PETROLOGY AND GEOCHEMISTRY OF ALKALI-BASALTS FROM JASON PENINSULA, OSCAR II COAST, GRAHAM LAND

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ABSTRACT. The geology of Jason Peninsula (lat. 66° 10′ S, long. 61° 10′ W) is dominated by sub-horizontal sequences of calc-alkaline dacitic to rhyolitic tuffs, ignimbrites and rare basic lavas of Mesozoic age. At Argo Point, however, a very young basaltic scoria cone underlain by cliffs of scoria and vesicular basalts occurs. Chemically and petrographically, the Argo Point basalts closely resemble basalts from the Pliocene–Recent province found farther north at the Seal Nunataks and James Ross Island. They are quite distinct from the calc-alkaline basalts and andesites of Graham Land and the South Shetland Islands, having significantly higher total iron, TiO_2 and Nb contents, and lower La/Nb, Zr/Nb, Ba/La and Ba/Nb ratios. It is suggested that this alkaline volcanicity has occurred in response to extensional tectonism, perhaps following cessation of subduction along the western side of Graham Land, although this explanation is less satisfactory for similar activity found in Patagonia.

THE occurrence of Cenozoic alkaline volcanism in north-east Graham Land, particularly in the James Ross Island area, is well documented (Nelson, 1975; Baker and others, 1977; Pankhurst, in press; Weaver and others, in press) and is broadly analagous to the alkaline volcanism associated with the Andean margin of South America (e.g. Patagonia; Hawkesworth and others, 1979). Published data indicate that the southern limit of the James Ross Island Volcanic Group is represented by the Recent and Pleistocene activity found at the Seal Nunataks (Fleet, 1968; Nelson, 1975; Baker and others, 1977), and that the volcanic activity recorded in successions along the Oscar II and Foyn Coasts is of Mesozoic age and calc-alkaline in character. However, during a visit to Jason Peninsula in 1953, A. J. Standring reported basalts similar to those found at the Seal Nunataks. Subsequent geological field work on Jason Peninsula in the 1977–78 season has indeed revealed that Argo Point (Fig. 1) is capped by a very young basalt scoria cone. Accordingly, samples were taken for analysis for comparison with basalts from the Seal Nunataks and James Ross Island. These results are presented here.

JASON PENINSULA

Jason Peninsula is a topographically smooth area extending to approximately 80 km east of the more mountainous plateau region of Graham Land (Fig. 1). The peninsula has a low relief, rising only occasionally to more than 450 m above sea-level, and is enclosed by the Larsen Ice Shelf. Rock exposures are rare and correlation between different exposures is difficult. The geology of Jason Peninsula is poorly documented and the following brief account is based on field work carried out by the author during the 1977–78 season.

The geology of the peninsula is dominated by thick sequences of apparently subaerially lain dacitic, rhyodacitic and rhyolitic tuffs and rare quartz-phyric lavas (R.211–214, 216). Many of the pyroclastic rocks are welded, and contain fragments of rhyolite, pumice and glass. Abundant fiammé occur within the welded tuffs exposed alongside the eastern side of Standring Inlet (e.g. R.214). Fine-grained pale grey intercalations within the pyroclastic sequences may represent ash bands. All of the pyroclastic rocks are severely weathered, frequently producing an orange iron-rich coating, and are not suitable for analytical work.

A succession of more basic lavas and tuffs crops out at station R.215 in north-east Standring Inlet. A thick basal andesite, of which approximately 10 m are exposed, is overlain by 20 m of weathered (? andesitic) tuffs which in turn are capped by at least 2 m of basalt. The sequence dips at about 15° to the north, similar to the tuffs at station R.214. Indeed, with the exception of the tuffs at station R.211 which dip at 45° to the north, all of the strata on Jason Peninsula have shallow dips, with broad open flexures being the only evidence of tectonic activity. This style of folding is in marked contrast to the severe disruption of the volcanic rocks observed at the

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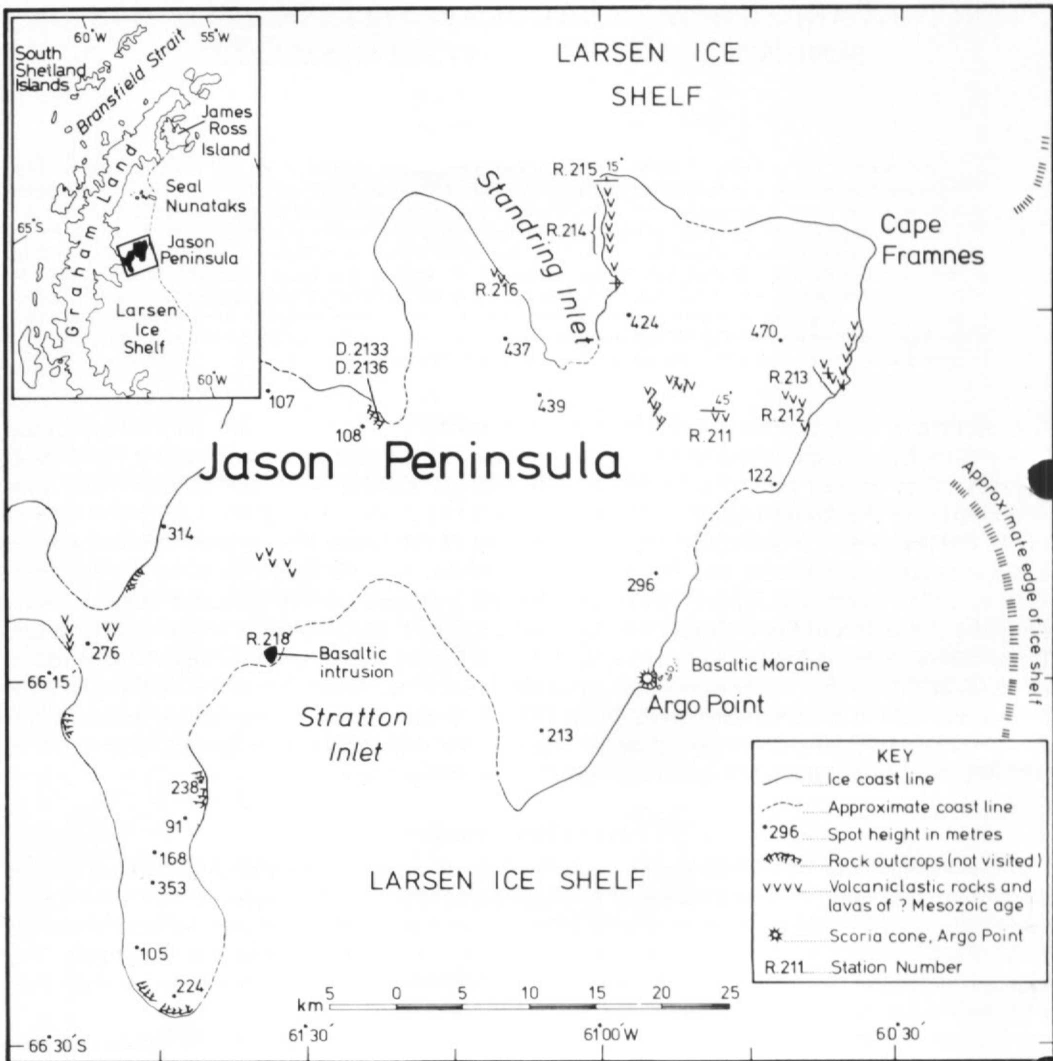

Fig. 1. Map of Jason Peninsula, Oscar II Coast, Graham Land, showing the locations of the main rock outcrops.

margins of Graham Land (e.g. in the McCarroll Peak area approximately 25 km west of Jason Peninsula) which was caused by the emplacement of later plutonic rocks. No plutonic rocks were seen on Jason Peninsula, although a small intrusion of haematite-coated basalt occurs at station R.218 in Stratton Inlet. Sample JP3 (Table I) was recovered at this locality. Intrusive basalts from the northern side of Jason Peninsula (D.2133, 2136; Fig. 1) have been dated by Rex (1976) and shown to have an average age of 171 Ma, implying a minimum Jurassic age for the main volcanic sequences of Jason Peninsula.

In terms of rock types and estimated age, the bulk of the volcanic rocks which comprise Jason Peninsula belong to the calc-alkaline "Mesozoic volcanic rocks" of Weaver and others (in press) or the "Antarctic Peninsula Volcanic Group" of Thomson (in press) and Gledhill and others (in press). They clearly represent an easterly continuation of the thick pyroclastic sequences exposed elsewhere along the eastern side of Graham Land, where they have an estimated thickness of 3 000 m, although on Jason Peninsula it appears that no more than 500 m are exposed.

Argo Point

The outcrops at Argo Point (R.217; Fig. 1) reveal rock types quite different to those found elsewhere on Jason Peninsula. The summit of the point consists of a small basalt scoria cone approximately 300 m across, which has been breached on its northern side. The flanks of the cone are dotted with numerous basaltic bombs and blocks and, although no fumarolic activity was observed, it is evident from its state of preservation that the cone is very young (probably less than 1 Ma old).

The cliffs of Argo Point, beneath the scoria cone, appear to comprise basalt and scoria but approach was prevented by severe crevassing of the ice shelf. The cliffs are undergoing severe ice erosion, as testified by the presence of a moraine which extends for over 1 km in a north-easterly direction from the point. The debris of the moraine comprises fresh, black olivine-microphyric basalt and basaltic scoria, generally highly vesicular, and frequently glass-coated. Ropy flow textures are common. Rare, partially absorbed felsic xenoliths, 1–1.5 cm in diameter, were found within the basalt.

Petrography of the Argo Point basalt

All samples studied are very fresh, with no visible alteration of glass or mesostasis. This corroborates field evidence that the basalts are very recent eruptives.

In thin section, all of the basalts are similar in their mineralogy. All contain phenocrysts of forsteritic olivine, although the abundance ranges from 5 to 15% by volume. The olivine phenocrysts rarely exceed 2 mm and are more commonly between 0.3 and 1.0 mm in diameter. Larger crystals tend to be more rounded. Inclusions within the olivine phenocrysts include glass and chrome spinel. Elongated (0.5–1.5 mm) skeletal laths of plagioclase, frequently forming small glomerocrysts with olivine, may be a second microphenocryst phase, but their abundance is generally subordinate to that of olivine (less than 5%). Sample R.215.5 contains clusters of prismatic pinkish brown titaniferous ferro-augite which appears to be a pre-eruptive liquidus phase.

Groundmass textures range from glassy to intersertal depending on the rate of cooling. Plagioclase and clinopyroxene microlites are developed in the more coarse-grained samples. A feature common to all samples is the high abundance of opaques, disseminated in the fine-grained samples, and separating as titanomagnetite and ilmenite in the more slowly cooled samples.

Chemistry

Nine samples of fresh basalt collected from Argo Point have been analysed for major and trace elements using a Philips PW1450 X-ray fluorescence spectrometer. Analytical techniques were the same as those given in Tarney and others (1979). For comparative purposes, a further five samples collected from the Seal Nunataks by Fleet (1968) have been analysed using the same machine conditions.

Representative analytical data are presented in Table I. The basalts from Argo Point show only minor variations in chemistry: FeO*/MgO ratio (where FeO* is total iron as FeO) ranges from 1.3 to 1.5, and Zr content from 91 to 126 ppm, with sympathetic variations in the abundances of other incompatible elements (Ti, K, P, Zr, Nb, La, Ce, Y and Ba). Most of the basalts contain normative nepheline which, together with high total alkali contents (Fig. 2), suggests that they should be classified as alkali-basalts. In terms of absolute element abundances, the Argo Point basalts clearly resemble the basalts from the Seal Nunataks: low Al_2O_3 and CaO, high total alkalis, high alkaline-earth elements (Ba and Sr) and high Nb. These similarities are further

TABLE I. REPRESENTATIVE ANALYSES OF BASALTS FROM JASON PENINSULA, THE SEAL NUNATAKS AND PAULET ISLAND

	1	2	3	4	5	6	7	8	9
SiO_2	49.25	50.95	50.18	50.89	49.20	50.85	49.36	46.41	50.32
TiO_2	1.66	1.83	1.72	1.69	1.98	2.32	1.96	2.60	0.74
Al_2O_3	14.78	14.92	14.35	14.68	14.89	14.93	14.24	16.33	17.52
tFe_2O_3	12.32	11.54	12.20	11.54	11.61	11.44	12.40	10.88	9.77
MnO	0.16	0.15	0.16	0.15	0.15	0.20	0.15	0.16	0.15
MgO	8.75	6.75	8.20	7.55	9.19	5.90	9.61	8.11	7.06
CaO	8.34	9.13	8.65	8.45	8.39	8.47	8.25	9.60	11.21
Na_2O	3.83	4.24	3.50	4.25	3.65	3.58	3.37	4.30	2.37
K_2O	0.74	0.83	0.61	0.79	1.11	1.19	0.87	1.34	0.61
P_2O_5	0.27	0.30	0.23	0.31	0.21	0.27	0.25	0.83	0.21
L.O.I.	—	+0.27	—	—	—	—	0.17	0.22	—
TOTAL	100.10	100.37	99.80	100.30	100.38	99.15	100.63	100.78	99.96
	TRACE ELEMENTS (ppm)								
Ni	197	75	136	133	167	83	—	—	26
Cr	238	214	245	233	276	87	—	—	120
La	19	20	15	19	15	20	—	—	10
Ce	37	41	32	37	35	40	54	119	21
Nd	17	18	15	18	16	20	—	—	—
Y	17	21	18	17	17	21	—	—	11
Zr	117	126	91	119	145	149	—	—	75
Nb	27	33	21	30	26	25	—	—	2
Sr	397	448	357	438	410	487	585	1 000	607
Rb	8	8	8	9	13	14	8	16	14
Ba	108	130	106	133	115	132	114	205	213
	SELECTED RATIOS								
Nb/Zr	0.23	0.26	0.23	0.25	0.18	0.17	—	—	0.03
La_N/Y_N	6.5	5.5	4.8	6.5	5.1	5.5	8.9*	9.1*	5.3
La/Nb	0.7	0.6	0.7	0.6	0.6	0.8	—	—	5.0
Ba/Nb	4.0	3.9	5.0	4.4	4.4	5.3	—	—	107
Rb/Sr	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.02	0.02
Ba/La	5.7	6.5	7.1	7.0	7.7	6.6	5.6*	4.6*	21.3
	C.I.P.W. NORMS								
Q	—	—	—	—	—	—	—	—	—
or	4.4	4.9	3.6	4.7	6.6	7.0	5.1	7.9	3.6
ab	31.4	34.3	29.6	35.6	28.5	30.3	28.5	19.0	20.1
an	21.0	19.2	21.6	18.6	21.0	21.1	21.2	21.3	35.4
ne	0.6	0.9	—	0.2	1.3	—	—	9.4	—
di	15.2	19.7	16.1	17.3	15.6	15.7	14.7	16.9	15.4
hy	—	—	9.9	—	—	12.0	4.9	—	18.2
ol	20.1	13.9	11.4	16.4	19.6	4.4	17.9	15.8	2.4
mt	2.8	2.6	2.7	2.6	2.6	2.6	2.8	2.4	2.2
il	3.2	3.5	3.3	3.2	3.8	4.4	3.7	4.9	1.4
ap	0.6	0.7	0.5	0.7	0.5	0.6	0.6	1.9	0.5

1. R.217.1: fresh, intersertal olivine-basalt, Argo Point, Jason Peninsula.
2. R.217.2: as for R.217.1.
3. R.217.4: hyalopilitic to variolitic olivine-basalt, Argo Point, Jason Peninsula.
4. R.217.9: olivine-basalt, Argo Point, Jason Peninsula.
5. D.4689.1: olivine-basalt, Bull Nunatak, Seal Nunataks (Fleet, 1968).
6. D.4691.1: olivine-basalt, Bruce Nunatak, Seal Nunataks (Fleet, 1968).
7. D.4114.1: hawaiite, Larsen Nunatak, Seal Nunataks (Baker and others, 1977; Pankhurst, in press).
8. 27788: alkali-basalt (hawaiite), Paulet Island (Baker and others, 1977; Pankhurst, in press).
9. JP3: haematite-coated basalt (? Mesozoic), Stratton Inlet, Jason Peninsula.

(Analyses 1–6 and 9 by A. D. Saunders.)

tFe_2O_3 total iron as Fe_2O_3; L.O.I. Total loss on ignition; C.I.P.W. norms calculated using an assumed Fe_2O_3/FeO ratio of 0.2; La_N/Y_N chondrite-normalized La/Y ratio.

*Values interpolated from the data in Pankhurst (in press).

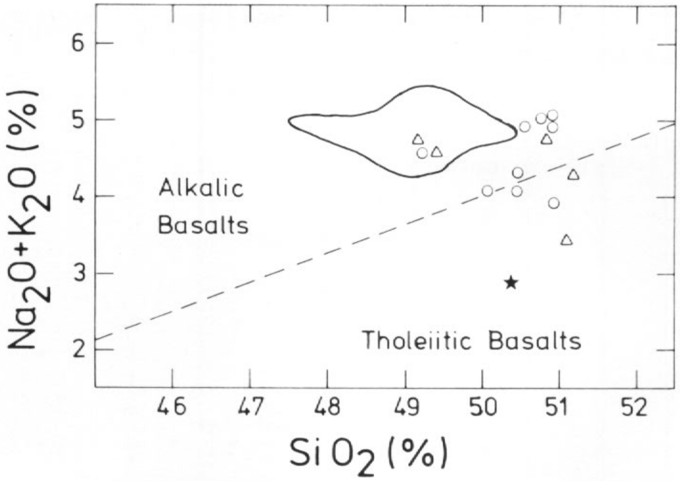

Fig. 2. New analyses of basalts from Argo Point (open circles) and the Seal Nunataks (open triangles) plotted with the field outlined by the James Ross Island basalts (Nelson, 1975) on an alkalis versus silica diagram. The star represents sample JP3 (Table I). The dashed line separating the tholeiitic and alkaline fields is from Macdonald and Katsura (1964).

emphasized when ratios involving incompatible elements are considered. Basalts from the three provinces — Argo Point, the Seal Nunataks and James Ross Island — all exhibit considerable relative light rare-earth element enrichment with La_N/Y_N ratios (where La_N/Y_N is the chondrite-normalized La/Y ratio) ranging from 4.8 to 6.5 at Argo Point, to over 8 at James Ross Island (Pankhurst, in press). Unfortunately, few other trace-element data are available for samples from James Ross Island, but basalts from both the Seal Nunataks and Argo Point have high Nb/Zr ratios and low Ba/La and La/Nb ratios when compared with calc-alkaline basaltic rocks from Graham Land (Figs 3 and 4, respectively). High Nb/Zr ratios are typical of alkaline provinces from both oceanic and continental intra-plate regions (see, for example, Weaver and others, 1972; Erlank and Kable, 1976; Tarney and others, 1980), whereas most ocean-ridge tholeiites, island-arc basalts and calc-alkaline basalts have very low Nb/Zr ratios (Saunders and others, 1980; analysis 9 in Table I). In some other respects — for example, the high absolute abundances of K, Rb, Ba and Sr — the Argo Point basalts are not very dissimilar to calc-alkaline basalts (e.g. JP3; Table I). It is possible that a portion of these alkali and alkaline-earth element contents were introduced during partial assimilation of sialic material (viz. felsic xenoliths at Argo Point, and buchites in the basalts from the Seal Nunataks (Fleet, 1968)), but it is considered that such contamination is probably very slight. For example, sialic contamination could not explain the high Nb content of these basalts, and indeed similar alkaline basalts from oceanic islands, where sialic contamination could not occur, also show elevated Ba, Sr, K and Rb contents (White and others, 1979). Rather, this must be a feature of the primary magma and/or of the mantle source.

The moderately high MgO, Cr and Ni contents of the more primitive Argo Point and Seal Nunatak basalts reveal that they are relatively unfractionated, which concurs with the general absence of plagioclase and pyroxene phenocrysts in most of the lavas. Although the basalts may not represent primary mantle melts, the degree of fractionation since partial melting has probably been slight and restricted to removal of olivine and possibly chrome spinel. Sr increases with increasing Zr, suggesting that removal of plagioclase from the melt has been negligible; this is supported by the general observation that no plagioclase phenocrysts occur in these rocks.

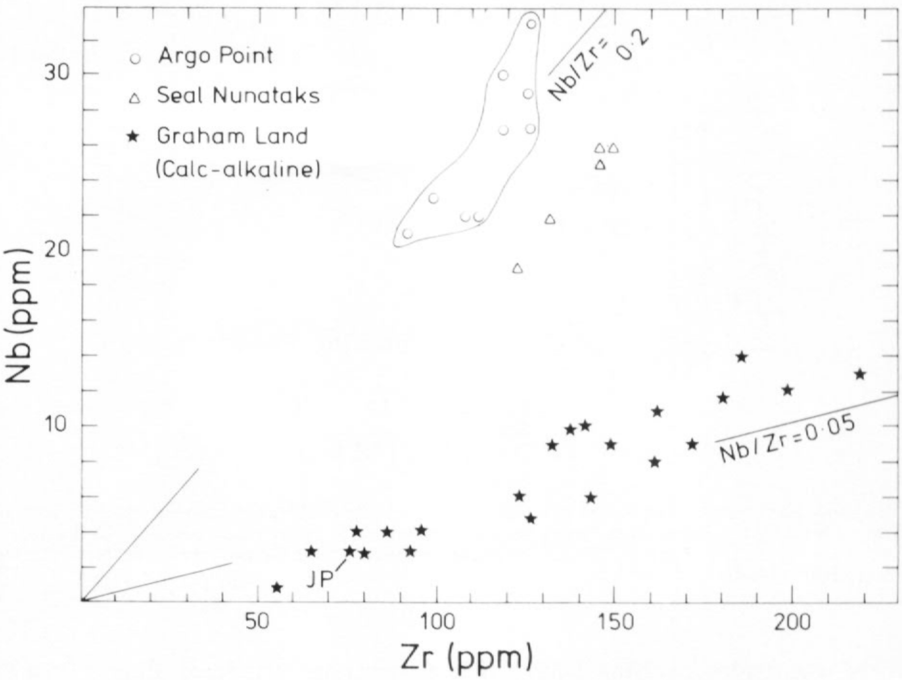

Fig. 3. Nb versus Zr diagram for alkali-basalts from Argo Point and the Seal Nunataks, and calc-alkaline basalts from Graham Land (Saunders, unpublished data). JP refers to sample JP3 (Table I). No data are available for basalts from James Ross Island.

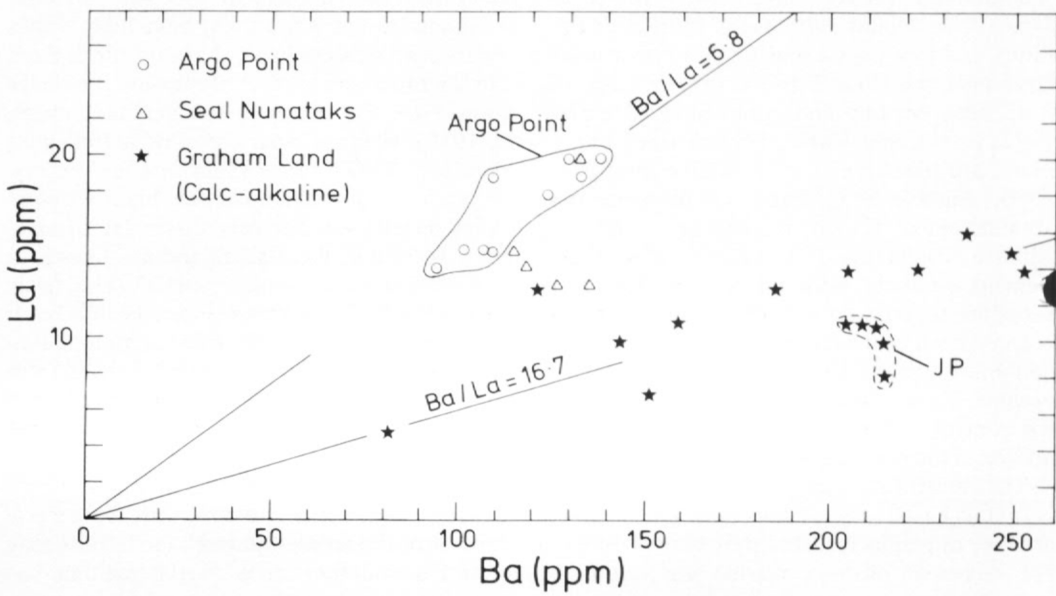

Fig. 4. La versus Ba diagram for alkali-basalts from Argo Point and the Seal Nunataks, and calc-alkaline basalts from Graham Land (Saunders, unpublished data). JP refers to sample JP3 and other basalts from the same exposure. No data are available for basalts from James Ross Island.

Discussion

The data presented in this paper demonstrate that the basalts from Argo Point and the Seal Nunataks are chemically distinct from adjacent, older calc-alkaline basalts from Jason Peninsula and the remainder of Graham Land. In particular, the alkaline basalts contain less Al_2O_3 and CaO, more total iron and have lower La/Nb, Ba/Nb and Ba/La ratios than the calc-alkaline basalts, although the absolute abundances of several incompatible elements, especially K, Rb, Sr and Ba, are broadly the same in both basalt types.

Nevertheless, the difference in La/Nb, Ba/Nb and Ba/La ratios between the different basalts imply that chemically distinct mantle sources, or at least chemically distinct primary magmas, have been involved in the genesis of the calc-alkaline and alkaline igneous provinces. The difference in age between the Mesozoic calc-alkaline volcanic rocks from the east coast of Graham Land and the much younger alkaline volcanic rocks is probably not a controlling factor, because Cenozoic (and, indeed Mesozoic) calc-alkaline basalts from the South Shetland Islands (Fig. 1) are broadly chemically similar to the Mesozoic basalts from Jason Peninsula (cf. Weaver and others, in press). Although there is a tendency for the basalts on the east coast of Graham Land, furthest away from the original trench axis, to be more enriched in K, Rb and Th, the La/Nb, Ba/Nb and Ba/La ratios remain essentially constant along a traverse across Graham Land.

The high La/Nb, Ba/Nb and Ba/La ratios found in calc-alkaline basalts are probably due to a combination of stabilization of minor mineral phases (e.g. ilmenite, rutile, apatite and zircon) within the subducting ocean crust and overlying mantle under conditions of high P_{H_2O}, together with preferential removal of hydrophile elements (particularly K, Rb, Sr and Ba, but not Ti, Zr and Nb) from the dehydrating slab (Hawkesworth and others, 1979; Saunders and others, 1980). Although a detailed discussion of calc-alkaline magma genesis is beyond the scope of this paper, the important feature to note is the strong relative depletion in Nb and to a lesser extent Zr and Ti in calc-alkaline basalts and andesites. This is demonstrably not observed in the Cenozoic alkaline volcanic rocks; rather, Nb is *enriched* relative to La, Ba and K. Similar alkaline volcanic rocks erupted in epeirogenic regions and ocean islands also exhibit Nb enrichment, and it has been suggested that this is an expression of metasomatism of the mantle source regions by alkalic, Nb-enriched fluids (e.g. Frey and others, 1978; Tarney and others, 1980). Whether such an enrichment mechanism has been operative beneath the eastern side of Graham Land, long after subduction activity ceased, is a contentious point without suitable Nd-isotopic data. Even more contentious, however, is the mechanism by which the Cenozoic alkaline activity began.

Baker and others (1977) have suggested that the James Ross Island volcanic activity is either an effect due to residual subduction at the South Shetlands trench, which stopped during the last 8 Ma (Barker and Griffiths, 1972), or that it is due to a separate thermal event. The evidence presented in this paper would appear to preclude the first alternative. Herron and Tucholke (1976) have demonstrated that easterly dipping subduction of Pacific Ocean crust stopped soon after the Aluk Ridge spreading centre impinged against Graham Land. The age of this collision varies along the peninsula, being oldest in the south and youngest in the north; in Drake Passage, for example, the spreading centre has not yet reached the trench. A consequence of this cessation of subduction is that calc-alkaline magmatic activity rapidly stopped, although not until late Cenozoic time in the South Shetland Islands (e.g. Rex and Baker, 1973). If the Cenozoic alkaline activity is directly linked to residual subduction-zone activity, then it would be expected that the volcanism would also young in a northward direction. This is not the case; indeed, the available evidence suggests that the volcanism on and around James Ross Island ranges in age from 7 Ma to less than 1 Ma, the basalts from the Seal Nunataks are too young to contain significant radiogenic argon (Rex, 1976), and that the Argo Point centre appears on field and petrographic criteria to be very young. In addition, the magnetic lineation data (Herron and Tucholke, 1976) indicate that the Aluk Ridge collided with the Graham Land trench opposite Jason Peninsula (*c.*

lat. 65° S) about 10–20 Ma ago, effectively precluding residual subduction-zone activity from being the driving mechanism behind the later alkaline activity. The situation in southern South America is more complex. At first sight, it would appear that the alkaline volcanism in Patagonia post-dates the subduction which stopped approximately 10 Ma ago (DeLong and Fox, 1977; Hawkesworth and others, 1979), thus comparing favourably with the situation in Graham Land. However, Baker and others (in press) have demonstrated that the Patagonian alkaline volcanicity spans much of the Cenozoic; the oldest dated alkaline basalts were formed approximately 55 Ma ago.

The second alternative, that the alkaline volcanicity is due to events not directly related to subduction, would appear to be more plausible. Simple extensional tectonics within and behind the main calc-alkaline magmatic belt, thus allowing egress of hot mantle material into the continental crust, has been invoked to explain ensialic marginal basins in southern Chile (Dalziel and others, 1974) and Bransfield Strait (Barker and Griffiths, 1972). The lavas produced in these basins, even at the inception of spreading, are however tholeiitic to calc-alkaline in chemistry (Saunders and others, 1979; Weaver and others, 1979), and quite different from the Patagonian or James Ross Island lavas. It is, however, possible that because both the Patagonian and northern Graham Land alkaline volcanism is significantly further removed from the origi[nal] trench axis than either the southern Chile or the Bransfield Strait basins, that the mantle source has not been contaminated by subduction-zone derived (? hydrous) components, and has hence retained a strong "intra-plate" chemical signature (e.g. high Nb/La and Nb/Zr ratios). Extensional tectonics appear to be characteristic of many ocean–continent collision zones and it could be expected to develop particularly when subduction ceased.

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