THE GEOLOGY OF BEETHOVEN PENINSULA, SOUTH-WESTERN ALEXANDER ISLAND

By C. M. BELL

ABSTRACT. Cenozoic volcanic rocks unconformably overlying arkosic sediments are described from the scattered nunataks of Beethoven Peninsula, south-western Alexander Island. Bedded palagonite-tuffs and breccias from subaqueous explosive eruptions of olivine-basalt are overlain by subaerial basaltic lava flows. These rocks represent new discoveries in the broad chain of Cenozoic volcanic eruptions extending across western Antarctica from the Ross Sea, through Marie Byrd Land, Ellsworth Land and the northern Antarctic Peninsula.

BEETHOVEN PENINSULA (Fig. 1) is situated between lat. 71° and 72° S., and long. 72° and 76° W. on the south-western coast of Alexander Island. It was possibly first sighted in 1910 by J.-B. Charcot (1911), who reported land far to the south of Charcot Island. In 1940, members of the United States Antarctic Service Expedition (Black, 1945) first observed nunataks on the peninsula from the air and described them as "... about ten rounded mountain features" south of Charcot Island.

After several photographic flights by the Ronne Antarctic Research Expedition, 1946–48 (Ronne, 1948), the area was first mapped as a huge westerly extension of southern Alexander Island. Subsequently, Searle (1963), on a new map of Alexander Island based mainly on the same air photographs, named the area Beethoven Peninsula and gave place-names to many of the more prominent topographical features. Thus for the first time the peninsula was accurately mapped.

In December 1969, I. F. Smith and B. Gargate visited Franck Nunataks, and during November 1970 the first reconnaissance geophysical and geological investigation of the whole peninsula was undertaken. Particular attention was paid to the volcanic rocks of Mussorgsky Peaks.

Beethoven Peninsula is a gently undulating ice plateau about 10,000 km.^{2} in area and averaging 500 m. in altitude. It lies between Wilkins Sound in the north and the Bach Ice Shelf in the south, and is deeply dissected by five inlets occupied by ice shelf. 14 nunataks and snow-covered hills (Fig. 2) range in height from 366 m. at Gluck Peak to 1,052 m. at Mount Greig. Mount Borodin and the Franck Nunataks are situated on a scarp above Boccherini Inlet and the remaining nunataks are scattered over an area of about 2,500 km.^{2} around Brahms Inlet. Mount Tchaikovsky and Chopin Hill are entirely snow-covered, and Mount Schumann has only two small areas of rock exposed high up on its northern side.

Mount Borodin and the Franck Nunataks have steep, jagged profiles because they are composed of resistant arkoses, whereas the other nunataks are more rounded and consist of relatively unconsolidated volcanic rocks. Mussorgsky Peaks comprise two nunataks; the larger is flat-topped and formed by the denudation of soft tuffs which are overlain by a resistant basalt cap (Fig. 3).

GEOLOGY AND PETROLOGY

Sheared and altered arkosic sediments form the basement of Beethoven Peninsula. Grikurov and others (1967) tentatively correlated similar sediments exposed in central Alexander Island with the (?) Carboniferous Trinity Peninsula Series of north-east Graham Land. These arkoses are unconformably overlain and intruded by vitrophyric tuffs and olivine-basalts which are lithologically and structurally similar to Cenozoic volcanic rocks found in many areas of western Antarctica (p. 82).

Because they are undisturbed and relatively unconsolidated, these volcanic rocks of Beethoven Peninsula are tentatively dated as late Tertiary or Quaternary.

Sediments

Arkose and pebbly arkose exposed at the Franck Nunataks and Mount Borodin are lithologically and structurally similar to more extensive arkosic outcrops in central Alexander

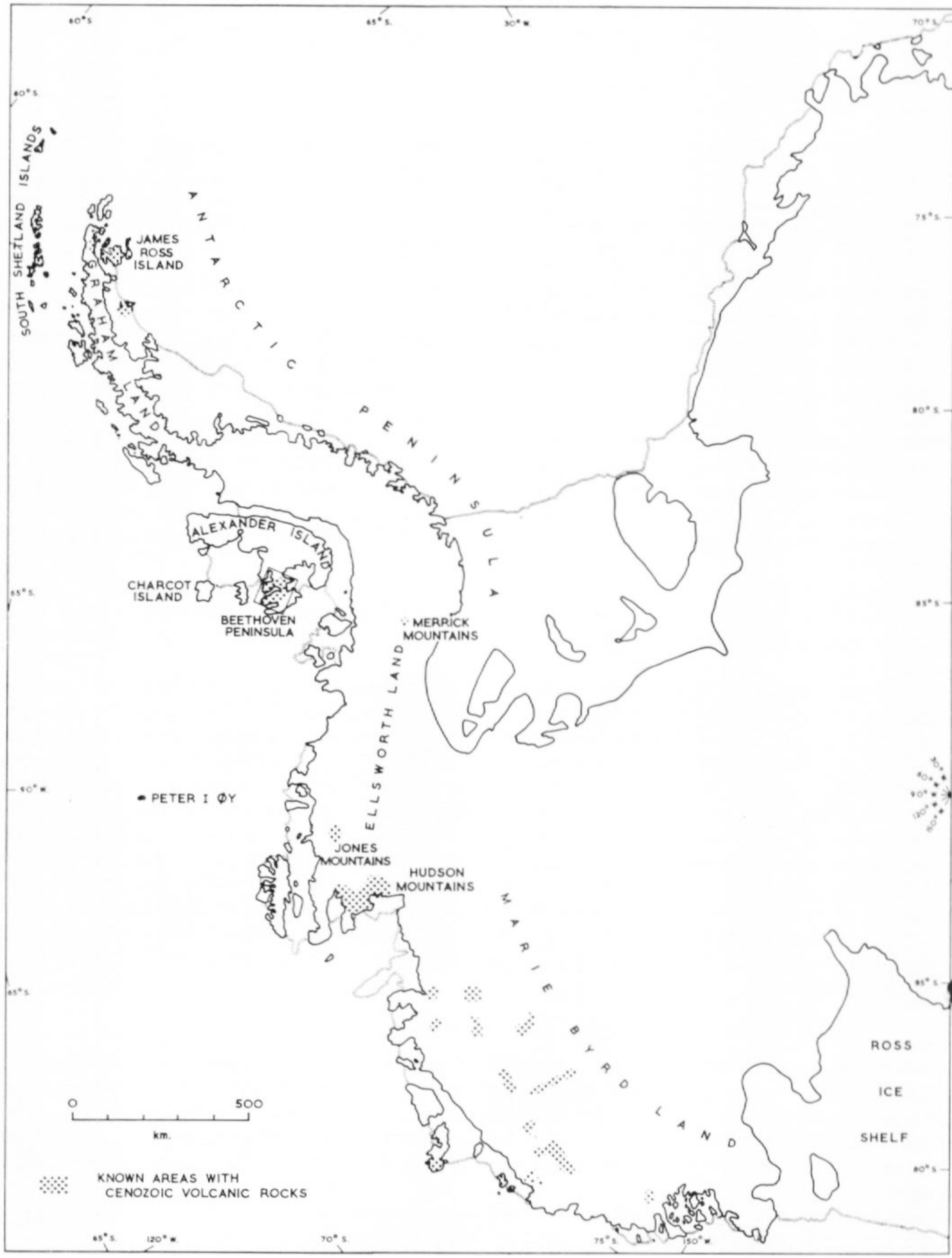

Fig. 1. Map of western Antarctica showing areas with known outcrops of Cenozoic volcanic rocks (after Craddock, 1970).

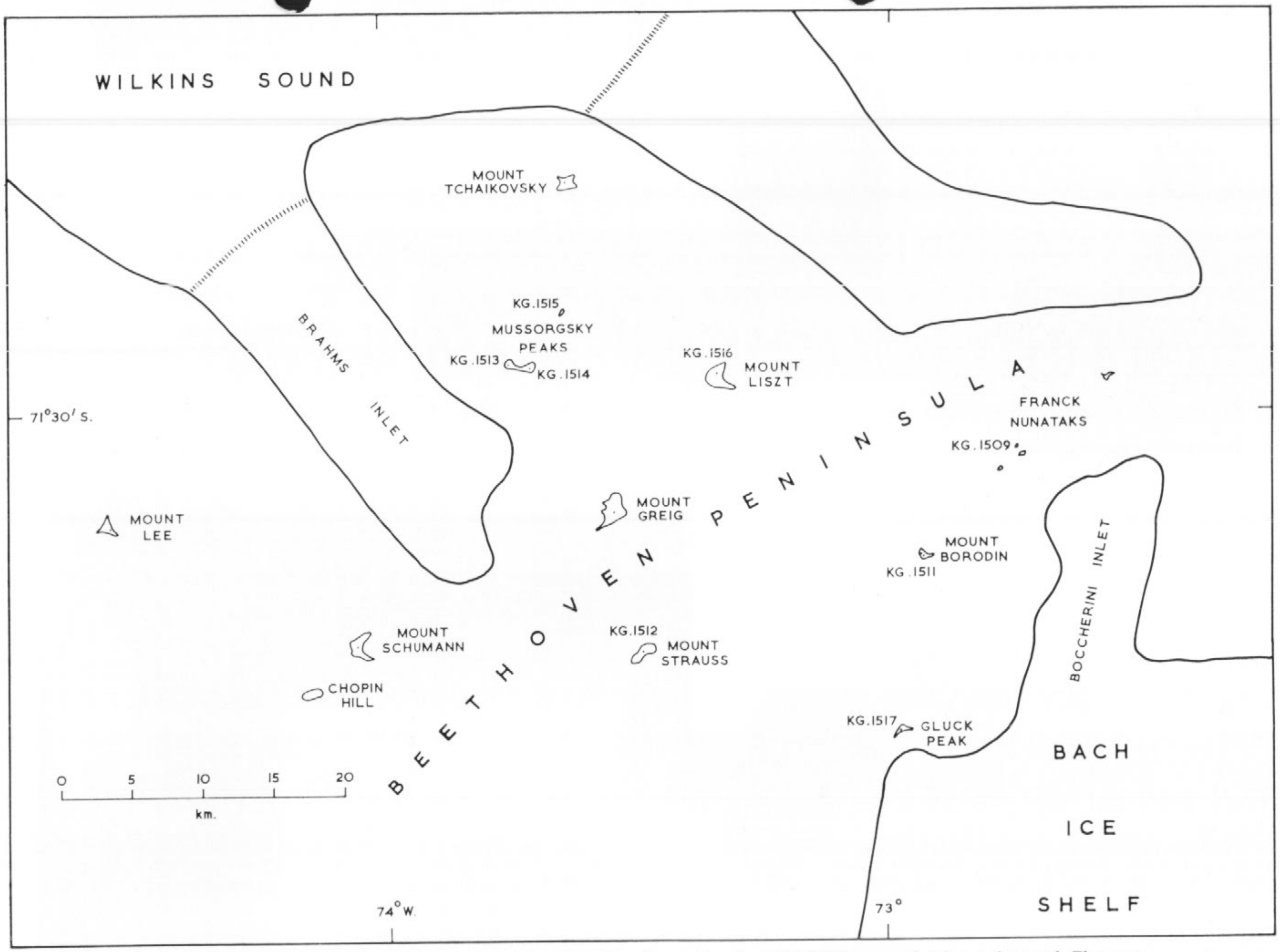

Fig. 2. Sketch map of Beethoven Peninsula compiled from the 1 : 1,000,000 map of Alexander and Charcot Islands (Searle, 1963) and a plane-table survey by A. N. Bushell.

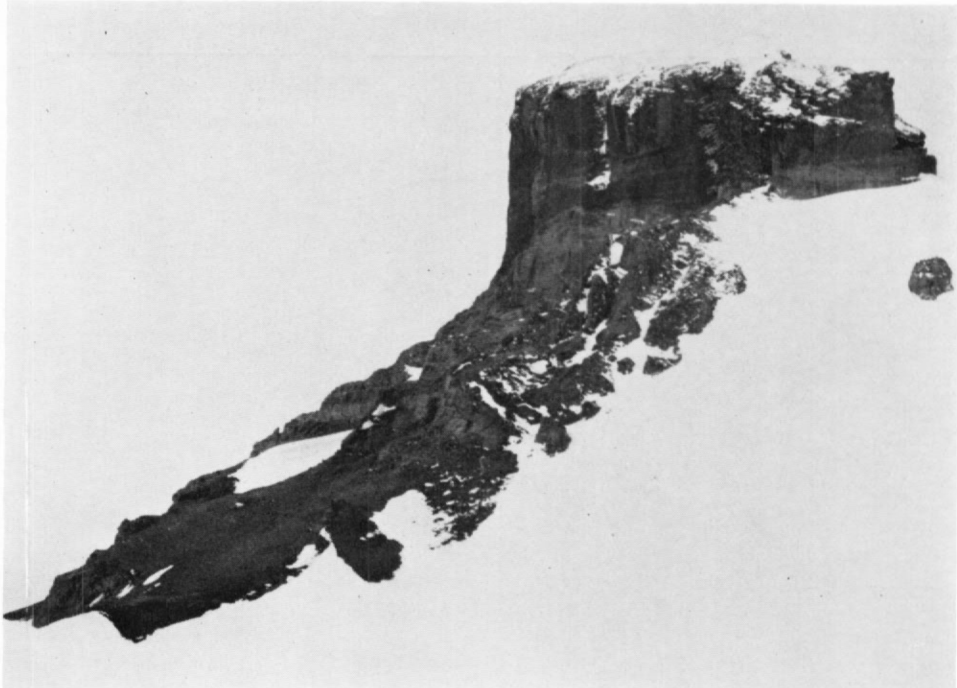

Fig. 3. Bedded palagonite-tuff overlain by a cap of resistant basalt flows at west Mussorgsky Peaks. The relief is about 300 m.

Island about 50 km. to the east. Sedimentary structures such as bedding have been masked by crushing and shearing. At Gluck Peak a small outcrop of arkose enclosed in younger volcanic rocks has undergone contact metamorphism. Pale-coloured inclusions consisting of recrystallized arkose fragments are numerous in the overlying vitrophyric tuffs (Fig. 4).

In the south-western part of the Franck Nunataks, a typical medium-grained arkose (KG.1509.1) is seamed with veins of quartz, penninite and epidote. Well-rounded and partly sericitized grains of plagioclase constituting about 70 per cent of the rock are associated with quartz grains with irregular extinction, and fragments of mudstone, quartz-muscovite-schist and feldspar-porphyry. An arkose (KG.1511.1) from Mount Borodin has similarly sericitized plagioclase, about 50 per cent well-rounded quartz grains and is veined with prehnite and quartz.

Cenozoic volcanic rocks

Overlying the arkoses are younger, relatively unconsolidated volcanic rocks which crop out on seven of the nunataks on Beethoven Peninsula. Although Mount Tchaikovsky and Chopin Hill have no exposures, their shape and position on the peninsula suggest that they are also composed of the same volcanic rocks. Because these nunataks and mountains are scattered over an area of 2,500 $km.^2$, it is not known whether they represent individual eruptive centres or the eroded remnants of more extensive outcrops. Coarsely bedded vitrophyric olivine-tuffs and palagonite-breccias are associated with olivine-basalt lava flows and dykes.

The lower 200 m. of Mussorgsky Peaks (Fig. 5) consists of soft, yellow-brown palagonite-tuff. Irregular beds between a few centimetres and 10 m. thick are cross-laminated and deep wash-out channels indicate that the material was water-lain and derived from the south-east. The tuff is mottled by black clasts of vesicular glass and hyalobasalt (Fig. 4), varying in size from microscopic shards to large blocks. Smaller pale-coloured inclusions are composed of recrystallized arkose in medium-grained aggregates of quartz, plagioclase and muscovite.

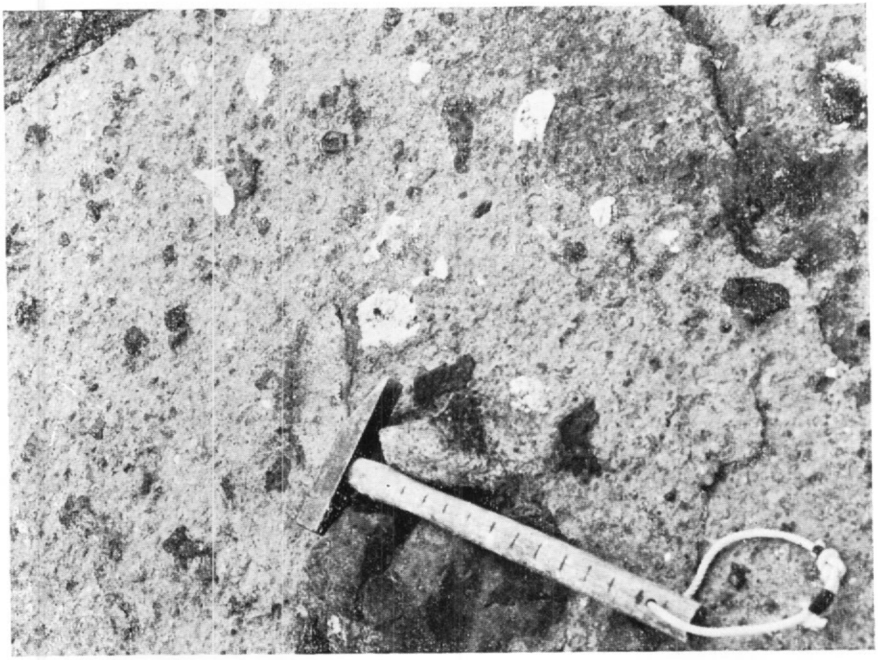

Fig. 4. Palagonite-tuff with inclusions of pale arkose, dark vesicular glass and hyalobasalt on west Mussorgsky Peaks. The hammer shaft is 35 cm. in length.

A vitrophyric palagonite-tuff (KG.1512.1) from Mount Strauss has a groundmass of pale brown vesicular palagonite (formed by the hydration of fragmented basalt glass) which encloses fragments of glass, microlites of plagioclase and olivine and a few scattered phenocrysts. There are two types of glass fragment (Fig. 6a):

i. Pale brown, transparent fragments with curved perlitic cracks and some elongated and bent vesicles.
ii. Less common black iron-rich fragments which enclose many olivine and plagioclase phenocrysts.

Large euhedral phenocrysts of forsteritic olivine with slightly corroded crystal outlines enclose small octahedral magnetite crystals. Plagioclase laths (An_{70}) are commonly glomeroporphyritic and several large plagioclase inclusions have opaque cores rimmed with later overgrowths of clear plagioclase.

East of the larger of Mussorgsky Peaks is a massive palagonite-breccia which crops out as irregular lenses and pillow-like masses composed of crystalline basalt enclosed in a matrix of palagonite-tuff. The highly vesicular matrix has a groundmass of pale brown glass characterized by amygdales and irregular perlitic cracks filled with calcite and chabazite (KG.1514.2). The margins of the glass shards and fragments and rims of vesicles are thinly lined with palagonite (Fig. 6b). Large euhedral phenocrysts of olivine have partly corroded crystal outlines and enclose minute crystals of magnetite and chrome spinel.

The resistant cap rock of Mussorgsky Peaks is formed of dark vesicular olivine-basalt (Fig. 6c). This basalt was not examined *in situ* due to inaccessibility but scree boulders with ropy lava surfaces, flattened vesicles and orientated plagioclase laths indicate subaerial eruption. At least two distinct types of basalt are present. The first type (KG.1513.1) is holocrystalline and consists of large euhedral phenocrysts of forsteritic olivine in a matrix of small plagioclase laths, which themselves are enclosed in an intergrown aggregate of pyroxene, olivine, plagioclase and acicular iron ore microlites. The second type is hyalo-ophitic (KG.1513.6) and is composed of almost 70 per cent dark iron-rich glass enclosing a mat of

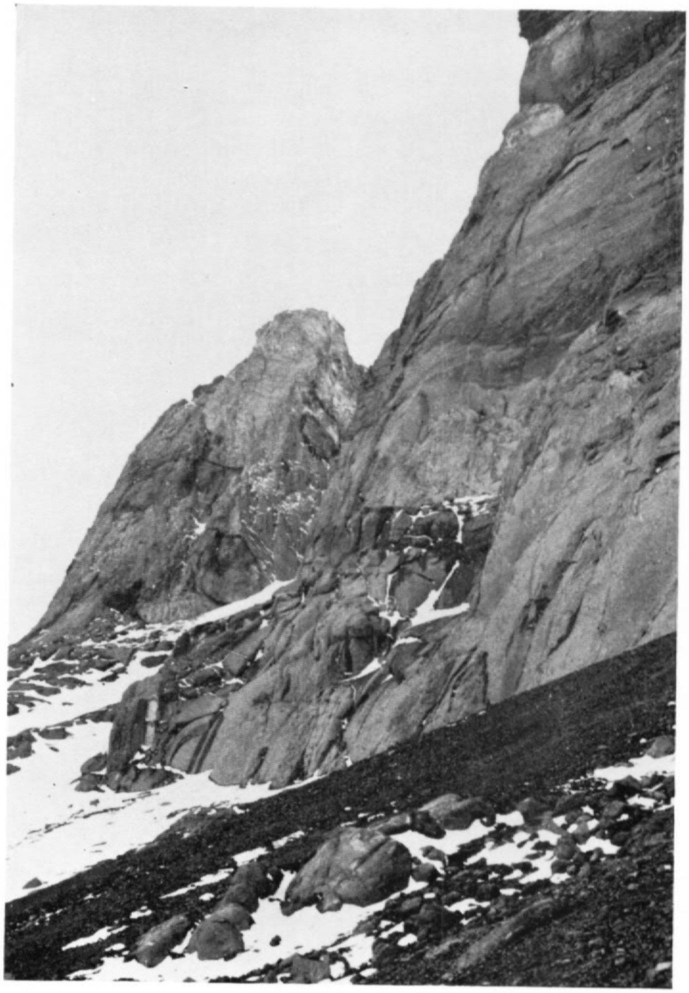

Fig. 5. Cross-laminated palagonite-tuff at west Mussorgsky Peaks. The cliffs are approximately 100 m. high.

zoned plagioclase laths and microlites of plagioclase, olivine and pyroxene (Fig. 6d). Euhedral olivine phenocrysts have small inclusions of opaque magnetite and dark brown chrome spinel. Vesicles are commonly rimmed with microlites. Inclusions with opaque cores of altered plagioclase surrounded by secondary overgrowths of clear feldspar are similar to those in specimen KG.1512.1.

An irregular vertical dyke of olivine-basalt about 0·5 m. wide cuts palagonite-breccias and tuffs at east Mussorgsky Peaks. This dyke, a feeder for overlying basalt lavas, has roughly zoned vesicular bands parallel to the walls.

In the modal analyses of 7 specimens from three nunataks (Table I), the percentages of the solid constituents have been recalculated in order to discount the proportion of vesicles. In some specimens most constituents are indistinguishable due to the fine grain-size and most of the material has been described as groundmass. The parent magma of the volcanic rocks of Beethoven Peninsula was an olivine-basalt and differences in rock types are attributed to different rates of cooling and degrees of hydration.

The glass- and palagonite-rich tuffs and breccias were probably formed by the sudden cooling and hydration of explosive submarine eruptions. The proportion of glass and pala-

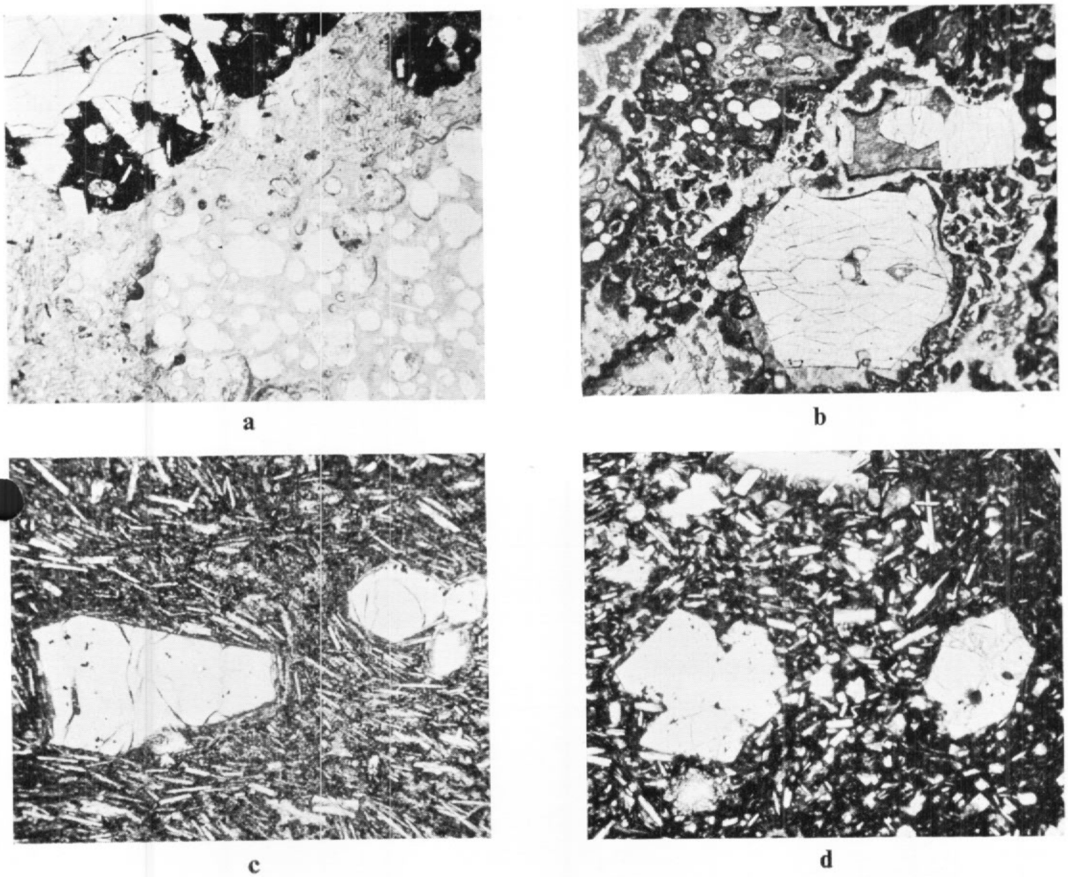

Fig. 6. a. Fragments of clear vesicular glass and black porphyritic glass in palagonite-tuff (KG.1512.1; ordinary light; ×30).
b. Tuff with olivine phenocrysts and vesicular glass shards rimmed with dark palagonite (KG.1514.2; ordinary light; ×32·5).
c. Basalt with orientated plagioclase laths surrounding olivine phenocrysts (KG.1517.1; ordinary light; ×35).
d. Hyalo-ophitic basalt with dark iron-rich glass enclosing plagioclase laths and euhedral olivine phenocrysts (KG.1513.6; ordinary light; ×35).

gonite in the vitrophyric tuffs varies from about 50 to 95 per cent, whereas the proportion of vesicles is between 15 and 25 per cent. Similar glass- and palagonite-rich rocks have been described from the James Ross Island Volcanic Group exposed in north-eastern Graham Land (Nelson, 1966) and from Marie Byrd Land (LeMasurier, 1971). Because of their high proportion of basaltic glass and the occurrence of palagonite-breccia composed of pillow-like nodules of crystalline basalt in a matrix of palagonite-tuff, the suites of rocks were considered to be subaqueous in origin. By contrast, vitric tuffs of terrestrial origin are almost invariably more siliceous.

LeMasurier (1971) compared the volcanic rocks of Marie Byrd Land with the subglacially erupted hyaloclastites of Iceland and concluded that the criteria for recognizing subglacial and submarine eruptions were essentially the same. Moreover, he suggested that the Marie Byrd Land deposits demonstrated that an ice sheet of substantial thickness has existed in Antarctica since the early Tertiary.

Volcanism in the Beethoven Peninsula area seems to have begun with the subglacial or submarine explosive eruption of basaltic lava which resulted in the deposition of coarse,

TABLE I. MODAL ANALYSES OF VOLCANIC ROCKS FROM BEETHOVEN PENINSULA

	1	2	3	4	5	6	7
Plagioclase	16·4	27·4	28·7	19·2	33·5	26·8	31·8
Clinopyroxene	*	*	39·2	*	36·8	45·4	*
Olivine	15·6	8·3	19·0	10·2	18·8	18·0	12·9
Iron ore	*	*	13·1	*	10·2	9·8	*
Glass and palagonite	*	*	—	58·2	—	—	—
Groundmass†	68·0	64·3	—	12·4	0·7	—	55·3
Plagioclase composition				An_{60}			
Vesicles‡	29·6	6·6	7·1	2·1	21·6	—	30·2

* Fraction not differentiated and included in groundmass.
† Groundmass includes microlites, calcite and the contents of amygdaloidal cavities.
‡ Vesicle proportion is discounted in the mineral percentages but is shown here as a percentage of the total rock.

1. KG.1513.1 Hypocrystalline basalt, west Mussorgsky Peaks.
2. KG.1513.2 Hypocrystalline basalt, west Mussorgsky Peaks.
3. KG.1513.3 Holocrystalline basalt, west Mussorgsky Peaks.
4. KG.1513.6 Vitrophyric basalt, west Mussorgsky Peaks.
5. KG.1514.1 Holocrystalline basalt, east Mussorgsky Peaks.
6. KG.1517.1 Holocrystalline basalt, Gluck Peak.
7. KG.1517.3 Holocrystalline basalt, Gluck Peak.

unsorted beds of palagonite-tuff and breccia. Once these hyaloclastite deposits built up above sea-level, subsequent basalt flows were erupted subaerially.

REGIONAL SETTING

A broad belt of Cenozoic volcanic rocks (Fig. 1) extends across western Antarctica from the Ross Sea through Marie Byrd Land and into Ellsworth Land. Similar volcanic rocks also occur in the vicinity of the James Ross Island group and the South Shetland Islands. K-Ar dates for these rocks are as yet too few and too inconsistent to give an accurate account of the volcanic history, but they are sufficient to indicate intermittent episodes of volcanism from the Oligocene to the present day.

Quaternary volcanic rocks occur in northern Victoria Land and Oates Land west of the Ross Sea (Warren, 1969). In Marie Byrd Land, intermittent largely subaqueous extrusions reached four peaks of activity between the Eocene and Pleistocene (LeMasurier, 1971). Similar Tertiary volcanic rocks occur in the Jones and Hudson Mountains of western Ellsworth Land (Craddock and others, 1964; Rutford and others, 1968, 1971). Peter I Øy, 800 km. west of Alexander Island, is also composed of volcanic rocks comparable to those of the Jones Mountains (Craddock and others, 1964). A small outcrop of Pliocene olivine-basalt has been described by Laudon (1971) from the Merrick Mountains, 350 km. south of Beethoven Peninsula.

Thus the volcanic rocks of Beethoven Peninsula provide a link between these outcrops of western Antarctica and the extensive Cenozoic volcanic sequence of the James Ross Island Volcanic Group located mainly on the islands north-east of the Antarctic Peninsula (Fig. 1). Rex (1971) has dated these rocks as late Pliocene or early Pleistocene. Cenozoic volcanism is also widespread in the South Shetland and South Sandwich Islands.

ACKNOWLEDGEMENTS

My thanks are due to Professor F. W. Shotton for facilities in the Department of Geology, University of Birmingham. I wish to thank the many members of the British Antarctic Survey who provided assistance and encouragement in the field, together with advice and criticism during the preparation of this paper.

MS. received 18 April 1972

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