POLISH POLAR RESEARCH	11	3—4	259—266	1990

Włodzimierz KOWALEWSKI, Stanisław RUDOWSKI and S. Maciej ZALEWSKI

Department of Polar and Marine Research
Institute of Geophysics
Polish Academy of Sciences
Księcia Janusza 64, 01-452 Warszawa, POLAND

Seismoacoustic studies within flooded part of the caldera of the Deception Island, West Antarctica

ABSTRACT: The results of the detailed seismoacoustic profilling (CSP, boomar) are presented. The investigation has been carried out in February 1985 and 1988 during two Geodynamical Expeditions organized by the Institute of Geophysics of the Polish Academy of Sciences. The boomar penetration of the caldera floor went down to 150 msec. Four seismoacoustic units of volcanic formations have been determined. The unit A corresponds to pre-caldera series and occurred only in the border part of the flooded caldera. The unit contains mainly pyroclastic rocks (consolidated agglomerates and tuffs) and probably some intercalations of lavas. The units B, C and D fill up the caldera bottom and correspond to post-caldera series. The units are composed of pyroclastic rocks, containing also materials redeposited by lahars, glaciers, landwaters and by wind. The units C and D (the youngest one) were certainly deposited under water. All the units are cut by numerous faults, vents and other types of intrusions. The larger faults, *en echelon* type, are situated around the bottom and form a ring-fracture. Caldera was formed by succesive stages of collapsing. This process is not finished yet and volcanic activity is still alive (especially in the western part of the flooded caldera).

Key words: Antarctica, Deception volcano, geophysics and geological structures.

Introduction

This report describes the results of marine seismoacoustic investigations conducted in the flooded caldera (Port Foster) of the Deception Island during the Polish Geodynamical Expeditions of 1984/85 and 1987/88, organized by the Institute of Geophysics of the Polish Academy of Sciences and led by Professor A. Guterch.

A preliminary seismoacoustic profilling was carried out in February 1985 (Kowalewski *et al.* 1987) aboard the vessel *Jantar*. It was the first seismoacoustic study in this area. In February 1988 the studies were continued. The detailed seismoacoustic investigations were taken also aboard the vessel *Jantar*. Numerous seismoacoustic profiles were made with profile lines situated *ca.* every 250 m. The investigations were taken by CSP (continuous seismoacoustic profiling) used EG and G (Boomar and Sparker) equipment.The boomar penetration of the caldera bottom went down to 150 msec. As a result, it was possible to distinguish and determine the bottom structure of the flooded caldera, to a depth of *ca.* 150—200 m beneath the level of the bottom. The profiles were located by radar bearings on the characteristic objects on the coast.

The research was sponsored by CPBP 03.03. Programme of the Polish Academy of Sciences.

Geographical location and general topography

Deception Island which is one of the two active volcanoes in the Antarctic, is situated in the Bransfield Strait near the southwestern end of the South Shetland Islands archipelago (Fig. 1), *ca.* 15 km south of the Livingstone Island. The geographical coordinates of the island are 62°57′ S and 60°38′ W.

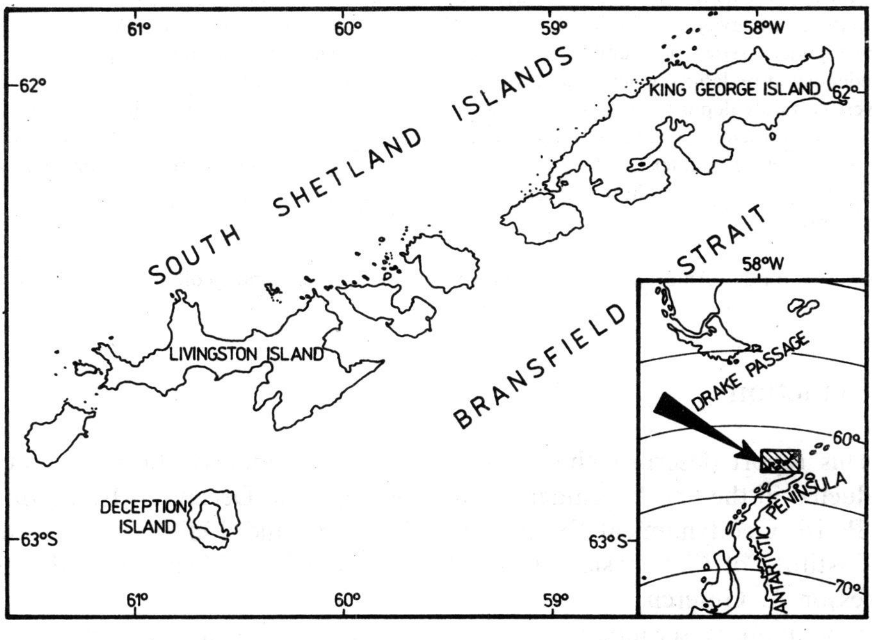


Fig. 1. Locality map of the Deception Island

The ring-shaped island (Fig. 2), 14 km in diameter, is an intermittently active, composite stratovolcano built by successive volcanic eruptions from a variety of vents, from the Tertiary (?) to Recent times with intervening periods

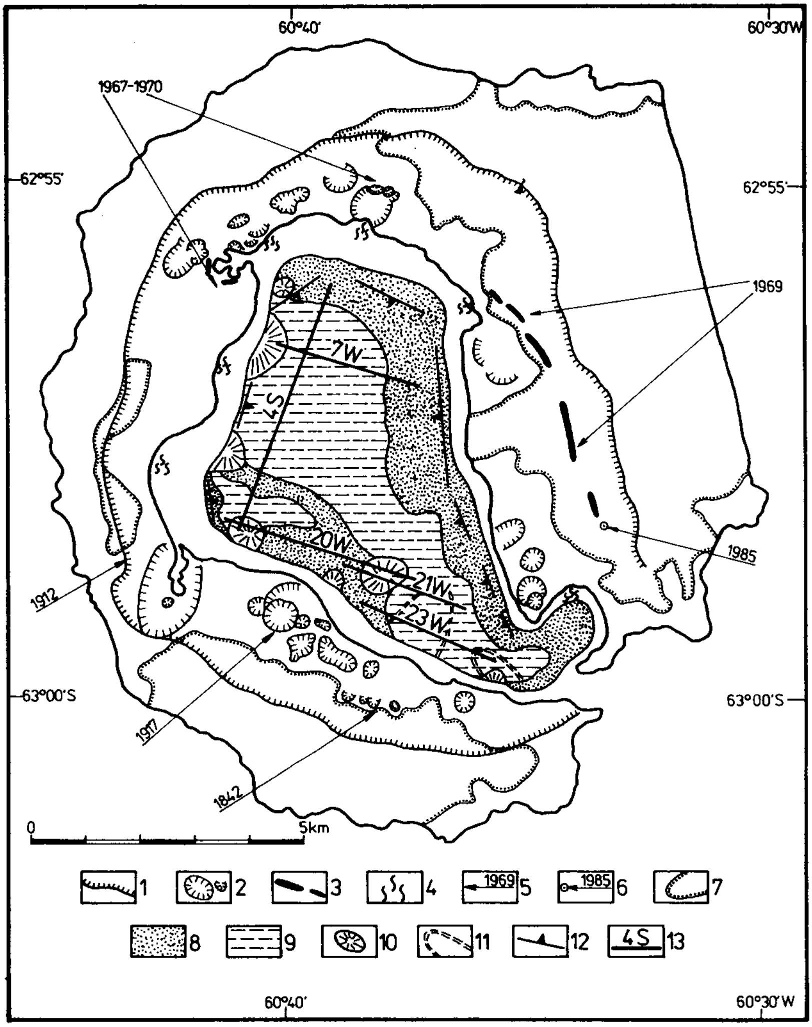


Fig. 2. Geomorphological sketch of caldera of the Deception Island. Onshore elements, marked mainly *after* Gonzales-Ferrán *et al.* (1971) and Newhall and Dzurisin (1988): 1 — caldera rim, 2 — craters, 3 — 1969 fissures, 4 — fumaroles, 5 — dated eruption centers, 6 — new small cone, active (mainly steam emission) in 1985 and 1988; 7 — limits of main ice fields. Offshore elements, based on seismoacoustic profile made during Polish Geodynamical Expeditions 1984/85 and 1987/88: 8 — uneven surface of an accumulative area of the pyroclastic rocks connected with cones and lahars, 9 — relatively flat surface of the accumulative area of the pyroclastic materials waterlain settled and horizontal bedded, 10 — cones on the floor, 11 — identified limits of the young (lakkolit-like ?) intrusions (pyroclastic agglomerates ?) only slightly reflected in the surface relief; 12 — main faults, 13 — lines of the selected seismoacoustic profiles (Pl. 1 – 3).

of subsidence (Ashcroft 1972). The average height of the island is *ca.* 300 m, the maximum height being 542 m above sea level, and *ca.* 1000 m above the surrounding sea bottom.

The present relief (Pl. 3, Fig. 2; Pl. 4) of the island is a result of the past and present volcanic activity (cones, craters, maars, lava flows *etc.*) combined with activity of the slope processes (mainly lahars) and glaciers, activity (moraines, sandurs *etc.*). Glaciers cover a considerable part of the island area.

The caldera, *ca.* 8—10 km in diameter, is largely occupied by sea. The irregular-shaped landlocked harbour Port Foster (*ca.* 3—5 km in diameter) has an average depth of *ca.* 130 m, reaching a maximum of 180 m. The narrow entrance, Neptun Bellows, *ca.* 500 m wide and *ca.* 300 m deep joins Port Foster with the open sea.

Previous works and historical volcanic activity

The onshore part of the island is relatively well investigated. The results of the geological studies have been summarized in a number of works, especially by Adie (1964), Gonzales-Ferrán *et al.* (1971), Baker *et al.* (1975, *after* Newhall and Dzurisin 1988). Two main geological series were distinguished: the pre- and post-caldera. The pre-caldera series contain lavas and pyroclastics (agglomerates). Lavas are predominantly sodic andesites or basaltic andestites (Newhall and Dzurisin 1988). Within the post-caldera series pyroclastic rocks are dominant. Pyroclastic rocks containing consolidated agglomerates, tuffs, non-consolidated young volcanic ashes and materials of the lahars — predominate on the exposed part of the island. The past and present volcanic activity (marked with fissures, craters, cones and fumaroles) is associated with the complex of ring-fracture around the caldera.

The offshore part of caldera, that is the sea floor of Port Foster, has been much less investigated. One profile of the seismic refraction was made during expeditions of the Department of Geology of the University of Birmingham (Ashcroft 1972). During the two Polish Geodynamical Expeditions of 1979/80 and 1984/85 some reflection and refraction studies were also carried out. The results will be published shortly. Also, Spanish-Argentine-Chilean Expedition made a geophysical research of this area in February 1988.

Discovered in 1820, Deception Island has never been properly settled. The only visitors to this area had been sailors, seal-hunters and whalers who used Port Foster as a good harbour and as their temporary base during the summer It was only in the mid 1940 s that the first permanent research stations, British next Chilean and Argentine were established. They were in operation until 1969. The scantiness of reports on the island volcanic activity (as listed below mainly *after* Newhall and Dzurisin 1988) reflects the periodic presence of people in this area.

1829: The occurrence of numerous fumaroles and subterranean sounds were reported.
1842: Reports of strong volcanic activity concerning 13 vents in the southern part of the island. Hawkes (1961, *after* Adie 1964) associates this with young volcanic lavas exposed in the region of Mt. Kirkwood. Roobol (1973, *after* Newhall and Dzurisin 1988) suggests that the volcanic activity of this period was probably connected with big fummaroles.
1912 and 1917: On the basis of an analysis of the pyroclastic materials interbedded with ice two eruptions have been postulated (Orheim 1972).
1923: Whalemen observed shore subsidence to the southwest of Port Foster. „Boiling" water washed paint off the ship hull.
1930: An earthquake was observed. Part of Port Foster floor near the Whalers' Bay subsided 4.5 m.
1967: After a series of earth tremors a powerfull eruption occured from four vents situated along the ring-fructure and fractures were formed. As a result this part of the shore of Port Foster changed significantly (Gonzales-Ferrán *et al.* 1971).
1969: Strong eruptions were registered. New fissure (5 km long) was formed along the ring fracture on the east side of the caldera. 20—30 new vents were formed within new fissure. The Chilean research station was completely destroyed. The British station was partly buried under a layer of pyroelastic materials carried down from caldera slope by lahars. The crews of the stations, together with the crew of the Argentine station which had remained intact, had to be evacuated.
1970: Stations located around Deception Island (at a maximum distance of 170 km) reported a profuse fall of volcanic ashes (Gonzales-Ferrán *et al.* 1971). In 1972 Shultz (*after* Newhall and Dzurisin 1988) reported landscape changes in the northwestern part of the caldera.
1984: During the Polish Geodynamical Expedition in February, Dr. E. Perchuć discovered a small (*ca.* 10 m height) new volcanic cone, situated in the south end of the fissure formed during the eruption o 1969. The activity of the cone (also in February 1988) was limited mainly to emission of steam.
1987: On 23 July local seismic activity was recorded at a research station on King George Island. On satellite images of this area a plume was seen, thought to be a volcanic cloud (Newhall and Dzurisin 1988).

Seismoacoustic studies within flooded caldera

The bottom structure of the flooded caldera (Port Foster) was investigated in detail by the continuous profiling. Four major seismoacoustic units were distinguished and described (Pl. 1—3). A general lithological interpretation of these units was introduced on the basis of our knowledge of the island onshore geology. The specifield correlation between the seismoacoustic units and onshore geology structure is very difficult and reguires research.

Unit A. The occurence of the unit A was identified only in border part of flooded caldera (Pl. 1, Fig. 1). Most probably unit A corresponds with pre-caldera series and is limited by large *en echelon* faults, dipping downward to the center of caldera (Fig. 2, Pls. 1—3). These faults correspond with caldera rims in the successive stages of its development. The unit A certainly consists mainly of pyroclastic agglomerates (strongly consolidated) and probably also interbedded lavas (locally).

Unit B. The unit B probably corresponds with a some older part of the post-caldera series. This unit fills up the center of flooded caldera and takes up the largest part of it. The maximum thickness of unit B is *ca.* msec, but its lower limit in the central part (like as lower limit of the unit A) has not been identified. Unit B is mainly composed of consolidated pyroclastic agglomerates and tuffs, associated with slopes of cones around the caldera rim. In our opinion this unit was formed before the opening the entrance and filling the caldera depression by sea water.

Unit C. The unit C was formed in its lower part (sub-unit C_1) mainly as a result of sudden deposition on the flooded caldera floor of large quantities of different size particles of the pyroclastic materials carried down by large lahars from onshore part (Pl. 1, Fig 2). The upper part of the unit C (sub-unit C_2) contains pyroclastic materials of associated cones or lahars and laterally interbedded layers of the waterlain deposition (common in central part of the floor). All the unit C has thickness *ca.* 50 msec in the central part of flooded caldera and from 5 to 15 msec in its border part. Dotted area (Fig. 2) on the floor corresponds with this unit.

Unit D. The unit D, the youngest of all fourth units, fills the depressions and covers the elevations of the floor as a more or less thick carpet *i.e.* the unit D lies discordantly on the older units (Pl. 1, Fig. 1). The cover it forms is approximately 1 to 25 msec thick. It is composed of interbedded layers of tuffits and agglomerates. The lower part of this unit (sub-unit D_1) contains layers of lahars with intercalations of the layers built of materials gravitionally deposited through the water. These waterlain deposited and distinctly horizontal stratificated layers predominant in the upper part of the unit D (sub-unit D_2). This sub-unit fills the center of the flooded caldera floor and occurred on its bottom surface. The dashed area (Fig. 2) correponds with the surface of the unit D, but only where the unit is thicker than 1—5 msec.

The surface of the caldera floor is so hard (*cf.* Ashcroft 1972) that it is impossible to take up core samples from the bottom by piston corer. The pyroclastic sediments deposited under water are quickly cemented by ashes in fine fraction that fill interstices between bigger particles. In addition, consolidation may be connected also with high temperature. On the shores where fumaroles were active, some kind of the hard plates were observed in 1988. These „beach rocks" occurred in shallow part of the bottom and were formed very recently from the loose materials creeped and slided from the coast (formed after the 1970 eruptions).

All the units are cut by numerous faults, vents and other kind of the intrusions. The bigger faults are situated around the caldera's floor as a ring-fracture in its border part (*e.g. see* faults in the east side of the profile 7W on the Pl. 1, Fig. 1). Some of the faults, especially in the western part of the caldera's floor are still active (*see* Pls. 1 and 2).

Volcanic vents have different sizes and occurred in the western part of the floor. Most probably they are composed of pyroclastic agglomerates. Some vents continue to the cones rise above the present floor level. All these cones and vents are young. The oldest ones are younger than the unit A, the youngest ones were probably formed during 1969-1970 eruptions.

In the southwestern part of the caldera floor large young intrusions were identified (Fig. 2), may be of lakkolit type. The border part of the one of them is presented in the east side (Pl. 2, Fig. 2) and west (Pl. 3, Fig. 1) sides.

Conclusions

On the ground of the detailed seismoacoustic profiling (CSP — boomar) the structure of the caldera in its flooded part was determined. Good penetration up to *ca.* 150—200 m beneath bottom level and good resolution were obtained. Four main seismoacoustic units were distinguished. The unit A probably corresponds to pre-caldera series and contains consolidated pyroclastics, agglomerates and tuffs and probably intercalations of the lavas. The units B, C and D belong to the post-caldera series and contain different pyroclastic materials also strongly consolidated. The unit B was formed mainly as a slope of cones surrounding the caldera rim. Units C and D are also abundant in the volcanic debris redeposited from the onshore part by lahars, glaciers, landwater, shore and slope processes and by wind.

All the units are cut by numerous faults and vents. The evidences of young and even today vital volcanic activity are common on the bottom, especially in its western part. The cones and vents which occurred here are undoubtedly of the post-caldera age. The youngest ones are associated with 1969—1970 eruptions.

Our results suggest that caldera was formed undoubtedly by collapse of central part of the single composite stratovolcano (*cf.* Adie 1964, Baker *et al.* 1969, Gonzales-Ferrán *et al.* 1971, Ashcroft 1972, Newhall and Dzurisin 1988). Collapsing occurred in successive stages, more or less *en block,* along ring faults — *en echelon* in types. The subsidence is still active.

The opening of the entrance in caldera rim and flooding the caldera bottom by sea was determined as formed after deposition of the unit B. The unit C and D were undoubtedly deposited under water on the flooded caldera floor.

References

Adie R. J. 1964. Geological history. — *In:* R. Priestley, R. J. Adie and G. Robin (eds), Antarctic Research. Butterworth, London; 118—126.

Ashcroft W. A. 1972. Crustal structure of the South Shetland Islands and Bransfield Strait. — Br. Antarct. Surv. Sci. Repts., 66: 1—43.

Baker P. E. 1969. A volcano erupts beneath the Antarctic ice. — Geograph. Magazine, London; 11: 115—126.

Baker P. E., Davies T. G. and Roobol M. J. 1969. Volcanic activity at Deception Island in 1967 and 1969. — Nature, 224: 553—560.

Gonzales-Ferrán O., Munizaga F. V. and Moreno H. R. 1971. Sintesis de la evolution volcánica de isla Deception. — Publ. INACH Ser. Cie., 1: 1—14.

Kowalewski W., Rudowski S., Zalewski S. M. and Żakowicz K. 1987. Investigations of the seafloor of the caldera of Deception Island by CSP methods. — Proc. 5-th Intern. Symp. Antarctic Earth Sci., Cambridge, vol. abstr., 81 p.

Kowalewski W., Rudowski S. and Zalewski S. M. 1989. Budowa dna zatopionej kaldery wyspy Deception (Antarktyka Zachodnia), na podstawie profilowania sejsmoakustycznego. — Mat. XVI Symp. Polar., Toruń.

Newhall Ch. G. and Dzurisin D. 1988. Historical unrest at large calderas of the world, 2. — Bull. Geological Surv., USA, sp. issue, 1013—1019.

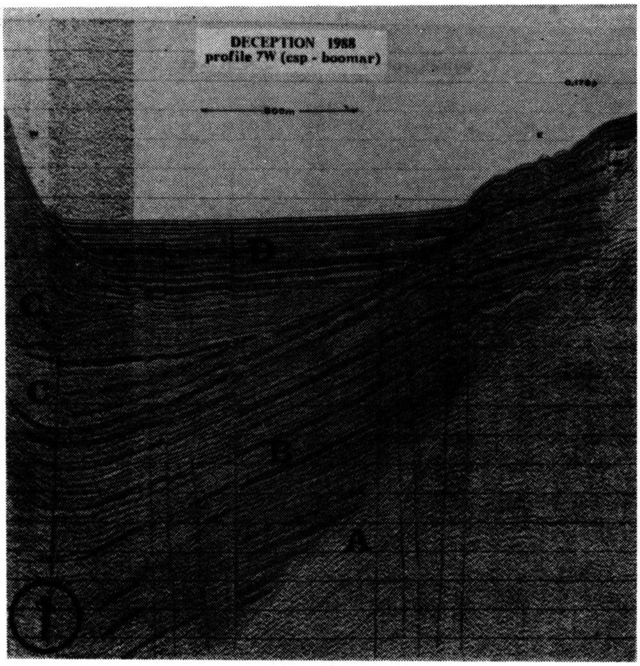
Schultz Ch. H. 1972. Eruption at Deception Island, Antarctica, 1970. — Bull. Geol. Soc. Amer., 83: 2837—2842.

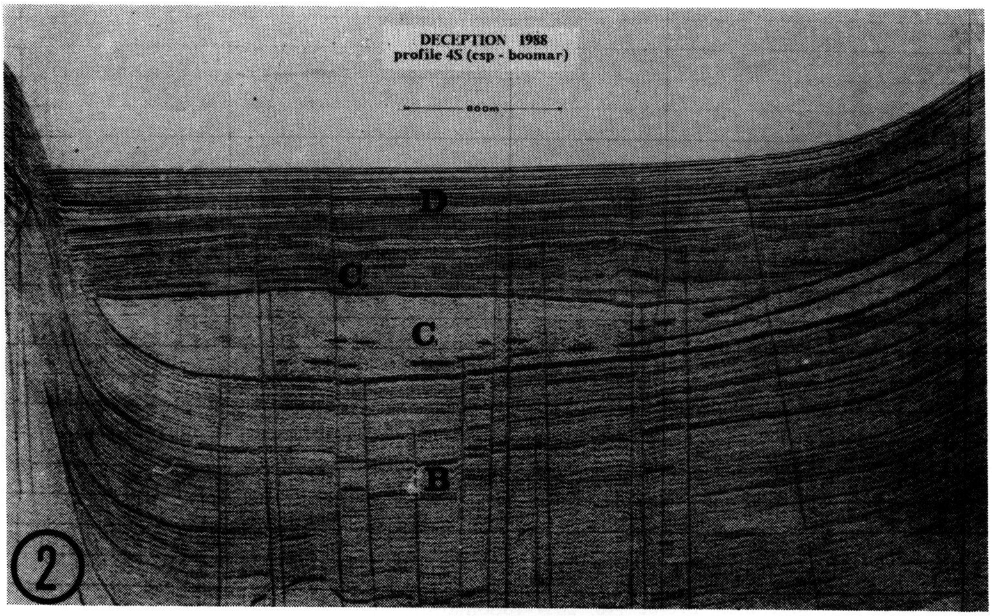
Received July 5, 1990
Revised and accepted July 20, 1990

Streszczenie

Wyspa Deception stanowi wulkan z kalderą połączoną z otwartym morzem wąską cieśniną (fig. 1 i 2). W pracy przedstawiono rezultaty profilowania sejsmoakustycznego (CSP, boomar) wykonanego podczas Ekspedycji Geodynamicznych do Antarktyki Zachodniej (pl. 1—4), zorganizowanych przez Instytut Geofizyki PAN w latach 1984/85 i 1987/88. Uzyskano dobrą penetrację do głębokości ok. 200 m poniżej poziomu dna zatopionej części kaldery. Wyróżniono cztery główne jednostki sejsmoakustyczne. Jednostka A odpowiada zapewne tzw. seriom prekalderowym i zbudowana jest z piroklastycznych, silnie skonsolidowanych aglomeratów i tufów, prawdopodobnie z wtrąceniami law. Jednostki B, C i D należą do serii postkalderowych i są zbudowane z różnorodnego, skonsolidowanego materiału piroklastycznego. Jednostka B zawiera głównie osady stożków otaczających kalderę. Jednostki C i D, utworzone pod wodą (już po zalaniu kaldery wodą morską — po powstaniu bramy w pierścieniu kaldery), zawierają także znaczne ilości kruszywa wulkanicznego redeponowanego z lądu przez lahary, lodowce, wody lądowe, procesy brzegowe i stokowe oraz przez wiatr. Jednostki są pocięte przez liczne uskoki i kominy wulkaniczne. Działalność wulkaniczna jest nadal żywa, zwłaszcza we wschodniej partii dna kaldery.

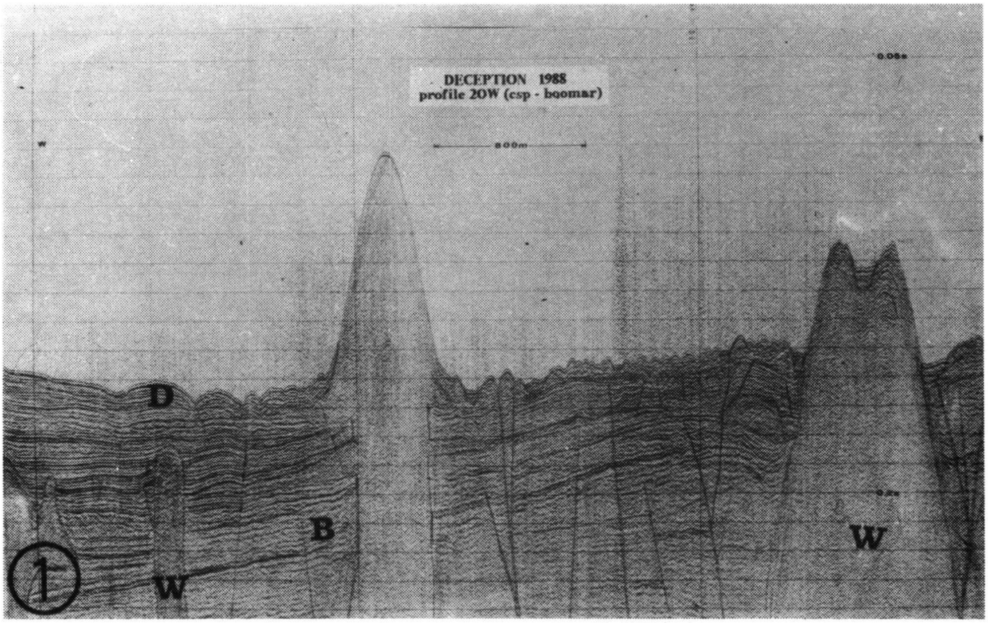
Rezultaty wykonanych badań wskazują na zapadliskowe pochodzenie kaldery w wyniku osiadania, mniej lub bardziej *en block*, centralnej partii pojedynczego, złożonego stratowulkanu. Osiadanie następowało etapami wzdłuż uskoków typu schodowego, położonych dookoła ścianv kaldery. Najmłodsze z nich są związane z wybuchami 1969—1970.

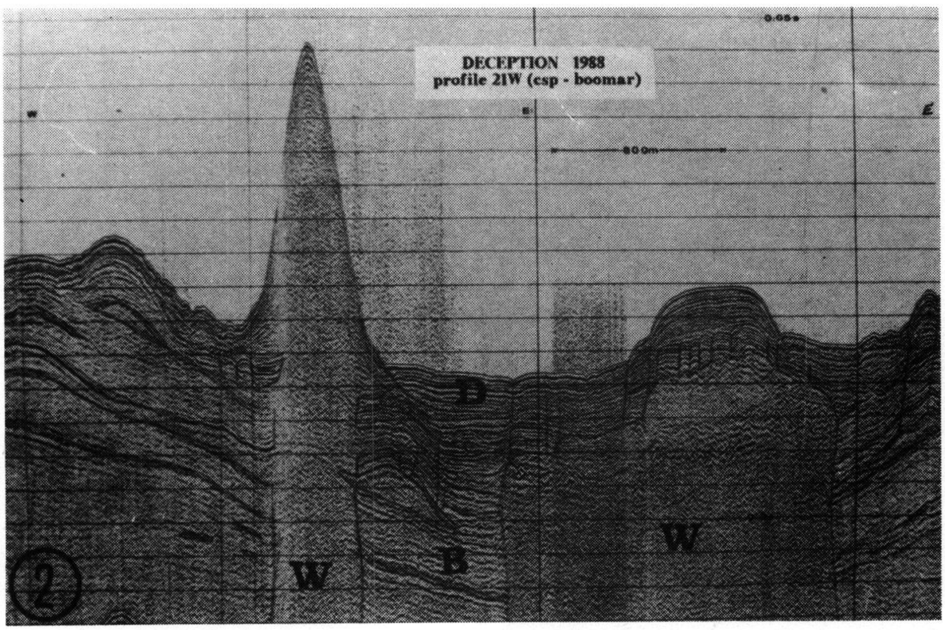




1. Selected seismoacoustic profile No. 7 W (boomar record). Location on the Fig. 1. Seismoacoustic units: A — pyroclastic agglomerate and tuffs, pre-caldera series; B — pyroclastic agglomerates and tuffs, mainly slopes of cones, older part of the post-caldera series; C — pyroclastic materials deposited on the flooded caldera floor, post-caldera series; sub-unit C_1 mainly lahars and locally slopes of cones; sub-unit C_2 lahars interbedded layers of tuffits, D — the youngest part of post-caldera series, sub-unit D_1 waterlain settled pyroclastic materials and lahars, sub-unit D_2 mainly materials waterlain settled horizontal bedding, only some intercalations of lahars, W intrusions, pyroclastic agglomerates riddle or not dykes. Faults are marked. Horizontal lines mark two-time travel every 10 msec

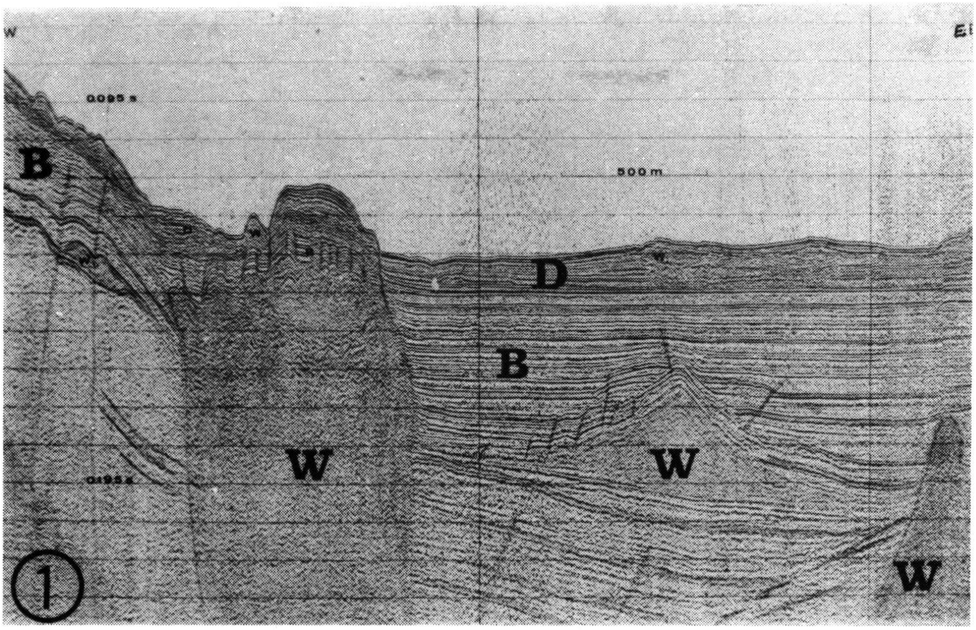
2. Selected seismoacoustic profile No. 4S (boomar record). Explanations on Pl. 1, Fig. 1





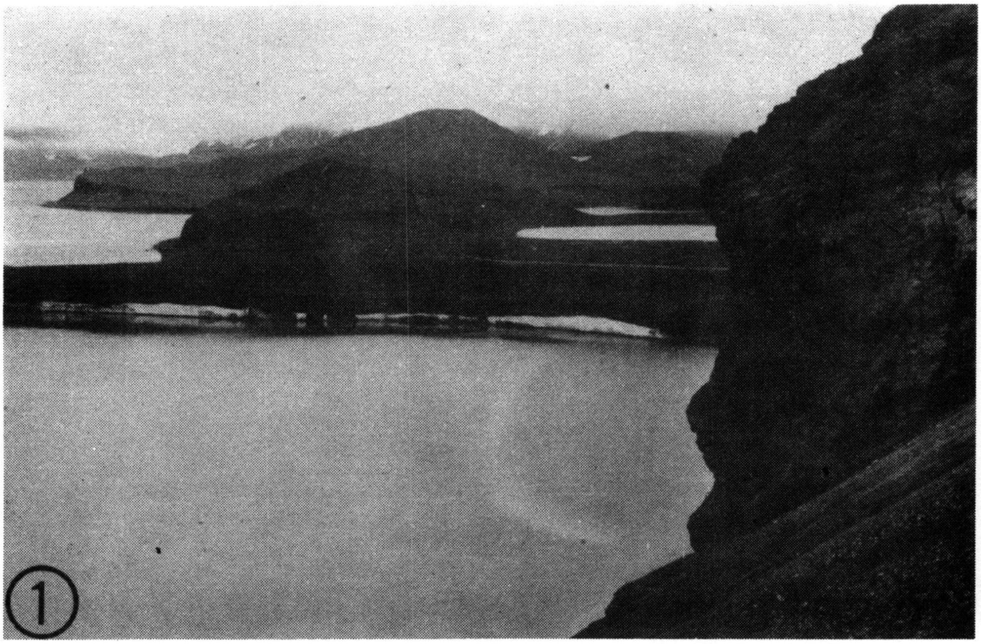
1. Selected seismoacoustic profile No. 20W (boomar record). Explanations on Pl. 1, Fig. 1

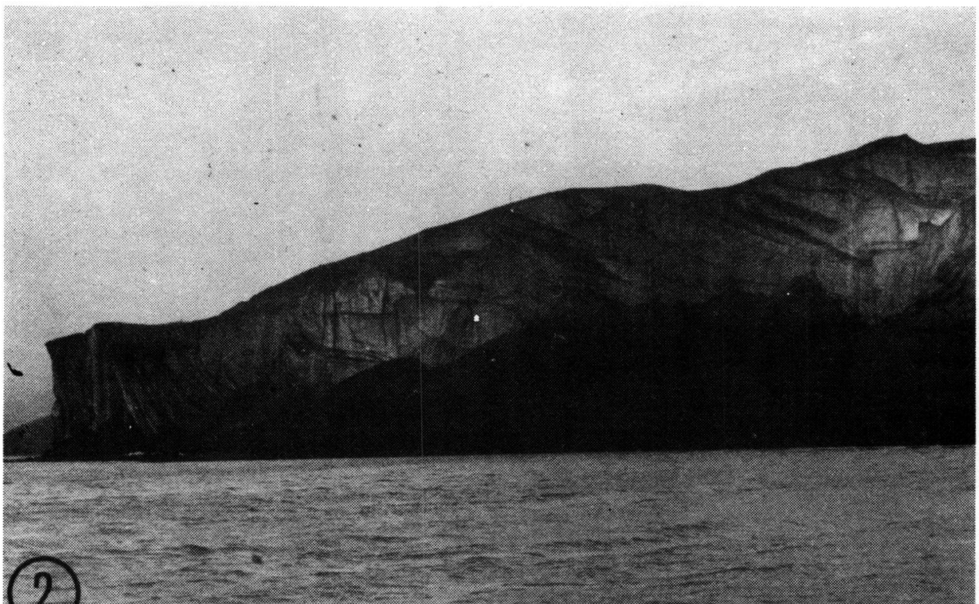
2. Selected seismoacoustic profile No. 21W (boomar record). Explanations on Pl. 1, Fig. 1



1. Selected seismoacoustic profile No. 23W (boomar record). Explanations on Pl. 1, Fig. 1

2. Southern part of the caldera. Mt. Kirkwood — region of the eruption in 1842 — in the back. An excellent example of the maar in the first plane. Photo by S. Rudowski, February 1988





1. Northwestern part of the caldera, the region of eruptions 1967—1970, new cones and craters in the back. A fragment of caldera rim (pre-caldera lavas?) in the first plane. Photo by S. Rudowski, February 1988

2. The „Black Glacier" in the east side of the caldera. Thick pyroclastic layers interbedded ice. A moraine below, at the glacier. Photo by S. Rudowski, February 1988