Mineral Resources Tasmania

Laboratory Report

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Geochronology and geochemistry of gem sapphires and zircons from the St Helens district and elsewhere in Tasmania

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Tasmanian Government

SUMMARY

Source rocks for sapphires in north-eastern Tasmania have recently been determined at a site on Logans Road in the Priory sapphire field, east of St Helens, where a small diatreme or breccia pipe has been emplaced within Devonian granite.

Fresh volcanic glass from the basanite diatreme was separated and dated using Ar/Ar multi-collector mass spectrometry to reveal a 42.0 (± 0.1) – 47.2 (± 0.1) Ma (2σ) age for this basanite diatreme.

Coarse red-brown gemmy zircons are present with the alluvial sapphires, although they were not identified within the basanite itself, and these were dated by the U-Pb method using laser ablation inductively coupled mass spectrometry (LA-ICPMS). Two populations were found, one between ~42 - 44 (± 4) Ma and one between 233 - 247 (± 4) Ma.

The younger Eocene zircon date closely matches the Ar/Ar date of the basanite host, and probably records partial resetting by that magma. The older Middle Triassic zircon population comes from an unknown, underlying source, possibly a Triassic intrusive.

The site at Logans Road helps to explain the origin of gem sapphires and zircons in this district, although their ultimate origin is enigmatic.

Data is also provided on sapphires and rubies from other parts of Tasmania.

INTRODUCTION

Many notable occurrences of gem sapphire are known in Tasmania, mostly in the extensive alluvial tin-bearing deposits in the northeast (Yim et al., 1985, McGee, 2005, Sutherland & Webb, 2007, Bottrill & Baker, 2008, Graham, et al., 2020; Fig. 1). The sapphires and zircons are very typically associated with coarse-grained, ferroan (pleonaste) spinel in alluvial deposits, but are rarely seen within any host rock, and thus their sources are enigmatic.

Recently some new work on these gem occurrences has been undertaken. Analyses of Tasmanian zircons have been reported by Sutherland et al (2019) and the first confirmation of Tasmanian rubies has been reported by Bottrill et al (2019a, 2019b) from the NE, Cygnet and Devonport districts.

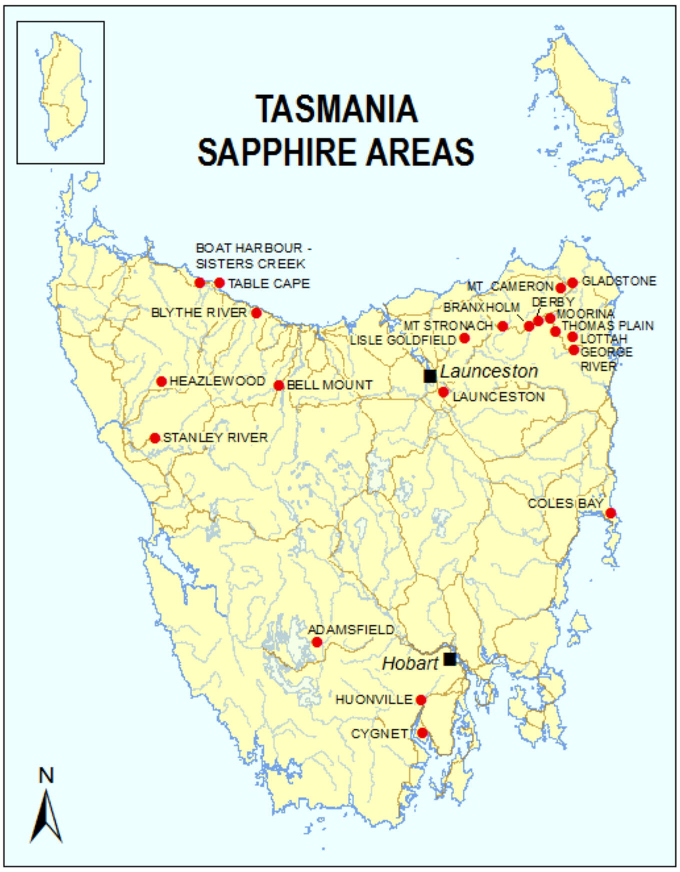

Figure 1. Sapphire locations in Tasmania

A source rock for sapphires in north-eastern Tasmania has recently been determined at a site on Logans Road in the Priory sapphire field, east of St Helens, where a small basaltic diatreme or breccia pipe has been emplaced within Devonian granite (Figs. 2 - 4). These diatremes are typically prominent in aeromagnetic images (Fig. 5). This area appears undisturbed by tin mining.

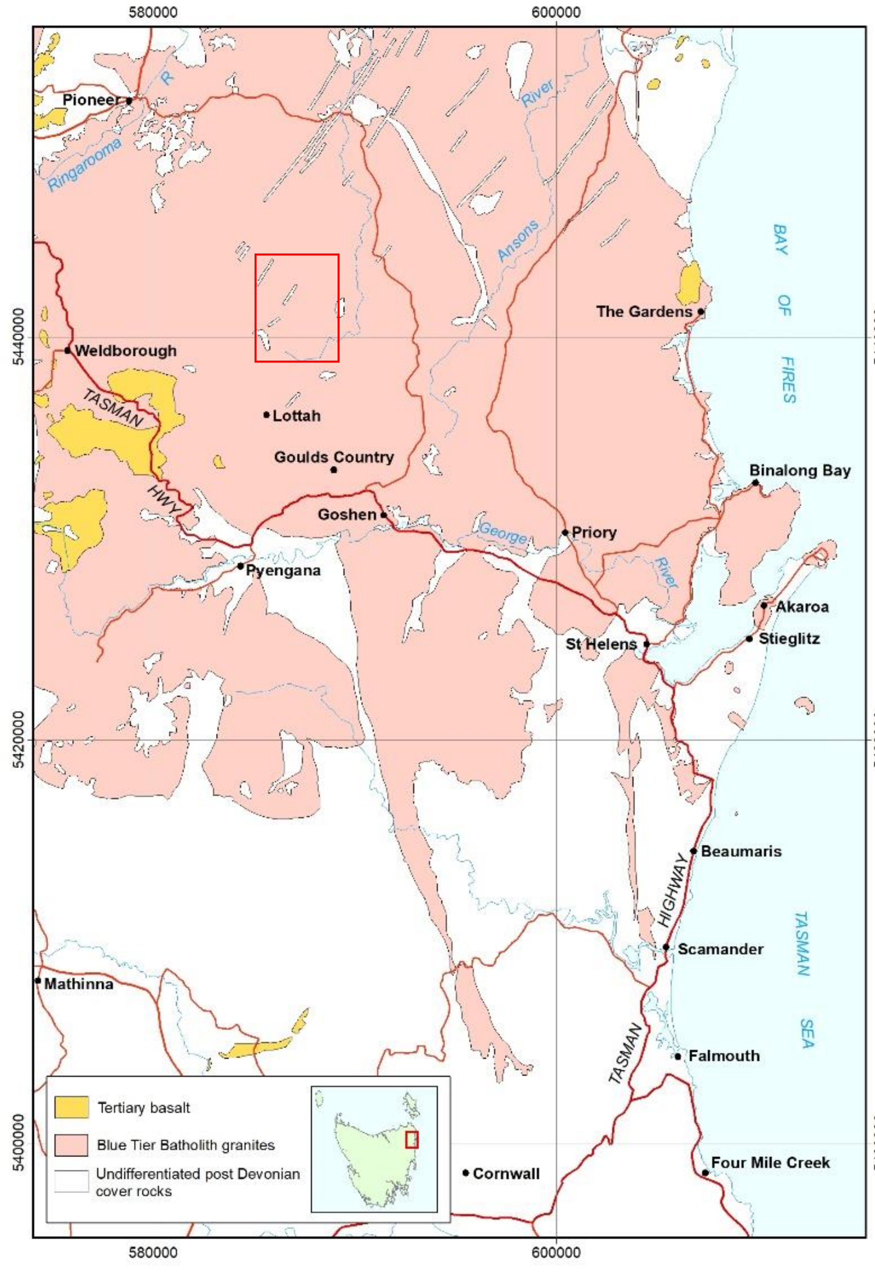

Fig. 2. *Geological map of the St Helens area showing the location of Fig. 2 & 3 (red box). From Morrison (2019)*

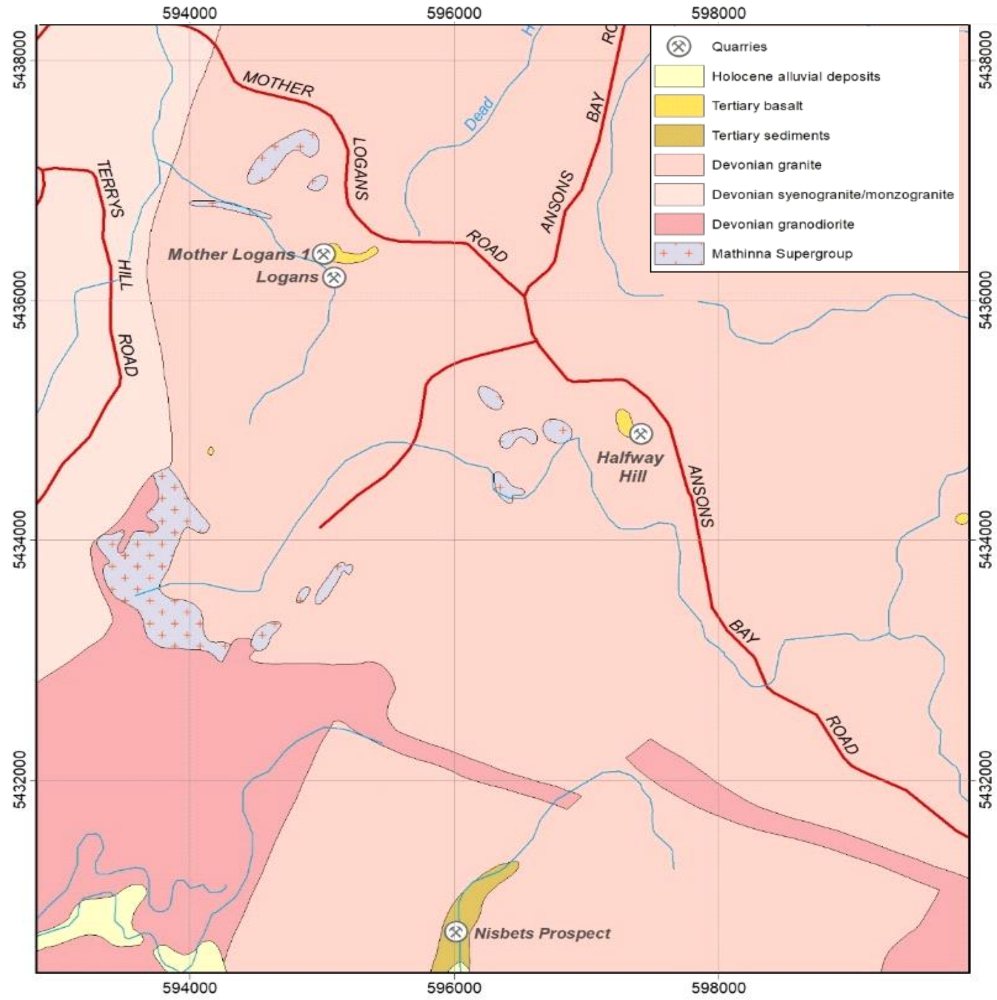

Fig. 3. *Geology, Logans Road area. From Morrison (2019).*

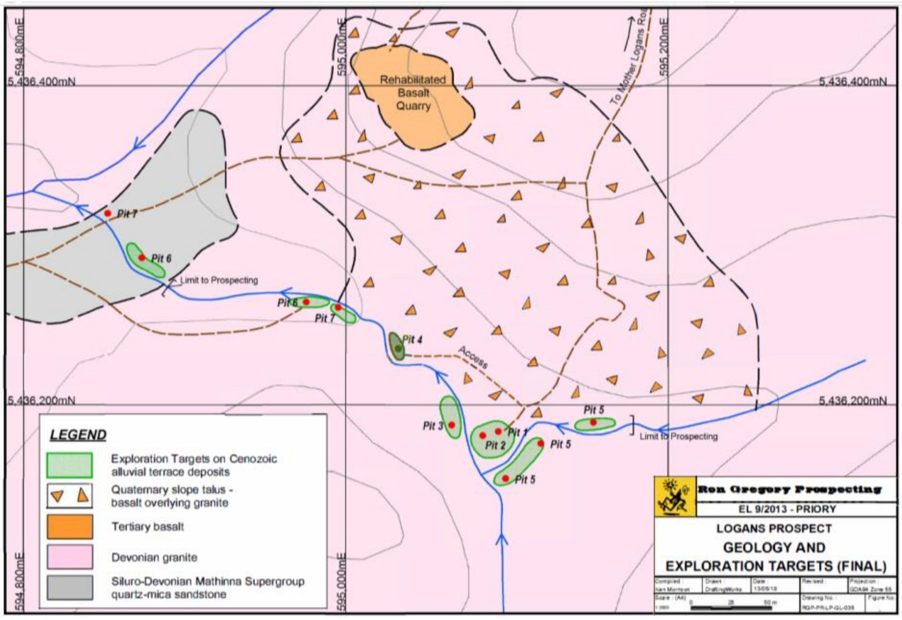

Fig. 4. *Geology, Logans Road Sapphire prospect area. From Morrison (2019).*

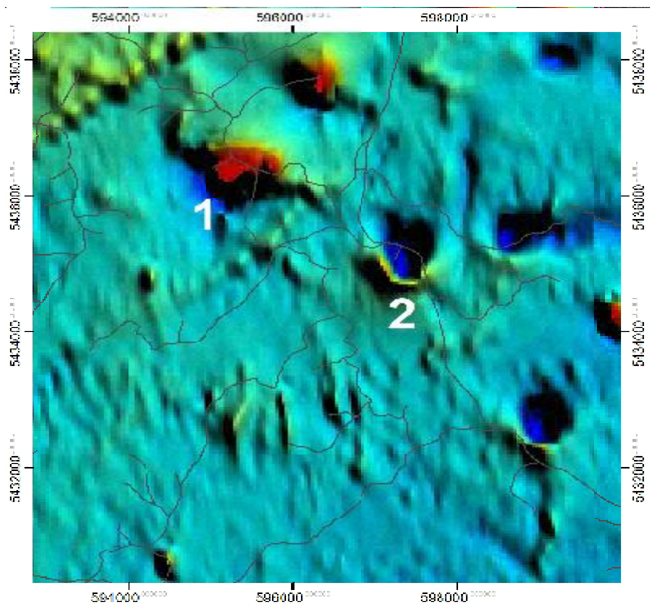

Fig. 5. *Total magnetic intensity image (red-normal polarity; blue - reversed polarity) of the Logans Rd area, showing basaltic diatremes in red and dark blue. From Morrison (2019).*

Fig 6. Sapphire in weathered basalt pebble, Logans Road Area. Field of view about 12cm.

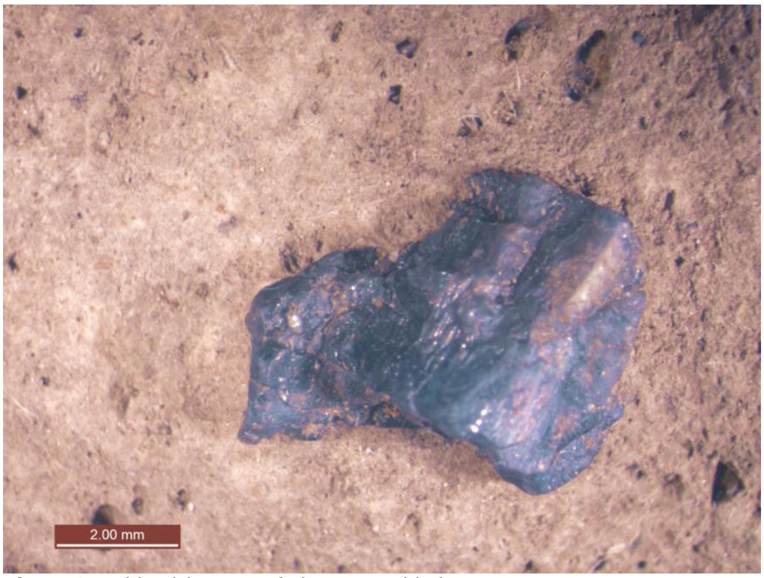

Fig. 7. Sapphire (close up of above sapphire).

The Logans Rd diatreme consists mainly of basanite clasts containing abundant partly disaggregated spinel lherzolite xenoliths and some altered granite xenoliths.

***Fig. 8**. Green spinel lherzolite xenoliths and white pyroxene and feldspar xenocrysts in hackly/nodular basalt, Mother Logans Road Quarry. Field of view about 12cm.*

Just 200m south of the Mother Logans diatreme, sapphires occur as detrital grains in the surrounding headwater drainage together with pleonaste spinel, zircon, pyroxenes and olivine, which mostly appear to derive from the diatreme. The mineral grain shapes are rather irregular and angular with little or no transport abrasion and are obviously adjacent to their source. The creeks also contain variably weathered basanite boulders and pebbles. On their soft brown weathered surfaces many mineral grains are emergent and readily identifiable. A single subrounded/subangular blue to grey sapphire, 7 mm across with a distinct parting with, was found partly exposed in a weathered, inclusion-rich pebble (Figs. 6 & 7)by a prospector, Michael Lloyd (Duncan & Lloyd, 2013). Thus, at least some of the Tasmanian sapphires have a basaltic source.

Some 1.5km to the SE of this quarry is another basaltic diatreme, well exposed in the Halfway Hill quarry (Fig. 3, 9).

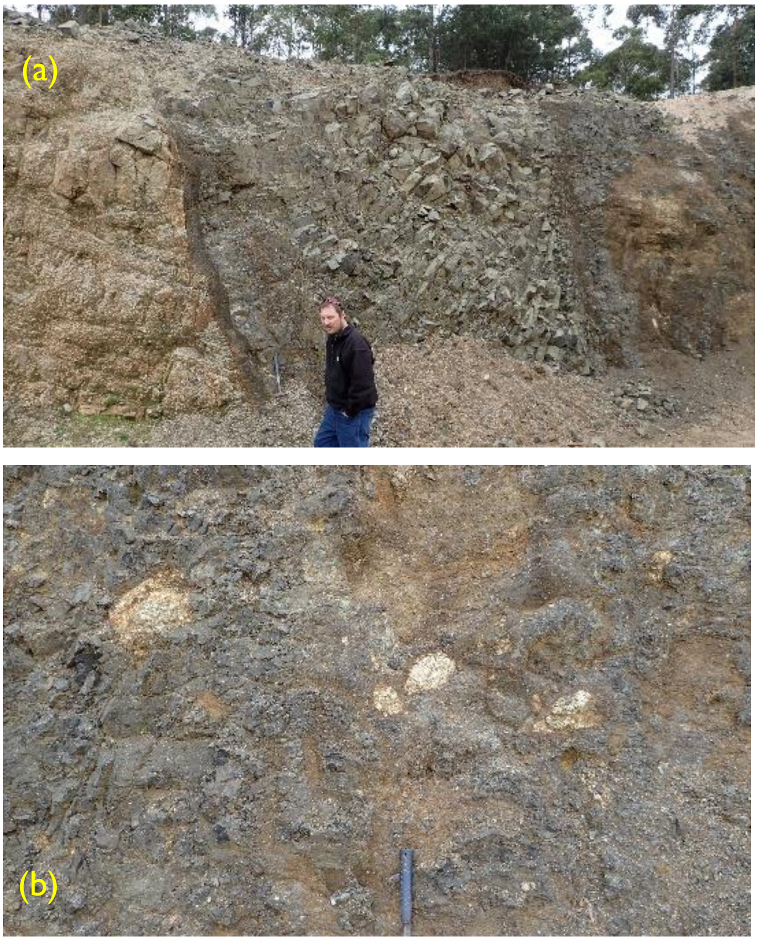

Fig. 9. *Halfway Hill quarry, showing a) weathered granite on the left, a glassy contact zone ~20cm thick, against a 5m zone of massive/blocky to columnar basalt, cut by a brown zone of tuffaceous to blocky basaltic to polymict breccia, probably a diatreme; b) rounded xenoliths of granite and basalt within the breccia zone.*

The diatreme contains varied xenoliths and xenocrysts, including granite, sanidine, syenite? And amphibole (kaersutite?) (Fig. 9, 10).

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Fig. 10*. Exposed breccias in Halfway Hill quarry showing clasts rich in: (a) sanidine (syenite?); (b) amphibole (kaersutite?) xenocrysts.*

WHOLE ROCK GEOCHEMISTRY

The host rocks at Logans Road and Halfway Hill were analysed by XRF and their compositions are relatively low in silica, with a moderately high alkali content, and plot as a basanite (Appendix 5., Fig. 10). They are similar to other local basanites in the Ansons Bay – St Helens area, and also the ~47 Ma basalts of the Weldborough area ~15 km to the west. The ~16 - 18 Ma lavas of the Ringarooma valley further west are mainly nephelinites and extend to much lower silica values.

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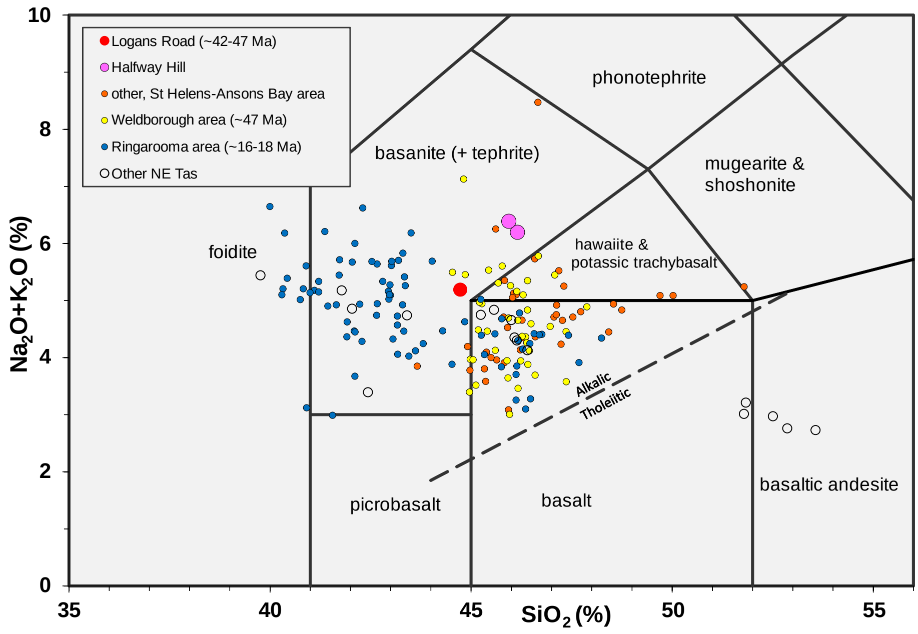

Fig. 11. *Total alkali-silica (TAS) plot, comparing host rocks at Logans Road and Halfway Hill with other Cenozoic basalts from NE Tasmania. Major elements recalculated to 100% anhydrous. IUGS classification also shown.*

SAMPLES STUDIED

Several grains of zircons, sapphires, rubies, apatite and spinel, from Mother Logans Rd and various other parts of Tasmania, were analysed to determine their identity, age and origin. Sample details are shown in Table 1.

Table 1: Sample details for samples tested by LAICPMS.

Reg No.	Location	Description	Source
G409328	Mother Logans Rd Qy, Priory	Sapphires	Michael Lloyd, D Duncan
G409289	Penguin district	Ruby, sappphire	Andrew Burke
G410241	Forsters Rt, Cygnet	Ruby, sappphire	C. Drayton
G410292	Black Ck , Pioneer	Zircons	M. De Salas
G410293	Mother Logans Rd Qy	Zircons	M. De Salas
G410294	Main Ck, Moorina	Zircons	M. De Salas
G410295	Frome R, Moorina	Zircons	M. De Salas
G410296	Weld R, Moorina	Zircons	M. De Salas
G410146	Weld R, Moorina	Chrysoberyl/apatite	T. Coyte
G410147	Weld R, Moorina	Purple-red ruby	T. Coyte
G410148	Weld R, Moorina	Red ruby/spinel	F.L. Sutherland

SAMPLES DESCRIPTION

Small font numbered labels over mineral grains on the following pictures correspond to the LA-ICPMS analysis number for U-Pb dating (e.g. Tables 2 and 3). FOV stands for the width of Field Of View.

G409328 Mother Logans Rd Qy Sapphires

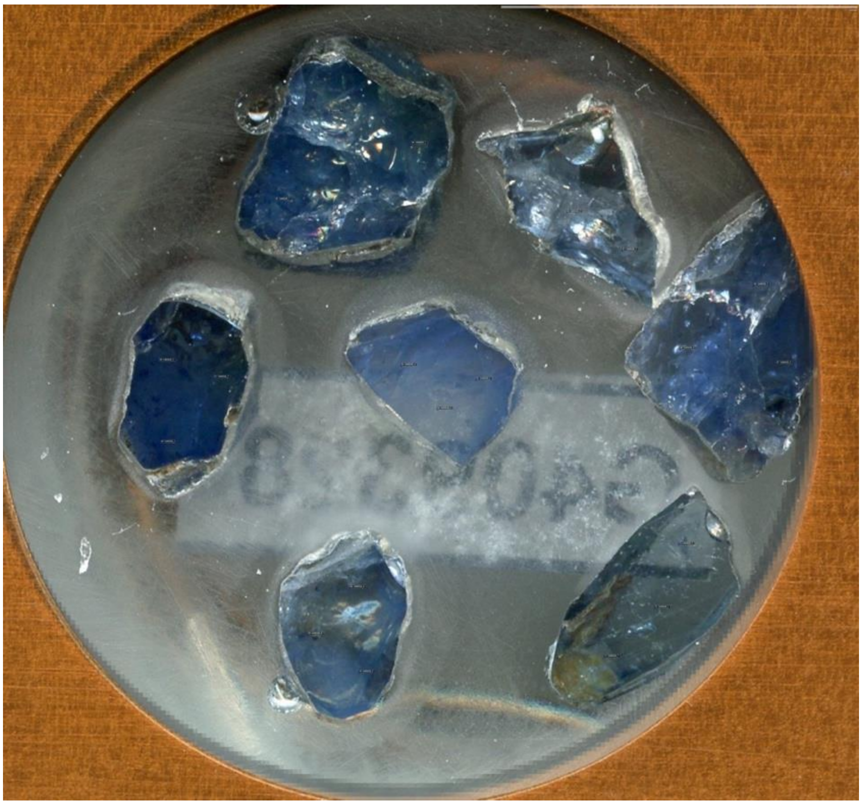

Fig 12. G409328. Gem sapphires. Polished block is 25mm diameter.

G409289 Penguin district Ruby, sapphire

Fig 13. G409289. Gem ruby and sapphire. Field of View (FOV) is ~18 mm.

G410241 Forsters Rt, Cygnet Ruby, sapphire

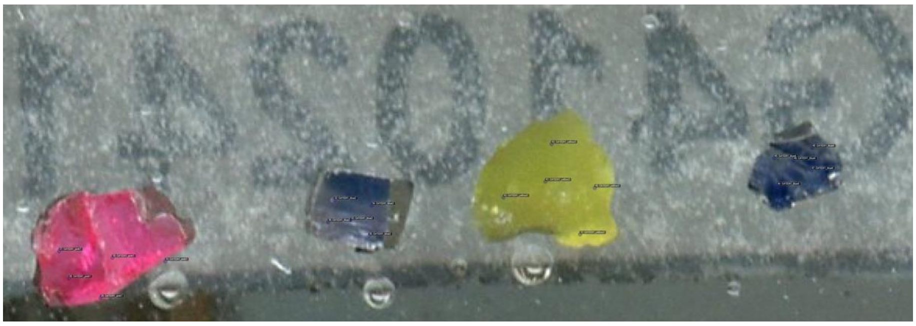

Fig 14. G410241. Gem ruby (pink), olivine (yellow-green) and sapphires (blue). Field of View (FOV) is ~20 mm

G410292 Black Ck , Pioneer Zircons M. De Salas

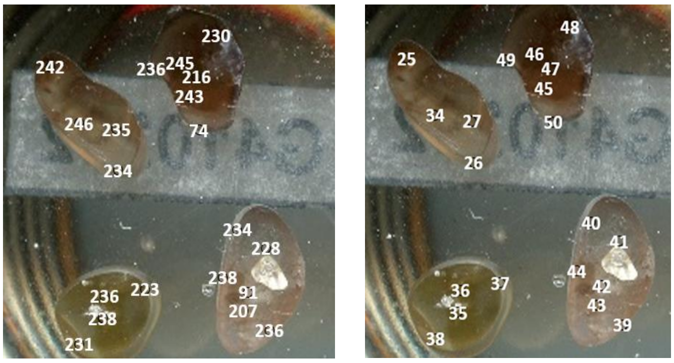

Fig 15. G410292. Gem zircons 3-5 mm each, showing analysis points and numbers. Field of View (FOV) is ~20 & 18 mm.

G410293 Mother Logans Rd Qy Zircons M. De Salas

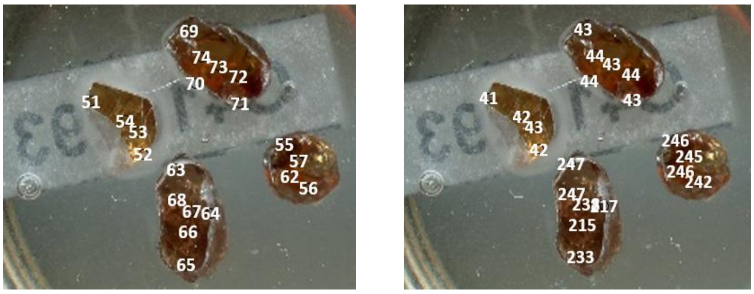

Fig 16. G410293. Gem zircons points and numbers. Field of View (FOV) is ~20 mm.

G410294 Main Ck, Moorina LAICPMS-Zr GC Zircons M. De Salas

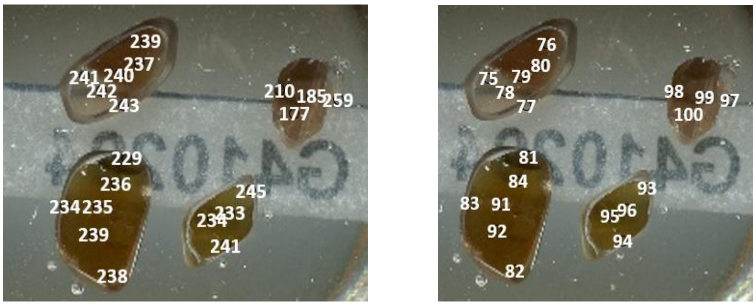

Fig 17. G410294. Gem zircons points and numbers. Field of View (FOV) is ~20 mm.

G410295 Frome R, Moorina Zircons M. De Salas

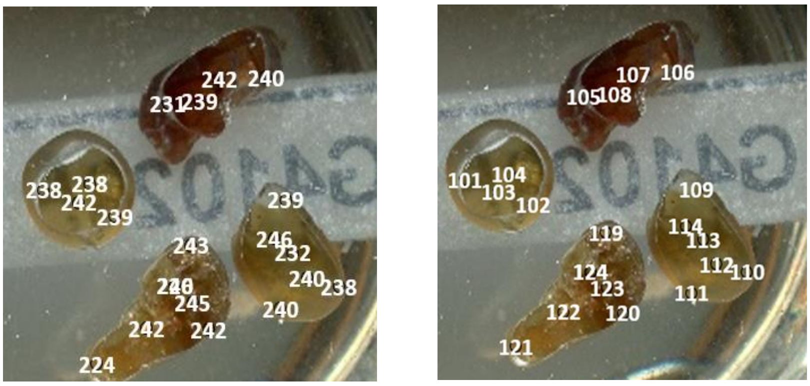

Fig 18. G410295. Gem zircons points and numbers. Field of View (FOV) is ~20 mm.

G410296 Weld R, Moorina Zircons M. De Salas

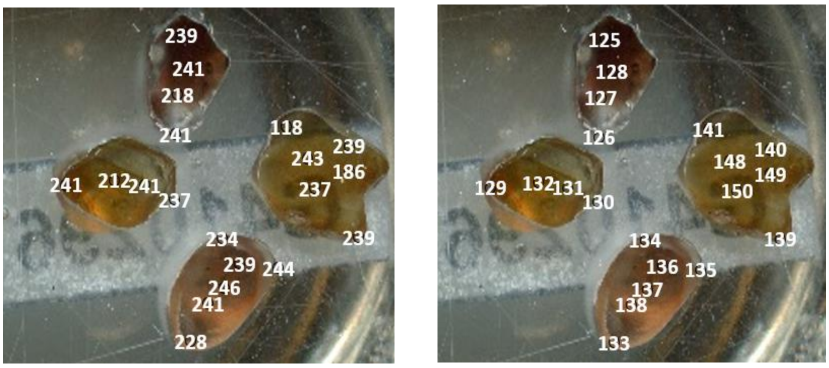

Fig 19. G410296. Gem zircons points and numbers. Field of View (FOV) is ~20 mm.

G410146 Weld R, Moorina Chrysoberyl/apatite

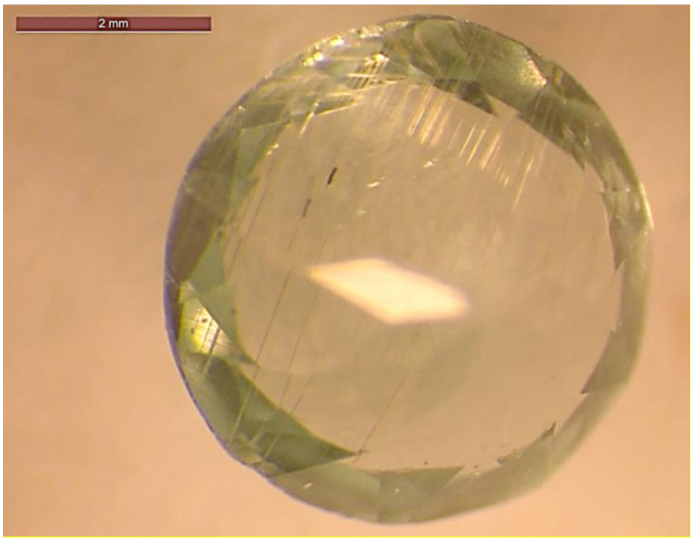

Fig 20. G410146. Gem apatite ("Chrysoberyl") from Weld R, Moorina. Field of View (FOV) is ~8 mm.

G410147 Weld R, Moorina Purple-red ruby

Fig 21. G410147. Rounded purple-red ruby. Field of View (FOV) is ~8 mm

G410148 Weld R, Moorina LAICPMS Red “ruby”/spinel

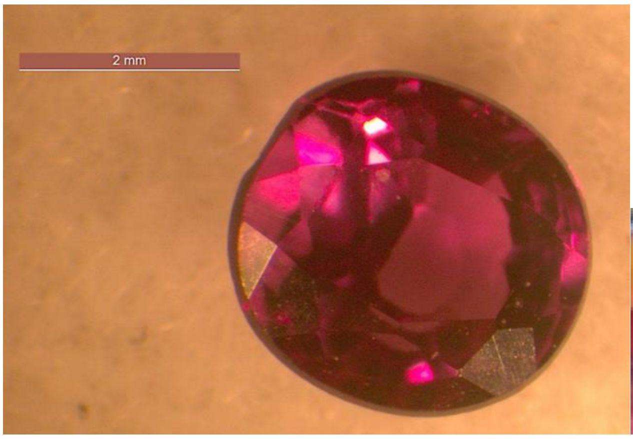

Fig 22. G410148. Weld R, Moorina, Red ruby/spinel euhedral crystal. RHS shows laser ablation spots.

METHODS

U-Pb geochronology was undertaken at the University of Tasmania using the LA-ICPMS technique. The zircons were mounted in epoxy resin, polished using a clean lap, washed and analysed using an Excimer (193 nm) laser fitted with a Resonetics M50 ablation cell and an Agilent 7500 quadrupole ICPMS. Samples were analysed using a 32 µm spot at 5 Hz and 2J cm^2. The 91500 Zircon (Wiedenbeck et al. 1995, 2005) was used as a primary standard and the Temora, Gj1 and Plesovice zircons (Black et al. 2003; Jackson et al. 2004;) were used as a secondary standard. Pb-Pb mass bias was corrected using the NIST610 standard glass. Age calculations were performed using the techniques described in various University of Tasmania publications (e.g. Sack et al. 2011; Halpin et al. 2014).

MINERAL ANALYSES

Representative geochemical composition of the minerals analysed by LA-ICPMS at CODES, UTAS are shown in Tables 2 and 3. The number before the element symbol corresponds to the mass of isotope used for analysis.

Table 2: Representative composition of apatite (G410146), ruby (G410147), and spinel (G410148) (wt.%).

Source Filename, CODES	**C20JUN 05A0006 .csv**	**C20JUN 05A0011 .csv**	**C20JUN 05A0012 .csv**	**C20JUN 05A0013 .csv**	**C20JUN 05A0014 .csv**	**C20JUN 05A0015 .csv**	**C20JUN 05A0003 .csv**	**C20JUN 05A0004 .csv**	**C20JUN 05A0005 .csv**
Reg. No	**G410146**			**G410147**			**G410148**		
Mineral	**apatite**	**apatite**	**apatite**	**ruby**	**ruby**	**ruby**	**spinel**	**spinel**	**spinel**
23Na	0.050	0.050	0.050	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
24**Mg**	0.005	0.004	0.004	0.004	0.004	0.004	**32.788**	**32.137**	**32.550**
27**Al**	<0.000	<0.000	<0.000	**99.316**	**99.304**	**99.321**	**65.663**	**66.354**	**65.875**
29Si	0.724	0.715	0.706	0.114	0.116	0.096	0.114	0.105	0.107
31**P**	**38.968**	**39.397**	**39.898**	<0.005	<0.005	<0.004	<0.004	0.004	<0.004
44**Ca**	**58.972**	**58.559**	**58.065**	<0.005	<0.005	<0.005	<0.004	<0.004	<0.004
49Ti	0.000	0.000	<0.000	0.007	0.024	0.010	0.032	0.032	0.036
51V	0.004	0.004	0.004	0.002	0.002	0.003	0.078	0.080	0.080
53Cr	<0.000	<0.000	<0.000	0.049	0.050	0.050	0.678	0.660	0.699
55Mn	0.014	0.014	0.014	<0.000	0.000	0.000	0.001	0.001	0.001
57Fe	0.005	0.006	0.005	0.482	0.474	0.487	0.500	0.484	0.507
66Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.106	0.104	0.107
71Ga	0.001	0.001	0.001	0.025	0.024	0.025	0.029	0.028	0.028
88Sr	0.258	0.257	0.255	<0.000	0.000	0.000	<0.000	<0.000	<0.000
89Y	0.036	0.036	0.036	0.000	0.000	0.000	<0.000	<0.000	<0.000
139La	0.225	0.222	0.223	0.000	0.000	0.000	<0.000	<0.000	<0.000
140Ce	0.474	0.469	0.472	0.000	0.000	0.000	<0.000	<0.000	<0.000
146Nd	0.160	0.159	0.160	<0.000	0.000	0.000	<0.000	<0.000	<0.000
147Sm	0.021	0.021	0.022	0.000	0.000	0.000	<0.000	<0.000	<0.000
232Th	0.072	0.073	0.071	0.000	0.000	0.000	<0.000	<0.000	0.000

Table 3: Representative LA-ICPMS analysis results of **yellow olivine** in the sample G410241 (wt.%). Spot size 51 µm.

Source Filename	C20MAY01A 0037.csv	C20MAY01A 0040.csv	C20MAY01A 0041.csv	C20MAY01A 0042.csv	C20MAY01A 0043.csv	C20MAY01A 0037.csv
11B	0.022	0.020	0.016	0.018	0.020	0.022
24Mg	**47.987**	**47.991**	**48.301**	**48.108**	**48.305**	**47.987**
27Al	0.530	0.544	0.460	0.545	0.479	0.530
29Si	**46.509**	**47.462**	**47.080**	**47.668**	**46.828**	**46.509**
44Ca	0.020	0.022	0.021	0.024	0.025	0.020
49Ti	0.006	0.008	0.005	0.011	0.005	0.006
53Cr	0.126	0.184	0.145	0.291	0.188	0.126
55Mn	0.169	0.157	0.126	0.146	0.119	0.169
57Fe	**4.312**	**3.293**	**3.502**	**2.908**	**3.672**	**4.312**
59Co	0.006	0.006	0.006	0.005	0.005	0.006
60Ni	0.266	0.239	0.278	0.226	0.270	0.266
66Zn	0.030	0.058	0.047	0.031	0.060	0.030

GEOCHRONOLOGY RESULTS

Coarse red-brown gemmy zircons are present with the alluvial sapphires, although they were not identified within the basanite itself, and these were dated at UTAS by NAMES using U-Pb method developed for laser ablation inductively coupled mass spectrometry (LA-ICPMS). Two populations were found, one between ~42-44 (± 4) Ma and one between 233-247 (± 4) Ma (Appendix 1).

The younger zircon date probably records partial resetting by the basanite host, as it closely matches its Ar/Ar date; the older date probably records an unknown, underlying Triassic intrusive source.

There is a 233 ± 5 Ma (K/Ar) alkali basalt flow near St Marys (Calver & Castleden, 1981) and a 214 ± 1 Ma (K/Ar) age from “felsic tuff” near Bicheno (Bacon & Green, 1984). Rhyolite clasts occur in the upper Triassic near St Marys, and may have a proximal source (Forsyth, 1989). No in situ Triassic felsic lavas or intrusives have been found in Tasmania, however.

SUMMARY AND CONCLUSIONS

Many significant occurrences of precious and semi-precious stones occur in Cainozoic sediments within Tasmania. These include: sapphire, zircon, chrysoberyl, spinel and ruby in alluvial tin-bearing deposits in northeast Tasmania (Bottrill & Mathews, 2006, Bottrill & Baker, 2008, Harris et al., 2014). They are rarely found in hard rock sources but sapphire, spinel and much of the zircon are thought to be sourced in alkali basalt diatremes and related rocks (Harris et al., 2014).

McGee (2005) found that oxygen isotope values in sapphires from northeast Tasmania indicate shallow mantle values, and they were probably brought to the surface in basaltic diatremes. Tertiary basalt is present in the Ringarooma River valley and as isolated remnants at higher levels, such as the Weldborough Pass basalt, including an eruptive centre, locally containing deep crustal to upper mantle xenoliths of lherzolite, anorthoclasite and sanidinite. These xenoliths are similar to xenoliths found at some of the related sapphire occurrences in Queensland (Robertson & Sutherland, 1992). Basalts near Derby contain lherzolite xenoliths including black spinel.

Source rocks for sapphires in north-eastern Tasmania have recently been determined conclusively at a site on Logans Road in the Priory sapphire field, east of St Helens, where sapphires and spinel occurs adjacent to a small basalt diatreme or breccia pipe that has been emplaced within Devonian granite. The diatreme consists mainly of basanite clasts containing abundant partly disaggregated spinel lherzolite xenoliths, but also contains altered granite xenoliths within the diatreme. A nearby diatreme contains syenitic xenoliths and probably kaersutite xenocrysts. This basanite has been dated at between 42 – 47 Ma , which matches the ages of some of the alluvial zircons nearby.

Some older zircons in the alluvium (233-247 (± 4) Ma.) have an unknown source but were presumably reset by the basalt intrusion.

The sapphires from Mother Logans prospect were confirmed analytically.

A “Chrysoberyl” from Weld R, Moorina, was actually found to be an apatite.

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Two “rubies” from Weld R, Moorina were analysed : one was confirmed as a ruby but the other was a red spinel, something not previously recorded from Tasmania.

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Ruby and sapphire were also confirmed from the Penguin and Cygnet districts, suggesting these gems may be more widespread in Tasmania.

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Appendix 1: LA-ICPMS results, University of Tasmania

Representative analysis of pink "ruby"

Representative oxygen-free analysis from sample **G409289**, from near Penguin. Note presence of chromium (Cr), iron (Fe), silicon (Si) and titanium (Ti) impurities in this pink ruby. Spot size 51 microns.

File name	C20MAY01A0003.csv	C20MAY01A0004.csv	C20MAY01A0005.csv	C20MAY01A0006.csv	C20MAY01A0007.csv	C20MAY01A0008.csv	C20MAY01A0009.csv	C20MAY01A0010.csv	C20MAY01A0011.csv	C20MAY01A0012.csv
24Mg	0.038	0.037	0.038	0.037	0.039	0.039	0.038	0.035	0.039	0.039
27Al	**99.234**	**99.231**	**99.229**	**99.268**	**99.233**	**99.224**	**99.226**	**99.268**	**99.227**	**99.241**
29Si	0.142	0.143	0.138	0.136	0.128	0.141	0.136	0.129	0.120	0.120
31P	0.004	0.004	0.003	0.004	<0.002	<0.003	<0.002	0.003	0.003	0.003
44Ca	<0.001	0.002	0.002	0.002	0.001	<0.001	<0.001	0.001	0.001	0.001
49Ti	0.013	0.013	0.013	0.013	0.014	0.014	0.014	0.014	0.015	0.015
51V	0.006	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.006	0.006
53Cr	**0.372**	**0.383**	**0.377**	**0.355**	**0.383**	**0.380**	**0.388**	**0.370**	**0.398**	**0.386**
57Fe	**0.187**	**0.177**	**0.189**	**0.175**	**0.191**	**0.192**	**0.188**	**0.172**	**0.186**	**0.186**

Representative analysis of blue sapphire

Representative oxygen-free analyses of blue sapphire, sample G409289 Penguin district. Note presence of impurities, namely, ~1.3 wt% of iron (Fe), and ~0.04 wt% of gallium (Ga), common in natural gems, as well as a lack of or very low content of Cr and other elements. Spot size 51 microns.

Source Filename	C20MAY01A0013.csv	C20MAY01A0014.csv	C20MAY01A0015.csv	C20MAY01A0016.csv	C20MAY01A0017.csv	C20MAY01A0022.csv	C20MAY01A0023.csv	C20MAY01A0024.csv	C20MAY01A0025.csv	C20MAY01A0026.csv
Sample	G409289_blue	G409289_blue	G409289_blue	G409289_blue	G409289_blue	G409289_blue	G409289_blue	G409289_blue	G409289_blue	G409289_blue
24Mg	0.002	0.002	0.003	0.007	0.002	0.002	0.003	0.005	0.003	0.002
27Al	**98.579**	**98.604**	**98.456**	**98.290**	**98.583**	**98.588**	**98.369**	**98.557**	**98.438**	**98.604**
29Si	0.092	0.089	0.087	0.099	0.093	0.089	0.081	0.085	0.091	0.085
31P	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.005	<0.002	0.003
44Ca	0.001	0.002	<0.001	<0.001	0.001	0.002	0.001	0.001	<0.001	0.002
49Ti	0.008	0.006	0.023	0.013	0.008	0.008	0.029	0.009	0.027	0.007
51V	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
55Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr										
57Fe	**1.273**	**1.258**	**1.389**	**1.538**	**1.263**	**1.270**	**1.465**	**1.289**	**1.403**	**1.261**
71Ga	**0.041**	**0.035**	**0.038**	**0.049**	**0.044**	**0.037**	**0.046**	**0.046**	**0.036**	**0.035**

Representative oxygen-free composition of blue sapphire, sample **G409328** Penguin district. Note presence of impurities, namely, ~0.6 wt% of iron (Fe) and ~0.3 wt.% of Ga, as well as a lack of or very low content of other elements in these blue sapphires. Spot size 51 microns.

Source Filename	C20MAY01 A0050.csv	C20MAY01A 0051.csv	C20MAY01A 0062.csv	C20MAY01A 0063.csv	C20MAY01A 0064.csv	C20MAY01A 0065.csv	C20MAY01A 0066.csv
Sample	G409328_3	G409328_3	G409328_4	G409328_4	G409328_4	G409328_5	G409328_5
24Mg	0.000	0.000	0.002	0.001	0.002	0.000	0.000
27Al	**99.031**	**99.393**	**99.349**	**99.346**	**99.298**	**99.306**	**99.224**
29Si	0.087	0.101	0.090	0.096	0.087	0.096	0.090
31P	0.005	0.004	<0.002	<0.002	0.003	<0.003	0.003
44Ca	0.002	<0.001	<0.001	0.001	0.002	0.002	<0.001
49Ti	0.008	0.002	0.091	0.084	0.119	0.009	0.009
51V	0.000	0.000	0.002	0.002	0.002	0.001	0.001
53Cr	<0.000	0.001	0.001	0.002	0.002	<0.000	<0.000
57Fe	**0.776**	**0.479**	**0.418**	**0.421**	**0.429**	**0.565**	**0.652**
71Ga	**0.028**	**0.019**	**0.045**	**0.044**	**0.044**	**0.021**	**0.020**
93Nb	0.023	0.000	0.000	0.000	0.002	0.000	<0.000
118Sn	0.001	0.000	0.000	0.000	0.000	0.000	0.000
181Ta	0.036	0.000	0.001	0.001	0.009	0.000	0.000

Representative oxygen-free composition of blue sapphire, sample **G409328** Mother Logan Road Quarry. Note presence of impurities, namely, ~0.5-1 wt% of iron (Fe), and ~0.2 wt% of gallium (Ga), common in natural gems, as well as lack of or very low content of other elements in these blue sapphires. Spot size 51 microns.

Filename	C20MAY01 A0052.csv	C20MAY01 A0053.csv	C20MAY01 A0054.csv	C20MAY01 A0059.csv	C20MAY01 A0060.csv	C20MAY01 A0061.csv	C20MAY01 A0049.csv
Sample	G409328_1	G409328_1	G409328_1	G409328_2	G409328_2	G409328_2	G409328_3
27Al	**98.757**	**98.933**	**98.970**	**99.317**	**99.319**	**99.347**	**99.195**
29Si	0.101	0.095	0.118	0.093	0.095	0.091	0.100
31P	0.005	0.004	0.003	0.003	<0.002	0.004	0.005
49Ti	0.119	0.043	0.024	0.018	0.014	0.009	0.037
51V	0.001	0.000	0.000	0.001	0.001	0.001	0.000
57Fe	0.993	0.902	0.865	0.549	0.552	0.527	0.638
71Ga	0.021	0.020	0.019	0.018	0.018	0.019	0.024

Source Filename	C20MAY01A 0067.csv	C20MAY01A 0068.csv	C20MAY01A 0069.csv	C20MAY01A 0070.csv	C20MAY01A 0071.csv	C20MAY01A 0072.csv	C20MAY01A 0073.csv
Sample	G409328_5	G409328_6	G409328_6	G409328_6	G409328_7	G409328_7	G409328_7
7Li	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	0.000
9Be	<0.000	0.000	<0.000	0.000	<0.000	<0.000	0.000
11B	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23Na	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
24Mg	0.000	0.002	0.003	0.004	0.001	0.001	0.004
27Al	99.204	99.162	99.233	98.932	99.150	99.260	98.797
29Si	0.089	0.090	0.094	0.095	0.084	0.079	0.077
31P	<0.003	0.003	0.003	0.003	<0.003	0.003	0.003
39K	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
44Ca	0.002	<0.001	0.001	0.002	0.002	0.001	<0.001
45Sc	<0.000	0.000	0.000	0.000	0.000	0.000	0.000
49Ti	0.015	0.005	0.012	0.071	0.011	0.025	0.047
51V	0.001	0.003	0.002	0.003	0.004	0.003	0.006
53Cr	<0.000	<0.000	0.000	<0.000	0.000	0.000	<0.000
55Mn	<0.000	0.000	0.000	0.000	0.000	0.000	0.000
57Fe	0.668	0.702	0.631	0.860	0.723	0.607	0.967
59Co	<0.000	<0.000	<0.000	0.000	<0.000	<0.000	<0.000
60Ni	<0.000	0.000	<0.000	0.000	0.000	<0.000	<0.000
65Cu	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
66Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
71Ga	0.022	0.024	0.022	0.024	0.025	0.021	0.027
85Rb	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
88Sr	0.000	0.000	<0.000	0.000	<0.000	<0.000	<0.000
89Y	0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
90Zr	0.000	0.000	0.000	0.000	<0.000	0.000	0.000

Source Filename	C20MAY01A 0067.csv	C20MAY01A 0068.csv	C20MAY01A 0069.csv	C20MAY01A 0070.csv	C20MAY01A 0071.csv	C20MAY01A 0072.csv	C20MAY01A 0073.csv
Sample	G409328_5	G409328_6	G409328_6	G409328_6	G409328_7	G409328_7	G409328_7
93Nb	<0.000	0.001	0.000	0.001	<0.000	0.000	0.029
98Mo	<0.000	<0.000	<0.000	<0.000	<0.000	0.000	<0.000
118Sn	0.000	0.000	0.000	0.000	0.000	0.000	0.001
137Ba	<0.000	0.000	<0.000	0.000	0.000	<0.000	<0.000
139La	<0.000	0.000	0.000	0.000	0.000	<0.000	0.000
140Ce	<0.000	<0.000	<0.000	0.000	<0.000	<0.000	0.000
146Nd	0.000	<0.000	0.000	0.000	<0.000	<0.000	0.000
147Sm	<0.000	0.000	<0.000	<0.000	<0.000	<0.000	0.000
172Yb	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
178Hf	0.000	0.000	0.000	0.000	<0.000	<0.000	0.000
181Ta	0.000	0.007	0.000	0.003	0.000	0.000	0.041
182W	<0.000	<0.000	<0.000	0.000	0.000	<0.000	0.000
208Pb	0.000	<0.000	<0.000	0.000	<0.000	0.000	0.000
232Th	<0.000	<0.000	<0.000	0.000	<0.000	<0.000	0.000
238U	<0.000	<0.000	<0.000	0.000	<0.000	0.000	0.000

Source Filename	C20MAY01A00 34.csv	C20MAY01A00 35.csv	C20MAY01A00 36.csv	C20MAY01A00 44.csv	C20MAY01A00 45.csv	C20MAY01A00 46.csv
Sample	G410241_blue2	G410241_blue2*	G410241_blue2	G410241_blue4	G410241_blue4	G410241_blue4
Spot Size (μm)	51	51	51	51	51	51
7Li	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
9Be	<0.000	<0.000	0.000	<0.000	<0.000	<0.000
11B	0.000	0.000	0.000	0.000	0.000	0.000
23Na	<0.001	<0.000	<0.000	<0.000	<0.000	<0.000
24Mg	0.012	0.013	0.008	0.036	0.011	0.009
27Al	99.400	99.353	99.412	99.075	99.215	99.269
29Si	0.063	0.079	0.070	0.074	0.062	0.057
31P	<0.003	0.008	0.003	<0.002	0.002	0.002
39K	<0.000	<0.000	<0.000	<0.000	0.000	<0.000
44Ca	0.003	0.001	0.001	0.002	0.002	0.001
45Sc	0.000	0.000	0.000	<0.000	<0.000	<0.000
49Ti	0.090	0.081	0.115	0.081	0.154	0.139
51V	0.013	0.013	0.012	0.001	0.001	0.001
53Cr	0.052	0.059	0.044	0.024	0.024	0.027
55Mn	<0.000	0.000	<0.000	<0.000	<0.000	<0.000
57Fe	0.356	0.377	0.323	0.702	0.525	0.492
59Co	<0.000	0.000	0.000	0.000	0.000	0.000
60Ni	0.000	0.000	0.000	0.001	0.000	0.000
65Cu	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
66Zn	0.000	0.000	0.000	0.000	0.000	0.000
71Ga	0.010	0.011	0.010	0.004	0.003	0.003
85Rb	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
88Sr	<0.000	0.000	<0.000	<0.000	<0.000	<0.000
89Y	<0.000	0.000	0.000	<0.000	<0.000	<0.000

Source Filename	C20MAY01A0034.csv	C20MAY01A0035.csv	C20MAY01A0036.csv	C20MAY01A0044.csv	C20MAY01A0045.csv	C20MAY01A0046.csv
Sample	G410241_blue2	G410241_blue2*	G410241_blue2	G410241_blue4	G410241_blue4	G410241_blue4
90Zr	0.000	0.002	0.000	<0.000	0.000	0.000
93Nb	0.000	0.000	0.000	0.000	0.000	0.000
98Mo	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
118Sn	0.000	0.000	0.000	0.000	0.000	0.000
137Ba	<0.000	0.000	<0.000	0.000	0.000	<0.000
139La	0.000	0.000	0.000	0.000	<0.000	0.000
140Ce	0.000	0.001	0.000	<0.000	<0.000	0.000
146Nd	<0.000	0.000	<0.000	<0.000	<0.000	<0.000
147Sm	<0.000	0.000	<0.000	<0.000	<0.000	<0.000
172Yb	0.000	0.000	0.000	<0.000	<0.000	<0.000
178Hf	0.000	0.000	0.000	<0.000	<0.000	<0.000
181Ta	0.000	0.000	0.000	0.000	0.000	0.000
182W	0.000	0.000	0.000	0.000	0.000	<0.000
208Pb	0.000	0.000	0.000	0.000	0.000	0.000
232Th	0.000	0.000	0.000	<0.000	0.000	0.000
238U	<0.000	0.000	0.000	<0.000	<0.000	<0.000

* Many inclusions with light REE, Y, Zr, U, Pb, Th, do not use these elements!

Source Filename	C20MAY01A0047.csv	C20MAY01A0048.csv	C20MAY01A0027.csv	C20MAY01A0028.csv	C20MAY01A0029.csv	C20MAY01A0030.csv
Sample	G410241_blue4	G410241_blue4	G410241_pink1	G410241_pink1	G410241_pink1	G410241_pink1
Spot Size (µm)	51	51	51	51	51	51
7Li	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
9Be	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
11B	0.000	0.000	0.000	0.000	0.000	0.000
23Na	<0.000	<0.000	<0.001	<0.000	<0.000	<0.001
24Mg	0.012	0.010	0.051	0.036	0.037	0.036
27Al	99.282	99.242	99.102	99.232	99.228	99.238
29Si	0.062	0.059	0.163	0.125	0.125	0.122
31P	0.004	0.004	0.003	0.004	0.004	0.003
39K	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
44Ca	0.001	<0.001	0.001	0.001	0.001	0.001
45Sc	<0.000	<0.000	0.000	<0.000	<0.000	<0.000
49Ti	0.090	0.157	0.012	0.011	0.011	0.011
51V	0.001	0.001	0.003	0.004	0.004	0.004
53Cr	0.029	0.024	0.401	0.422	0.421	0.421
55Mn	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
57Fe	0.515	0.500	0.259	0.160	0.164	0.158
59Co	0.000	0.000	0.000	0.000	0.000	0.000
60Ni	0.000	0.000	0.001	0.000	0.000	0.000
65Cu	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
66Zn	0.000	0.000	0.000	0.000	0.000	0.000
71Ga	0.003	0.003	0.004	0.004	0.004	0.004
85Rb	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
88Sr	0.000	<0.000	0.000	0.000	<0.000	<0.000

Source Filename	C20MAY01A0047.csv	C20MAY01A0048.csv	C20MAY01A0027.csv	C20MAY01A0028.csv	C20MAY01A0029.csv	C20MAY01A0030.csv
Sample	G410241_blue4	G410241_blue4	G410241_pink1	G410241_pink1	G410241_pink1	G410241_pink1
89Y	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
90Zr	0.000	0.000	0.000	0.000	0.000	0.000
93Nb	0.000	0.000	0.000	<0.000	<0.000	0.000
98Mo	<0.000	<0.000	<0.000	<0.000	<0.000	0.000
118Sn	0.000	0.000	0.000	0.000	0.000	0.000
137Ba	0.000	0.000	<0.000	0.000	<0.000	<0.000
139La	0.000	<0.000	0.000	0.000	0.000	<0.000
140Ce	<0.000	0.000	<0.000	0.000	<0.000	0.000
146Nd	0.000	<0.000	<0.000	<0.000	<0.000	<0.000
147Sm	<0.000	<0.000	0.000	0.000	0.000	<0.000
172Yb	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
178Hf	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
181Ta	0.000	0.000	<0.000	<0.000	<0.000	<0.000
182W	0.000	0.000	0.000	<0.000	<0.000	<0.000
208Pb	0.000	0.000	0.000	0.000	0.000	0.000
232Th	0.000	<0.000	<0.000	<0.000	0.000	<0.000
238U	0.000	<0.000	<0.000	<0.000	<0.000	<0.000

Source Filename	C20MAY01A0037.csv	C20MAY01A0040.csv	C20MAY01A0041.csv	C20MAY01A0042.csv	C20MAY01A0043.csv	C20MAY01A0037.csv
Sample	G410241_yellow3	G410241_yellow3	G410241_yellow3	G410241_yellow3	G410241_yellow3	G410241_yellow3
	not Ruby	not Ruby	not Ruby	not Ruby	not Ruby	not Ruby
Spot Size (µm)	51	51	51	51	51	51
7Li	0.000	0.000	0.000	0.000	0.000	0.000
9Be	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
11B	0.022	0.020	0.016	0.018	0.020	0.022
23Na	0.004	0.003	0.002	0.004	0.006	0.004
24Mg	47.987	47.991	48.301	48.108	48.305	47.987
27Al	0.530	0.544	0.460	0.545	0.479	0.530
29Si	46.509	47.462	47.080	47.668	46.828	46.509
31P	0.006	0.006	0.005	0.006	0.008	0.006
39K	0.002	0.002	0.002	0.003	0.005	0.002
44Ca	0.020	0.022	0.021	0.024	0.025	0.020
45Sc	0.000	0.001	0.000	0.002	0.000	0.000
49Ti	0.006	0.008	0.005	0.011	0.005	0.006
51V	0.001	0.002	0.001	0.002	0.001	0.001
53Cr	0.126	0.184	0.145	0.291	0.188	0.126
55Mn	0.169	0.157	0.126	0.146	0.119	0.169
57Fe	4.312	3.293	3.502	2.908	3.672	4.312
59Co	0.006	0.006	0.006	0.005	0.005	0.006
60Ni	0.266	0.239	0.278	0.226	0.270	0.266
65Cu	0.000	0.000	0.000	0.000	0.001	0.000
66Zn	0.030	0.058	0.047	0.031	0.060	0.030
71Ga	0.000	0.000	0.000	0.000	0.000	0.000

Source Filename	C20MAY01A0037.csv	C20MAY01A0040.csv	C20MAY01A0041.csv	C20MAY01A0042.csv	C20MAY01A0043.csv	C20MAY01A0037.csv
Sample	G410241_yellow 3	G410241_yellow 3	G410241_yellow 3	G410241_yellow 3	G410241_yellow 3	G410241_yellow 3
	not Ruby	not Ruby	not Ruby	not Ruby	not Ruby	not Ruby
85Rb	0.000	0.000	0.000	0.000	0.000	0.000
88Sr	0.000	0.000	0.000	0.000	0.000	0.000
89Y	0.000	0.000	0.000	0.000	0.000	0.000
90Zr	0.000	0.000	0.000	0.000	0.000	0.000
93Nb	0.000	0.000	0.000	0.000	0.000	0.000
98Mo	0.000	0.000	0.000	0.000	0.000	0.000
118Sn	0.000	0.000	0.000	0.000	0.000	0.000
137Ba	0.000	0.000	0.000	0.000	0.000	0.000
139La	0.000	0.000	0.000	0.000	0.000	0.000
140Ce	0.000	0.000	0.000	0.000	0.000	0.000
146Nd	0.000	0.000	0.000	0.000	0.000	0.000
147Sm	0.000	0.000	0.000	0.000	0.000	0.000
172Yb	0.000	0.000	0.000	0.000	0.000	0.000
178Hf	0.000	0.000	0.000	0.000	0.000	0.000
181Ta	0.000	0.000	<0.000	0.000	0.000	0.000
182W	0.000	0.000	0.000	0.000	0.000	0.000
208Pb	0.002	0.002	0.002	0.003	0.003	0.002
232Th	0.000	0.000	0.000	0.000	0.000	0.000
238U	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1: Zircon dating by LA-ICPMS, University of Tasmania

file	reg no	Loc	age	+/-1 ster
			207 cor 206Pb/238U	
C20APR30A0042.csv	G410292-c	Black ck rd	91	4
C20APR30A0043.csv	G410292-c	Black ck rd	207	5
C20APR30A0047.csv	G410292-c	Black ck rd	216	3
C20APR30A0041.csv	G410292-c	Black ck rd	228	3
C20APR30A0027.csv	G410292-c	Black ck rd	235	4
C20APR30A0036.csv	G410292-c	Black ck rd	236	4
C20APR30A0035.csv	G410292-c	Black ck rd	238	4
C20APR30A0045.csv	G410292-c	Black ck rd	243	3
C20APR30A0046.csv	G410292-c	Black ck rd	245	3
C20APR30A0034.csv	G410292-c	Black ck rd	246	3
C20APR30A0050.csv	G410292-r	Black ck rd	74	6
C20APR30A0037.csv	G410292-r	Black ck rd	223	5
C20APR30A0048.csv	G410292-r	Black ck rd	230	3
C20APR30A0038.csv	G410292-r	Black ck rd	231	3
C20APR30A0040.csv	G410292-r	Black ck rd	234	4
C20APR30A0026.csv	G410292-r	Black ck rd	234	3
C20APR30A0039.csv	G410292-r	Black ck rd	236	4
C20APR30A0049.csv	G410292-r	Black ck rd	236	7
C20APR30A0044.csv	G410292-r	Black ck rd	238	5
C20APR30A0025.csv	G410292-r	Black ck rd	242	3
C20APR30A0054.csv	G410293-c	Mother Logans	42	5
C20APR30A0053.csv	G410293-c	Mother Logans	43	3
C20APR30A0073.csv	G410293-c	Mother Logans	43	4
C20APR30A0072.csv	G410293-c	Mother Logans	44	4
C20APR30A0074.csv	G410293-c	Mother Logans	44	1
C20APR30A0066.csv	G410293-c	Mother Logans	215	6
C20APR30A0067.csv	G410293-c	Mother Logans	238	4
C20APR30A0057.csv	G410293-c	Mother Logans	245	2
C20APR30A0062.csv	G410293-c	Mother Logans	246	2
C20APR30A0068.csv	G410293-c	Mother Logans	247	3
C20APR30A0051.csv	G410293-r	Mother Logans	41	2
C20APR30A0052.csv	G410293-r	Mother Logans	42	10
C20APR30A0069.csv	G410293-r	Mother Logans	43	2
C20APR30A0071.csv	G410293-r	Mother Logans	43	1
C20APR30A0070.csv	G410293-r	Mother Logans	44	2
C20APR30A0064.csv	G410293-r	Mother Logans	217	3

file	reg no	Loc	age	+/-1 ster
C20APR30A0065.csv	G410293-r	Mother Logans	233	6
C20APR30A0056.csv	G410293-r	Mother Logans	242	3
C20APR30A0055.csv	G410293-r	Mother Logans	246	2
C20APR30A0063.csv	G410293-r	Mother Logans	247	3
C20APR30A0100.csv	G410294-c	Main ck,	177	5
C20APR30A0099.csv	G410294-c	Main ck,	185	4
C20APR30A0096.csv	G410294-c	Main ck,	233	5
C20APR30A0095.csv	G410294-c	Main ck,	234	4
C20APR30A0091.csv	G410294-c	Main ck,	235	3
C20APR30A0084.csv	G410294-c	Main ck,	236	3
C20APR30A0080.csv	G410294-c	Main ck,	237	3
C20APR30A0092.csv	G410294-c	Main ck,	239	3
C20APR30A0079.csv	G410294-c	Main ck,	240	4
C20APR30A0078.csv	G410294-c	Main ck,	242	3
C20APR30A0098.csv	G410294-r	Main ck,	210	3
C20APR30A0081.csv	G410294-r	Main ck,	229	3
C20APR30A0083.csv	G410294-r	Main ck,	234	3
C20APR30A0082.csv	G410294-r	Main ck,	238	3
C20APR30A0076.csv	G410294-r	Main ck,	239	3
C20APR30A0075.csv	G410294-r	Main ck,	241	4
C20APR30A0094.csv	G410294-r	Main ck,	241	4
C20APR30A0077.csv	G410294-r	Main ck,	243	6
C20APR30A0093.csv	G410294-r	Main ck,	245	3
C20APR30A0097.csv	G410294-r	Main ck,	259	5
C20APR30A0124.csv	G410295-c	Frome R	226	4
C20APR30A0113.csv	G410295-c	Frome R	232	4
C20APR30A0104.csv	G410295-c	Frome R	238	5
C20APR30A0108.csv	G410295-c	Frome R	239	2
C20APR30A0125.csv	G410295-c	Frome R	239	3
C20APR30A0112.csv	G410295-c	Frome R	240	3
C20APR30A0124.csv	G410295-c	Frome R	240	2
C20APR30A0122.csv	G410295-c	Frome R	242	4
C20APR30A0103.csv	G410295-c	Frome R	242	4
C20APR30A0107.csv	G410295-c	Frome R	242	2
C20APR30A0123.csv	G410295-c	Frome R	245	2
C20APR30A0114.csv	G410295-c	Frome R	246	4
C20APR30A0121.csv	G410295-r	Frome R	224	3
C20APR30A0105.csv	G410295-r	Frome R	231	2
C20APR30A0101.csv	G410295-r	Frome R	238	4
C20APR30A0110.csv	G410295-r	Frome R	238	4
C20APR30A0109.csv	G410295-r	Frome R	239	4
C20APR30A0102.csv	G410295-r	Frome R	239	4
C20APR30A0106.csv	G410295-r	Frome R	240	2

file	reg no	Loc	age	+/-1 ster
C20APR30A0111.csv	G410295-r	Frome R	240	3
C20APR30A0120.csv	G410295-r	Frome R	242	2
C20APR30A0119.csv	G410295-r	Frome R	243	2
C20APR30A0149.csv	G410296-c	Weld R	186	3
C20APR30A0132.csv	G410296-c	Weld R	212	4
C20APR30A0133.csv	G410296-c	Weld R	228	3
C20APR30A0150.csv	G410296-c	Weld R	237	3
C20APR30A0139.csv	G410296-c	Weld R	239	3
C20APR30A0128.csv	G410296-c	Weld R	241	4
C20APR30A0129.csv	G410296-c	Weld R	241	3
C20APR30A0138.csv	G410296-c	Weld R	241	3
C20APR30A0137.csv	G410296-c	Weld R	246	3
C20APR30A0141.csv	G410296-r	Weld R	118	4
C20APR30A0127.csv	G410296-r	Weld R	218	5
C20APR30A0134.csv	G410296-r	Weld R	234	5
C20APR30A0130.csv	G410296-r	Weld R	237	3
C20APR30A0136.csv	G410296-r	Weld R	239	4
C20APR30A0140.csv	G410296-r	Weld R	239	3
C20APR30A0131.csv	G410296-r	Weld R	241	3
C20APR30A0126.csv	G410296-r	Weld R	241	4
C20APR30A0148.csv	G410296-r	Weld R	243	3
C20APR30A0135.csv	G410296-r	Weld R	244	4

Appendix 3: Ar/Ar Geochronology report

Commented [CT4]: Another Extract?

Report UM20-0801

$^{40}Ar/^{39}Ar$ step-heating analysis of basanite groundmass sample R013378/NJ449

E. Matchan

School of Earth Sciences The University of Melbourne Parkville, VIC, 3010.

January 2020

1. Introduction

John Everard, Mineral Resources Tasmania supplied a basanite whole-rock specimen, NJ449 R013378, to UoM (Erin Matchan) for $^{40}Ar/^{39}Ar$ dating. John Everard inspected petrographic thin-sections prepared from the core of the specimen and observed “some very minor brown alteration (probably hisingerite) of olivine, and also immediately adjacent to a few hair-line fractures, but we can’t detect any glass.”

2. Analytical procedures

A groundmass concentrate was prepared using standard crushing, sieving, de-sliming and magnetic separation methods. Grains were hand-picked under binocular microscope, avoiding visibly altered fragments and phenocrysts/xenocrysts. Grains were cleaned in an ultrasonic batch with 5% HNO_3 (10 min ´ 2), followed by de-ionised water and acetone. Samples were enclosed in aluminium foil packets and placed into a quartz glass irradiation canister (Can UM#88) together with aliquots of the neutron flux monitor Fish Canyon Tuff (FCT) sanidine (Age = 28.1260 ± 0.0093 Ma (1σ); Phillips et al., 2017). The canister was irradiated for 40 MWhr in the CLICIT facility of the Oregon State University TRIGA reactor, USA.

After irradiation, the mineral separate was removed from its packaging and aliquots of ~5 mg were placed into a custom-designed copper laser sample tray. $^{40}Ar/^{39}Ar$ step-heating analyses were carried out on a Thermofisher ARGUSVI multi-collector mass spectrometer following procedures previously described by Matchan and Phillips (2014). Samples were outgassed using the 6 mm beam homogenized beam of a Photonmachines Fusions 10.6 CO_2 continuous wave laser operated at low power (1–2%) to remove the bulk of atmospheric argon and were then step-heated over 3– 35% laser power. Blanks were monitored routinely and subtracted from sample measurements. Blanks were negligible compared to sample signals (2–6 f A ^{40}Ar blank compared to typical sample values of 500–2000 fA; **Table A1**). Analytical results are summarised below and detailed in the data appendix (**Table A1 & A2**). Unless otherwise stated, reported uncertainties are two standard deviations. Inclusion of errors in the J-value and age of flux monitor (FCT sanidine) have a negligible impact on uncertainties. Decay constants are those of Steiger & Jaeger (1977). The ^{40}Ar/^{39}Ar dating technique is described in detail by McDougall and Harrison (1999).

3. ^{40}Ar/^{39}Ar Analytical Results

The four aliquots analysed (R013378/NJ449-1,-2,-3 and -4) produced discordant age spectra characterised by younger apparent age for the initial 1–2 steps (18(±1)-43.7(±0.2) Ma) followed by a broad decrease in apparent ages from 47.2(±0.1)–49.5(±0.1) Ma to 41.4(±0.1)–42.0(±0.1) Ma with increasing temperature (**Fig. 1**). Aliquots R013378/NJ449-2 and R013378/NJ449-3 yielded slightly older apparent ages of 42.6 ±0.3 Ma and 43.4 ±0.1 Ma, respectively, for the final heating (fusion) steps (**Fig. 1b,c**).

Total gas ages are slightly discordant at the 2s-level: 45.4 ± 0.1 Ma (R013378/NJ449- 1), 44.1 ± 0.2 Ma (R013378/NJ449-2), 43.7 ± 0.1 Ma (R013378/NJ449-3), and 44.8 ± 0.1 Ma (R013378/NJ449-4).

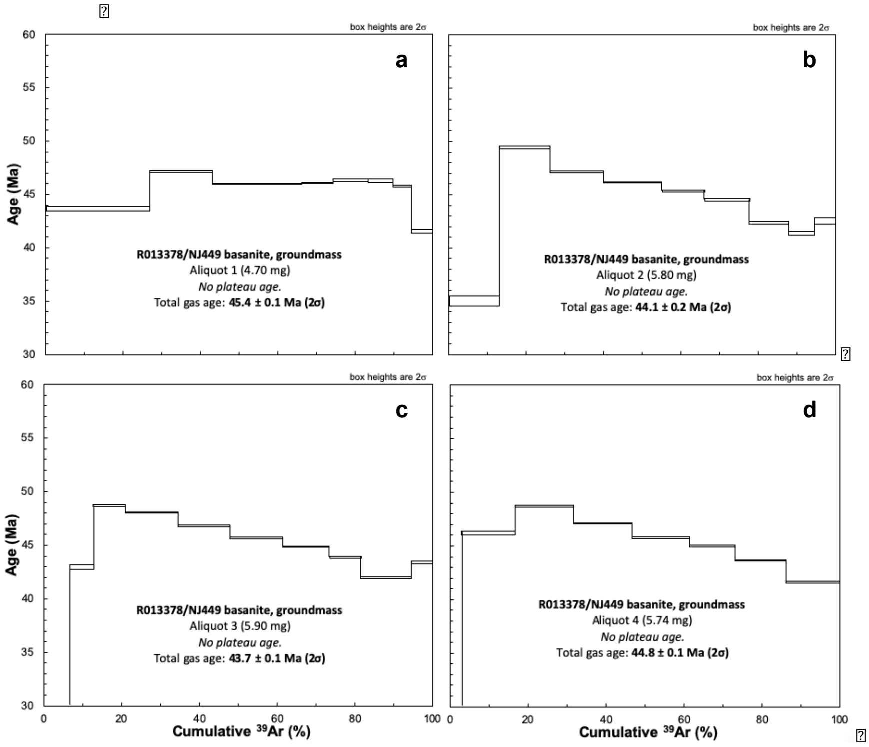

Figure 1. $^{40}Ar/^{39}Ar$ age spectra for N3449 R013378, groundmass aliquots.

Robust inverse isochrons could not be generated due to the high-scatter of data in $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ space (**Fig. 2**). The intermediate data (steps 3–8) for the aliquot with least discordant age spectrum, R013378/NJ449-1, yield a non-robust (as indicated by the high mean square weighted deviation (MSWD) value) inverse isochron (**Fig. 2a**) with an age of 46.15 ± 0.49 Ma (95% CI; MSWD = 14, p = 0) and a corresponding atmospheric $(^{40}Ar/^{36}Ar)_i$ value of 300.2 ± 9.6 (95% CI).

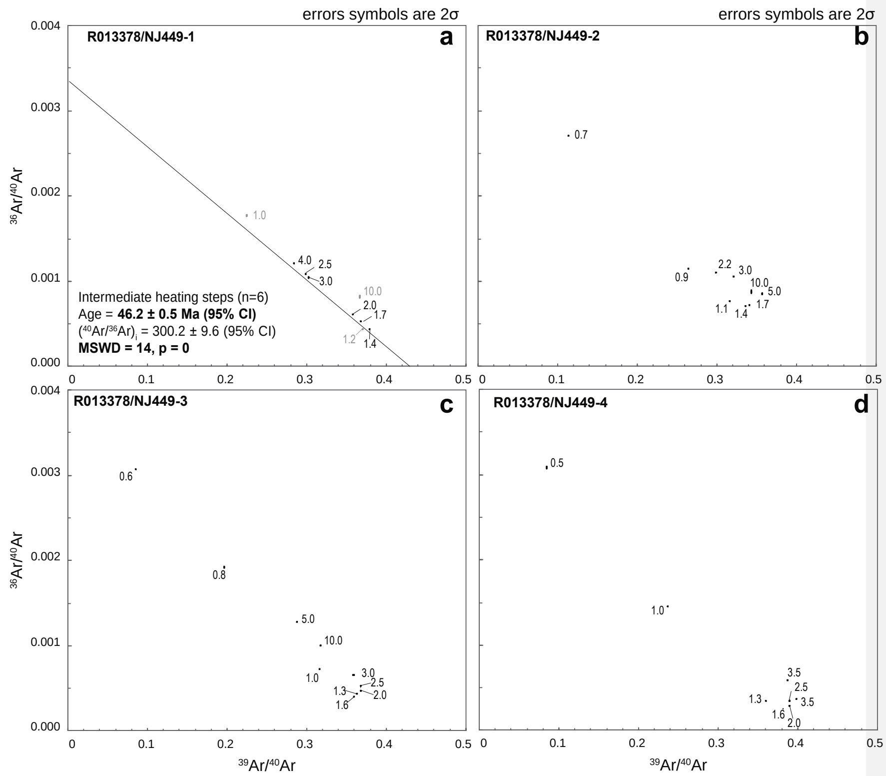

Figure 2. Step-heating data for N3449 R013378 groundmass aliquots as plotted in $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ space. Laser power (%) annotated for each heating step. An inverse isochron could be constructed only for the intermediate heating steps (n=6) of R013378/NJ449-1 (rejected steps indicated in grey).

4. Discussion

Young initial apparent ages followed by largely decreasing apparent ages are often observed for fine-grained mafic volcanic groundmass samples (e.g. Jourdan and Renne, 2014; Heath et al., 2018). This pattern is widely considered to reflect sub-micrometer scale nuclear recoil of ^{39}Ar and ^{37}Ar between fine-grained K-rich/Ca-poor and K-poor/Ca-rich phases during neutron irradiation, leading to decoupling of $^{40}Ar^{*}/^{39}Ar$ ratios referred to as 'argon recoil loss/redistribution'. ^{39}Ar recoil loss/redistribution in particular affects argon isotope systematics such that inverse isochron analysis is compromised and can serve only as a first-order check for the presence of excess ^{40}Ar in the samples. Absolute initial ($^{40}Ar/^{36}Ar$) ratios

(($^{40}Ar/^{36}Ar)_i$) values are unreliable for severely recoil-affected samples, as are inverse isochron ages. For this reason, the crystallisation age is predicted to be intermediate between the oldest and youngest apparent ages for the descending portion of the age spectrum, and the total gas age is thus considered a good approximation for the crystallization age (Jourdan and Renne, 2014). The increase to slightly older apparent ages for the fusion steps of Aliquots #1 and #2 may reflect outgassing of solid inclusions containing small amounts of extraneous ^{40}Ar. Assuming that argon recoil redistribution is the cause of the descending age spectrum shape, and that there has been no significant amount of ^{39}Ar- or ^{40}Ar-loss, the total gas ages should approximate the crystallisation age. The atmospheric ($^{40}Ar/^{36}Ar)_i$ value (300.2 ± 9.6 (95% CI; MSWD = 14, p = 0) defined by the intermediate heating steps of aliquot R013378/NJ449-1 supports negligible ^{39}Ar- or ^{40}Ar-loss, and negligible excess ^{40}Ar. The total gas ages for each aliquot are slightly discordant at the 2s-level, ranging from 43.7 ±0.1 Ma to 45.4 ±0.1 Ma (2σ), giving a non-robust weighted mean value of 44.6 ±1.3 Ma (95%CI; MSWD = 207; p = 0) and an arithmetic mean of 44.5 Ma. A range of 42.0(±0.1)–47.2(±0.1) Ma (2σ), defined by the youngest age yielded by the first step of the descending portion of an age spectrum (R013378/NJ449-1b) and the oldest age yielded by the final step of the descending portion (R013378/NJ449-3i). Given the discordance of the total gas ages, the range of **42.0(±0.1)–47.2(±0.1) Ma (2σ)** is considered a more conservative and reliable estimate for the crystallisation age than the narrower total gas age range.

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Appendix 4: SAPPHIRES in Tasmania

Commented [CT5]: Is this an extract? Is it needed here?

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Many significant occurrences of sapphire are known in Tasmania. and most of these occur in alluvial tin-bearing Cainozoic sediments in northeast Tasmania (Bottrill, 1996, McGee, 2005, Bottrill & Mathews, 2006, Sutherland & Webb, 2007, Bottrill & Baker, 2008). Small scale mining and prospecting is periodically undertaken for sapphires but many were recovered as a by-product of alluvial tin mining operations in northeast Tasmania, most of which ceased in the 1970s. Van Dieman Mines plc initiated mining operations near Gladstone in northeast Tasmania particularly for cassiterite and sapphire, but the operations closed before there was any significant production.

The sapphires are typically a medium to dark blue (~80%), but range from colourless to yellow, green, pink, purple and black. Star sapphires and pale ruby or pink sapphires have been recorded in several areas. Parti-coloured stones are not uncommon, usually with blue and yellow-green colours. One stone with a pink triangular core and a blue outer zone has been seen. The largest recorded sapphire is a 52.8 g (264 carats) parti-coloured stone from the Weld River area, but most are much smaller (Bottrill & Baker, 2008).

They are most abundant in the north-eastern tin fields, particularly in the Ringarooma River drainage basin at Branxholm, Derby, Gladstone, Lottah, George River, Moorina, Mt Stronach, Mt Cameron, Thomas Plain and especially the Weldborough - Weld River area (Bottrill, 1996; Fig. 1). Cassiterite, topaz, zircon, olivine (“peridot”) and black “pleonaste” spinel are typically associated, plus sparse green “cats-eye” chrysoberyl. These minerals may have mixed sources, some from Devonian granitoids (cassiterite, zircon and topaz) whilst olivine and spinel are sourced from Paleogene basalts (Yim et al., 1985). Various forms of gem quartz can be found in many sapphire-bearing gravels including rock crystal, amethyst, citrine, rose quartz and smoky quartz, probably mostly derived from Devonian and older rocks. Minor almandine, andalusite and gold locally occur in association. Other areas with sapphires reported include The Lisle goldfield, Coles Bay and Launceston in the northeast, Cygnet and Huonville in the southeast, Adamsfield in the southwest and Boat Harbour - Sisters Creek, Blythe River, Table Cape, Bell Mount, Stanley River, and Heazlewood River in the northwest (Bottrill and Baker, 2008, Bottrill and Mathews, 2006, Bottrill, 1996, Fig. 1).

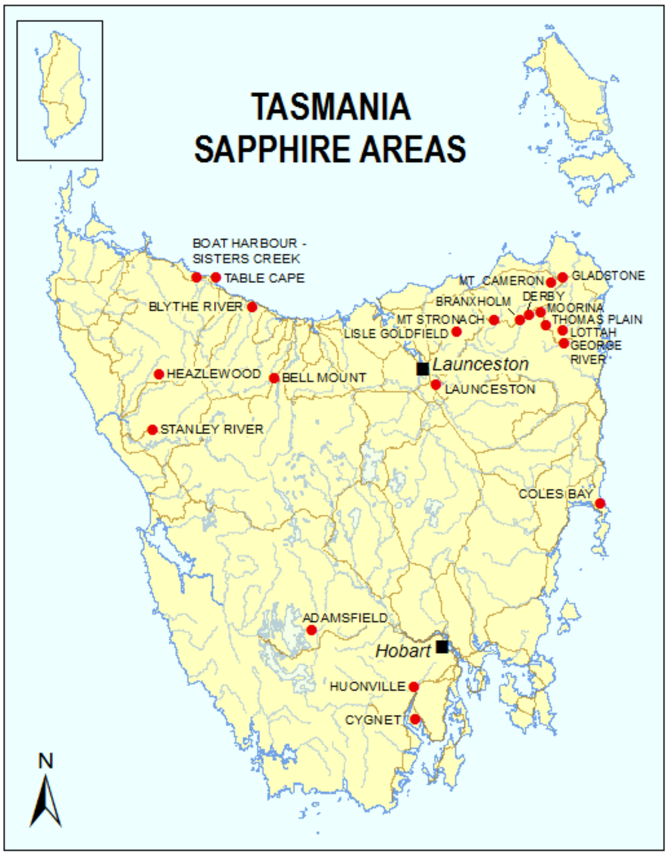

Fig. 1. Sapphire locations in Tasmania.

Ruby has also been reported rarely from the tin workings in northeastern Tasmania, but has not been confirmed chemically or mineralogically (Tasmania Department of Mines, 1970). Some of these stones may actually be red zircons (W. L. Mathews, pers. comm.), although Boyd Sweeney, a gemmologist, has stated (pers. comm.) that he has received a positive response to a Chelsea Filter optical test for ruby on one pink stone.

Mineral Resources Tasmania

Some source rocks for the sapphires have recently been determined. One probable direct source rock is small plug of inclusion-rich basalt of possible breccia pipe origin surrounded by Devonian granite on Logans Road, near Priory, east of St Helen's, which has been found to have sapphires as detrital grains in the surrounding headwater drainage as well as abundant pleonaste spinel, zircon, pyroxene and olivine. The mineral grain shapes are juvenile with little or no transport abrasion and are obviously adjacent to source. This area is undisturbed by tin mining. During the search for sapphires in the drainage, it became apparent that the creeks contained variably weathered boulders and pebbles of the adjacent basalt with many mineral grains emergent and readily identifiable on the soft, brown weathered surfaces. Eventually, with persistence, a 7mm blue to grey sapphire, as a single subrounded/subangular grain with a distinct parting, was found partly exposed in an a weathered, inclusion-rich basalt pebble (Figs. 2 & 3) by a prospector, Michael Lloyd (Duncan & Lloyd, 2013). Thus at least some of the Tasmanian sapphires have a basaltic source.

The sapphire sources in other areas are uncertain but Tertiary (Paleogene) basalt flows are present in most of the sapphire-bearing drainage basins, eg. the Ringarooma River valley and with most occurrences in the Northwest of Tasmania. The basalts include some eruptive centres, locally containing xenoliths of peridotite (some with spinel), and sparse felsic clasts like anorthoclasite and sanidinite. These rocks suggest a deep crustal source similar to some of the related sapphire occurrences in Queensland (Robertson & Sutherland, 1992).

Fig. 2. Sapphire in weathered basalt pebble, Logans Road Area. Field of view about 12cm.

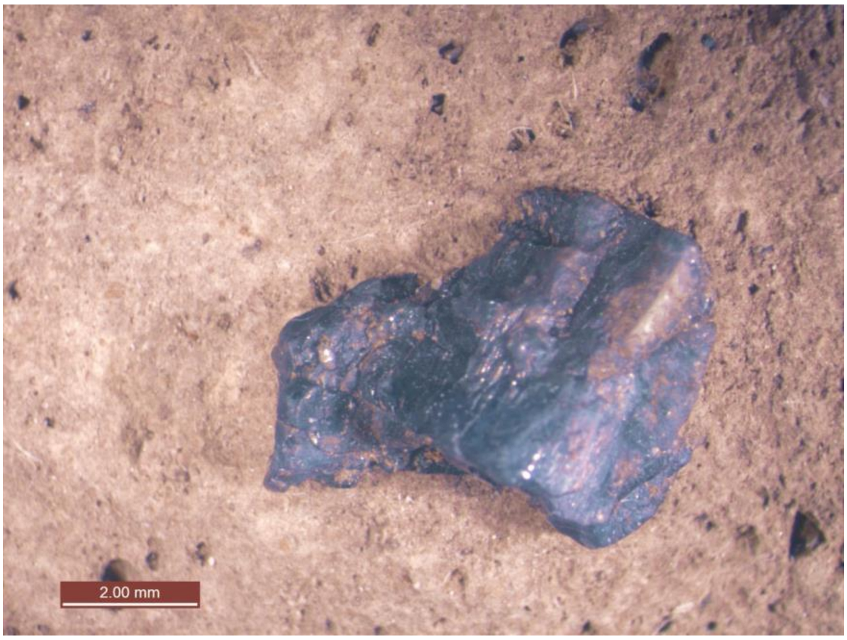

Fig. 3 Sapphire (close up of above sapphire). Field of view about 3cm.

Mineral Resources Tasmania

McGee (2005) studied the sapphires from Weldborough and found they contain olivine, feldspar, spinel, zircon, molybdenite and Nb-Ta-rich phases as mineral inclusions. The composition of zircon inclusions indicates a highly evolved source. Primary fluid inclusions indicate a minimum trapping pressure of 4.5 kbar at 1000 to 1200ºC. LA-ICPMS analysis indicates the sapphires have Fe, Ti, Ga and Ta as the most abundant trace elements; Cr, Be, Mg, V and Nb are low. Two element associations were recognised in the sapphires: an Fe-V-Ga association and an Nb-Ta-Be association, the latter consistent with either a granite pegmatite or a carbonatite origin. O-isotope values of + 4.4 ‰ to + 6.3 ‰, indicate the sapphires are in O-isotope equilibrium with mantle rocks, with little or no crustal interaction. The zircon inclusions in the sapphires have a U-Pb age of 47± 4 Ma which is identical to the age of the (Eocene) Weldborough basalts, indicating they have been reset during entrainment in basaltic magma. In summary, McGee considered the Weldborough sapphires were probably sourced in carbonatitic rocks of the upper mantle and entrained and brought to the surface by the Weldborough basalts 47 million years ago.

Khin Zaw, et al. (2006) also found sapphires from Weldborough to be magmatic with CO_2-rich fluid inclusions and Fe and Ti as chromophores. Geochronology on companion zircons suggests several sources (from 290 Ma to 47 Ma) which were intruded and sampled by post Eocene basaltic melts (<47 Ma). The valley basalts are mostly Miocene in age (<23 Ma).

Another potential sapphire source is within the Cambrian Mt Read Volcanics in the Bond Range, Central North Tasmania, where corundum – andalusite - diaspore rocks occur in intensely altered felsic volcanics, although gem quality sapphires have not been found in this occurrence (Bottrill, 1998).

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Appendix 5. Whole rock analyses

MRT Reg No	R013378	75/375	76/854	
Field No	NJ449	MBT13	MBT128	
Analysis No.	20100107	20080316	762462	
Other ID	Logans Rd	Halfway Hill		
mEgda94	595052	597312	597312	
mNgda94	5436443	5435006	5434883	
SiO2	43.36	44.45	44.70	
TiO2	2.28	2.60	2.60	
Al2O3	13.09	14.50	14.80	
Fe2O3	2.83	3.39	3.30	
FeO	8.20	7.80	8.30	
MnO	0.19	0.21	0.21	
MgO	11.70	8.15	7.70	
CaO	9.80	9.01	8.70	
Na2O	3.66	3.95	4.80	
K2O	1.37	2.23	1.20	
P2O5	0.74	0.81	0.87	
H2O+	2.44	2.16	1.90	
H2O-	nd	nd	0.12	
CO2	0.10	0.10	nd	
S	<0.01	nd	nd	
SO3	<0.02	0.02	nd	
Cl	0.02	nd	nd	
TOTAL	**99.76**	**99.39**	**99.20**	
LOI*	1.63	1.39		
Mg# (0.20)*	69.61	61.25	58.97	

	R013378	75/375	76/854	76/854
trace method	*XRF*	*XRF*	*XRF*	*ICPMS*
Li	nd	nd	29	*8.32*
Be	nd	nd	nd	*3.47*
Sc	20	17	nd	*18.41*
Ti	nd	nd	nd	*17993*
V	190	155	134	*170.75*
Cr	490	230	326	*232.32*
Co	54	47	41	*38.11*
Ni	310	165	145	*152.46*
Cu	60	54	52	*54.46*
Zn	89	100	100	*94.34*

	R013378	75/375	76/854	76/854
trace method	*XRF*	*XRF*	*XRF*	*ICPMS*
Ga	18	21	nd	*17.11*
As	5	<20	nd	*nd*
Rb	33	63	45	*52.67*
Sr	900	1350	1180	*1100.56*
Y	27	34	33	*33.62*
Zr	250	380	339	*316.14*
Nb	76	105	85	*134.48*
Mo	6	6	nd	*9.13*
Cd	nd	nd	nd	*0.06*
Sn	2	<9	nd	*3.7*
Sb	<2	nd	nd	*0.15*
Cs	<3	nd	nd	*0.68*
Ba	450	620	660	*537.38*
La	53	78	nd	*67.68*
Ce	105	130	nd	*119.32*
Pr	nd	nd	nd	*14.62*
Nd	49	62	nd	*53.4*
Sm	nd	nd	nd	*9.59*
Eu	nd	nd	nd	*3.01*
Gd	nd	nd	nd	*8.56*
Tb	nd	nd	nd	*1.22*
Dy	nd	nd	nd	*6.4*
Ho	nd	nd	nd	*1.16*
Er	nd	nd	nd	*3.04*
Yb	nd	nd	nd	*2.55*
Lu	nd	nd	nd	*0.36*
Hf	nd	nd	nd	*6.49*
Ta	nd	nd	nd	*9.72*
W	<2	<10	nd	*2.5*
Pb	2	<10	nd	*4.78*
Bi	2	<5	nd	*nd*
Th	6	11	nd	*8.67*
U	2	<10	nd	*2.38*
CIPW norms*				
or	8.33	13.58	7.32	
ab	8.49	11.59	19.12	
an	15.69	15.69	15.73	
ne	12.67	12.41	12.32	
di	23.65	20.28	18.65	
ol	22.19	16.64	16.80	
mt	2.72	2.75	2.85	

	R013378	75/375	76/854	76/854
trace method	*XRF*	*XRF*	*XRF*	*ICPMS*
il	4.46	5.10	5.08	
ap	1.80	1.97	2.05	
total	**100.00**	**100.00**	**99.92**	
An(plag) mol%	63.52	56.06	43.67	
****calculated at Fe2O3/FeO = 0.20***				