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Cenozoic volcanism in the Antarctic

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With the cessation of subduction along the western margin of Antarctica, Mesozoic calc-alkaline activity gradually gave way in the Cenozoic to more alkaline volcanism associated with an extensional régime. Calc-alkaline volcanism persisted well into the Tertiary in the South Shetland Islands and has started to develop in the Quaternary in the South Sandwich Islands, though most of the Pliocene–Recent products of this group are of island-arc tholeiite affinity.

The Cenozoic volcanic rocks of the Ross Sea and Marie Byrd provinces are generally highly undersaturated basanitoids, alkali basalts and phonolites. In contrast, those of the more northerly parts of the Antarctica Peninsula and its off-lying islands are for the most part mildly alkaline or transitional. However, Paulet Island, the youngest volcano on the northeast side of the Peninsula, is distinctly more alkalic than its Pliocene predecessors. Deception Island, distinctive on account of its strongly sodic differentiates, is probably connected with residual back-arc extension along Bransfield Strait.

Introduction

In the 16 years that have elapsed since the publication of the Catalogue of Active Volcanoes of Antarctica (Berninghausen & Van Padang 1960) very considerable advances have been made not only in documenting Cenozoic volcanoes and their products but also in understanding the implications of the activity. Much of the progress has been due to the collaborative efforts of geophysicists, structural geologists and geochemists concerned with the relationship of volcanism to tectonic evolution (e.g. Barker & Griffiths 1972; Gonzalez-Ferran & Katsui 1970; Dalziel & Elliot 1973). Increasing emphasis has been placed on the continuity of particular geological events which have affected southern South America as well as the Scotia arc and northern Antarctic Peninsula (e.g. Dalziel, Dott, Winn & Bruhn 1975). Radiometric dating has played a crucial rôle in establishing the chronological framework for the igneous and tectonic evolution of the region (e.g. LeMasurier 1972; Rex 1972).

In the following review which incorporates some new K/Ar age determinations and some new chemical data, an attempt is made to summarize the main Cenozoic volcanic episodes and to examine their significance in relation to the dynamic processes that were operative.

Mesozoic volcanism

A Jurassic volcanic sequence of andesitic, dacitic and rhyolitic pyroclastic rocks and lava flows is extensively distributed throughout the Antarctic Peninsula, the South Shetland Islands and the southern part of the Andean cordillera. These Jurassic volcanics, which are of calc-alkaline composition, are widely held to be related to subduction along the Pacific margin of Gondwanaland (e.g. Dalziel 1975). The contrast between the dominance of andesites on the western side of the Antarctic Peninsula and more acid volcanics on the eastern side (Adie 1972) is consistent with an easterly dipping subduction zone. Broadly contemporaneous with these

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TABLE 1. NEW K/AR AGE DETERMINATIONS ON VOLCANIC ROCKS FROM NE ANTARCTIC PENINSULA AND SOUTH SANDWICH ISLANDS

no.	rock type	locality	% K	vol. ^{40}Ar rad. scc./g × 10^{-6}	% ^{40}Ar rad.	age/Ma
27809	basaltic andesite	Islet E of Dundee Is.	0.62	1.812	56.4	72 ± 3
27788	alkali basalt	N end Paulet Is.	1.08	0.0180	7.6	0.3 ± 0.1
				0.0079	4.8	
27812	alkali basalt	Red Island	1.16	0.0731	27.1	1.6 ± 0.2
				0.0700	21.1	
27831	alkali basalt (hawaiite)	NW side Tabarin Peninsula	0.90	0.0276	10.6	0.9 ± 0.2
				0.0334	16.7	
SSF. 5.1	andesite	Freezeland Rock, South Sandwich Islands	0.88	0.1093	40.2	3.1 ± 0.1
				0.1070	31.3	
SSL. 3.1	andesite	Leskov Is., South Sandwich Islands	0.79	0.0116	8.2	0.5 ± 0.1
				0.0174	10.5	
SSM. 4.1	basalt	Horsburgh Point, Montagu, South Sandwich Islands	0.26	0.0083	2.3	1.0 ± 0.3
				0.0126	4.3	
SSW. 12.2	basalt	Sulphur Point, Visokoi Is., South Sandwich Islands	0.48	0.0055	1.6	0.3 ± 0.1
				0.0069	2.1	

$\lambda_\beta = 4.72 \times 10^{-10}\ a^{-1} \quad \lambda_e = 0.584 \times 10^{-10}\ a^{-1}$

$^{40}K/K = 0.0119$ at %

orogenic volcanics were the tholeiitic basalts and related Ferrar dolerites that occur in the Transantarctic Mountains (Elliot 1972; Rex 1972; Gunn 1963). They are probably related to the incipient rifting and fragmentation of Gondwanaland.

Cretaceous volcanic rocks are not abundant in Antarctica. Craddock (1971) shows Cretaceous–Tertiary volcanics along the west coast of the peninsula between Adelaide and Alexander islands. K/Ar age determinations on lavas from two small islets off the east coast of Dundee Island have shown ages of *ca.* 72 Ma (table 1). These are fresh two-pyroxene basaltic andesites of clear calc-alkaline affinity (table 2). They almost certainly owe their origin to a subduction episode although it is perhaps doubtful if this should simply be regarded as a localized

TABLE 2. CHEMICAL ANALYSES AND C.I.P.W. NORMS OF DATED VOLCANIC ROCKS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SiO_2	46.41	47.64	47.80	48.28	48.69	49.36	52.34	52.53	55.70	58.62
TiO_2	2.60	1.86	2.73	2.57	1.15	1.96	1.34	0.70	0.75	0.72
Al_2O_3	16.33	15.25	15.13	15.37	16.72	14.24	17.80	19.29	17.71	18.29
Fe_2O_3	2.18	2.05	2.97	2.39	4.12	1.98	5.70	1.88	4.24	1.92
FeO	7.83	8.82	8.77	8.15	5.71	9.38	4.24	7.31	3.88	4.72
MnO	0.16	0.18	0.14	0.18	0.16	0.15	0.19	0.18	0.18	0.14
MgO	8.11	9.66	7.64	7.26	9.29	9.61	4.16	3.88	3.39	3.04
CaO	9.60	8.49	8.46	9.75	9.70	8.25	9.36	10.88	7.51	7.94
Na_2O	4.30	3.71	3.65	3.97	2.59	3.37	3.27	2.02	3.56	3.05
K_2O	1.34	1.26	1.35	1.42	0.41	0.87	0.30	0.24	1.41	0.94
H_2O^+	0.09	0.65	0.58	0.00	0.96	0.34	0.60	0.12	0.35	0.30
H_2O^-	0.13	0.05	0.17	0.05	0.06	0.06	0.07	0.05	0.93	0.03
P_2O_5	0.83	0.44	0.47	0.50	0.20	0.25	0.29	0.00	0.29	0.12
Total	99.91	100.06	99.86	99.89	99.76	99.82	99.66	99.08	99.90	99.83
Qz	—	—	—	—	—	—	8.7	8.1	9.6	14.4
Or	7.9	7.5	8.0	8.4	2.4	5.1	1.8	1.4	8.3	5.6
Ab	19.6	23.4	28.1	23.8	21.9	28.5	27.7	17.1	30.1	25.8
An	21.3	21.2	20.9	19.9	32.8	21.2	33.0	42.9	28.2	33.4
Ne	9.1	4.3	1.5	5.3	—	—	—	—	—	—
Di	16.9	14.6	14.6	20.4	11.2	14.7	9.1	9.2	5.8	4.2
Hy	—	—	—	—	18.1	5.0	7.3	16.1	8.4	11.6
Ol	14.9	20.8	15.5	12.5	3.7	17.7	—	—	—	—
Mt	3.2	3.0	4.3	3.5	6.0	2.9	8.3	2.7	6.2	2.8
Il	4.9	3.5	5.2	4.9	2.2	3.7	2.5	1.3	1.4	1.4
Ap	2.0	1.0	1.1	1.2	0.5	0.6	0.7	—	0.7	0.3
H_2O	0.2	0.7	0.7	0.1	1.0	0.4	0.8	0.2	1.3	0.3

Key to columns

(1) 27788. Alkali basalt (hawaiite). North end of Paulet Island. Analyst F. Buckley.
(2) 27831. Alkali basalt (hawaiite). NW side of Tabarin Peninsula. Analyst F. Buckley.
(3) 29139. (D4105.1) Hawaiite. Akerludh Nunatak, Seal Nunataks. Analyst F. Buckley.
(4) 27812. Hawaiite. Red Island, James Ross Group. Analyst F. Buckley.
(5) 23959. (BS 52.3) Olivine tholeiite. Tower Island. Analyst F. Buckley.
(6) 29138. (D.4114.1) Hawaiite. Larsen Nunatak, Seal Nunataks. Analyst F. Buckley.
(7) 23958. (BS. 1.2) Tholeiite. Two Hummock Island. Analyst F. Buckley.
(8) SSM.4.1. Basalt. 200 m northwest of Horsburgh Point, Montagu Is., South Sandwich Islands. Analyst J. R. Bowden-Dan.
(9) 27808 (nearest equivalent to 27809 in table 1). Basaltic andesite. Central of three islets northeast of Paulet Island. Analyst F. Buckley.
(10) SSL.4.1 (nearest equivalent to SSL.3.1 in table 1). Two-pyroxene andesite, east side Leskov Is., South Sandwich Islands. Analyst P. E. Baker.

K/Ar dates for these samples are in table 1 of this paper or in Rex (1976), appendix, table III.

continuation of the major Jurassic subduction zone. Conceivably there was a distinct but short-lived episode of subduction from the east, related to the interaction of the west Antarctic and South American plates in the late Mesozoic.

Cenozoic volcanism

The principal regions of Cenozoic volcanism in Antarctica are illustrated in figure 1 and are discussed in turn below.

South Sandwich Islands

Forming the eastern margin of the Scotia Sea, the South Sandwich Islands are regarded as an oceanic island arc in a relatively early stage of development (Baker 1968). An andesitic dyke cutting pyroclastic rocks on Freezeland Rock, believed to be the oldest exposed part of the South Sandwich chain, has given a K/Ar age of *ca.* 3 Ma. Radiometric dates on other lavas from these islands are around or less than 1 Ma (table 1). In contrast to the majority of circum-Pacific island-arcs, basalt is the dominant rock type in the South Sandwich Islands. Most of the rocks are of tholeiitic type (Baker 1968) and would appear to belong to the island-arc tholeiite series (Jakeš & Gill, 1970). From analyses by Baker (1968, 1976) and McReath (1972) a number of chemical trends may be distinguished:

(i) a tendency towards marked iron enrichment in differentiated rocks, particularly evident in the southern islands of Cook, Thule and Bellingshausen. Some of the northern islands such as Visokoi and Zavodovski might belong to the same series but samples are confined to basaltic rocks.

(ii) a trend of moderate iron enrichment is exhibited by the suites of Candlemas and Vindication islands which also show, at least in part, a very low K_2O versus SiO_2 trend.

(iii) Leskov island is unique in the South Sandwich Islands in that it is composed of two pyroxene-andesites of calc-alkaline type, lying on a trend showing no iron enrichment.

More than one series may be represented on some of the islands and in some instances the absence of differentiated types makes it impossible to define any trend adequately. However, it is clear that the rocks of the South Sandwich Islands, though broadly similar in age (mostly Pleistocene–Recent) are of diverse affinities. It is perhaps especially significant that the only island to develop typical calc-alkaline andesites, Leskov island, is situated about 50 km west of the main arcuate axis of the chain, over the deeper part of the Benioff zone. The variable degree of iron enrichment shown by these tholeiitic rocks may be due to differences in fractionation conditions, e.g. oxygen fugacity, but variations in K and in some of the trace elements may mean a heterogeneous source.

Forsyth (1975) comments on differences in the stress pattern of the subducted slab as illustrated by focal mechanisms of earthquakes in the northern and southern parts of the arc. The ridge-transform fault system between the South Sandwich Islands and the South Atlantic triple junction is such that younger lithosphere is being subducted beneath the southern part of the island-arc. Changes in the properties of the lithosphere which seem to be responsible for north–south variations in seismicity may also account for some of the differences apparent in the overlying volcanic rocks.

Strontium isotope ratios in volcanic rocks of the South Sandwich Islands are significantly higher than values quoted for ocean floor basalts (e.g. Hart 1971). Regardless of differentiation stage, the $^{87}Sr/^{86}Sr$ ratios remain fairly constant at around 0.7040, which is consistent with derivation of the more evolved types by crystal fractionation from basaltic liquids (Gledhill & Baker 1973).

On the basis of magnetic anomaly patterns Barker (1972*a*) has suggested that most of the Scotia Sea formed during the past 40 Ma. Barker & Griffiths (1972) show that the central part of the Scotia basin is older than the rest and that the youngest segments are to be found in Drake Passage and the eastern part of the Scotia Sea. The latter is associated with a small active spreading axis which has been identified behind the South Sandwich Islands (Barker 1972*b*). The South Sandwich plate is bounded by this spreading axis on the west and the South Sandwich trench to the east. It has developed during the past 8 Ma (Barker & Griffiths 1972) by accretion at the fast-spreading axis (4 cm/year current half-rate according to Forsyth 1975).

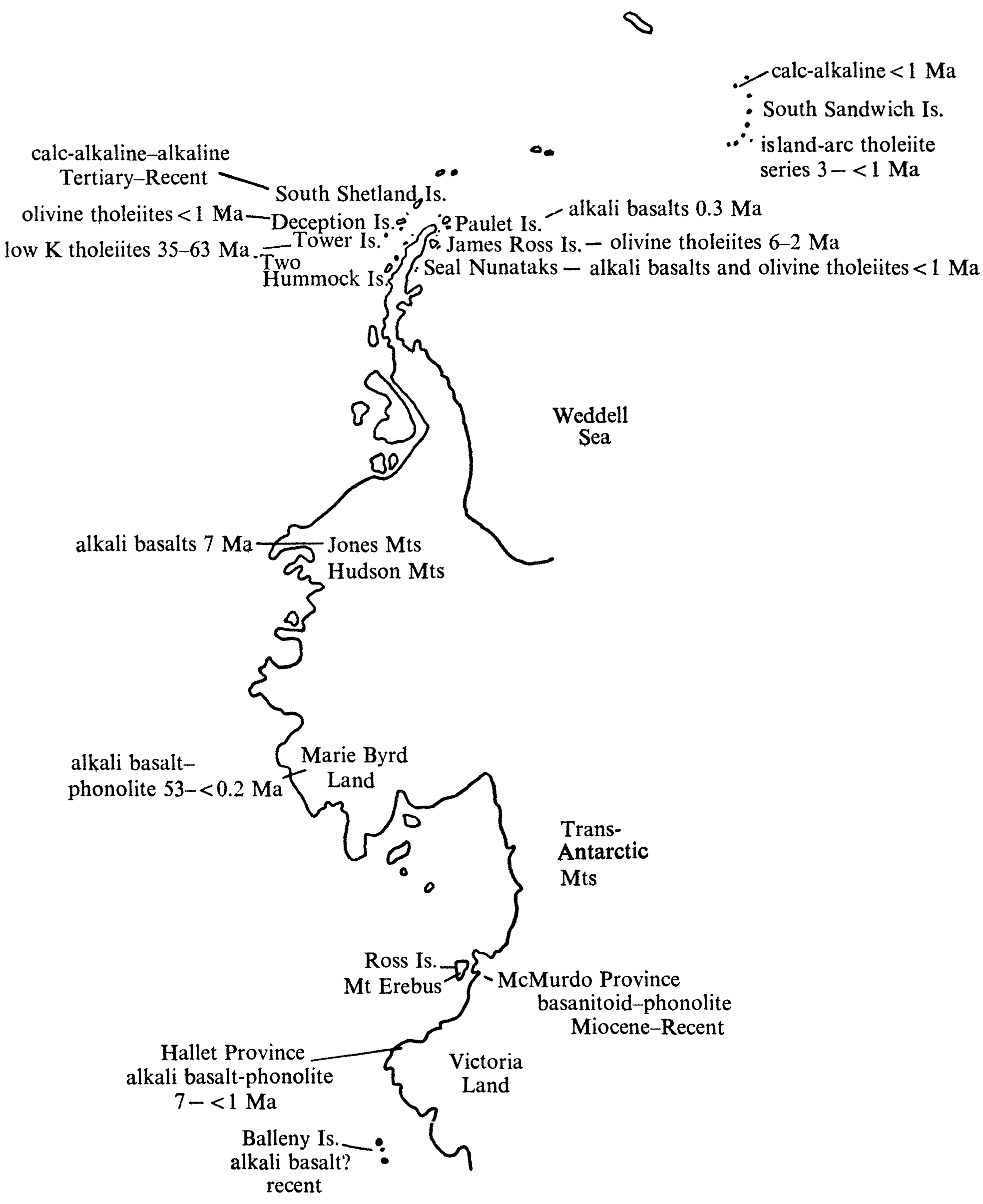

FIGURE 1. Location of the principal Cenozoic volcanic provinces of Antarctica indicating approximate age and composition of the eruptive rocks.

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As suggested by Barker & Griffiths (1972), it would appear that the South Sandwich plate has developed by a process of back-arc extension analogous to that proposed for the marginal basins of the western Pacific (Karig 1971).

Geochemical data on basalts dredged from the spreading axis, referred to as the Scotia Sea Rise, have yet to be published. There will undoubtedly be considerable interest in these rocks as marginal basin development seems to have played an important rôle in the evolution of the cordillera of the Americas and West Antarctica (see, for example, Dalziel, de Wit & Palmer 1974; Schweickert 1976). Work by Hawkesworth, O'Nions & Pankhurst (1976) has demonstrated significant differences in $^{87}Sr/^{86}Sr$ ratios and rare earth element distribution in the Scotia Sea rise basalts compared with those of the South Sandwich island-arc. In the case of basalts dredged from behind the Mariana island arc, Hart, Glassley & Karig (1972) have demonstrated a broad similarity with those erupted at mid-ocean ridge axes; there are minor differences in some incompatible elements, which they attribute to a deeper source and a slower spreading process in the marginal basin environment.

South Shetland Islands

The geological succession in the South Shetland Islands is generally comparable with that encountered on the northern part of the Antarctic Peninsula and its off-lying islands. There is some evidence of a pre-Jurassic basement complex and the ubiquitous upper Jurassic acid volcanics of calc-alkaline type are represented, for example on King George Island (Hawkes 1961 *a*) and Livingston Island (Hobbs 1968). The South Shetland Island crustal block is thought to have been separated from the Antarctic Peninsula by a process of back-arc extension along Bransfield Strait as a corollary to subduction at the South Shetland Islands trench during the Upper Tertiary (Barker & Griffiths 1972).

Two-pyroxene andesites and associated calc-alkaline rocks of Tertiary age (Hawkes 1961 *a*) can reasonably be attributed to subduction of Pacific ocean crust in a southeasterly direction along the line of the South Shetland trench. However, the more recent olivine tholeiites of Penguin Island (Gonzalez-Ferran & Katsui 1970) and the anomalous volcanic series of Deception Island, have decidedly different affinities from the Tertiary volcanics and are probably related to the extensional tectonic régime which brought about the opening of Bransfield Strait. The unusual transitional nature of the Deception Island series was first commented upon by Hawkes (1961 *b*) and was further substantiated by Baker *et al.* (1975). Harvey (1974) also notes that within the young volcanic rocks of Deception Island certain characteristics of calc-alkaline, alkaline and tholeiitic series can be recognized. However, he does note that there is a bias towards more tholeiitic varieties among the younger post-caldera group. The initial $^{87}Sr/^{86}Sr$ isotopic ratios for basic rocks from Deception Island average *ca.* 0.7030 (McReath in Baker *et al.* 1975), a value significantly lower than those for the South Sandwich Islands (Gledhill & Baker 1973) and other island arcs.

In terms of their major element chemistry, high Na/K ratios and strontium isotope values, the basalts of Deception Island show a resemblance to those dredged from the spreading centre behind the Mariana island-arc (Hart *et al.* 1972). However, there are some differences, especially for example in the distinctly higher Sr concentrations in the Deception basalts. The structural situation and geochemistry make it probable that the Deception Island volcanism is closely connected with a marginal basin type of extension along Bransfield Strait. What is perhaps unusual for this type of environment is the fact that volcanism was locally persistent and led not only to the building of a substantial volcanic pile but also to the evolution of strongly differentiated lavas with unique characteristics.

The Elephant and Clarence Islands group appears to form part of the South Shetland continental sliver that was separated from the Antarctic Peninsula. Although no young volcanic rocks occur on these islands, the granodiorite of Cornwallis Island has been dated at only 9.5 Ma (Rex & Baker 1973). Its generation may have been connected with subduction at the South Shetland trench and it perhaps represents a continuation of the roots of the South Shetland island-arc which failed to have any surface expression in the north.

Tower and Two Hummock Islands

Tower Island is situated off Trinity Peninsula to the southeast of Deception Island and Two Hummock Island is located south of here on the western side of Gerlache Strait. Volcanic rocks from these two islets give Eocene–Oligocene ages (Rex 1972). At this time, prior to the opening of Bransfield Strait they would have been in relatively close juxtaposition to the Tertiary volcanics of the South Shetland Islands. Only four analyses are available from these islands and examples are quoted in table 2. Two rocks from Tower Island are a tholeiite and an olivine tholeiite both with relatively high MgO contents (i.e. around 9%). The other two samples are quartz-normative tholeiites with relatively high SiO_2, low MgO and low K_2O. The first two rocks are very similar to some of the basalts from Robert Island (Gonzalez-Ferran & Katsui 1970, table 1, p. 134) and the latter two are of island-arc tholeiite type, very similar to the modern lavas of the South Sandwich Islands. The volcanic rocks of these two small islands are therefore interpreted as being closely associated with those of the South Shetland Islands: in composition they seem to be of a type broadly comparable with that erupted during an early stage of island-arc evolution.

The James Ross Island volcanic group

Volcanic activity in this province on the Weddell Sea side of the Antarctic Peninsula is of Pliocene to Recent age. Much of the region is composed of an eroded basalt/palagonite breccia plateau within which younger volcanic cones developed. On James Ross Island itself the flows range in age from approximately 6 to 2 Ma (Rex 1976) and they are virtually all olivine tholeiites (hawaiites) with a relatively high Na_2O content: they resemble some of the basic lavas of Deception Island except that K_2O is lower in the latter. Northwards from James Ross Island the small volcanic islets of Prince Gustav Channel and Tabarin Peninsula are slightly younger in age (table 1 and figure 2) and have the composition of mildly undersaturated hawaiites (table 2 and figure 3). This trend is continued northwards to Paulet Island which is the youngest of the group (*ca.* 0.3 Ma, see table 1) and where the lavas are distinctly more undersaturated (figure 3).

Some 120 km to the southwest of James Ross Island are the Seal Nunataks where the lavas are so young that they have failed to yield any radiogenic argon (Rex 1976). Chemically they are olivine tholeiites or slightly undersaturated hawaiites with relatively high MgO contents and fairly high K_2O.

Comparing the Pliocene–Quaternary volcanism on the two sides of the Antarctic Peninsula the following conclusions may be drawn: (i) Most of the basaltic rocks are olivine tholeiites or mildly alkalic basalts. They tend towards oversaturation on the western side of the Peninsula and undersaturation on the east. (ii) The only place where pronounced differentiation has occurred is on Deception Island where a strongly sodic suite of distinctive character has evolved bearing little similarity to other well established volcanic rock series. On the eastern side of the Peninsula the only evidence for differentiation comes from segregation veins in the James Ross Island volcanics (Nelson 1966) and these have a decidedly alkaline affinity. (iii) The K_2O/Na_2O ratio is higher in the James Ross Island volcanics than it is in the Deception Island lavas or in those of Penguin and Bridgeman Islands.

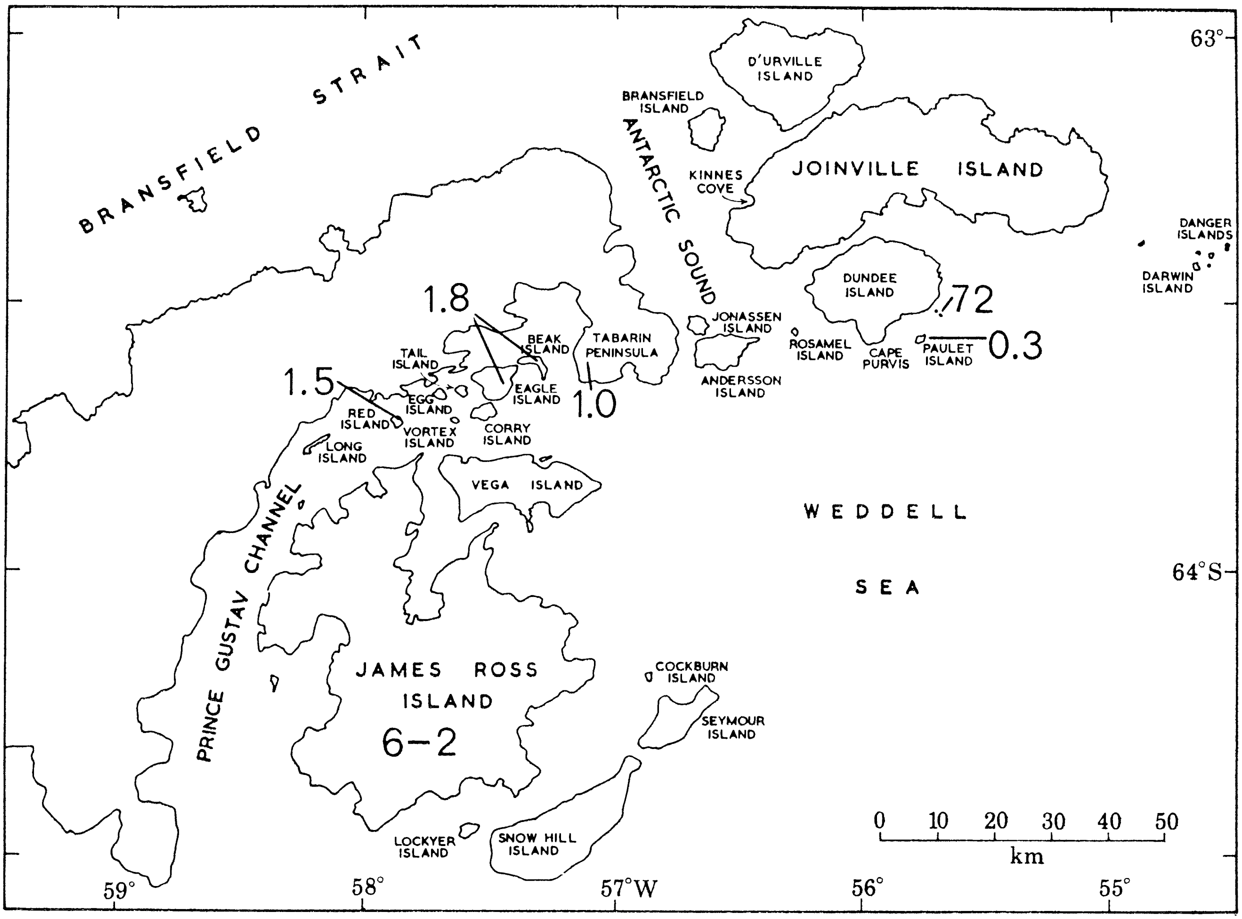

FIGURE 2. Location map for the James Ross Island Volcanic Group and associated islands. Figures indicate approximate K/Ar ages in million years.

It seems probable that all of these late Cenozoic lavas are related to the same tectonothermal event, which may have involved magmatism and crustal extension occurring in a back-arc situation as a corollary to subduction at the South Shetland trench. However, magnetic lineations suggest that subduction at this trench ceased sometime during the past 8 Ma (Barker & Griffiths 1972). This being so, then the more recent activity may either be regarded as a residual effect of this subduction or must be treated as an independent thermal event. Certainly the more alkalic and more potassic composition of the lavas on the eastern side of the Peninsula is consistent with an origin from greater depth which may perhaps imply ascent from over the deeper part of an easterly dipping Benioff zone.

Jones Mountains, Ellsworth Land

Miocene and Pliocene volcanic rocks are known from both the Jones and Hudson Mountains. Potassium-argon age determinations indicate that the volcanic rocks of the Jones Mountains were erupted at least 7 Ma ago. The lower part of the succession includes basaltic tuffs and agglomerates with a high percentage of basaltic glass and palagonite. This fragmental unit is thought to have formed by lava-ice interaction and is an indication that this part of the continent was undergoing glaciation at least 7 Ma ago. The lavas have an alkali basalt composition (Rutford, Craddock, White & Armstrong 1972).

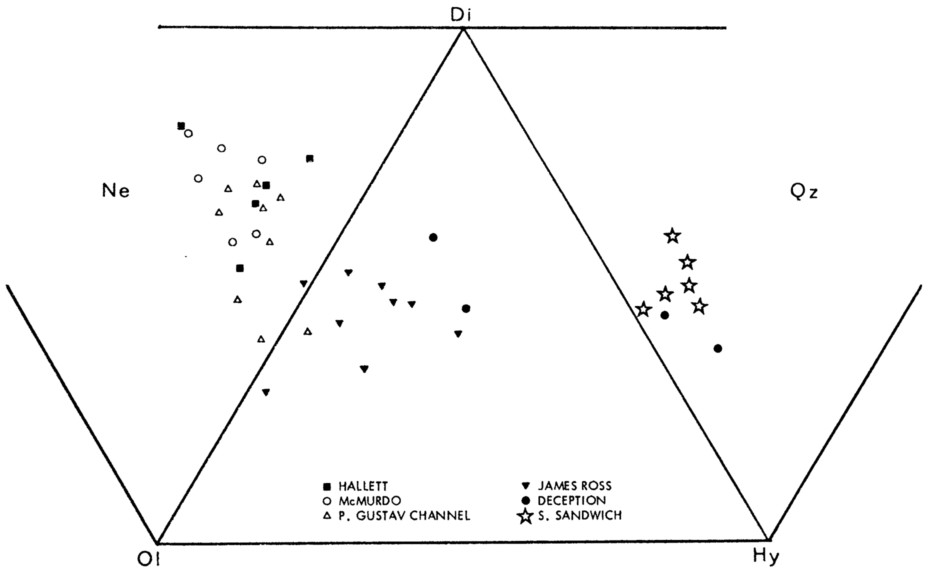

FIGURE 3. Basaltic rocks of some of the Cenozoic provinces of Antarctica plotted according to normative ratios of Di (diopside), Ol (olivine), Hy (hypersthene), Qz (quartz) and Ne (nepheline).

Marie Byrd Land

Much of the Cenozoic volcanic succession of Marie Byrd Land is represented by a basaltic, often hyaloclastite, plateau which reaches a thickness of the order of 2000 m. K/Ar dates indicate that this volcanism extends from the Eocene to the Pleistocene (LeMasurier 1972). However there are also reports of Recent activity (Gonzalez-Ferran & Gonzalez-Bonorino 1972). The basic rocks are strongly alkalic nepheline normative alkali basalts. Though a typical alkali basalt series, rocks of intermediate composition such as hawaiites and mugearites, are relatively uncommon. Differentiates including trachytes, phonolites and alkali rhyolites make up strato-volcanoes which rise from the plateau volcanics. According to Gonzalez-Ferran & Gonzalez-Bonorino this Plio-Pleistocene volcanism was fracture controlled and migrated north–south with time. LeMasurier (1971) draws a comparison of the Marie Byrd Land eruptive environment with that of the African rift valleys, Iceland and the North Atlantic Tertiary province.

Ross Sea petrologic province

Hamilton (1972) referred to the Upper Cenozoic volcanic rocks around Victoria Land as comprising the Ross Sea petrologic province. He distinguished three subdivisions: (i) the McMurdo province which is characterized by high subaerial volcanoes and includes Ross

Island and Mount Erebus. (ii) The Hallett volcanic province which consists of rather low coastal exposures dominated by fragmental basaltic rocks. (iii) The Balleny province which comprises a group of oceanic volcanoes forming the islands of that name. Like the Hallet province, the Balleny Islands seem also to be composed of brecciated basalts.

Potassium-argon age determinations on the volcanic rocks from the Hallett province suggests that they date back to the Pliocene (*ca.* 7 Ma) but activity has persisted up to the present time. Palagonite breccias and tuffs are a major feature of the succession in much of the Ross Sea province. They are interpreted as being of sub-glacial origin, having been erupted beneath an ice-sheet that was once considerably more extensive than at present. The Dry Valley Drilling Project is an attempt to evaluate the glacial and geological history of this area, through a series of drill holes in the vicinity of McMurdo Sound. Detailed stratigraphic and geochemical studies on the McMurdo volcanics are being carried out as part of this programme (e.g. Treves & Kyle 1973).

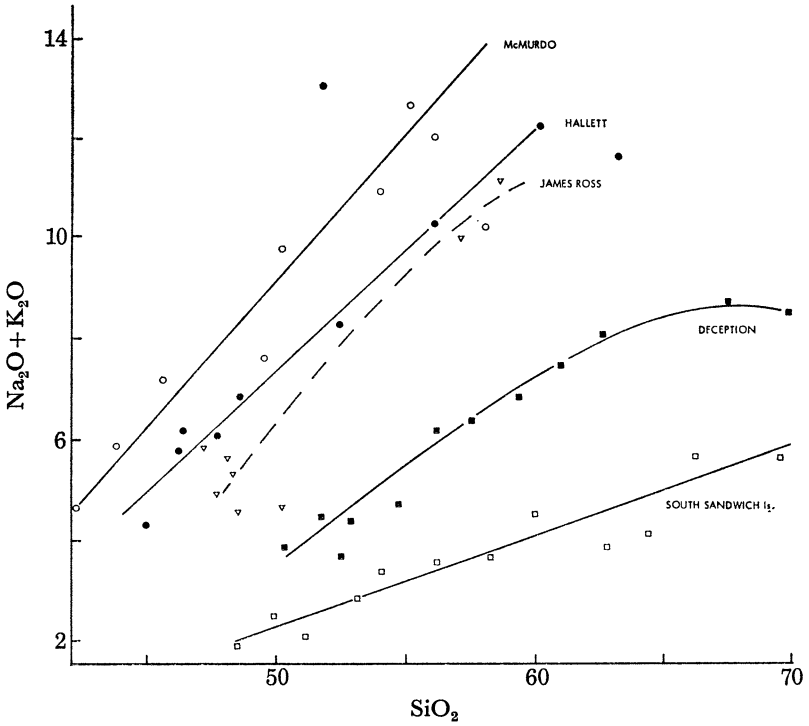

FIGURE 4. Comparative total alkalis versus silica plot (mass %) for some of the Cenozoic volcanic series of Antarctica.

The Ross Sea province comprises a highly undersaturated volcanic association including in the McMurdo region the most alkalic Cenozoic rocks in Antarctica (figure 4). As in Marie Byrd Land, Hamilton (1972) reports that the rocks of the Hallett province belong to a bimodal series, 70% of which is basaltic and 15% trachyte: the remainder includes rock types such as basanite, latite and phonolite. The series includes some of the most sodic igneous rocks that are known. The mafic and felsic rocks occur together as breccias, dykes, plugs etc.

Goldich, Treves, Suhr & Stuckless (1975) have described the volcanic rocks from Ross Island and vicinity. They include basanitoids or alkali basalts, trachybasalts, anorthoclase phonolites, and trachytes. $^{87}Sr/^{86}Sr$ ratios are in the range 0.7020–0.7048. Mineralogical and trace element data support an origin of the basanitoid magma through small degrees of partial melting of peridotite and suggests a crystal fractionation origin for the remaining members of the series. It is suggested that fractionation at depth would yield a trachybasalt residuum whilst at shallower levels it would lead to phonolitic compositions (Goldich *et al.* 1975).

The line of highly undersaturated Cenozoic volcanics comprising the Ross Sea petrologic province marks the front of the Transantarctic Mountains. Treves & Kyle (1973) consider that this volcanic zone is an expression of large-scale tensional fracturing of the continent.

Summary and conclusions

In Western Antarctica calc-alkaline igneous activity had prevailed throughout the Mesozoic. This is thought to have been associated with subduction of Pacific crust beneath the margin of Gondwanaland. During the Cenozoic this type of activity was gradually superseded by more alkaline volcanism associated with fracturing, rifting and crustal extension. However, there are exceptions to this general pattern.

Judging by the composition of volcanic rocks, intermittent subduction occurred along the western margin of the Antarctic Peninsula throughout much of the Tertiary persisting at the South Shetland Islands trench until the Pliocene. The only currently active Benioff zone is that beneath the South Sandwich Islands where the island-arc tholeiite and calc-alkali series are almost entirely of Quaternary age.

The olivine tholeiites of Deception Island and James Ross Island and the more alkalic basalts of Prince Gustav Channel are all interpreted as belonging to a back-arc extensional régime, though in some instances this implies a degree of residual magmatism over a now inactive Benioff zone. There is some evidence of increasing alkalinity in the more easterly and in the younger volcanics, both conditions being met in the case of Paulet Island where some of the lavas could be termed basanitoids.

In the more southerly provinces of Marie Byrd Land and the Ross Sea Cenozoic eruptives have been consistently alkalic. They are more strongly undersaturated and tend to be compositionally bimodal with abundant alkali basalt and phonolite/trachyte and few intermediates. By analogy with East Africa and other volcanic provinces it is likely that the highly alkalic volcanism of this part of Antarctica is controlled by a major fracture or rift structure within the continental crust.

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