplaced near the margins of, or peripheral to, the older, giant, layered mafic intrusions, presumably using layering and intrusion–country rock contacts as planes of weakness. Smaller, dyke-like intrusions of the Alcurra suite most commonly follow north to northeast trends (typically 000–020° and 040–060°), which likely reflect conjugate extensional planes throughout the period of deformation. GSWA's recent regional gravity survey shows significant contrasts across these extensional planes, which have clearly had a major control over the large-scale crustal architecture of the region, and would have potentially been significant conduits for Alcurra suite magmas. If mixing of magmas was an important step in producing significant orthomagmatic mineralization, as suggested above, then these conduits, as well as the intersection of northwest-trending lithological or structural trends and northeast trending dykes or fractures, might be realistic targets for mineral exploration.

References

- Black, LP, Kinny, PD and Sheraton, JW 1991, The difficulties of dating mafic dykes: an Antarctic example. *Contributions to Mineralogy and Petrology*, v. 109, p. 183–194.
- Claoué-Long, JC, Compston, W, Roberts, J and Fanning, CM 1995, Two Carboniferous ages: a comparison of SHRIMP zircon dating with conventional zircon ages and $^{40}\text{Ar}/^{39}\text{Ar}$ analysis, in *Time Scales and Global Stratigraphic Correlation* edited by WA Berggren, DV Kent, M-P Aubrey and J Hardenbol: Society for Sedimentary Geology, Special Publication 54, p. 3–21.
- Compston, W, Williams, IS and Meyer, C 1984, U–Pb geochronology of zircons from lunar breccia 73217 using a sensitive high mass resolution ion microprobe: *Journal of Geophysical Research*, v. 89, p. B252–B534.
- Daniels, JL 1974, The Geology of the Blackstone region, Western Australia: Geological Survey of Western Australia, Bulletin 123, 257p.
- Evins, PM, Howard, HM and Smithies, RH in prep., Finlayson, WA Sheet 4546: Geological Survey of Western Australia, 1:100 000 Geological Series.
- Evins, PM, Smithies, RH, Howard, HM and Kirkland, CL in press, Devil in the detail: the 1150 – 1000 Ma magmatic and structural evolution of the Ngaanyatjarra Rift, west Musgrave Province, Central Australia: *Precambrian Research*.
- Evins, PM, Smithies, RH, Howard, HM and Maier, WD 2009, Holt, WA Sheet 4546: Geological Survey of Western Australia, 1:100 000 Geological Series.
- Glikson, AY, Stewart, AT, Ballhaus, GL, Clarke, GL, Feeken, EHT, Level, JH, Sheraton, JW and Sun, S-S 1996, Geology of the western Musgrave Block, central Australia, with reference to the mafic–ultramafic Giles Complex: Australian Geological Survey Organisation (Geoscience Australia), Bulletin 239, 206p.
- Geochemical Earth Reference Model, 2009, Earth Reference Data and Models, viewed 4 April 2009, <<http://earthref.org/GERM>>.
- Howard, HM, Smithies, RH and Pirajno, F 2007, Geochemical and Nd isotopic signatures of mafic dykes in the west Musgrave Complex: Geological Survey of Western Australia, Annual Review 2005–06, p. 64–71.
- Howard, HM, Smithies, RH, Pirajno, F and Skwarnecki, MS 2009a, Bates, WA Sheet 4646: Geological Survey of Western Australia, 1:100 000 Geological Series.
- Howard, HM, Smithies, RH, Pirajno, F and Skwarnecki, MS 2009b, Bell Rock, WA Sheet 4645: Geological Survey of Western Australia, 1:100 000 Geological Series.
- Kirkland, CL, Wingate, MTD, Evins, PM, Howard, HM and Smithies, RH 2009, 194354: gabbro dyke, Domeyer Hill; *Geochronology Record* 799: Geological Survey of Western Australia, 4p.
- Kirkland, CL, Wingate, MTD and Bodorkos, S 2008, 174761: Geochronological dataset 721, in *Compilation of geochronological data: Geological Survey of Western Australia*, June 2008 update, 4p.
- Marsh, B 2004, A magmatic mush column rosetta stone: the McMurdo Dry Valleys of Antarctica, EOS, Transactions, American Geophysical Union, v. 85, p. 497–508.
- Morris, PA and Pirajno, F 2005, Mesoproterozoic sill complexes of the Bangemall Supergroup, Western Australia: geology, geochemistry, and mineralization potential: Geological Survey of Western Australia, Report 99, 75p.
- Poldervaart, A 1956, Zircons in rocks. 2. Igneous rocks. *American Journal of Science*, v. 254, p. 521–554.
- Seat, Z 2008, Geology, petrology, mineral and whole-rock chemistry, stable and radiogenic isotope systematics and Ni–Cu–PGE mineralization of the Nebo–Babel Intrusion, west Musgrave, Western Australia: University of Western Australia, PhD thesis (unpublished).
- Seat, Z, Beresford, SW, Grguric, BA, Waugh, RS, Hronsky, JMA, Gee, MAM, Groves, DI and Mathison, CI 2007, Architecture and emplacement of the Nebo–Babel gabbro-hosted magmatic Ni–Cu–PGE sulphide deposit, West Musgrave, Western Australia: *Mineralium Deposita*, v. 42, p. 551–581.
- Schmidt, PW, Williams, GE, Camacho, A and Lee, JKW 2006, Assembly of Proterozoic Australia: implications of a revised pole for the ~1070 Ma Alcurra Dyke Swarm, central Australia: *Geophysical Journal International*, v. 167, p. 626–634.
- Scrimgeour, IR and Close, DF 1999, Regional high pressure metamorphism during intracratonic deformation: the Petermann orogeny, central Australia: *Journal of Metamorphic Geology*, v. 17, p. 557–572.
- Smithies, RH, Howard, HM, Evins, PM, Kirkland, CL, Bodorkos, S and Wingate, MTD 2009a, The west Musgrave Complex — new geological insights from recent mapping, geochronology, and geochemical studies: Geological Survey of Western Australia, Record 2008/19, 20p.

- Smithies, RH, Howard, HM, Evins, PM and Maier, WD 2009b, Blackstone, WA Sheet 4545: Geological Survey of Western Australia, 1:100 000 Geological Series.
- Stacey, JS and Kramers, JD 1975, Approximation of terrestrial lead isotope evolution by a two-stage model: *Earth and Planetary Science Letters*, v. 26, p. 207–221.
- Sun, S-S, Sheraton, JW, Glikson, AY and Stewart, AJ 1996, A major magmatic event during 1050–1080 Ma in central Australia, and an emplacement age for the Giles Complex: *AGSO Journal of Australian Geology and Geophysics*, v. 24, p. 13–15.
- Thompson, RN, Morrison, MA, Hendry, GL and Parry, SJ 1984, An assessment of the relative roles of crust and mantle in magma genesis: an elemental approach: *Philosophical Transactions of the Royal Society*, v. A310, p. 549–590.
- Traka Resources Quarterly Activity Report Dec 2008, Traka Resources Ltd, Perth, viewed 10 April 2009, <<http://www.trakaresources.com.au/quarterly.asp>>.
- Wingate, MTD and Kirkland, CL 2009, Introduction to geochronology information released in 2009: Geological Survey of Western Australia, 5p.
- Wingate, MTD, Pirajno, F and Morris, PA 2004, Warakurna large igneous province: a new Mesoproterozoic large igneous province in west-central Australia: *Geology*, v. 32, p. 105–108.
- Zhao, J-X and McCulloch, MT 1993, Sm–Nd mineral isochron ages of Late Proterozoic dyke swarms in Australia: evidence for two distinctive events of mafic magmatism and crustal extension: *Chemical Geology*, v. 109, p. 341–354.

AGE AND GEOCHEMISTRY OF THE ALCURRA SUITE IN THE
WEST MUSGRAVE PROVINCE AND IMPLICATIONS FOR
ORTHOMAGMATIC NI-CU-PGE MINERALIZATION DURING THE
GILES EVENT

This Record is published in digital format (PDF) and is available online at:
www.dmp.wa.gov.au/GSWApublications.
Laser-printed copies can be ordered from the Information Centre for the
cost of printing and binding.

Further details of geological publications and maps produced by the
Geological Survey of Western Australia can be obtained by contacting:

Information Centre
Department of Mines and Petroleum
100 Plain Street
EAST PERTH, WESTERN AUSTRALIA 6004
Phone: (08) 9222 3459 Fax: (08) 9222 3444
www.dmp.wa.gov.au/GSWApublications

