Zircon U-Pb dating of Mesozoic volcanic and tectonic events in Northwest Palmer Land and Southwest Graham Land, Antarctica

P.T. LEAT[1*], M.J. FLOWERDEW[1], T.R. RILEY[1], M.J. WHITEHOUSE[2]
J.H. SCARROW[3] and I.L. MILLAR[4]

[1]British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK

[2]Swedish Museum of Natural History, Box 50007, S-104 05 Stockholm, Sweden

[3]Department of Mineralogy and Petrology, University of Granada, Campus Fuente Nueva Granada 18002, Spain

[4]NERC Isotope Geosciences Laboratory, Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG, UK

**ptle@bas.ac.uk*

Abstract: New whole rock Rb-Sr and zircon U-Pb geochronological data and Sm-Nd isotopic data are presented from the central magmatic arc domain of the Antarctic Peninsula in the area of northwest Palmer Land and southwest Graham Land, Rb-Sr isochrons indicate an age of 169±6 Ma for basement orthogneisses and 132±9 to 71±9 Ma for plutons. A U-Pb age of 183 ± 2.1 Ma, with no detectable inheritance, on zircons from an orthogneiss from Cape Berteaux provides the first reliable age for the orthogneisses, which are interpreted as metamorphosed silicic volcanic rocks, and Sm-Nd data indicate derivation in a mature volcanic arc. The age indicates they may be correlatives of the Jurassic 'Chon Aike' volcanism of the eastern Antarctic Peninsula. A U-Pb zircon age of 107 ± 1.7 Ma on a terrestrial volcanic sequence overlying an uncomformity strongly suggests a mid-Cretaceous age for the extensive volcanic cover of northwest Palmer Land that was previously thought to be Jurassic. The unconformity is interpreted to have been a result of compressional uplift related to the Palmer Land event. This is the first date for the event in the western part of the central magmatic arc terrane of the Antarctic Peninsula.

Key words: Antarctic Peninsula, geochronology, terrane accretion, Palmer Land event, orthogneiss, magmatic arc

Running title:

Zircon U-Pb dating of the central Antarctic Peninsula

Introduction

Geochronological relationships at the junction of northwest Palmer Land and southwest Graham Land, a zone of distinct physiographic change in the Antarctic Peninsula, are relatively poorly known compared to some other parts of the Antarctic Peninsula. The area is a classic magmatic arc terrane, dominated by plutonic, hypabyssal and subaerial volcanic rocks with no significant sedimentary formations. It forms part of the aerogeophysically and geologically defined Western Zone of the Central Domain of the Antarctic Peninsula (Fig. 1), a Mesozoic magmatic arc terrane that formed in response to subduction along the Pacific margin of Gondwana (Vaughan & Storey 2000, Ferraccioli *et al*. 2006). Most of the area shown in Figure 2 is poorly described in the literature. The area dominated by volcanic rocks southwest of the Fleming Glacier has been described by Davies (1984) and Leat & Scarrow (1994), and the volcanic rocks were Rb-Sr dated by Thomson & Pankhurst (1983). Most of the area north of the Fleming Glacier is dominated by plutons and orthogneises, with minor volcanic sequences. Although uncomformable and intrusive relationships have been observed locally, age relationships are inevitably heavily dependant on geochonological data.

We report whole rock and zircon U-Pb geochonological data in this paper. Multiple samples of plutons or orthogneiss sequences we mapped in the field were chosen for Rb-Sr geochronology. A subset of samples was analysed for Sm-Nd isotopes. One sample of orthogneiss and one volcanic sample were chosen for U-Pb dating of zircon crystals.

Regional field relationships and Rb-Sr and Sm-Nd results

The Rb-Sr whole rock geochronology forms a basis for understanding age relationships in the area, so is discussed with the field information and Nd isotope data. Rb-Sr and Sm-Nd analytical methods used for data in this paper are those of Royse *et al.* (1998). Whole-rock Rb-Sr geochronological data are shown in Figure 2 and Table 1, and Nd isotopic data are shown in Table 2. Apart from four Rb-Sr and three Sm-Nd analyses (including three pairs) reported in supplementary data tables by Millar *et al.* (2001), all the data in Tables 1 & 2 are previously unreported.

Basement rocks (ie. crystalline, metamorphic rocks) in the area of Figure 2 are represented by scattered exposures of orthogneisses that outcrop from the Elton Hill area in the north to the head of the Seller Glacier in the south. These orthogneisses are poorly known in the area, but are thought to represent deformed and metamorphosed volcanic and plutonic rocks of dominantly intermediate to silicic composition (e.g. Davies 1984). Whole rock Rb-Sr dating of an outcrop west of Hag Pike indicates a 169±6 Ma, mid-Jurassic protolith age for the orthogneiss (Table 1), and a suite of orthogneisses from around Elton Hill yielded no meaningful isochron. Evolved Nd signatures for silicic gneisses (εNd_{183} = -2.9 and -2.6; Table 2) shows that an older crustal component was sourced during petrogenesis. A gabbro-granodiorite plutonic suite that intruded the orthogneisses dominates outcrop in the area north of the Fleming Glacier (Fig. 2). This suite is apparently undeformed, apart from magmatic foliations clearly associated with intrusive contacts with other plutons or the orthogneisses. Rb-Sr whole-rock isochrons for two granodiorite plutons of this suite, exposed around Clarke Glacier and in a group of unnamed nunataks at the head of the Seller Glacier yield ages of 116 ± 2 and 132 ± 9 Ma, although the accuracy of these ages is uncertain, because the long magmatic history of the area suggests the potential for resetting the Rb-Sr system. Nd isotopes for these granodiorites are less negative than the gneisses (εNd_t = -1.8 to -0.4; Table 2). A distinctive group of later, vuggy, red-weathering high-level granites represents the last observed plutonic episode, outcropping in a zone from Cape Berteaux to the head of Fleming Glacier (Fig. 2), and showing clear intrusive relationships with older units. These granites range from subalkaline to peralkaline (comenditic: Davies 1984; authors' unpublished data), have yielded Rb-Sr isochrons in the range 71 ± 9 to 96 ± 2 Ma (Table 1). They correspond to the alkali microgranites described from Mount Lepus and other parts of northwest Palmer Land by Scarrow *et al*. (1997) and Vaughan *et al*. (1999). The Nd isotopic signature of the later plutonic rocks ($\varepsilon Nd_t = 0.0$ to $+0.8$; Table 2) is more juvenile than the basement ($\varepsilon Nd_{87} = -3.6$ to -3.0 for silicic orthogneisses and -0.9 to -2.3 for older Cretaceous plutonic suite; Table 2) , indicating an increased contribution from a mantle-derived component during petrogenesis.

The volcanic rocks that dominate south and west of Fleming Glacier belong to a basalt to rhyolitic sequence that is weakly deformed by long-wavelength folding. The sequences are interpreted as eroded remnants of large, central volcanoes, including a caldera structure at Zonda Towers (Leat & Scarrow 1994). Davies (1984) interpreted the volcanic rocks as Upper Jurassic in age by comparison to dated volcanic sequences elsewhere in the Antarctic Peninsula. A Jurassic age was apparently confirmed by Thomson & Pankhurst (1983), who found that the northern Palmer Land volcanic rocks trended along a Rb-Sr reference line of approximately 180 Ma, and R.J. Pankhurst (personal communication, 1993), who suggested a Rb-Sr age of 153 ± 2 for volcanic rocks from a single location near Mount Edgell. The generally higher crustal level (mostly volcanic rocks) exposed south of the Fleming Glacier compared to the north (mostly plutonic and metamorphic rocks) suggests that the Fleming Glacier may overlie a significant fault that downthrows to the north. This coincides with a lineament along which sinistral strike-slip movement is inferred from displacement of aeromagnetic anomalies associated with the underlying batholith (Garrett 1990, Johnson 1997). There are large numbers of hypabyssal intrusions, mostly mafic dykes dated by K-Ar methods as Cretaceous to Early Tertiary in the area which intrude all other rock types (Scarrow *et al.* 1998).

Zircon U-Pb geochronological results

We present new U-Pb geochronological data on zircons from an orthogneiss and a volcano-sedimentary sequence that uncomformably overlies a granodiorite. These provide better constraints on volcanic and tectonic events in the arc terrane, and we relate these to regional events. U-Pb zircon analyses were carried out using a Cameca 1270 ion-microprobe housed at the NORDSIM facility, Swedish Museum of Natural History, following the method of Whitehouse & Kamber (2005). Results are presented in Table 3.

Orthogneiss sample R.5414.7

The orthogneiss comes from a 2.5 km-long outcrop on a north-south trending ridge which is situated on the south coast of Cape Berteaux, 6 km northwest of Hag Pike, southwest Graham Land (Fig. 2). The sample was collected from the west-facing slopes of the ridge, which exposes silicic-intermediate medium-grained orthogneiesses which are foliated and highly folded with sparsely developed crenulation cleavage. The gneisses are cut by folded amphibolite sheets, and they are interpreted as an igneous succession cut by mafic dykes, the whole sequence having been deformed and metamorphosed at about ambibolite grade. Sample R.5414.7 is a medium-grained, moderately foliated quartz-feldspar dominated metamorphic rock. The medium grain size and an interpreted relict phenocrystic texture indicate volcanic rather than plutonic protoliths. Zircons are prismatic and, although generally non-luminescent under CL, faint growth zoning is evident and no inherited component was detected in the images. Zircons yielded a well-defined U-Pb zircon concordia age of 183 ± 2.1 Ma. Discordant analyses contain common Pb or are interpreted to have suffered Pb loss (Table 3; Fig. 3). This new radiometric age is interpreted to date emplacement of the igneous protolith comprising the local basement and demonstrates that our whole-rock Rb-Sr isochron age of 169±6 Ma is erroneous (Fig. 2). The Rb-Sr age probably reflects resetting or original emplacement of magmas with variable ^{87}Sr/^{86}Sr ratios, consistent with multiple crust and mantle magma sources in a magmatic arc, or continental margin environment.

Volcanic sample R.5869.4

The volcanic sample R.5869.4 is from a volcanic and sedimentary succession that uncomformably overlies a granodiorite at the head of the Fleming Glacier, northern Palmer Land (Fig. 1). The location was described by Davies (1984) and re-examined in season 1992/93 (Scarrow & Leat 1993). The granodiorite has a weak magmatic foliation, and has experienced alteration of feldspars and epidote veining (Davies 1984). The basal beds overlying the uncomformity consist of poorly sorted, graded sandstones and siltstones, that dip 28° to the northwest and contain plutonic clasts up to 1 m across. These are overlain by a 10 m thick, silicic, massive, lava-like unit, from which sample R.5869.4 was taken. This is in turn overlain by a 4 m thick unit of fine-grained, planar bedded, silicic tuffs. The beds are ca. 1 cm thick, graded or reverse graded and some contain accretionary lapilli. The sequence is interpreted as terrestrial. Sample R.5869.4 is homogeneous, plagioclase-phyric and fine-grained with no obvious pyroclastic features. It contains abundant minor fractures associated with epidote crystallization and has clearly suffered minor deformation. Zircons are prismatic, bright, have well-developed crystal facets and are luminescent under CL with growth and sector zoning, features typical for volcanic zircon. Under CL, core-rim structures are obvious with rims being more luminescent with internally simple structure compared with less luminescent cores and xenocrysts. Volcanic grains without inherited cores have the same CL character as the rims. The sample yielded a U-Pb zircon age of 107 ± 1.7 Ma (Table 3; Fig. 3) that is interpreted as the eruption age. Cores and xenocrysts yield older ages of around 130 Ma confirm the inheritance suggested by the CL images.

Discussion

Basement

The Early Jurassic age of 183 ± 2.1 Ma for orthogneiss sample R.5414.7 is interpreted as the age of eruption/emplacement of its igneous protolith. The Early Jurassic age indicates that Palaeozoic to Triassic basement protoliths, that have been identified elsewhere in the Antarctic Peninsula by U-Pb zircon geochronology (Millar *et al.* 2002; Fig. 1), may be absent from this area. At the very least, such Palaeozoic to Triassic basement is absent from this locality. However, εNd at 183 Ma of –2.9 (Table 2) indicates that these rocks are not juvenile crustal additions, suggesting that an older crustal basement is unexposed or unsampled in the area. This is consistent with the study of Millar *et al.* (2001), who found a widespread Proterozoic lower crustal component in granitoids of Palmer Land. It is intriguing that the age of 183 Ma corresponds with the first of the three episodes of widespread voluminous Chon Aike silicic volcanism identified along what is interpreted as the Jurassic margin of Gondwana, in the Antarctic Peninsula and in Patagonia (Pankhurst *et al.* 1998, Riley & Leat 1999). The protoliths of the southwest Graham Land orthogneisses may have been outliers of this episode, or alternatively may have been magmatic arc rocks related directly to subduction processes occurring at the same time. The first (V1) episode of Chon Aike magmatism (188-178 Ma) is interpreted to have been linked to the Karro-Ferrar mantle plume-related volcanism and is represented in Patagonia by the voluminous Marifil Formation, and in the southern Antarctic Peninsula by the Mount Poster and Brennecke formations (Pankhurst *et al.* 2000). Cape Berteaux lies between these occurrences, indicating that V1 may have been originally more continuous, but perhaps obscured by later deformation along the continental margin. Moreover, the εNd_t of –2.9 and the initial $^{87}Sr/^{86}Sr$ ratios of 0.7051 to 0.7078 (Tables 1 & 2) of the Cape Berteaux orthogneiss at 183 Ma is very similar to most Antarctic Peninsula and Patagonian Chon Aike representatives (-2 to -3 and 0.706 to 0.707 respectively), consistent with melting of a similar Proterozoic lower crustal source (Riley *et al.* 2001) for all these Jurassic silicic magmas.

Age of the volcanic cover

The 107 ± 1.7 Ma U-Pb age for silicic lava R.5869.4 clearly demonstrates a mid-Cretaceous age for the volcanic and sedimentary sequence overlying the uncomformity. Davis (1984) assumed, by analogy with wider stratigraphic relationships in the Antarctic Peninsula, that all the volcanic rocks in the area, including those above the unconformity, were Jurassic, and older than the plutonic rocks of the ‘Andean Intrusive Suite’. This assumption led to problems in stratigraphic correlation, as Davis was forced to invent a separate lithostratigraphic category ‘Pre-Volcanic Plutonic Rocks’ in which to place (along with plutonic rocks from Mount Charity, Palmer Land) the granodiorites that are below the uncomformity. This term is now redundant, as there is no requirement for the granodiorites below the uncomformity to be older than most other (Cretaceous) plutonic rocks in the area, We interpret the new U-Pb data to further indicate that the large outcrop of volcanic rocks between Cape Jeremy and Crescent Scarp (Fig. 2) is more likely to be Cretaceous than Jurassic, as previously supposed (Thomson & Pankhurst 1983, Davies 1984, Leat & Scarrow 1994). Although the volcanic succession above the uncomformity is not continuous with the larger outcrop, the Cretaceous U-Pb age is the only unequivocal age for volcanic rocks from this area. All these sequences have similar degrees of deformation and metamorphic grade, up to prehnite-pumpellyite facies (Davies 1984), quite different from the higher grade orthogneisses for which we have established a Jurassic or older protolith age in southern-most Graham Land. A Jurassic age for the volcanic cover of northwest Palmer Land would require large variations in metamorphic grade of Jurassic volcanic rocks within the same terrane and over a geographically restricted area, for which there is no evidence.

Given that the dated volcanic rock rests unconformably on granodiorite, it is feasible that the granodiorite or related rocks were the source for the inherited, 124-134 Ma zircons in sample R.5869.4, the zircons being scavenged during eruption. Such an interpretation is consistent with the Rb-Sr whole rock age of 134±9 Ma for the 'Nunataks' granodiorite (Table 1) which is exposed in numerous nunataks at the head of the Seller Glacier, and indicates that this pluton also predates the unconformity (Fig. 2).

Relationship to the Palmer Land event

The new U-Pb age for the subaerial volcanic rocks demonstrates uplift of the granodiorite to above sea level and exhumation by 107 ± 1.7 Ma. It is a minimum age for the main part of the uplift. A degree of caution is necessary when comparing this age to these that directly date deformation events. Nevertheless, the age is remarkably similar to dates obtained from eastern

Palmer Land for the mid-Cretaceous compressive deformation and associated magmatism of the Palmer Land event: an Ar-Ar biotite cooling age of 102.8 ± 3.3 Ma from a mylonite (Vaughan *et al*. 2002a), and especially a U-Pb zircon age of 106.9 ± 1.1 Ma from a syn-deformational microgranitic dyke (Vaughan *et al*. 2002b). The same event can be interpreted to be present in eastern Ellsworth Land where Flowerdew *et al*. (2005) provided a U-Pb zircon age of 105.2 ± 1.1 Ma for a diorite pluton that intrudes a volcano-sedimentary sequence that is interpreted to have been deformed along the Eastern Palmer Land Shear Zone (EPLSZ; Fig. 1), likely part of the same Palmer Land event. Although the new U-Pb age is a minimum age for a significant uplift and exhumation event rather than compressive deformation, we suggest that the exhumation was related to the Palmer Land compressive event. If this is correct, it is the first date for the event from western Graham Land or northwestern Palmer Land, consistent with an origin for the event by collision/accretion of outboard terranes of the Antarctic Peninsula (Vaughan *et al*. 2000, 2002a,b, Ferraccioli *et al*. 2006).

Summary of tectonic implications

The new data help to provide new constraints on the tectonic development of the area. We identify the following main events:

Jurrasic magmatism. Eruption/emplacement of protoliths of the gneisses is dated by the 183 ± 2.1 Ma U-Pb age on the Cape Berteaux orthogneiss. This event formed within a Mesozoic (?Permian – Cretaceous) magmatic arc that is now observed aerogeophysically as the relatively mafic magmatic arc terrane known as the Western Zone of the Central Domain

(Ferraccioli *et al*. 2006). It is not known where this magmatic arc was situated during Jurassic times, and it may have been distant from its current position (Vaughan & Storey 2000; Vaughan *et al*. 2002a,b). The Early Jurassic eruption/emplacement age and similar Nd and Sr isotope relationships to those of Chon Aike sicicic rocks erupted along the Gondwana margin at the same time (Pankhurst *et al*. 2000) may not be a coincidence. The suspected mantle plume associated with contemporaneous Karro-Ferrar magmatism (Storey 1995) may have generated enhanced convergence and volcanism along the Gondwana active margins.

Cretaceous plutonism. This is the main plutonic episode recognized in the area, forming most of the gabbro-diorite-granodiorite suite which was intruded into the Jurassic basement rocks which was metamorphosed before or during this plutonism. The age of plutonism is not well determined, as whole rock Rb-Sr systems should be treated with caution. Rb-Sr ages for the suite are around 116 Ma and 132 Ma (Fig. 2). The later age corresponds to inherited zircons in silicic lava R.5869.4 and is a most plausible age for the local peak of plutonism. It is probably significant that this age is within the age range of the major plutonism further south in the same terrane in western Palmer Land dated by Ar-Ar geochronology (Vaughan *et al*. 1998). The 132 Ma age is also consistent with peaks of batholithic magmatism in the Antarctic Peninsula and elsewhere along the Gondwana margin identified in earlier syntheses (Pankhurst 1990, Leat *et al*. 1995). During this plutonism, the location of the arc is unknown, although it was probably close to the Antarctic margin.

Palmer Land event. The mid-Cretaceous U-Pb zircon age of 107 ± 1.7 Ma for the lava above the unconformity gives the first interpreted age for the Palmer Land event in western Graham Land or Palmer Land. The event is interpreted as collision and compression of the magmatic arc(s) against the Gondwana margin (Vaughan *et al*. 2002a,b). Aeogeophysical interpretation suggests that two distinct arcs may have been involved, with an inner arc sandwiched between this one and the Gondwana margin (Ferraccioli *et al.* 2006).

Emplacement of high-level granites. These distinctive, vuggy granites were emplaced at a relatively high crustal level and have mid- to Late Cretaceous Rb-Sr whole rock ages between 71 ± 9 and 96 ± 2 Ma. They appear to be contemporaneous with a distinctive pulse of compositionally diverse mafic dyke intrusions in the area dated (K-Ar) between 95 and 65 Ma (Scarrow *et al.* 1997, 1998). This pulse comprises tholeiitic, shoshonitic and ocean island basalt (OIB)-like basalts, as well as the calc-alkaline subduction-related basalts that characterize the continuous background of mafic dyke magmatism during Cretaceous to Early Tertiary times (Scarrow *et al.* 1997, 1998). The 95-65 Ma dykes are associated with extensional and strike-slip faulting of the arc that Scarrow *et al.* (1997) related to collision of an oceanic spreading centre with the trench, for which there is independent evidence from 75 Ma boninitic high-Mg andesites on Alexander Island (McCarron & Millar 1997). The peralkaline chemistry of some of the granites is consistent with emplacement in an extending arc setting and comparison can be made to peralkaline rhyolites in arc terranes in Papua New Guinea bordering the extending Woodlark Basin, and Mayor Island in the extensional Bay of Plenty, New Zealand (Smith *et al.* 1977, Stolz *et al.* 1993).

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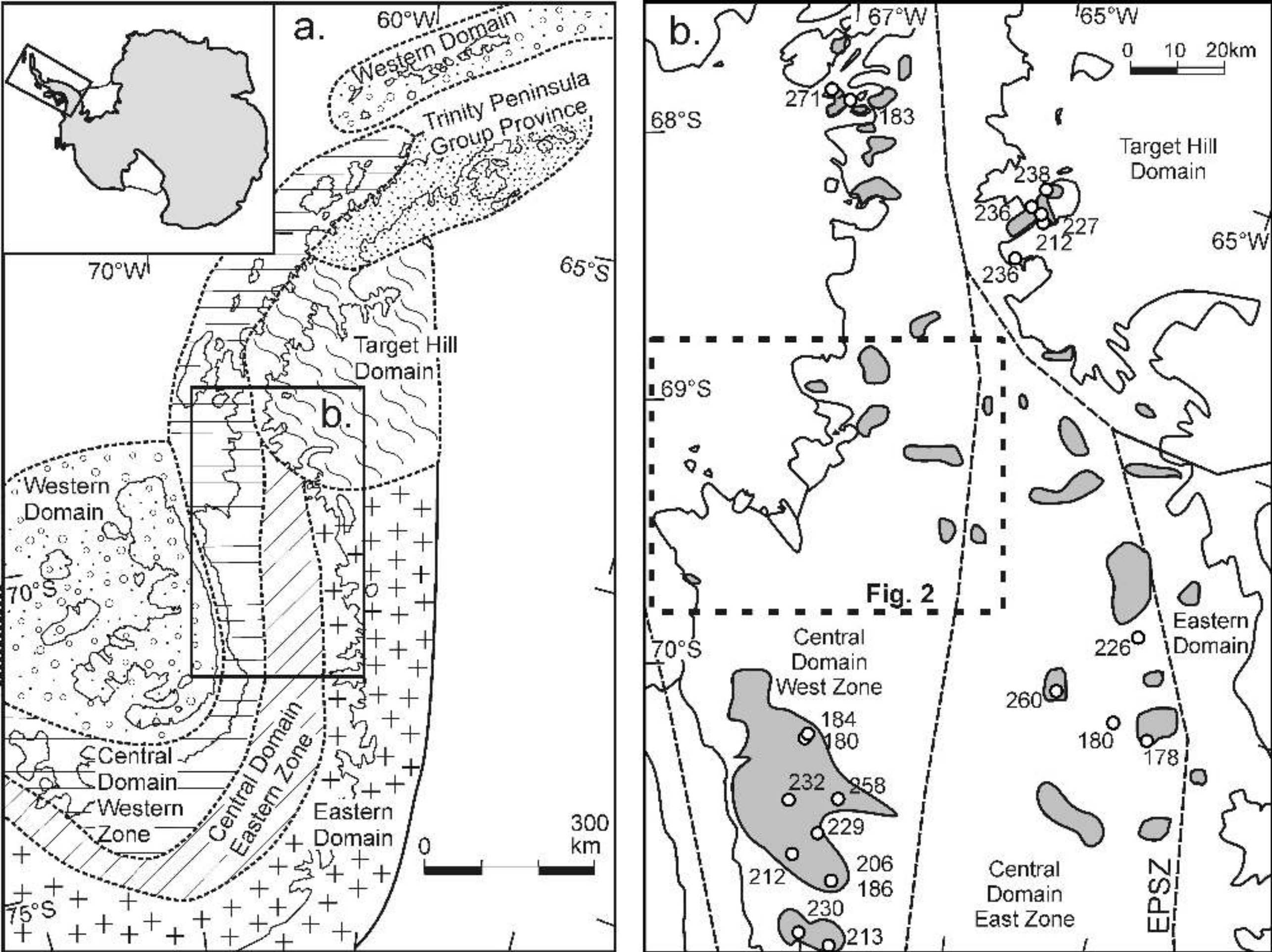
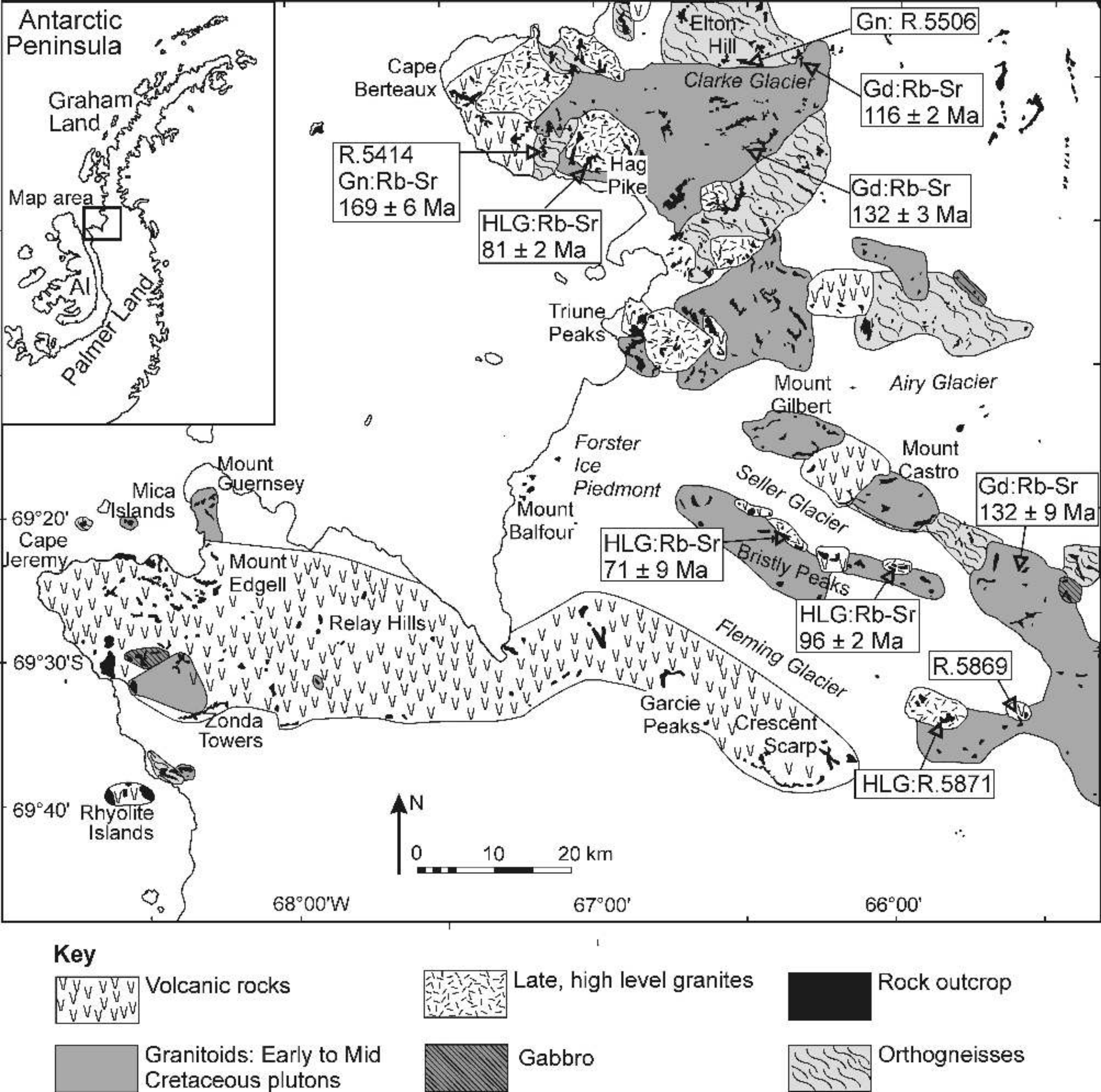
Figure captions

Fig. 1. **a.** Terrane map for the Antarctic Peninsula after Vaughan & Storey (2000) and Ferraccioli *et al*. (2006). The area shown in panel b is indicated. **b.** Areas with significant ‘basement’ outcrops. Spots indicate U-Pb zircon ages for the protoliths and metamorphism affecting them. Age information from Vaughan *et al.* (1999), Millar *et al*. (2002), Flowerdew *et al.* (2006) and BAS unpublished data.

Fig. 2. Geological sketch map of northwest Palmer land and southwest Graham Land showing the location of the dated samples. The map is compiled from Davies (1984), unpublished reports by Wyeth (1972, 1973), and fieldwork by PTL, JHS and ILM in the seasons 1991-92 and 1992-93. The Rb-Sr ages are from the authors’ unpublished data: Gn, gneiss; Gd, granodiorite; HLG, high-level granite. Inset shows the location within the Antarctic Peninsula; AI, Alexander Island.

Fig. 3. U-Pb Concordia diagrams for **a.** orthogneiss sample R.5414.7 and **b.** Silicic lava sample R.5869.4. Dashed ellipses are not included in age calculations and are interpreted as either inherited, containing common Pb or having suffered Pb loss.


a.
60°W
Western Domain
Trinity Peninsula Group Province
70°W
65°S
Target Hill Domain
b.
Western Domain
70°S
Central Domain Western Zone
Central Domain Eastern Zone
Eastern Domain
75°S
0
300 km
b.
67°W
65°W
0 10 20km
68°S
271
183
Target Hill Domain
238
236
227
212
236
65°W
69°S
Fig. 2
70°S
Central Domain West Zone
184
180
232
258
229
206
212
186
230
213
226
Eastern Domain
260
180
178
Central Domain East Zone
EPSZ


Antarctic Peninsula
Graham Land
Map area
AI
Palmer Land
Cape Berteaux
Elton Hill
Gn: R.5506
Clarke Glacier
Gd:Rb-Sr 116 ± 2 Ma
R.5414 Gn:Rb-Sr 169 ± 6 Ma
Hag Pike
HLG:Rb-Sr 81 ± 2 Ma
Gd:Rb-Sr 132 ± 3 Ma
Triune Peaks
Mount Gilbert
Airy Glacier
Forster Ice Piedmont
Mount Castro
Mount Guernsey
Mica Islands
69°20'
Cape Jeremy
Mount Balfour
Seller Glacier
Gd:Rb-Sr 132 ± 9 Ma
HLG:Rb-Sr 71 ± 9 Ma
Bristly Peaks
Mount Edgell
Relay Hills
HLG:Rb-Sr 96 ± 2 Ma
Fleming Glacier
69°30'S
R.5869
Garcie Peaks
Crescent Scarp
Zonda Towers
HLG:R.5871
69°40'
Rhyolite Islands
N
0
10
20 km
68°00'W
67°00'
66°00'
Key
Volcanic rocks
Late, high level granites
Rock outcrop
Granitoids: Early to Mid Cretaceous plutons
Gabbro
Orthogneisses

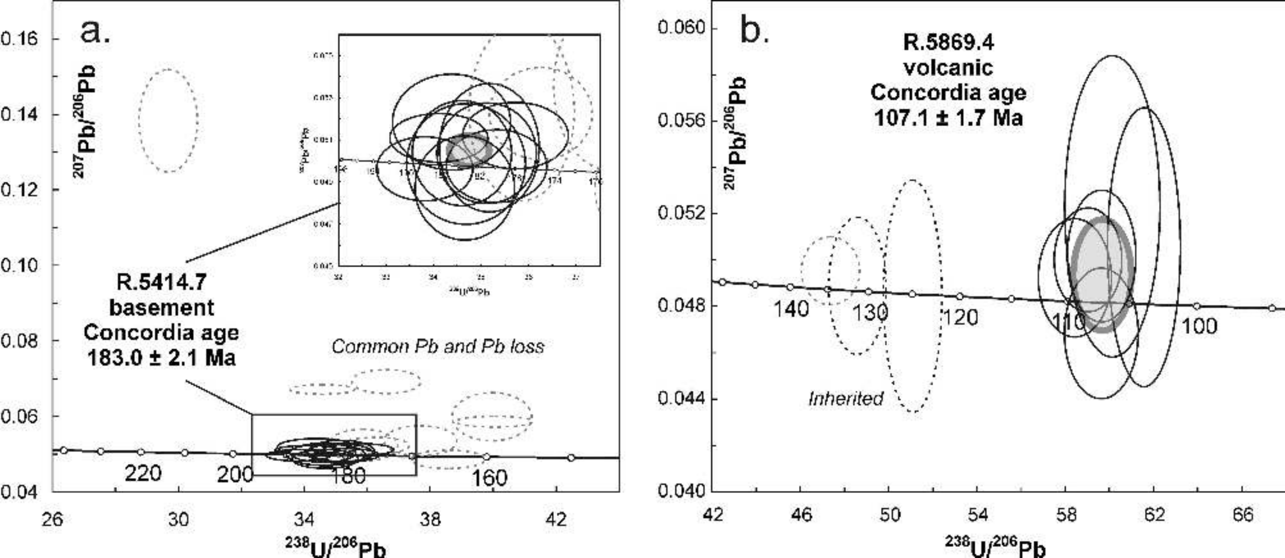

a.
$^{207}Pb/^{206}Pb$
0.16
0.14
0.12
0.10
0.08
0.06
0.04
R.5414.7
basement
Concordia age
183.0 ± 2.1 Ma
Common Pb and Pb loss
220
200
180
160
26
30
34
38
42
$^{238}U/^{206}Pb$
b.
R.5869.4
volcanic
Concordia age
107.1 ± 1.7 Ma
$^{207}Pb/^{206}Pb$
0.060
0.056
0.052
0.048
0.044
0.040
140
130
120
110
100
Inherited
42
46
50
54
58
62
66
$^{238}U/^{206}Pb$

Table 1. Whole rock Rb-Sr data

Sample[1]	lithology[2]	age	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	±2σ	$^{87}Sr/^{86}Sr$	±2σ	$^{87}Sr/^{86}Sr_i$
Hag orthogneiss - Rb-Sr isochron for granitic gneiss 169 ± 6 Ma									
R.5414.3	mGN	183	104.32	451.7	0.6682	0.0100	0.707357	0.000012	0.705618
R.5414.4	mGN	183	99.12	392.2	0.7312	0.0110	0.707015	0.000012	0.705113
R.5414.5	gGN	183	170.14	101.1	4.8751	0.0731	0.720510	0.000012	0.707825
R.5414.6	gGN	183	150.26	65.6	6.6381	0.0996	0.724585	0.000012	0.707313
R.5414.7	gGN	183	168.17	57.21	8.5233	0.1278	0.729316	0.000014	0.707138
Elton Hill orthogneiss - no meaningful Rb-Sr isochron									
R.5506.1	gGN	183	223.9	16.59	39.4740	0.5921	0.818394	0.000014	0.715684
R.5506.2	gGN	183	183.9	20.1	26.6880	0.4003	0.790872	0.000014	0.721430
R.5506.3*	gGN	183	185.66	39.03	13.8160	0.2072	0.746965	0.000012	0.711016
R.5506.4	mGN	183	98.01	355.23	0.7980	0.0120	0.706788	0.000014	0.704711
Nunataks granite - Rb-Sr isochron for granodiorite 132 ± 9 Ma									
R.5860.1*	Gd	132	116.62	424.25	0.7953	0.0119	0.707165	0.000012	0.705673
R.5860.3	Gd	132	99.44	433.1	0.6642	0.0100	0.706909	0.000014	0.705663
R.5862.2	Gd	132	89.01	501	0.5140	0.0077	0.706639	0.000012	0.705675
R.5594.1	Gd	132	76.71	535.67	0.4143	0.0062	0.706416	0.000014	0.705639
R.5595.10	Di	132	56.26	248.43	0.6665	0.0100	0.884541	0.000014	0.883291
R.5595.9	Gd	132	53.38	533.68	0.2893	0.0043	0.706226	0.000012	0.705683
Clarke Glacier Gd 2									
R.5507.1	Gd	132	134.32	601.39	0.6460	0.0097	0.707353	0.000014	0.706141
R.5507.2	mGd	132	151.88	225.85	1.9461	0.0292	0.709736	0.000014	0.706085
R.5507.3	mGd	132	153.71	256.33	1.7354	0.0260	0.709603	0.000012	0.706347
R.5507.4	mGd	132	153.46	235.28	1.8873	0.0283	0.709646	0.000014	0.706105
R.5507.5	mGd	132	161.56	217.86	2.1461	0.0322	0.710082	0.000012	0.706055
Clarke Glacier Gd 1 - Rb-Sr isochron for pegmatite 116 ± 2 Ma									
R.5505.1	Gd	116	80.24	545.88	0.4253	0.0064	0.706806	0.000014	0.706105
R.5505.10	Peg	116	220.01	79.47	8.0190	0.1203	0.719346	0.000014	0.706126
R.5505.11	Peg	116	234.13	84.32	8.0424	0.1206	0.719520	0.000012	0.706261
R.5505.2	Gd	116	83.52	563.24	0.4290	0.0064	0.706792	0.000012	0.706084
R.5505.3	Gd	116	82.99	532.26	0.4510	0.0068	0.706866	0.000012	0.706122
R.5505.4	Gd	116	79.67	553.84	0.4160	0.0062	0.706797	0.000014	0.706111
R.5505.5	Gd	116	80.68	548.61	0.4256	0.0064	0.708658	0.000014	0.707956
R.5505.6	Gd	116	90.01	566.45	0.4260	0.0064	0.706836	0.000014	0.706133
R.5505.7	Peg	116	143.39	120.91	3.4320	0.0515	0.711775	0.000014	0.706117
R.5505.8	Peg	116	126.65	179.87	2.0370	0.0306	0.709494	0.000014	0.706136
R.5505.9	Ap	116	211.33	103.13	5.9333	0.0890	0.715936	0.00001	0.706155
Camp col - Rb-Sr isochron for Granite 96 ± 2 Ma									
R.5551.1*	Gr	96	127.62	67.36	5.4844	0.0823	0.713095	0.000014	0.705614
R.5552.1*	Gr	96	122.05	88.02	4.0132	0.0602	0.711054	0.000012	0.705580
R.5565.1	Gr	96	128.3	250.54	1.4816	0.0222	0.707634	0.000012	0.705613
R.5565.3	Ap	96	154.25	18.41	24.3175	0.3648	0.739781	0.000014	0.706608
Fleming Glacier HLG - no meaningful Rb-Sr isochron									
R.5871.1	Gr	96	177.32	9.62	53.6988	0.8055	0.778448	0.000012	0.705196
R.5871.2	Gr	96	116.87	4.24	80.5606	1.2084	0.811760	0.000014	0.701865
R.5871.3	Ap	96	149.54	9.21	47.2638	0.7090	0.770127	0.000014	0.705653
R.5872.1	Gr	96	159.34	8.77	52.9336	0.7940	0.779024	0.000014	0.706816
Hag Pike High level granite - Rb-Sr isochron for granite 81 ± 2 Ma									
R.5411.1	Gr	81	117.32	6.02	57.8640	0.8680	0.777832	0.000014	0.711238
R.5411.4	Gr	81	122.74	5.18	69.1100	1.0367	0.790625	0.000014	0.711089
R.5411.6	Gr	81	119.55	11.21	30.9690	0.4645	0.746796	0.000014	0.711155
West bristles granite - Rb-Sr isochron for granite 71 ± 9 Ma									
R.5567.1	Gr	71	127.74	23.7	15.6177	0.2343	0.723027	0.000012	0.707274
R.5567.2	Gr	71	126.6	23.66	15.5042	0.2326	0.722854	0.000014	0.707215
R.5568.1	Gr	71	130.7	27.6	13.7190	0.2058	0.721084	0.000012	0.707246
R.5569.1	Gr	71	131.47	26.86	14.1806	0.2127	0.721549	0.00001	0.707245

1.*indicates data published in Millar *et al*. (2001)

2. mGN = mafic gneiss, gGN = granitic gneiss, Gd = granodiorite, mGd = microgranodiorite, DI = diorite, Gr = granite, Peg = pegmatite, ap = aplite

Table 3. U-Pb ion-microprobe zircon data

Spot[1]	U (ppm)	Th (ppm)	Pb (ppm)	Th/U	f^{206} (%)[2]	^{238}U/^{206}Pb	±σ (%)	^{207}Pb/^{206}Pb	±σ (%)	^{206}Pb/^{238}U age (Ma)	±σ	^{207}Pb corr. age (Ma)[3]	±σ
Orthogneiss sample R.5414.7													
1	262	105	8	0.400	0.83	37.687	1.26	0.05355	3.04	167.4	2.1	167.9	2.1
2	481	203	15	0.423	2.13	36.604	1.22	0.06921	1.87	170.1	2.1	169.4	2.1
3	577	141	17	0.244	0.19	38.571	1.25	0.04863	2.04	164.7	2.0	165.2	2.1
4*	329	174	11	0.528	0.52	35.172	1.22	0.05063	2.46	179.8	2.2	180.5	2.2
5*	546	422	20	0.772	0.20	35.116	1.22	0.05037	1.94	180.6	2.2	180.9	2.2
6	2267	1704	82	0.752	2.41	34.572	1.22	0.06715	0.76	179.4	2.2	179.8	2.2
7	1875	474	52	0.253	1.42	40.038	1.26	0.05861	0.99	156.8	1.9	157.1	2.0
8	2318	664	63	0.286	9.76	37.435	1.23	0.12412	1.26	153.5	1.9	153.8	2.8
9	180	99	6	0.547	1.42	35.856	1.26	0.05235	3.30	174.8	2.2	176.7	2.2
10*	647	306	22	0.473	0.31	34.657	1.23	0.04872	2.07	182.8	2.2	183.6	2.3
11*	541	319	19	0.589	0.57	34.597	1.23	0.05037	2.02	182.7	2.2	183.5	2.3
12*	1617	955	55	0.591	0.19	35.726	1.27	0.05120	1.26	177.6	2.2	177.6	2.2
50*	1016	429	35	0.422	0.22	33.813	1.23	0.04963	1.25	187.5	2.3	187.9	2.3
51	384	262	12	0.682	2.01	39.961	1.29	0.05987	4.37	156.2	2.0	157.2	2.1
13*	887	800	33	0.902	0.17	35.328	1.23	0.04975	1.42	179.6	2.2	179.9	2.2
14	559	238	18	0.426	0.42	36.257	1.22	0.05225	1.71	174.7	2.1	174.8	2.1
15*	2190	2054	86	0.938	0.30	34.110	1.23	0.05110	0.92	185.7	2.3	186.0	2.3
16	1044	738	38	0.706	12.26	29.678	1.27	0.13827	4.01	187.8	2.5	189.8	4.2
17*	649	479	24	0.738	0.32	34.380	1.47	0.05185	1.79	184.3	2.7	184.3	2.7
18*	1324	800	47	0.605	0.51	34.684	1.47	0.04986	2.35	183.2	2.7	183.2	2.7
Andesite sample R.5869.4													
1*	444	659	11	1.484	0.79	59.641	1.07	0.05017	2.32	106.4	1.1	106.9	1.1
2i	112	82	3	0.732	1.08	51.089	1.06	0.04843	4.23	123.6	1.3	125.0	1.4
3*	676	857	16	1.268	0.29	59.031	1.06	0.05001	1.83	108.0	1.1	108.0	1.1
4*	495	626	12	1.265	0.14	58.428	1.16	0.04923	2.12	109.2	1.3	109.3	1.3
5*	395	552	10	1.397	0.27	59.635	1.14	0.04683	2.46	106.9	1.2	107.4	1.2
7i	1207	640	31	0.530	0.14	47.366	1.13	0.04953	1.21	134.5	1.5	134.5	1.5
8i	315	226	8	0.718	0.78	48.587	1.09	0.04889	2.47	130.3	1.4	131.3	1.4
9*	82	46	2	0.560	4.20	60.119	1.46	0.05231	5.08	101.9	1.7	105.8	1.6
10*	125	121	3	0.970	1.07	61.563	1.09	0.05055	4.87	102.8	1.1	103.5	1.2

[1] Analysis identification. Asterisks are included in age calculations, i indicates inherited grains. In sample R.5869.4, points 8 and 9 are the core and rim respectively of the same cryst

[2] Percentage of common ^{206}Pb estimated from the measured ^{204}Pb. Data is not corrected for common Pb.

[3] Derived by correcting for common Pb assuming a ^{207}Pb/^{206}Pb value of 0.83 (present day terrestrial average of Stacey & Kramers (1975)).

Calculations were made using Isoplot 3.1 (Ludwig 2003) and used the decay constants of Steiger & Jäger (1977) tal.

Table 2. Whole rock Sm-Nd data.

Sample[1]	lithology2	age	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	±2σ	$^{143}Nd/^{144}Nd$	±2σ	εNd_t	t_{DM}
Hag orthogneiss										
R.5414.3	mGN	183	2.45	10.02	0.1480	0.0001	0.512683	0.000010	1.9	905
R.5414.4	mGN	183	2.43	9.54	0.1540	0.0002	0.512661	0.000010	1.3	1031
R.5414.7	gGN	183	7.71	37.52	0.1242	0.0001	0.512411	0.000010	-2.9	1106
Elton Hill orthogneiss										
R.5506.3*	gGN	183	8.34	30.61	0.1647	0.0002	0.512464	0.00001	-2.6	1725
Nunataks granite										
R.5860.1*	Gd	132	2.68	15.87	0.1021	0.0001	0.512531	0.000012	-0.5	742
R.5595.9	Gd	132	3.35	17.91	0.1130	0.0001	0.512544	0.000008	-0.4	797
Clarke Glacier Granodiorite 1										
R.5505.4	Gd	116	2.39	12.93	0.1119	0.0001	0.512479	0.000006	-1.8	880
Camp Col HLG										
R.5552.1*	Gr	99	5.04	26.99	0.1128	0.0001	0.512586	0.000008	0.0	738
Fleming Glacier HLG										
R.5871.1	Gr	87	5.03	22.24	0.1367	0.0001	0.512646	0.00001	0.8	837
R.5872.1	Gr	87	5.28	22.59	0.1413	0.0001	0.512648	0.00001	0.8	880
Hag Pike HLG										
R.5411.6	Gr	84	8.529	42.003	0.1228	0.0001	0.512639	0.000008	0.8	730

1. *Indicates data published in Millar *et al*. (2001)
2mGN = mafic gneiss, gGN = granitic gneiss, Gd = granodiorite, Gr = granite
Model ages were calculated using the model of Depaolo *et al.* (1991).