Tasmanian Geological Survey
Record 2013/04

Felsic porphyry sills in Surprise Bay Formation near Currie, King Island, dated at ~775 Ma (LA-ICPMS, U-Pb on zircon)

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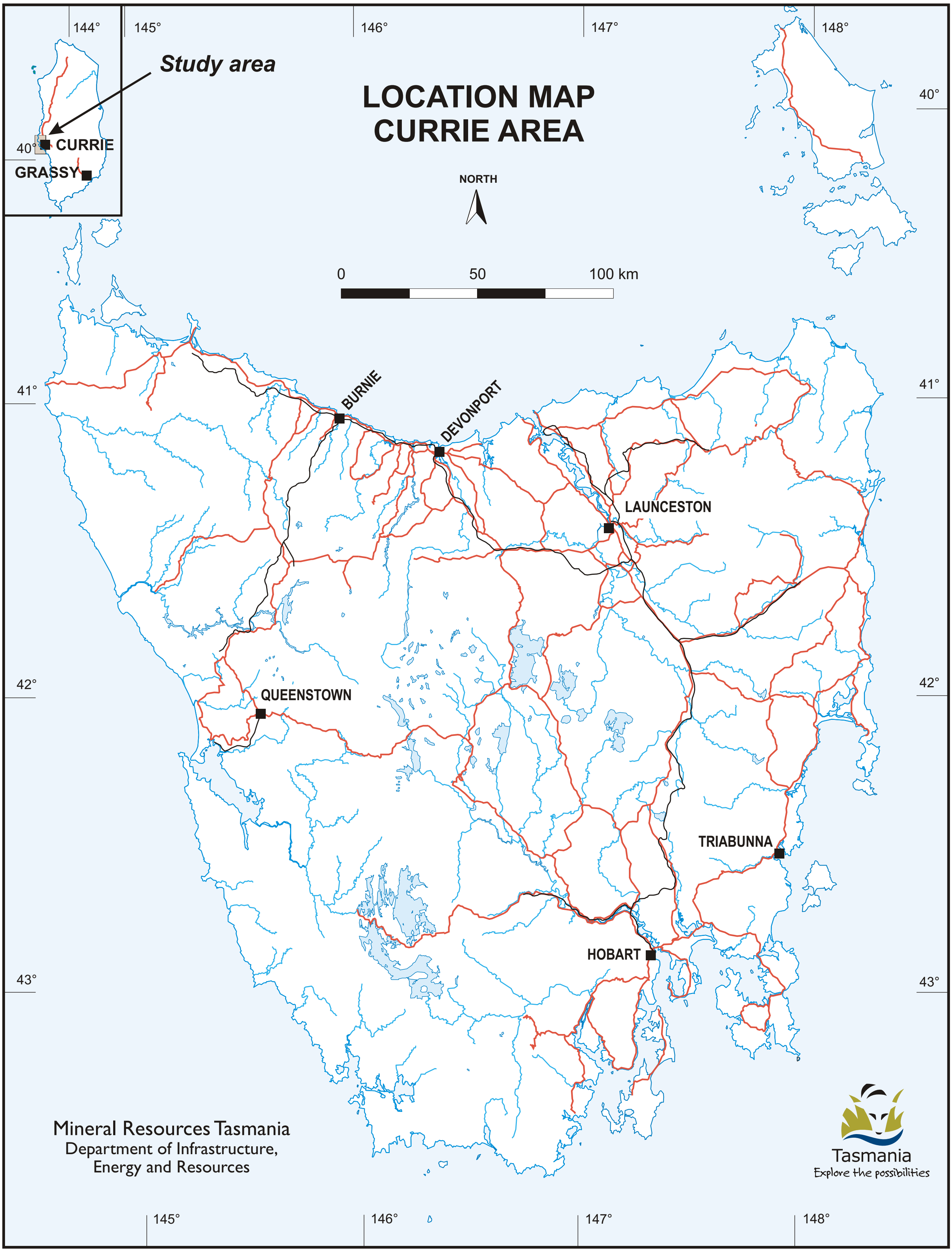

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Abstract

A correlate of the Mesoproterozoic (c. 1300 Ma) Surprise Bay Formation, outcropping on the west coast of King Island near Currie, contains numerous thin (0.1–10 m) sills of quartz-feldspar porphyry. Two of these have been dated by U-Pb on zircon, using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS), at c. 776 ± 6 and 772 ± 7 Ma. Geochemical data are equivocal on the question of a petrogenetic relationship with the nearby Loorana Granite (748 ± 2 Ma) and Cape Wickham Granite (760 ± 12 Ma).

Introduction

The metasediments of the Surprise Bay Formation, at c. 1300 Ma, are amongst the oldest rocks known in the southeast Australia region. These rocks record a tectono-metamorphic event at ~1290 Ma (Berry *et al*., 2005), as yet unknown on mainland Tasmania, that gave rise to amphibolite-facies metamorphism and pervasive deformation (Blackney, 1982). A maximum age constraint for the Surprise Bay Formation is given by the age of the youngest detrital zircons (~1350 Ma, Black *et al*., 2004). Together with the Cryogenian granites that intrude them, the metasediments make up the western half of King Island.

Geological mapping of the Currie coastal area in 2011–2012 (Calver and Everard, 2013*a*; fig. 1) revealed the presence of a number of thin (0.1–10 m), conformable bodies of quartz-feldspar porphyry within a faulted inlier of Surprise Bay Formation rocks. The porphyry bodies appear to contain the same layer-parallel primary foliation as the enclosing metasediments. The porphyries were initially interpreted as possible pyroclastic layers coeval with sedimentation, and two samples were submitted to CODES for LA-ICPMS dating. Both returned early Cryogenian dates close to 775 Ma. They are now considered to be sills, possibly comprising an early phase of the magmatism that produced the Cryogenian granites. The penetrative foliation in this inlier is inferred to post-date the regional D_1.

Figure 1

Simplified outcrop map of the Currie inlier, with locations of felsic porphyry outcrops and sample numbers.

Geological setting

A sequence correlated with the Surprise Bay Formation extends along the coast from Netherby Point to Johnson Rock, near Currie (fig. 1). Bedding mainly dips steeply west, and is right-way-up (youngs to the west). The sequence has a faulted N–S contact with the Loorana Granite to the east, known as the Currie Fault, which is exposed as a mylonite zone in several places. The Surprise Bay Formation correlate here comprises an inlier (the Currie inlier) that is separate from the rest of the formation that lies to the east of the Loorana Granite. Tectono-metamorphic grade is relatively low in the Currie inlier, with pelites being phyllite or cleaved mudstone rather than schist, although 0.5 mm porphyroblasts of garnet are locally present. There is no indication of contact metamorphism from the Loorana Granite. The succession consists of interbedded, laminated siliceous siltstone, fine-grained quartzose sandstone and cleaved mudstone or phyllite. Sedimentary features typical of turbidites are common. Overall, there is a very similar association of lithologies and sedimentary facies to the type section of the Surprise Bay Formation in the Surprise Bay area (Calver and Everard, in prep.).

A few (?Meso–Neoproterozoic) metadolerite dykes are present, and there is an undeformed quartz-feldspar porphyry dyke of probable Carboniferous age at Netherby Point (Calver and Everard, 2013*a*).

Felsic porphyry sills

A total of twelve felsic sills were noted within the Surprise Bay Formation correlate between Netherby Point and Johnson Rock (fig. 1). These are generally 1–2 m thick, but range from 150 mm to 10 m thick. Few can be followed more than a few tens of metres along strike because of outcrop limitations and minor faulting. The porphyry is medium grey, weathering to pale grey or brown, with a strong layer-parallel foliation (fig. 2, 3). Phenocrysts (1–2 mm) of quartz, feldspar and minor biotite comprise 10% to 30% of the rock, in a fine-grained foliated groundmass. Some of the sills contain rafts of metasediment up to two metres long, similar to the enclosing succession. Some sills have aphyric contact zones 100–150 mm wide. Tops and bases of the sills may be sharp, or appear gradational with the enclosing sediment. Most sills appear perfectly conformable with enclosing bedding, but local slight discordance was recorded (fig. 4). The felsic porphyry sills have not been observed anywhere else in the Surprise Bay Formation (i.e. east of the Loorana Granite). Granitic sills and dykes are locally common near intrusive contacts with Cryogenian granite (e.g. at Cape Wickham) but these are of undeformed granite, microgranite and pegmatite.

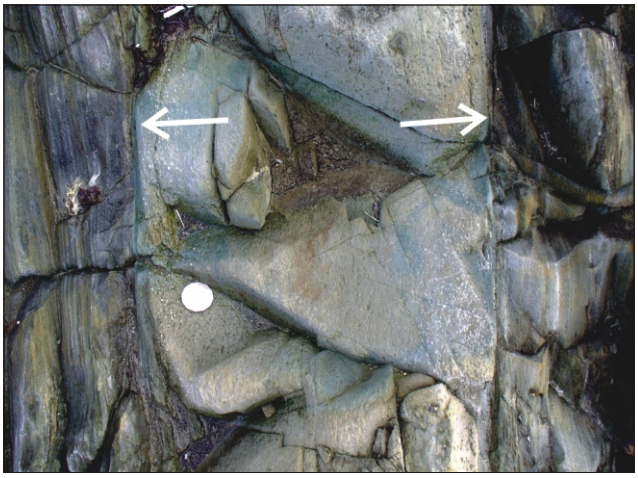

Figure 2
400 mm thick felsic porphyry sill near Currie breakwater (see Figure 1 for location). Contacts arrowed.

Figure 3
Three metre thick felsic porphyry sill (see Figure 1 for location). Contacts arrowed.

Thin sections show phenocrysts of variably altered, subhedral K-feldspar up to 3 mm, quartz (up to 2 mm) with typically rounded and embayed outlines, minor brown biotite, and minor plagioclase. The abundant groundmass consists of fine-grained quartz, sericite, feldspar and biotite, and the texture varies from sample to sample. In samples N122 and N142 a rough anastomosing cleavage overprints possible poorly preserved shards (fig. 5). The groundmass of N125 has well-defined phyllitic seams up to 1 6 mm, orientated parallel to cleavage, that could be entirely of tectonic origin, or could be deformed clasts (fig. 6). The groundmass in other samples has a poorly defined, patchy heterogeneity that resembles altered lithic or vitric clasts.

The foliation present in all samples is an anastomosing seamed cleavage. The same deformation has also caused brittle fracture and extension of some feldspars, and strain (undulose extinction, lenticular shapes) of quartz phenocrysts. The phenocrysts show no evidence of rotation (simple shear). The possible pyroclastic origin of the groundmass microtextures in samples N122, N142 and N125, and the conformity of the felsic porphyry bodies with bedding, led to an initial interpretation as possible ash beds, and prompted submission of two samples to CODES for zircon dating to directly date the depositional age of the Surprise Bay Formation.

Figure 4
Slightly discordant western contact (arrowed) of the sill in Figure 3, looking north.

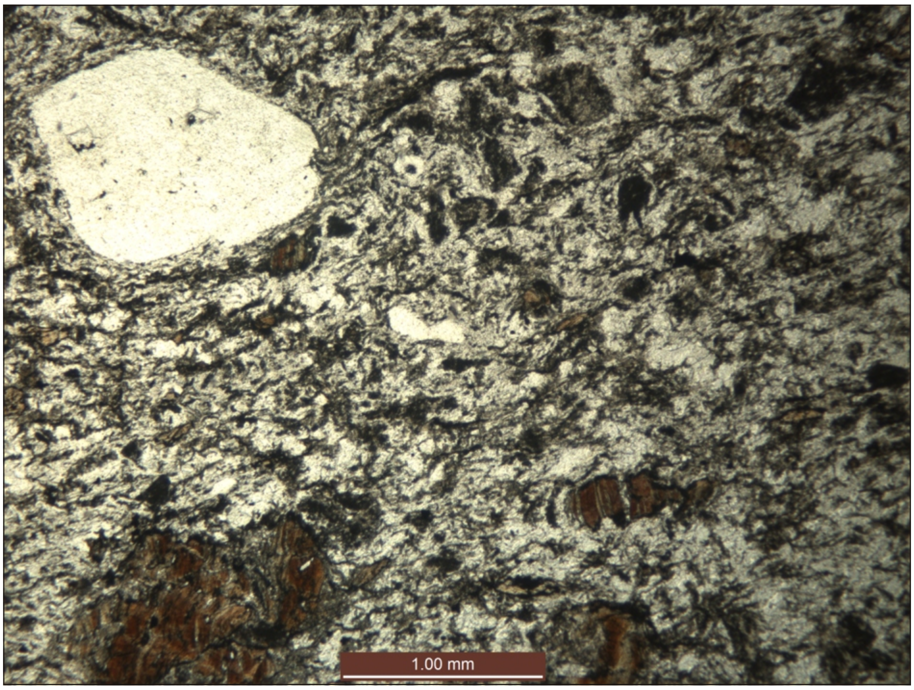

Figure 5
Thin section microphotograph (plane-polarised light) of dated sample N122, showing phenocrysts of rounded quartz and biotite, and inhomogeneous groundmass texture with possible shard textures.

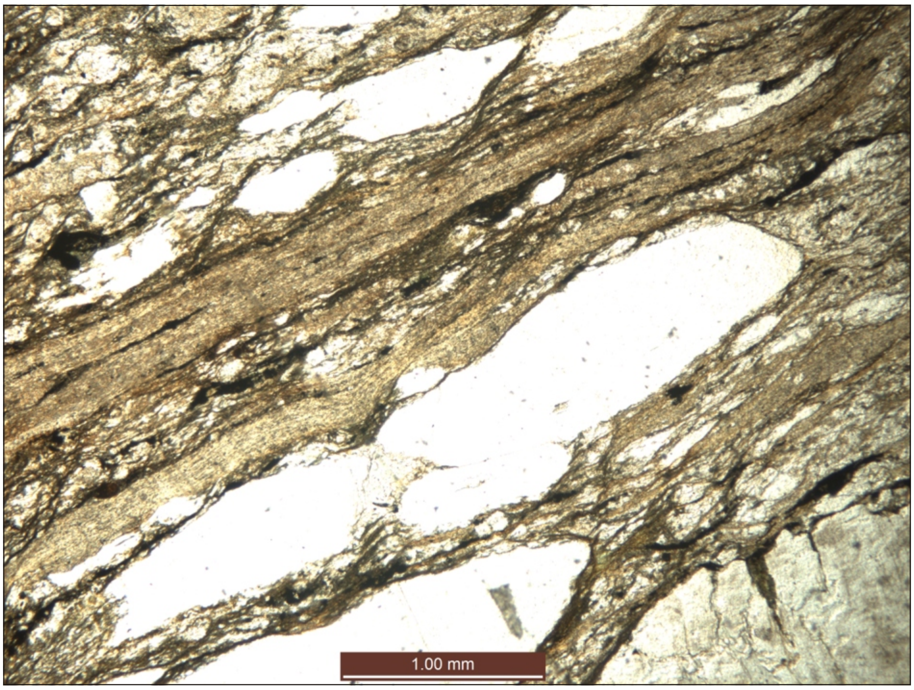

Figure 6
Thin section (plane-polarised light) of sample N125, showing broad phyllitic seams alternating with quartz-rich and feldspar-rich domains.

Geochronology

U-Pb geochronology was performed at the University of Tasmania using the LA-ICPMS technique. The zircons were separated using a gold pan and a hand magnet from 200 g of rock powder crushed to a coarse sand using a ring mill. The zircons were hand-picked from the non-magnetic concentrate, 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 zircons (Wiedenbeck *et al*., 1995) were used as primary standard and the Temora, Gj1 and Plesovice zircons (Black *et al*., 2003; Jackson *et al*., 2004; Sláma *et al*., 2008) were used as secondary standards. 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).

The zircons from both samples are dominated by a single age population centred around 776 Ma, with concordant inherited cores ranging in age between 1530 and 1700 Ma (Table 1). The data from sample N122 suggest that a small amount of Pb loss has occurred and three of the analyses from sample N154 plot on discordia between the Paleoproterozoic and the Neoproterozoic, suggesting that the laser sampled both inherited core and rim in a single analysis (fig. 7*a*).

The most precise ages (^{206}Pb/^{238}U) suggest crystallisation at 776 ± 6 and 772 ± 7 Ma (2) for samples N154 and N122 respectively. It is possible that these ages could be slightly too old as the analyses are slightly reversely discordant, with the average ^{206}Pb/^{207}Pb age of non-inherited zircons from both samples combined averaging 763 ± 8 Ma (fig. 7*b*).

Table 1

Isotopic and age data from LA-ICPMS analysis of zircons in samples N154 and N122

	age (Ma) $^{206}Pb/^{238}U$	±1 se	$^{206}Pb/^{238}U$ ratio	±1 rse	$^{208}Pb/^{232}Th$ ratio	±1 rse	$^{207}Pb/^{206}Pb$ ratio	±1 rse	^{204}Pb ppm	^{206}Pb ppm	^{207}Pb ppm	^{208}Pb ppm	^{232}Th ppm	^{238}U ppm	^{178}Hf ppm
N154															
MA28A125	**763**	**8**	0.1256	1.1%	0.0374	1.6%	0.0658	1.6%	0.00	92	6	11	280	709	11 157
MA28A115	**768**	**6**	0.1265	0.8%	0.0374	1.3%	0.0644	0.6%	0.00	133	9	11	297	1074	14 259
MA28A119	**767**	**6**	0.1264	0.8%	0.0382	1.3%	0.0640	0.7%	0.00	120	8	13	338	959	12 005
MA28A124	**770**	**7**	0.1270	0.9%	0.0377	1.3%	0.0647	0.8%	0.02	158	10	12	318	1237	13 637
MA28A126	**771**	**7**	0.1270	0.9%	0.0386	1.3%	0.0642	0.8%	0.00	116	7	12	318	941	12 520
MA28A120	**775**	**7**	0.1277	0.9%	0.0367	1.5%	0.0636	0.9%	0.03	70	4	6	176	558	11 657
MA28A129	**776**	**8**	0.1280	1.1%	0.0393	1.6%	0.0656	0.7%	0.11	124	8	13	321	977	13 418
MA28A117	**780**	**7**	0.1286	0.9%	0.0381	1.3%	0.0648	0.7%	0.00	148	10	14	366	1176	13 054
MA28A116	**782**	**6**	0.1290	0.8%	0.0390	1.3%	0.0638	0.6%	0.00	119	8	12	320	937	12 616
MA28A127	**788**	**7**	0.1300	0.9%	0.0378	1.3%	0.0641	0.9%	0.04	90	6	8	223	714	12 750
MA28A128	**793**	**7**	0.1308	0.9%	0.0402	1.3%	0.0644	0.8%	0.00	96	6	11	267	749	12 701
MA28A118	944	9	0.1577	0.9%	0.0486	1.5%	0.0763	0.9%	0.00	94	7	10	202	583	12 199
MA28A123	956	15	0.1599	1.5%	0.0559	1.5%	0.0766	1.2%	0.01	106	8	12	234	713	12 546
MA28A122	1733	17	0.3085	1.0%	0.0875	1.2%	0.1033	0.5%	0.02	135	14	21	244	449	10 177
MA28A121	1325	15	0.2282	1.1%	0.0744	1.5%	0.0959	1.3%	0.12	109	10	15	192	463	12 992
Mean of 11 analyses (**bold**) = 776 ± 6 Ma 95% conf. MSWD 1.7															
N122															
MA28A109	**742**	**7**	0.1220	0.9%	0.0457	1.6%	0.0803	1.3%	0.15	115	9.1	23.6	526	963	11 113
MA28A099	**724**	**7**	0.1188	0.9%	0.0367	1.5%	0.0644	1.0%	0.00	116	7.5	11.4	299	949	13 080
MA28A100	**750**	**7**	0.1233	0.9%	0.0360	1.3%	0.0647	1.0%	0.01	49	3.2	9.0	251	408	11 747
MA28A105	**759**	**7**	0.1250	0.9%	0.0398	1.6%	0.0644	1.0%	0.00	64	4.1	4.5	113	525	14 109
MA28A098	**761**	**7**	0.1252	0.9%	0.0374	1.3%	0.0649	0.7%	0.00	131	8.5	18.7	499	1053	12 159
MA28A097	**768**	**7**	0.1265	0.9%	0.0378	1.4%	0.0649	0.9%	0.00	65	4.2	4.9	130	520	13 987
MA28A111	**771**	**7**	0.1270	0.9%	0.0403	1.2%	0.0655	0.7%	0.03	126	8.2	12.9	322	1011	13 199
MA28A110	**771**	**7**	0.1270	0.9%	0.0374	1.3%	0.0655	0.8%	0.07	111	7.3	15.8	427	896	11 565
MA28A108	**772**	**7**	0.1272	0.9%	0.0380	1.3%	0.0648	0.7%	0.02	134	8.7	15.0	393	1073	12 395
MA28A101	**774**	**6**	0.1275	0.8%	0.0381	1.3%	0.0648	0.7%	0.02	115	7.5	12.4	325	919	12 352
MA28A107	**783**	**10**	0.1291	1.2%	0.0398	1.7%	0.0645	1.2%	0.00	83	5.4	11.1	294	696	10 663
MA28A104	**787**	**8**	0.1298	1.0%	0.0399	1.4%	0.0641	1.2%	0.00	72	4.6	12.2	319	588	11 474
MA28A103	**789**	**7**	0.1302	0.9%	0.0385	1.4%	0.0647	0.9%	0.02	56	3.6	5.8	151	441	11 537
MA28A106	799	7	0.1319	0.9%	0.0403	1.3%	0.0655	0.8%	0.00	112	7.4	14.9	360	837	12 220
MA28A102	1532	18	0.2683	1.2%	0.0738	2.2%	0.0960	1.9%	0.14	81	7.8	8.3	104	293	12 043
Mean of 10 analyses (**bold**) = 772 ± 7 Ma 95% conf. MSWD 2.0															

Abbreviations: se = standard error, rse = relative standard error, ppm = parts per million of each isotope

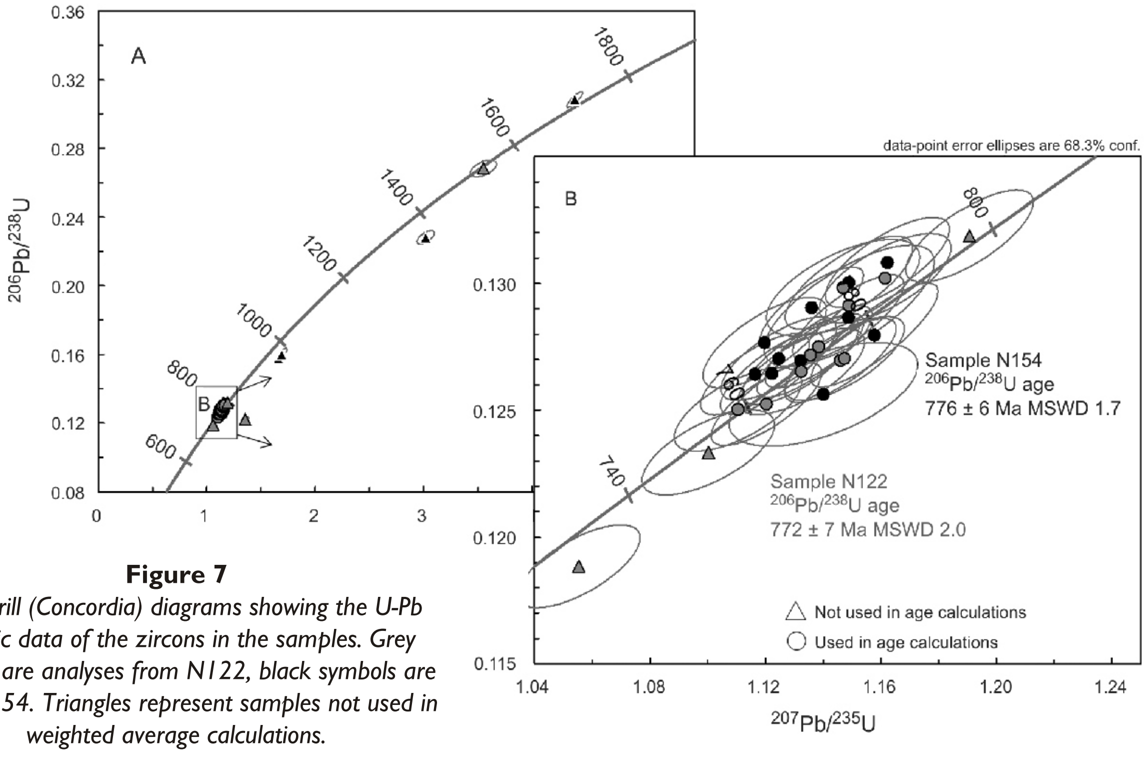

Figure 7

Wetherill (Concordia) diagrams showing the U-Pb isotopic data of the zircons in the samples. Grey symbols are analyses from N122, black symbols are from N154. Triangles represent samples not used in weighted average calculations.

Geochemistry

Major and trace element contents of porphyry sample N192 were determined at Mineral Resources Tasmania by standard XRF techniques. The sample is broadly andesitic, and notable for its high K_2O/Na_2O (Table 2). Some loss of Na_2O and/or addition of K_2O during weathering and alteration may be possible, but assuming that the analysis represents a magmatic composition, it falls in the S_3 (trachyandesite) field of the IUGS total alkali-silica classification for volcanic rocks (Le Maitre, 2002). Because of its potassic character ($K_2O > Na_2O - 2$), it may be termed a latite. It is also moderately peraluminous (alumina saturation index, i.e. molar $Al_2O_3/(Na_2O + K_2O + CaO)$ = 1.094).

The trace element data are notable for strongly anomalous arsenic (As 830 ppm), suggesting the presence of minor arsenopyrite, and weakly anomalous W (21 ppm) and Sn (11 ppm).

An obvious question is the possible relationship of the porphyry sills to the Loorana Granite, against which the enclosing sequence is faulted to the east. Compared to twelve analyses of fresh or weakly altered Loorana Granite samples (Table 2), the porphyry is markedly lower in SiO_2 (58.6% v. 66.9–73.7%), whereas most other major and trace elements are higher. Two analyses of mafic enclaves within the granite (from Cataraqui Point and near Porky Creek, respectively) more closely match the porphyry for some elements (e.g. TiO_2, Fe_2O_3, MgO, CaO, Sc and Cr), but also have higher SiO_2 than, and lack the strongly potassic character of, the porphyry.

A mantle-normalised incompatible element plot (fig. 8) shows a strong resemblance between the porphyry dyke and the Cryogenian Loorana and Cape Wickham granites; both units show marked negative Ba, Nb and Ti anomalies and a positive Pb anomaly. This, however, is a typical crustal signature and does not necessarily imply a petrogenetic link between the porphyry and the granites; for example a similar pattern is displayed by the Carboniferous Sandblow Granite and other unrelated Tasmanian Devonian granites (fig. 9).

There are few other rocks of andesitic composition known from King Island. About 250 m east of the mouth of Dromedary Creek (234 767 mE, 5 554 101 mN, zone 55 GDA94), in the south of the island, a metadolerite sill in the Surprise Bay Formation contains narrow subparallel (~250 mm) fine-grained felsic dykes. An analysis of one of these dykes (sample KE825b, Table 2) differs from the quartz porphyry sill near Currie in several important respects, notably K_2O/Na_2O, Rb and Sr contents. Any correlation with the andesitic sills of the Grimes Intrusive Suite (~575 ± 5 Ma) or microgranodiorite dykes in the Sandblow Granite (~350.8 ± 1.7 Ma) is immediately ruled out on age grounds.

Pods of sodic granitoid enclosed in the Bowry Formation, within the Arthur Metamorphic Complex of northwest Tasmania, yielded an almost identical age of 777 7 Ma (U-Pb SHRIMP on zircon, Turner *et al.*, 1998), but these are dissimilar in many major and trace elements to the western King Island porphyry.

Discussion

The ~775 Ma dates on the felsic porphyries clearly imply an intrusive, rather than pyroclastic origin for these rocks, given that Berry *et al.* (2005) demonstrated a c. 1290 Ma age for syn-D_1 metamorphic monazite in the Surprise Bay Formation in the Surprise Bay–Fitzmaurice Bay area. The ambiguous groundmass textures (fig. 5, 6) may in large part be due to disjunctive S_1 cleavage development. An alternative interpretation, that the porphyries are pyroclastic layers in a ~775 Ma sedimentary sequence, is not favoured here because of the strong lithologic similarities of the Currie inlier with the Surprise Bay Formation of the Surprise Bay–Fitzmaurice Bay area (Calver and Everard, in prep.).

The new dates on the felsic porphyry sills raise a problem with respect to the age of local D_1 in the Currie inlier. The strong cleavage in the sills is subparallel to layering and to the penetrative S_1 foliation in the enclosing phyllites. It may be inferred that the primary cleavage in the Currie area is younger than 775 Ma, although Berry *et al.* (2005) dated the primary S_1 schistosity in the Surprise Bay–Fitzmaurice Bay area at ~1290 Ma. There is a clear implication that the penetrative S_1 cleavage in the Currie inlier does not correlate with S_1 elsewhere in the Surprise Bay Formation. The former also differs from S_1 elsewhere, in that F_1 hinges (and S_0/S_1 intersection lineations) plunge steeply NW rather than gently north or south, as in the rest of the Surprise Bay Formation (Calver and Everard, in prep.).

Although the porphyry sills have a similar incompatible trace element chemistry to that of the Loorana Granite, the age dating and the major element chemistry rules out a direct relationship. The dating shows that felsic magmatism in western King Island extends back to ~775 Ma. Granitoids with an almost identical age are known from northwest Tasmania (Turner *et al.*, 1998; Holm *et al.*, 2003), but are geochemically quite different. Magmatic rocks of this age are rare outside this region; in mainland Australia, they are restricted to a few localities such as a tuffaceous sedimentary unit (Preiss, 2000) and a micro-granite dyke in the Adelaidean sequences of South Australia (Preiss *et al.*, 2009). Zircons of this age are also not well represented within the local detrital zircon populations; the 740–780 Ma period generally forms a prominent trough in probability density diagrams (e.g. those of Berry *et al.*, 2001; Black *et al.*, 2004; Squire *et al.*, 2006). Magmatism in this region at this age is thought to be related to the protracted and multi-stage rifting of Rodinia (Holm *et al.*, 2003; Wang and Li, 2003). Magmatic rocks and detrital zircons of this age are common in South China, with some studies arguing for correlation between the two regions (Wang and Li, 2003).

Table 2

Analytical data (major elements in %; trace elements in ppm) of the porphyry sill sample N192, the Loorana Granite, enclaves within the Loorana Granite, felsic dyke at Surprise Bay, and the granitoids within the Bowry Formation (Turner et al., 1998)

	porphyry sill	Loorana Granite*			enclaves		dyke	Bowry Formation granitoid			
	N192	mean	min	max	KE1494	KE2498A	KE825b	NC483	NC486	NC487	0005**
SiO_2	58.59	69.18	66.92	73.69	66.73	64.52	62.04	74.26	70.92	64.94	66.81
TiO_2	0.70	0.48	0.23	0.63	0.58	0.70	0.76	0.63	0.85	1.66	1.00
Al_2O_3	19.04	14.75	13.67	15.56	15.70	15.81	17.89	11.97	12.49	13.18	12.61
Fe_2O_{3tot}	4.83	3.32	1.76	4.11	4.67	5.50	6.04	2.34	4.12	7.94	5.38
MnO	0.07	0.05	0.02	0.06	0.06	0.08	0.05	0.01	0.03	0.02	0.03
MgO	2.21	1.13	0.41	1.53	1.87	2.47	1.15	0.90	2.43	1.69	2.22
CaO	3.63	2.03	0.59	3.37	3.82	3.95	1.42	0.19	0.12	0.58	1.43
Na_2O	2.67	2.58	2.23	3.09	3.43	3.00	7.16	7.93	6.79	8.79	7.26
K_2O	5.92	4.81	3.40	6.19	1.99	2.38	1.22	0.25	0.27	0.16	0.07
P_2O_5	0.16	0.14	0.11	0.15	0.13	0.14	0.07	0.17	0.19	0.44	0.19
SO_3	0.12	0.02	0.00	0.07	0.02	0.00	0.05	0.04	0.04	0.51	1.29
LOIC	1.50				0.79	0.76	1.60	0.73	1.78	0.96	2.01
Total	**99.44**				**99.79**	**99.31**	**99.45**	**99.42**	**100.03**	**100.87**	**100.30**
S	0.05	0.01	0.01	0.03	0.01	0	0.02				5180
Cl	0.02	0.04	0.012	0.067	0.062	0.039	0.019				
Sc	13	8.8	4	13	14	17	18	-9	18	20	17
V	75	44.8	10	63	69	83	91	41	78	195	110
Cr	61	25.1	7	35	64	60	59	67	44	80	5
Co	7		-2	8	10	11	13	-8	-8	17	
Ni	9	6.7	2	9	13	16	22	14	15	13	9
Cu	8	9.4	2	22	10	3	23	6	16	71	17
Zn	86	41.3	25	61	60	72	76	19	19	14	8
Ga	24	17.9	15	19	21	19	23	17	19	20	20
As	830		-3	7	2	7	5	-20	-20	-20	1
Rb	390	255.7	114	350	213	260	35	6	8	9	3
Sr	195	102.8	47	165	101	82	436	13	6	12	13
Y	37	35.9	24	42	34	29	53	52	56	66	46
Zr	250	183.4	120	210	239	250	255	500	450	340	341
Nb	19	17.4	15	21	19	18	20	29	23	24	22
Mo	-1		-1	1	1	-1	1	-5	-5	-5	
Sn	11	3.2	2	5	2	2	4	-9	-9	-9	4
Sb	3		1	4	-2	-2	1	-10	-10	-10	
Cs	20	9.2	3	15	18	13	1				
Ba	680	496.6	220	650	110	185	458	23	-23		15
La	76	50.7	31	83	95	32	59	13.87	-26	40.86	12
Ce	135	106.5	70	163	167	65	112	40.48	72	85.77	3
Nd	51	47.4	35	65	69	35	52	29.4	24	47.28	17
W	21	2.7	1	4	1	-2	2	23	-10	40	
Pb	42	23.0	11	35	10	8	11	-11	-11	-11	
Bi	1		-1	1	-1	-1	-1	-5	-5	-5	
Th	24	23.5	16	40	21	21	23	21	-10	-10	16
U	11	7.8	4	13	4	4	4	-12	-12	-12	2.5

* based on 12 fresh or slightly altered samples

Bowry Formation granitoid samples from Rocky River, N. J. Turner data, except:

** AGSO sample 93220005

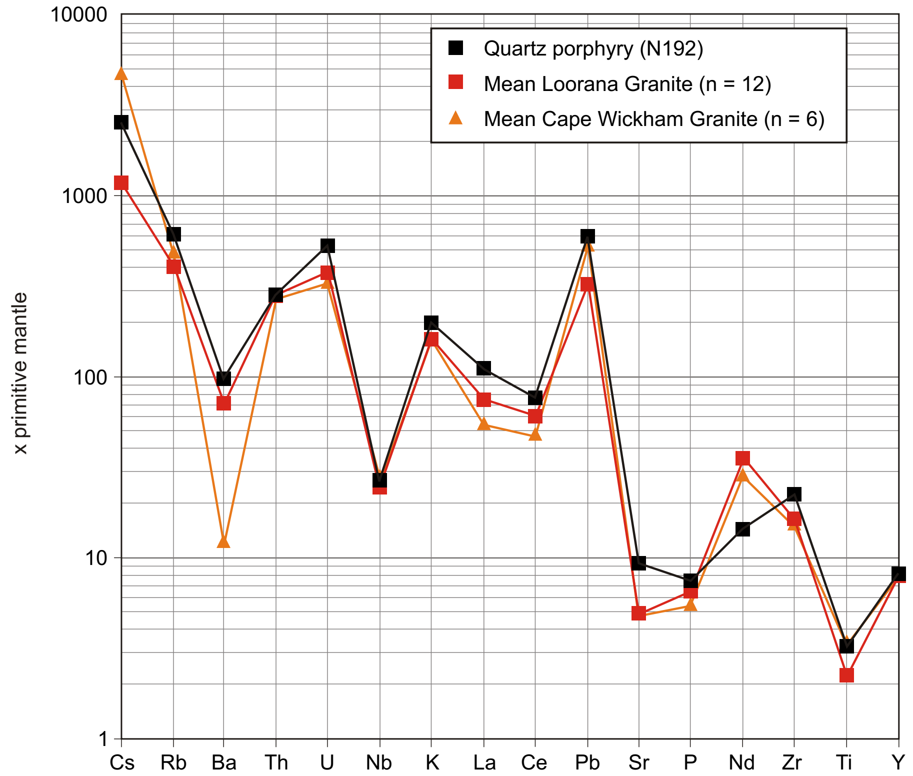

Figure 8

Mantle-normalised incompatible element plot comparing porphyry dyke sample N192 with the Loorana and Cape Wickham granites (MRT, XRF data). Mantle normalisation factors from Sun and McDonough (1989).

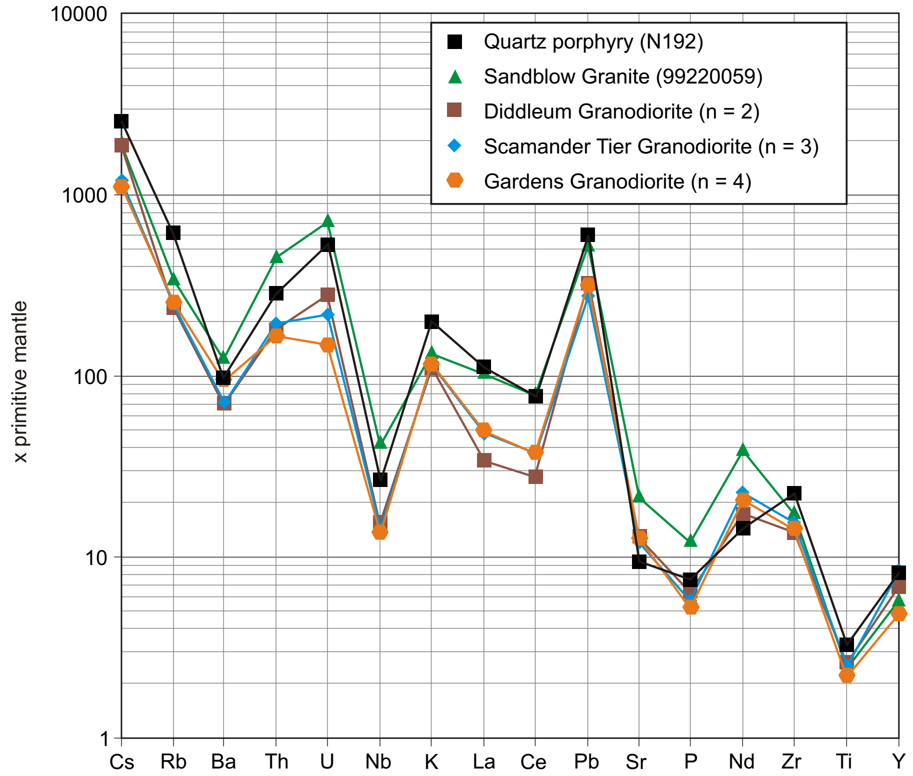

Figure 9

Mantle-normalised incompatible element plot comparing porphyry dyke sample N192 with unrelated Tasmanian Carboniferous–Devonian granites (Geoscience Australia, trace element data by ICPMS).

Acknowledgements

An earlier draft of this report was improved following review by A. N. McNeill.

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[19 August 2013]