THE VOLCANIC HAZARD AT DECEPTION ISLAND, SOUTH SHETLAND ISLANDS

By M. J. Roobol*

Abstract. Interest in the natural resources of the Southern Ocean has prompted an assessment of the volcanic hazard at the large natural harbour inside the Deception Island caldera. The evolutionary stage of the volcano, the frequency, sites and styles of eruption, and jökulhlaup (a syn-eruption melt-water flood) risk are considered in compiling a volcanic hazard map, which is presented here. As the island lacks instruments and trained observers, the only pre-eruption phenomenon which can be used at present for a warning relies on the build-up of magma pods within the caldera ring-fault zone. Such a build-up is believed to be accompanied by a lateral extension and temperature increase of the areas of surface heat escape (steam columns and boiling sea-water) around the shores of the harbour which corresponds to the caldera ring-fault zone. Such observations might be made by any visiting ship. As a result of the recent studies and with such observations, there seems to be no reason why the harbour should not be used with greater safety than it has been since 1820.

Deception Island, in the South Shetland Islands at the north-western edge of the Antarctic Peninsula, has been abandoned since the 1967, 1969 and 1970 volcanic eruptions. These totally destroyed the Chilean station and severely damaged the British station but left the Argentine buildings intact (Baker and others, 1975). The large central caldera, which is flooded by the sea (Fig. 1), provides an excellent natural harbour for the Antarctic continent. It combines the advantage of being readily accessible from the Southern Ocean with that of having a northerly latitude (lat. 62–63°S), which results in a longer ice-free period each year. There is also a natural dust-bowl action whereby black volcanic ash is wind-blown on to the winter's snow, leading to early melting and a relatively ice-free landmass.

The present increase in interest in the natural resources of the Southern Ocean, and in particular of the crustacean "krill" (Economist Intelligence Unit Ltd., 1976), suggests that a new wave of commercial exploitation of the Southern Ocean is about to begin. Any increase in shipping in the Southern Ocean at once raises the question of the safety of the harbour at Deception Island and of any installations which might be placed there. Most previous users had assumed that the volcano was extinct. The studies following the three recent eruptions have provided a great deal of information and it is concluded here that in future the harbour can be used far more safely than in the past.

Apart from many visits by scientific expeditions, the harbour had been used during each of the previous waves of commercial exploitation of the Southern Ocean. The first of these was from 1821 to 1825, when the South Shetland Islands fur seal was hunted to extinction. The second was from 1906 to 1931, when Deception Island was used as a shore base for the whaling industry, prior to the extensive use of factory ships with slipways. The harbour has also had a military role; during World War II, the strategic value of the island at the junction of the Atlantic and Pacific Oceans became important and the island was policed by the Royal Navy until a small base was established there (Christie, 1951). After World War II, British, Chilean and Argentine stations were established there and manned until the recent eruptions.

Evolutionary Stage of the Volcano

The recent work on Deception Island, much of which appears in Baker and others (1975), suggests that the volcano has undergone three stages in its evolution:

i. At first a cone or cone complex of yellow palagonitized tuffs and lava flows was built

* Institute of Applied Geology, P.O. Box 1744, Jeddah, Saudi Arabia.

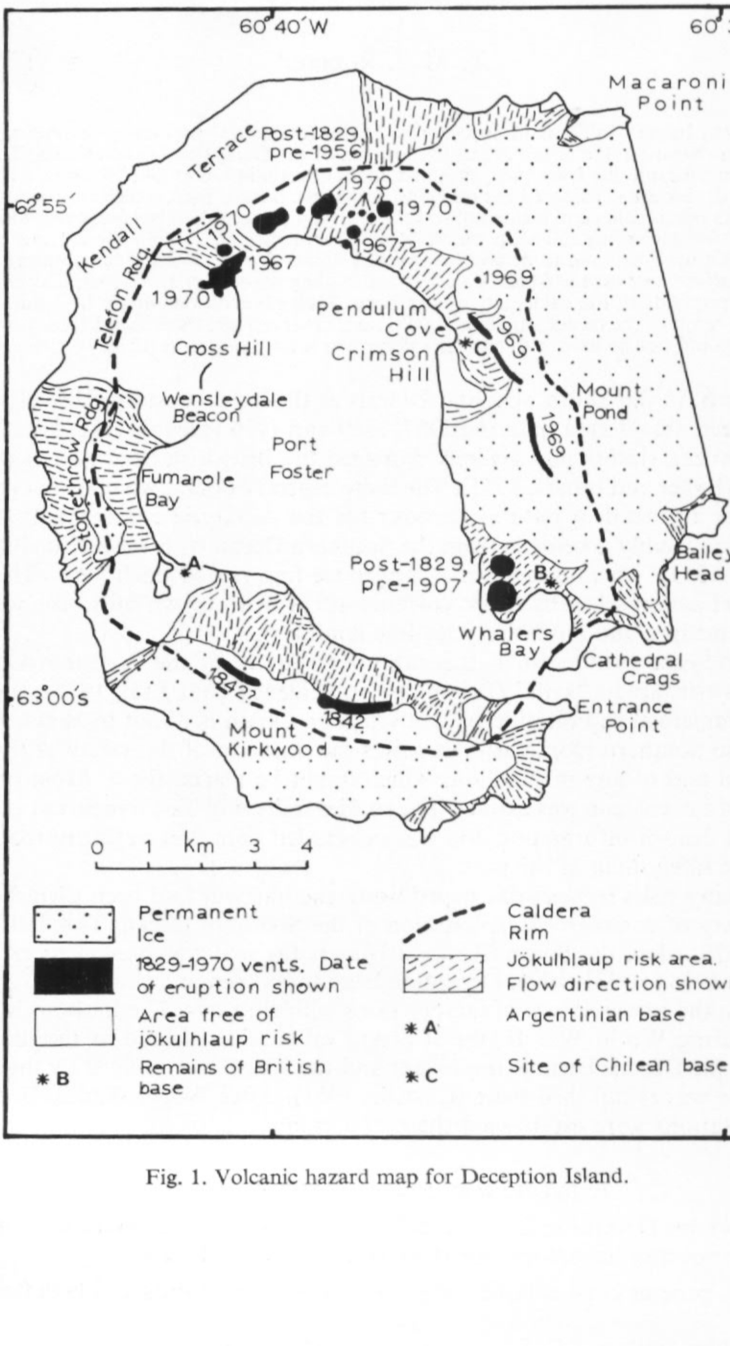


Fig. 1. Volcanic hazard map for Deception Island.

up. Much of the tuff is material re-worked by water, perhaps indicating a later uplift of the subaqueous parts of the volcano.

ii. The second stage was the emptying of a central magma chamber, which probably produced the pyroclastic flow deposits of Cathedral Crags and Fumarole Bay (Fig. 1). During this stage the central parts of the volcano subsided into the emptying magma chamber to produce the 8 km by 10 km central caldera of Port Foster.

iii. The third and present stage is the eruption of small volumes of magma from the ring-fault zone which bounds the central area of subsidence.

The 1967, 1969 and 1970 eruptions form the latest single episode of the present stage, which has built up the ring of ash and tuff cones inside the caldera rim, forming the lower land around the shores of Port Foster.

Twenty-three analysed samples from Deception Island (Baker and others, 1975, table IX) show a uniquely sodic magma series. Prior to cauldron subsidence, mainly basalts were erupted. Following the formation of the caldera, the material erupted has varied from basalts and basaltic andesites to sodic andesites and dacite.

Future Evolution of the Volcano

The varied chemistry of the products, the lack of evidence of pyroclastic flows and the small volumes of magma erupted during the present stage of evolution of the volcano all suggest that it is in a post-caldera late, or old-age, stage of development. This stage involves the in-filling of the caldera and appears to have a long way to go. Such a late stage was recognized by MacDonald (1972) for some of the Hawaiian shield volcanoes. Rejuvenation can occur but the present evidence points to an early old-age stage and that continued infilling of the caldera should continue.

Historical Frequency and Sites of Eruption

Study of seasonal wind-borne dust layers and pyroclastic deposits within the ice caps as exposed in the 1969 and 1970 vents (Orheim, 1971), as well as morphological comparisons with the 1829 topographic map of Kendal (1831), by Roobol (1973) and the historical records (Roobol, 1980), all indicate that several eruptive episodes have occurred since 1829. The historical pattern appears to be one of several closely spaced eruptions followed by several decades of dormancy. The suggested post-1829 events are listed in Table I.

Table I. Probable eruptions of Deception Island since its discovery in 1820

[illegible]nt	*Site of eruptive episode*	*Number of craters*	*Date*	*Reference*
1	Mount Kirkwood	8 or 12	About 1842	Wilkes (1845)
2	Kroner Lake	2	Post-1829, pre-1908	Roobol (1973)
3	North shores of Port Foster	2	Post-1829, pre-1956, possibly 1912–17	Roobol (1973) Orheim (1971)
4	Northern and eastern sectors of ring-fault zone	About 28	1967, 1969, 1970	Baker and others (1975)

The sites of the historical vents are shown on the volcanic hazard map (Fig. 1), on which they can be seen to lie within a belt occupied by the youthful ash cones around Port Foster and mark the ring-fault zone. The faults probably provide channels for the rise and storage of magma.

The historical record suggests that the frequency of eruption is about four episodes during the past 150 years, where one episode may consist of several closely spaced eruptions. This implies an average dormancy of about 35 years or two or three eruptive episodes per century.

Future Eruptions and Their Sites

On the basis of the historical frequency of eruptions, it is reasonable not to expect another eruptive episode before 1990 and the next activity might occur in the early part of the twenty-first century. This speculation excludes the possibility of seismic or volcano-seismic crises (the latter when magma approaches the surface without extrusion). Two possible events of this kind were recorded by the whalers during their summer visits to Whalers Bay between 1906 and 1931 (Roobol, 1980).

It can reasonably be expected that the future vents will lie inside the 2.5 km wide caldera ring-fault zone. During the present post-caldera stage, two fissure eruptions have occurred on Kendall Terrace outside the caldera rim. Here, there are youthful cinder cones and lava flows which overlie and drape the sea cliffs cut into the oldest palagonite-tuff remnant of the early volcano (Hawkes, 1961, geological map). The risk of such eruptions, outside the ring-fault zone, can be roughly estimated by comparing these two events with the very minimum estimate of 20–30 eruptive episodes required to build the post-caldera cones on the ring-fault zone around the shores of Port Foster.

Volume and Style of Past Eruptions

The eruptive style during the post-caldera stage has varied considerably and appears to have been controlled by the physical nature of the vent rather than being directly the result of magma composition. Where the vents were submarine or situated in the waterlogged shorelines of Port Foster or beneath the ice caps, the results have been pyroclastic explosions producing airfall deposits as found with the last eruptive event. Where the fissures opened on dry ice-free ground of some elevation, spatter cones and short lava flows resulted, as with Mount Kirkwood around 1842. Nowhere in this post-caldera stage have pyroclastic flow deposits been found, only airfall deposits.

The volume of erupted material has been small. In 1967 about 0.05 km^3 of pyroclastic material was produced compared to about 0.03 km^3 in 1969 (Baker and others, 1975). For the three eruptions of the last episode (1967–70), the total volume of material erupted (all pyroclastic) was perhaps about 0.12 km^3, representing about 0.08 km^3 of magma. Such small-volume airfall pyroclastic eruptions are relatively safe in the overall field of volcanism. Thus, in 1967 there were 42 men at the British and Chilean stations and more at the Argentine station, while in 1969 there were five men in the British station when pyroclastic explosions commenced. In both cases no lives were lost. Again, a ship inside the flooded caldera had a safe passage at a distance of 3.2 km from one of the erupting vents on 7 December 1967 (Baker and others, 1965, p. 17).

Volume and Styles of Future Eruptions

The pattern of small-volume pyroclastic fall-type eruptions is likely to continue with the local occurrence of lava flows. The observation of major importance is the lack of pyroclastic flow deposits in the youthful belt around the shores of Port Foster. In other volcanoes, these are a major volcanic risk as they indicate the occurrence of clouds of ash and hot gas capable of covering large areas of the volcanoe's flanks at high speeds (e.g. Mont Pelée, Martinique; Lacroix, 1904; Perret, 1937). Without these, the main pyroclastic risk at Deception Island is proximity to the opening vent. As these are most likely to occur in the caldera ring-fault zone, the high-risk area unfortunately includes all of the low land surrounding the harbour of Port Foster. The construction of permanent shore buildings cannot therefore be recommended, as emphasized by the loss of two stations during the last eruptive episode. The safest place to construct a permanent building (why not a volcanic observatory?) is on Kendall Terrace outside the ring-fault zone. If there were two small well-spaced (several kilometres) buildings there, it is extremely unlikely that one would not survive the rather remote possibility of a lava flow there. All future use of Port Foster may cease at some future date due to the sealing off of the narrow sea entrance (Neptunes Bellows) by a future eruption.

Jökulhlaups

These are floods of melt water released by the glaciers when the vents open below and partly melt the ice cover. They were first noted on Deception Island during the early stages of the 1969 eruption. It seems that the eruption may commence for several hours below the ice cap before a flood of melt water, carrying blocks of ice up to several metres in diameter, together with blocks of soil lithified by permafrost, breaks through the ice cap to rush down-hill. The name is Icelandic and such occurrences have been common throughout the historical record of Iceland. The deposits from jökulhlaups consist only of ice and permafrost blocks which sit on or in a cover of washed fluvial debris or alternatively on eroded gullied terrain. During the summer season, the ice and permafrost melt, leaving only a few depressions and heaps of soil. The presence of gullies near the 1968 vents hinted that jökulhlaups probably accompanied that eruption. Jökulhlaup deposits are not striking and cannot readily be recognized in the stratigraphical column. It was the jökulhlaups of the 1969 eruption that destroyed the stations and produced some of the morphological changes on the slopes of Deception Island.

Future Jökulhlaup Risk

On Deception Island, in its present stage of evolution, it is the jökulhlaups that present the greatest risk to life and property. As the positions of the ice caps are known, as are the probable sites of future vents and, because the jökulhlaup flows down-hill to be diverted only by hills and gullies, it is a simple matter to make a jökulhlaup risk map. The probable direction of flow of future jökulhlaups is shown by the dashes on the volcanic hazard map (Fig. 1). Many headlands and hills below the ice caps are free of this risk. These include Baily Head, Cathedral Crags, Entrance Point, Crimson Hill and Wensleydale Beacon, which may prove valuable sites for equipment for future volcanological observations. Small obstacles can divert the jökulhlaups and create small islands (Baker and others, 1975, fig. 24) but these minor features cannot be predicted. The frequency and volume risk of jökulhlaups increases with the thickness and area of the ice cap. For Deception Island, the greatest risk is along the eastern shores of Port Foster below Mount Pond. Another although small risk is presented by the Mount Kirkwood ice cap, while there is a slight risk of small-volume jökulhlaups below the thin narrow ice caps of Stonethrow and Telefon Ridges.

The undamaged Argentine station at Fumarole Bay is protected from jökulhlaup risk by intervening topography. Nonetheless, the survival of this station during future activity cannot be assured, as it is situated well within the caldera ring-fault zone.

Pre-eruption "Early Warning" Phenomena

There are several "early warning" phenomena as indicated by the observations of the station members on the island before and during the last eruptions. For several weeks before an eruption there is a build-up of felt and heard earth tremors. Again, for some days at least, before an eruption there is probably an increase in the temperatures of existing areas of hot water. However, without equipment and with the island abandoned, there is for the immediate future little chance of such routine observations being made.

There is a third approach which could be used in the present situation. There may be an expansion and build-up of areas of heat escape within the ring-fault zone over a period of years prior to eruption. This may correspond to a build-up of magma pods within the ring-fault zone. The eruption of several of these can account for the type of eruptive episode where there are several closely spaced events of somewhat different compositions. This model has been proposed by Roobol (1980) and is based on a review of historical records of the positions of the areas of heat escape and a study of the composition of the magma erupted in the last episode, relative to the positions of the vents. The records of this century show that there was a slow build-up in the areas and numbers of sites of heat escape prior to the last eruptive episode. In particular, there was a noticeable build-up at a period between 16 and 11 years prior to 1967. The newer and expanded areas of heat escape appear to have marked those sectors of the ring-fault zone where the 1967, 1969 and 1970 vents occurred at a later date. It is not known whether eruption occurs because the ring-fault zone becomes filled with magma pods (possibly lubricating the fault zone) or alternatively that eruption from such magma-filled zones is readily triggered by an external seismic event. Either way, the first step in further understanding the mechanism, in order to allow prediction, must come from a recognition of periods with and without magma in the ring-fault zone.

The infrequent visits by ships to the harbour of Deception Island provide a future inexpensive means of noting the sites and changes in the areas of heat escape. On a calm day, the harbour can be circumnavigated by a man in a rubber dinghy equipped with a motor. Instructions and blank maps for recording observations can be obtained from the British Antarctic Survey, Cambridge.

Conclusions

The Deception Island caldera is regarded as being in an early stage of old age, which is characterized by the infilling of the caldera. The activity at this stage is in the form of small-volume eruptive episodes producing airfall pyroclastic deposits from "wet" vents and short lava flows from "dry" vents. Activity in the present evolutionary stage is almost entirely restricted to the 2.5 km wide caldera ring-fault zone. This zone unfortunately includes all of the low land around the shores of Port Foster and also includes small bays such as Whalers Bay and Fumarole Bay. The ring-fault zone is subject to two main volcanic hazards: proximity to future vents and their volcanic products, and jökulhlaup risk below the main ice caps. Permanent installations cannot be recommended around the shores of Port Foster.

It seems reasonable to conclude that the next eruptive episode is not due until the end of the present century or the early part of the next century. Some indication of pre-eruption phenomena, which could be utilized for prediction, is given here. However, while Deception Island remains abandoned and without equipment, the only approach appears to be sporadic observation of the distribution of areas of heat escape; it is probable that there will be a build-up in size and number of such areas some years before the next eruptive episode. The lack of pyroclastic flow deposits amongst the young unconsolidated deposits around Port Foster is a strong indication that the overall volcanic hazard on the island is less than that in the densely populated Lesser Antilles islands of the Caribbean, where pyroclastic flows occur. It is suggested that, should a krill fishing industry be established in the Southern Ocean, the advantages of the harbour at Deception Island (for emergencies, break-downs, or shelter from storms) considerably outweigh the small volcanic hazard for short-term visits. The advantages of the harbour at Deception Island could be increased if a new airstrip were to be constructed there so that in medical emergencies people could be flown in or out.

Acknowledgements

I am grateful to the Royal Society, the British Antarctic Survey and Dr P. E. Baker for the opportunity to participate in the study of the 1967 and 1969 eruptions; also to Dr R. J. Adie for assistance with the present work. Dr C. Ramsay, Institute of Applied Geology, Jeddah, kindly read the manuscript and offered valuable criticism.

MS received 29 November 1977

REFERENCES

Baker, P. E., McReath, I., Harvey, M. R., Roobol, M. J. *and* T. G. Davies. 1975. The geology of the South Shetland Islands: V. The volcanic evolution of Deception Island. *British Antarctic Survey Scientific Reports*, No. 78, 81 pp.

Christie, E. W. H. 1951. *The Antarctic problem*. London, George Allen & Unwin Ltd.

Economist Intelligence Unit Ltd. 1976. *Economic survey of the Falkland Islands*. London, Foreign and Commonwealth Office. 2 vols.

Hawkes, D. D. 1961. The geology of the South Shetland Islands: II. The geology and petrology of Deception Island. *Falkland Islands Dependencies Survey Scientific Reports*, No. 27, 43 pp.

Hydrographic Department. 1974. *The Antarctic pilot. Comprising the coasts of Antarctica and all islands southward of the usual route of vessels*. 4th edition. London, Hydrographer of the Navy.

Kendal, E. N. 1831. Account of the Island of Deception, one of the New Shetland Isles. *J. R. geogrl Soc.*, **1**, 62–66.

Lacroix, A. 1904. *La Montagne Pelée et ses éruptions*. Paris, Masson et Cie.

MacDonald, G. A. 1972. *Volcanoes*. New Jersey, Prentice Hall Ltd.

Orheim, O. 1971. Volcanic activity on Deception Island, South Shetland Islands. (*In* Adie, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 117–20.)

Perret, F. A. 1937. The eruption of Mt. Pelée 1929–32. *Publs Carnegie Instn*, No. 458, 126 pp.

Roobol, M. J. 1973. Historic volcanic activity at Deception Island. *British Antarctic Survey Bulletin*, No. 32, 23–30.

———. 1980. A model for the eruptive mechanism of Deception Island from 1820 to 1970. *British Antarctic Survey Bulletin*, No. 49, 137–56.

Wilkes, C. 1845. *Narrative of the United States Exploring Expedition, during the years 1838, 1839, 1840, 1841, 1842*. Vols. I–V, Atlas. Philadelphia, Lea & Blanchard.

APPENDIX

Request to Mariners visiting the Harbour at Deception Island, South Shetland Islands

Since the 1967, 1969 and 1970 eruptions of the Deception Island volcano, the island has proved to be too remote to justify the installation of scientific equipment to understand better the volcanological mechanisms. At the present time the infrequent visits of shipping provide the only means available of collecting useful scientific data from the island.

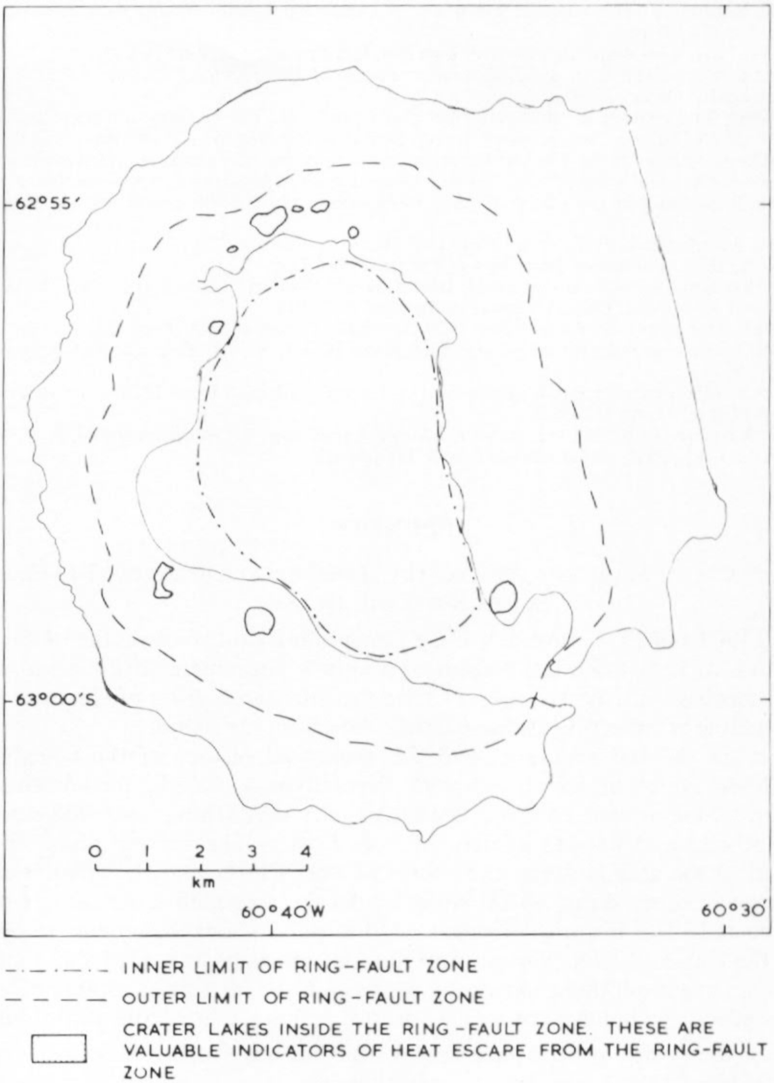
A full report on the last eruptions and the geological history of the volcano has been published in *British Antarctic Survey Scientific Report* No. 78. Briefly, the volcano is believed to have built up a cone or cone complex, the centre part of which has subsided below sea-level to form the harbour and flooded caldera of Port Foster. The present phase of activity is largely confined to the area between the shores of Port Foster and the circular ridge of the island. This circular zone, about $2\frac{1}{2}$ km wide, marks the ring-fault zone along which central subsidence occurred. The historical records of the island show that areas of obvious heat escape within the ring-fault zone vary in position and intensity. It is probable that, for up to 20 years before an eruption, there is a steady increase in the intensity and area of heat escape. This probably reflects the build-up of magma or lava within the fault zone prior to its eruption.

Any record of the positions of these areas of heat escape, which can be made on the map given below will be of great assistance in understanding the volcanological mechanism of the volcano. One man equipped with a rubber dinghy and motor can circumnavigate the inner shore of Port Foster on a calm day and record those sections (length is important) where there is obvious heat escape, with notes such as:

i. Boiling water, steam column and sulphurous odour.
ii. Boiling water and steam column.
iii. Steam column.
iv. Snow-free warm ground.

Any record made with a thermometer is also valuable. The following should also be marked on the map:

i. Name of ship and date of observations.


62°55′
63°00′S
0 1 2 3 4
km
60°40′W
60°30′
INNER LIMIT OF RING-FAULT ZONE
OUTER LIMIT OF RING-FAULT ZONE
CRATER LAKES INSIDE THE RING-FAULT ZONE. THESE ARE VALUABLE INDICATORS OF HEAT ESCAPE FROM THE RING-FAULT ZONE

ii. Location and extent of areas of heat escape.

iii. Location and extent of areas visited where there was no obvious heat escape.

iv. Areas not visited.

As well as the shorelines of Port Foster, the flooded craters near the shores are also valuable sites for observing obvious heat escape.

Information can be forwarded to: British Antarctic Survey, Madingley Road, Cambridge CB3 0ET, England, so that a chronological compilation can be made. The last eruptions surprised everyone and it is hoped that any further ones will not. Co-operation in the collation of such information could lead to an informative compilation.