Polarforschung 59 (3): 173–178, 1989 (erschienen 1991)

Deception Island Volcanism (South Shetland Islands, Antarctica): Results from Thin-Section Investigations

By H.E. de Wit[1], J.W.A. van Enst[2] and Cornelius Laban[2]

Summary: Rock samples from Deception Island were studied macro- and microscopically. Based on the results of this study and in comparison with the literature it was possible to distinguish 3 different stages of magma evolution. 1) Early formation of plagioclase (An > 60 %) and early mafics. 2) Formation of younger plagioclase (An 30-60 %) as phenocrysts and rims around older plagioclase cores, both sometimes enclosing partly resorbed phase 1 mafics. Clinopyroxene rims surrounding older clinopyroxene cores. 3) Groundmass crystallization together with the breakup (leaching) of older Plagioclase phenocrysts and subsequent overgrowth in an almost equal composition.

Thin-section results confirmed the basic idea that the magma underwent fractional crystallization with subsequent increase in SiO_2 content and Fe/Mg depletion of the remaining magma. The final breakup of plagioclase phenocrysts and subsequent overgrowth in phase 3 was caused by leaching and is explained by late magmatic heat and volatile fluxes without the intrusion of new, more basic, magma.

Zusammenfassung: Die makroskopische und mikroskopische Untersuchung von Vulkanitproben von Deception Island ermöglichte, unter Berücksichtigung der Literatur, die Unterscheidung von drei Phasen der Magmenentwicklung. 1) Die frühe Bildung von Plagioklas (An > 60 %) und mafischen Anteilen. 2) Eine jüngere Bildung von Plagioklasen (An 30-60 %) mit Einsprenglingen und Rinden um ältere Plagioklaskerne. Beide Bildungen umschließen manchmal teilweise resorbierte mafische Anteile der Phase 1. Klinopyroxenrinden umschließen ältere Klinopyroxenkerne. 3) Die Kristallisation der Grundmasse erfolgt zusammen mit dem Aufbrechen (und Anlösung) älterer Plagioklas-Einsprenglinge und einer nachfolgenden Überwachsung nahezu gleicher Zusammensetzung.

Dünnschliff-Untersuchungen bestätigten die Vorstellung, daß das Magma eine fraktionierten Kristallisation durchlief mit einer Zunahme des SiO_2-Gehaltes und Fe/Mg-Verarmung der verbleibenden Schmelze. Das abschließende Aufbrechen der Plagioklas-Einsprenglinge und die Überwachsung während der Phase 3 wurde durch Lösung verursacht und wird erklärt mit einem spätmagmatischen Erhitzung und Zufuhr von Volatilen, ohne daß es zur Intrusion von neuem, mehr basischem, Magma kam.

INTRODUCTION

The Geological Survey of the Netherlands (RGD) collected a number of volcanic rock samples on Deception Island during the 1985 ANTARKTIS-IV/2 expedition with RV „Polarstern" of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, FRG.

Deception Island is located in the Bransfield Strait and is part of the South Shetland Islands. It was formed by a number of volcanoes around a central crater (Fig. 1). The crater Lake, Port Foster, is in open contact with the Bransfield Strait via a small entrance, Neptunes Bellow. With small vessels Port Foster can be entered. Deception Island was discovered in 1820 and since then numerous volcanic explosions have taken place, recently in 1967, 1969 and 1970. Prior to these explosions there were three research stations situated on Deception Island; a Britsih, a Chilean and an Argentine respectively.

The volcanic history of Deception Island has been studied in detail by various authors. In this paper some additional data are presented and compared to the existing literature.

The sampled section is indicated on the map in Fig. 1. One fresh ash sample was taken near the shoreface in Whalersbay. From the 24 samples taken, 17 thin-sections were cut and studied microscopically in order to test whether the magma models which are described in the literature are valid with respect to the thin-section results.

[1] Dr. H.E. de Wit (deceased spring 1990)
[2] Dr. J.W.A. van Enst and Dr. Cornelius Laban, Geological Survey of the Netherlands, P.O.Box 157, 2000 AD Haarlem, The Netherlands.
Manuscript received: 13. 2. 1989; accepted 9. 3. 1990

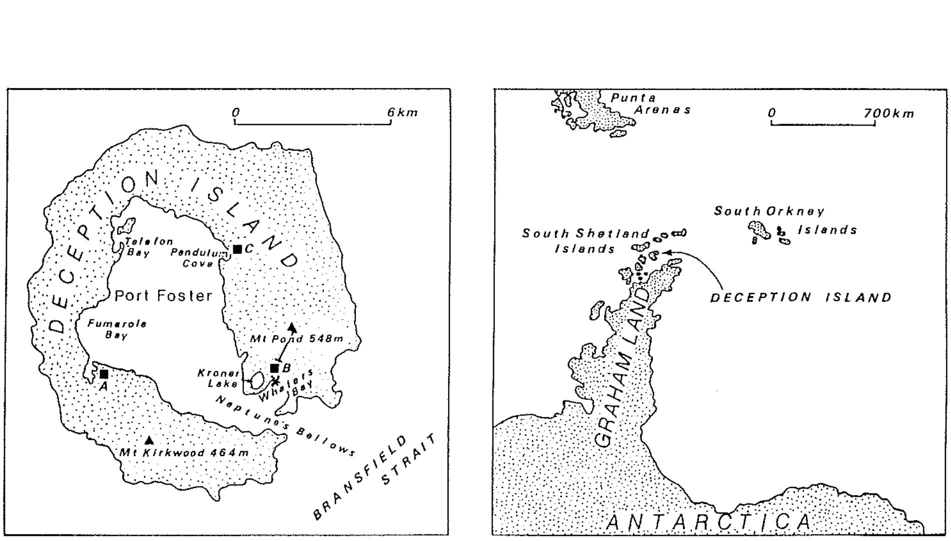

Fig. 1: Sketch maps of the Antarctic Peninsula and Deception Island. The sample section is indicated near Whalers Bay.

Abb. 1: Übersicht über Deception Island und seiner Lage in den Süd-Shetland-Inseln. Die Lage des Probenprofils an der Whalers Bay ist angedeutet.

PETROGRAPHY

Literature

Deception Island volcanism has invariably been described as a suite which varies from olivine basalts to (rhyo)dacites which can be related to fractional crystallization (SAUNDERS & TARNEY 1982). The rocks are nearly always porphyric with a fine crystalline or glassy groundmass. The mineralogy of the basaltic lavas consists of plagioclase (An 83-44), olivine (Fo 80), augite, pigeonite and magnetite-ilmenite. Andesites and low-Si dacites contain plagioclase (An 42-35), augite, olivine, titanomagnetite and occasionally hypersthene. High-Si dacites contain 20 % phenocrysts, predominantly plagioclase (An 28-15), augite, hypersthene, fayalitic olivine (Fo 20), olivine and ilmenite-titanomagnetite. Amongst the various authors only TARNEY (1977) mentions the occurrence of hornblende.

The chemical composition mentioned by the various authors coincide very well. Deception Island is situated on the spreading axis of a back-arc spreading zone in the Bransfield Strait. The geochemical characteristics of the lavas are transitional between oceanic basalt and calc-alkaline volcanic rocks (TARNEY et al. 1982).

Classification

1. Macroscopic classification led to a subdivision of six groups. The classification I to VI is based on colour index, phenocryst phases, grain size, gas content of the magma (as fas as the observed vesicles in the samples may be used for an estimation of the gas content).

Group I: basaltic, black dense and glassy; mostly homogeneous with a small amount of very small feldspar phenocrysts (FG01, FG05, FG13, FG17, FG18).

Group II: dark gray lavas with variable porosity and changing feldspar and mafic phenocrysts contents (FG10, FG19, FG20, FG22).

Group III: cinderous black or red lavas with a variable porosity and few to non phenocrysts (FG03, FG07, FG09, FG15, FG24).

Group IV: light grey, dense glassy lavas with vesicles of considerable size (FG04, FG06, FG11, FG12, FG14).

Group V: yellow welded polymict agglomerates, with fragmented pumaceous matric and dark grey cinders of variable (fine) porosity (FG08, FG16, FG21).

Group VI: fine-grained tuffs with variable content of various fragments (FG02, FG23).

2. Microscopic classification is based on the anorthite contents of the plagioclase phenocrysts. The observed decreasing anorthite content agrees with an increasing acidity of the rocks. The numbers between brackets indicate the sample numbers in which the plagioclase occurs in minor quantities. Microscopic anorthite measurements were impossible in samples FG03 and FG16.

Group A:	An > 60 %	FG(01), (10), (19).
Group B:	An 42-47 %	FG07, 13, (19).
Group C:	An 27-37 %	FG06, 19, (22).
Group D:	An 18-27 %	FG01, (07), 10, 11, 18, 20, 21, 22, 24.

The diagram in Fig. 2 depicts the relation between various macroscopically defined groups (I to VI) and the variation of the content of Anorthite of the several observed plagioclase phenocrysts within the groups. A general trend that can be noticed from the diagram is a decreasing An-content towards Group VI. Additionally, it appears from the diagram that groups I and II partly contain plagioclase phenocryst phases of higher An-content. With this simple diagram two major features of Deception Island volcanism are indicated:
1) A general trend towards the more Si-rich compositions between and within the groups I to VI which points towards fractional crystallization as the leading process.
2) Thin-section examination reveals an aphyric quality of the rocks. Most of them contain 10-20 % phenocrysts. The ratio of occurrence of plagioclase, augite and opaque minerals always approximates 10:1:1.

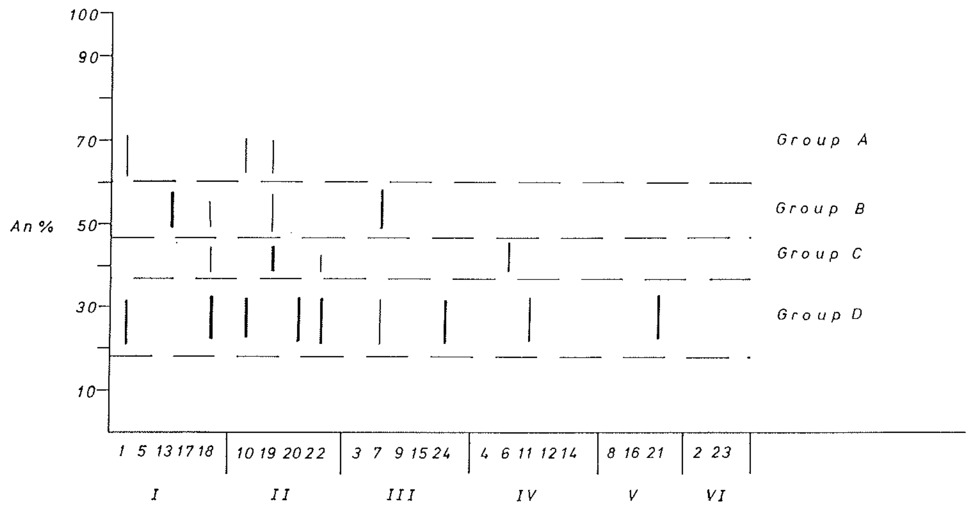

Fig. 2: Macroscopic classes (I - VI) versus microscopically measured percentage of Anorthite of investigated RGD samples. Classes I to VI reflect the increasing SiO_2 content of the rocks.

Abb. 2: Makroskopisch definierte Gesteinsgruppen (I - VI) aufgetragen gegen den mikroskopisch bestimmten Anorthit-Gehalt. Die Anordnung der Gruppen I bis VI entspricht einem zunehmenden SiO_2-Gehalt.

The petrographical and mineralogical descriptions of the samples coincides with the data mentioned in the literature. Therefore, it has been assumed that the chemical compositions should also match reasonably. If so, this would mean that groups C and D belong to the high-Si dacites and Group B to the low-Si dacites and andesites. With respect to the RGD samples which were studied here, the above leads to the general idea that the RGD samples belong to the more acid volcanic suite of Deception Island.

MAGMATIC MODELS

Literature

Deception Island volcanism reveals a changing composition ranging from low-Si (basaltic) to high-Si (andesitic) magma. From models based on quantitative LIL-element ratios and LREE patterns, it has been argued that advanced crystal fractionation is the major cause of magma differentiation (TARNEY et al. 1977).

Sr and Cr-Ni depletion together with negative Eu anomalies show plagioclase and (clino)pyroxene fractionation. More recent stages of magmatism are characterized by magma mixing resulting from a rising mantle plume, possibly in relation to the dehydration of deeper (oceanic) slab material. Based on conflicting ratios of K and Rb and radiogenic Sr, last equilibration of the magma (mantle composition) at a depth of 80 km is assumed. Strong mixing of the magma and the mantle material can, however, be excluded, due to small Fe^{2+} enrichment of the Deception Island volcanic rocks compared to the composition of MORB.

RGD samples

Interpretations based on the petrography of the samples match very well with the literature mentioned above. The early crystallization of plagioclase and mafic minerals is confirmed by the crystallization sequence observed in the samples which were studied here. Based on microscopic observations, the thin-sections revealed the sequence:

1) Early plagioclase (An > 60 %, Group A) + early mafic minerals (olivine and pyroxene).

2) Later plagioclase (Group B, C) as rims around slightly dissolved plagioclase phenocryst cores and with partly dissolved inclusions of the early (phase 1) mafic minerals (Fig. 3). The second growth phase of plagioclase also formed new phenocrysts which enclose corroded rests of early (phase 1) mafic minerals. A second phase of mafics may also be found as rims around older, partly resorbed clinopyroxene phenocrysts (Fig. 4).

3) The third growth phase is formed by the crystallization of the ground mass, mostly very small plagioclase crystals, opaque metal oxides and very fine-grained mafics.

The three growth phases, mentioned above, already show in detail the described features: fractionation (at about 80 km, WEAVER et al. 1979), and later re-equilibration at a shallower depth. The small amount of mafic phenocrysts and the rather constantly low An-content of the plagioclase , which is not always zonal, shows that a major part of the early magmatic phenocrysts did not rise to the surface together with the more Si-rich fraction. The lack of early mafic minerals and opaque metal oxides in the groundmass, indicates a Fe/Mg depletion relative to the more basic compositions generally decribed from Deception Island samples. Therefore, it seems that mixing with significant amount of magma can be excluded.

DISCUSSION AND FUTURE RESEARCH

From the literature it can be deduced that the geochemistry of the Bransfield Strait volcanic rocks is transitional between oceanic basalts and calc-alkaline volcanic rocks, which reflects the changing geotectonic setting of a primarily subduction related island arc to the cessation of subduction (4 Ma) and the creation of an extensional back-arc basin (SAUNDERS & TARNEY 1982, TARNEY et al. 1982). More recent (Quaternary) phases of Deception Island magmatism show a more acid volcanism which is explosive, although basaltic magma appears to have been available throughout the history of the volcano.

The chemical trends as observed in Deception Island lavas, ranging from olivine-tholeiite to rhyodacite, indicate fractional crystallization of a mantle derived magma, but generated under more hydrous melting conditions due to interactions with downgoing slab material (TARNEY et al. 1982).

The RGD samples clearly give evidence of the features as they are mentioned in the literature. A primitive magma composition, with basic plagioclase compositions, olivine and orthopyroxene, can be found as older, partly resorbed instable phenocrysts. Later stages in the fractional crystallization path are represented by strong zonal plagioclase phenocrysts with oeder resorbed clinopyroxenes in the cores and in the rims. Changing conditions due to an increasing P H_2O can be observed by an increase in SiO_2 content and the large amounts of vesicles in the rocks. The effect of the increasing P H_2O can be studied accurately when the features in stage 3 are considered.

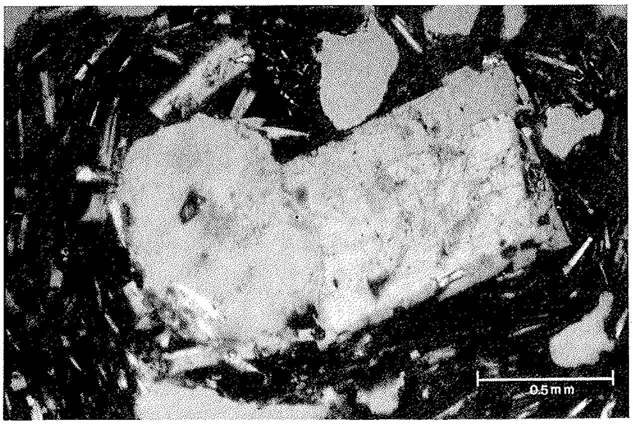

Fig. 3: Zoned plagioclase phenocryst with partly resorbed phase 1 clinopyroxene phenocrysts enclosed in phase 2 related to rims (FG11, crossed nicols + gypsum).

Abb. 3: Zonierter Plagioklas-Einsprengling mit teilweise resorbiertem Klinopyroxene-Einsprengling der Phase 1 eingeschlossen von Rändern der Phase 2 (FG11, gekreuzte Nicols + Gips).

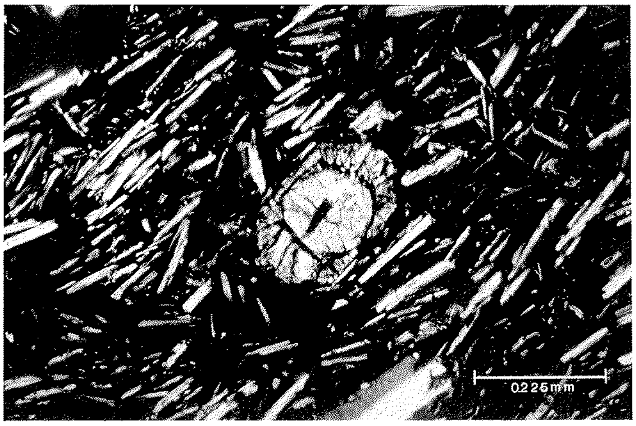

Fig. 4: Phase 2 clinopyroxene overgrowth around a resorbed phase 1 clinopyroxene phenocryst (FG13, crossed nicols).

Abb. 4: Resorbierter Klinopyroxen-Einsprengling der Phase 1 mit Klinopyroxen-Überwachsung der Phase 2.

Fig. 5: Phase 1 plagioclase with phase 2 rims, resorbed and partly filled with phase 3 groundmass plagioclase laths and glass (FG22, crossed nicols).

Abb. 5: Plagioklas der Phase 1 mit Überwachsungen der Phase 2; resorbiert und teilweise mit Plagioklasleisten der Grundmasse und Glas der Phase 3 gefüllt (FG22, gekreuzte Nicols).

In stage 3 the (zoned) phenocrysts are strongly leached (Fig. 5). The outer rims of the plagioclase show equal percentages of An compared to the corroded inner rims of the phenocrysts. In the last stage the phenocrysts tend to break up and the interstices between the broken crystals are filled with groundmass plagioclase and vitrous material. The observations indicate a desequilibrium between the phenocrysts and the remaining melt due to the effects of advanced crystallization and probably an increase in volatile content.

Apart from fractional enrichment of the melt towards more siliceous compositions, an alledged increase in volatile content (H_2O, CO_2, halogens?) would cause increased polymerization of the magma and frothing (FRAZER 1977). Heat and possibly volatile intrusion from deep seated sources would lead to a temporary temperature raise in the magma chamber prior to eruption (HILDRETH 1981, BAILEY 1982). A model for the Deception Island volcanism which includes late-magmatic fluxes of heat and volatiles, however, whithout significant admixture of fresh magma, would suitably explain corrosion of plagioclase phenocrysts and their subsequent overgrowth in an almost equal composition, as was observed in the RGD samples. Thus the petrography of the samples discussed here may provide indications of magmatic processes which mark the transition from volcanic-arc towards back-arc spreading magmatism.

The samples that were studied so far, offer a number of possibilities for future research. First of all the effects of P H_2O on the melt should be studied in greater detail; moreover, microprobe investigation of phenocrysts and glass should reveal more information on the P-T conditions of the various stages the magma went through.

ACKNOWLEDGEMENTS

The authors wish to thank the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, for its generous invitation to participate in ANT-IV/2 expedition, and especially the captain and crew of RV „Polarstern" who brought the scientists safely back on the ship again, despite of the bad weather.

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