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2–D seismic models of the lithosphere in the area of the Bransfield Strait, West Antarctica

ABSTRACT: During the Polish Antarctic Geodynamical Expeditions in 1979–91, deep seismic sounding measurements were performed in the transition zone between the Drake and South Shetland Microplates and the Antarctic Plate in West Antarctica. For the Bransfield Strait area, the seismic records of five land stations in South Shetland Islands and two stations at the Antarctic Peninsula were used. The interpretation yielded two–dimensional models of the crust and lithosphere down to 80 km depth. In the uppermost crust, the unconsolidated and poorly consolidated young sediments with velocities of 1.9–2.9 km/s cover the layers 4.0–4.2 and 5.6–5.9 km/s. The crustal structure beneath the trough of Bransfield Strait is highly anomalous. The presence of a high velocity body, with longitudinal seismic wave velocities $v_p > 7.0$ km/s, was detected in the 6–30 km depth range. This inhomogeneity was interpreted as an intrusion, coinciding with the Deception–Bridgeman volcanic line. For the uppermost crust, a qualitative comparison was made between the results from the reflection profiles (GUN) and deep seismic sounding profiles (DSS). In the study area, the Moho boundary depth ranges from 10 km beneath the South Shetland Trench to 40 km under the Antarctic Peninsula. In the transition zone from the Drake Passage to the South Shetland Islands, a seismic boundary in the lower lithosphere occurs at a depth ranging from 35 to 80 km. The dip of both the Moho and this boundary is approximately 25°, and indicates the direction of subduction of the Drake Plate lithosphere under the Antarctic Plate. The results obtained were compared with earlier results of seismic, gravity and magnetic surveys in West Antarctica. A scheme of geotectonic division and a geodynamical model of the zone of subduction of the Drake Plate under the Antarctic Plate is compared with subduction zones in other areas of the circum-Pacific belt.

Key words: West Antarctica, Bransfield Strait, deep seismic sounding, lithospheric structure, subduction zone.

Introduction

Four Polish Geodynamical Expeditions to West Antarctica were organized in the years 1979–1991 by the Institute of Geophysics of the Polish Academy of

Sciences. The main purpose of the expeditions was to carry out the structure studies of the Earth's crust and lower lithosphere by using different geophysical methods, within the general programme of geodynamic studies of West Antarctica. Special attention was paid to tectonically active zones and to the contact zones between the blocks of the Earth's crust and the lithospheric plates. As a part of the programme, seismic refraction and reflection soundings in the Bransfield Strait area were made during expeditions in 1979–80, 1987–88 and 1990–91.

Geology and plate-tectonics of the region

The Antarctic Peninsula and the South Shetland Islands had a similar geologic history up to the Jurassic. These regions were morphologically contiguous with the south Andes Mountains in the Mesozoic (Arctowski 1895; De Witt 1977) and were separated during the formation of the Scotia Sea in the Tertiary (Dalziel and Elliot 1973). The opening of Drake Passage and Western Scotia Sea took place between 28 and 6 Ma, when the North and South Scotia ridges separated from the southernmost South America (Acosta *et al.* 1992). A simplified tectonic scheme for this region is shown (Fig. 1).

In general, the Pacific margin of the Antarctic Peninsula is characterized by a very complex subduction history. The ocean floor of the South Pacific was formed over the past 110 Ma at the Pacific Antarctic Ridge. Part of the Pacific margin of Antarctica between Shackleton Fracture Zone and Hero Fracture Zone, as well as nearby segments of the Aluk Ridge, have subducted oceanic lithosphere over the past 21 Ma. The subduction was totally coupled to spreading in the western Drake Passage to the north, which produced a new ocean floor from 20 Ma to about 4 Ma, and then the subduction was stopped. There is no observed earthquake activity connected with the subducted slab at present (Barker 1982; Barker and Dalziel 1983). The Pacific oceanic crust and its Late Cenozoic sedimentary cover are clearly recognizable at the outer margin of the trench. The South Shetland Trench, some 5000 m deep, is filled with undisturbed Late Cenozoic (Quaternary and ?Pliocene) sediments plunging down under the leading edge of the South Shetland Island crustal wedge. The South Shetland Platform (Microplate) represents a crustal wedge (overriding plate) bounded by the Bransfield Rift on the southeast and by the South Shetland Trench on the northwest.

The Bransfield Rift, together with the Bransfield Platform, represent a back-arc basin with respect to the Late Mesozoic-Cenozoic South Shetland Islands volcanic arc. After Birkenmajer (1989) and Birkenmajer *et al.* (1990), the initiation of the Bransfield Basin dates back to the Late Oligocene - Early Miocene times, as evidenced by a system of rift parallel antithetic faults along the outer margin of the rift. These faults displace the Early Oligocene and older

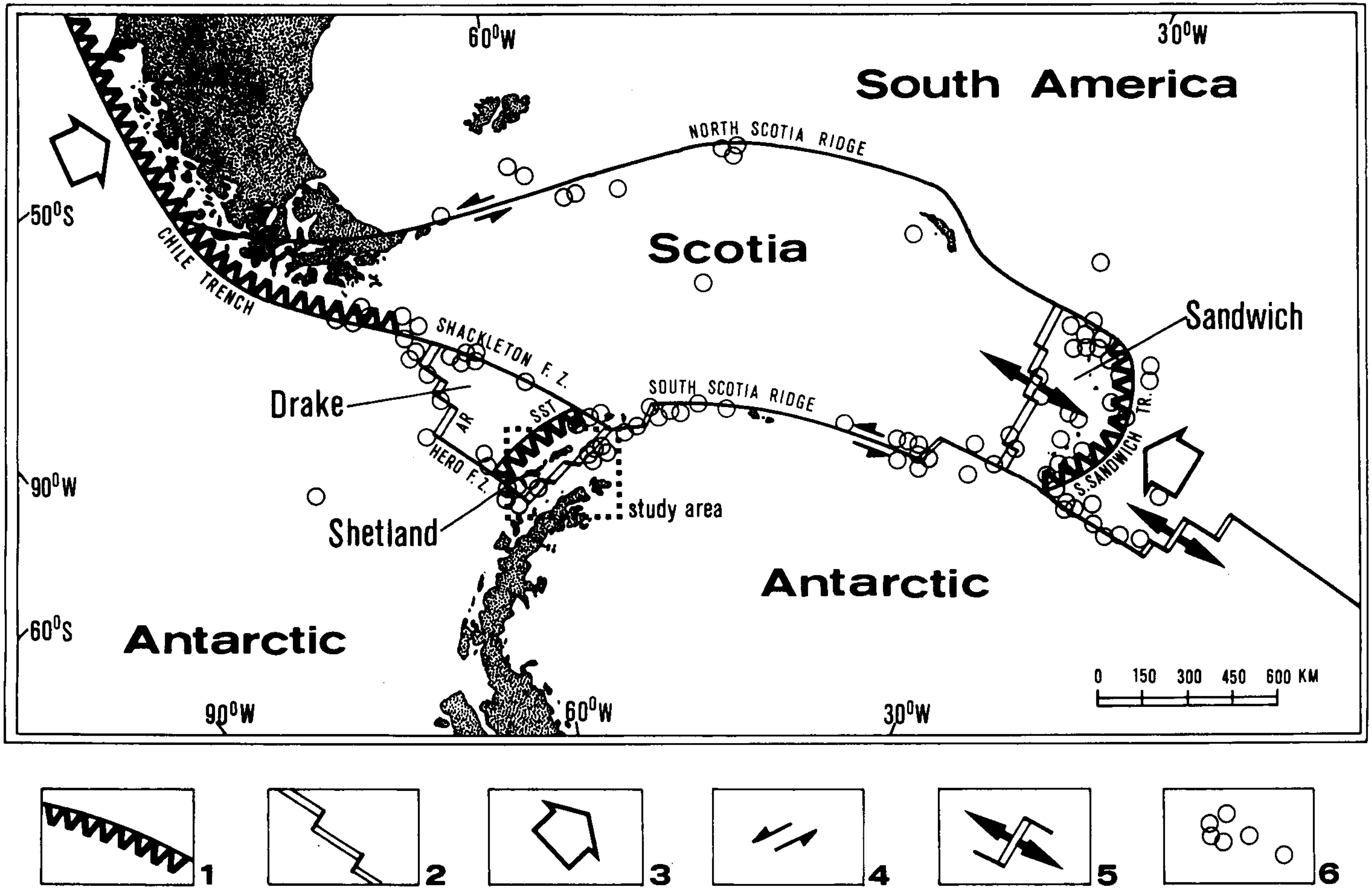

Fig. 1. Plate-tectonic elements around the Scotia region. Compiled from the Tectonic Map of the Scotia Arc 1985; Pelayo and Wiens 1989; Birkenmajer *et al.* 1990. SST — South Shetland Trench, AR — Aluk Ridge. 1 = subduction trench; 2 = divergent plate boundary, ridge and transform faults; 3 = direction of the subduction; 4 = relative motion at the plate boundary; 5 = direction of the relative motion at spreading ridges; 6 = epicentres of the 1963-1985 earthquakes (for earthquakes with $m_b > 5.0$; east of 30°W only for earthquakes with $m_b > 6.0$). Box shows the location of study area.

rocks of King George Island, and had been used by basaltic dykes K – Ar dated at 21 – 20 Ma. The rift in Bransfield Strait is a Late Cenozoic tensional structure, about 40 km wide near King George Island which separates the Bransfield Platform from the South Shetland Islands Microplate (González-Ferrán 1985). The central part of the rift graben, only 15 – 20 km wide, contains several subaerial and submarine volcanoes on a line between the Deception and Bridgeman islands. The Deception Island volcano is still active and with the volcanic eruptions a precursory seismicity was sometimes observed (Hawkes 1961; Baker *et al.* 1975; Lorca 1976; Roobol 1979; Newhall and Dzurisin 1988; Pelayo and Wiens 1989; Kowalewski *et al.* 1990). A subparallel volcanic line links the Penguin Island and Melville Peak volcanoes, situated on the southern margin of the South Shetland Island crustal block. The central, submarine trough, 1000 – 2000 m deep, is filled with horizontal strata of considerable thickness, probably mainly tephra and young glacio – marine sediment. The Quaternary volcanoes comprise three compositionally distinct volcanic suites: alkaline and calc – alkaline lavas occur in the Penguin, Deception, Bridgeman and Melville Peak volcanoes, whereas the seamounts are composed of tholeiites (Gonzáles-Ferrán and Katsui 1970; Weaver *et al.* 1979; Pankhurst 1982; Birkenmajer *et al.* 1990; Birkenmajer and Keller 1990; Jeffers *et al.* 1991; Fisk *in press*). This difference may reflect not only the youth of the basin, but also the crustal structure below the volcanoes. The normal continental crust, about 30 km thick, occurs below the Melville Peak and Penguin volcanoes situated on, or near to the King George Island, while highly anomalous crust has been recognized below the Bransfield Trough (Ashcroft 1972; Guterch *et al.* 1985; Birkenmajer and Keller 1990; Środa 1991; Grad *et al.* 1992, 1993). Teleseismic observations of earthquakes in the Bransfield Strait, close to the Deception Island, show NW-SE tension in agreement with geological evidence indicating rifting and extension (Pelayo and Wiens 1989).

The region of West Antarctica around the South Shetland Islands, Bransfield Strait and the Antarctic Peninsula (Fig. 1) has a complicated structure. This manifests itself by the observed gravity and magnetic anomalies and geological composition (Fig. 2). In the Drake Passage, the depth of the bottom reaches a maximum value of 5000 m in the South Shetland Trench. In the Bransfield Strait, between the South Shetland Islands and Antarctic Peninsula Shelf, the depth of the bottom exceeds 1000 m (Fig. 2). Bouguer anomalies run in accord with the arcs of islands and the Antarctic Peninsula Shelf. They have in this area positive values in the range of 20 – 140 mgals (Renner *et al.* 1985). Aeromagnetic anomalies are negative (to – 500 nT) around the South Shetland Islands, Bransfield Strait and the Antarctic Peninsula and positive (up to + 1000 nT) in the Drake Passage (Garrett 1990; Parra *et al.* 1988). The depth of the Moho discontinuity increases from about 10 km for the oceanic crust of the Drake Plate (also referred to in the literature as the "Phoenix" and "Aluk" Plate), to about 25 km for the South Shetland Islands Shelf and 30 – 33 km for

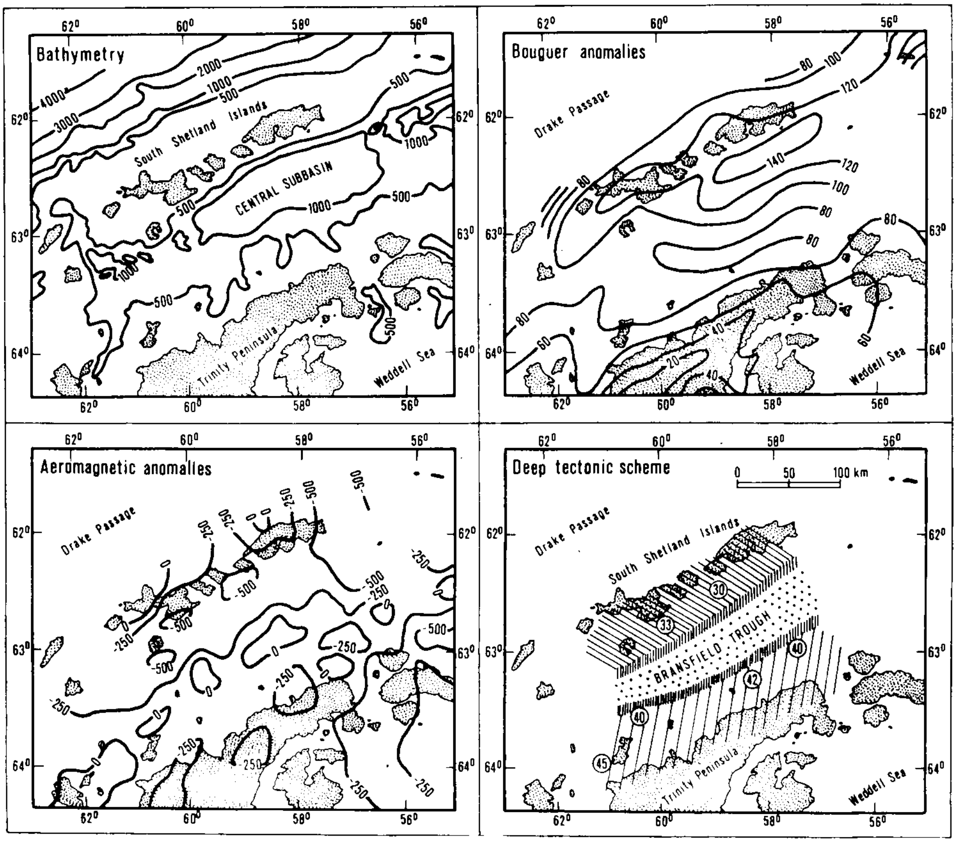

Fig. 2. The structure and geophysical fields of West Antarctica: bathymetry (bottom depth in meters), Bouguer anomalies (in miligals; contour interval 20 mgal), aeromagentic anomalies (in gammas, contour interval 250 nT), and deep tectonic scheme (Moho depth in km; dashed area — Antarctic Peninsula block, densely dashed — South Shetland Islands block). Compiled from Jeffers and Anderson (1990), Garrett (1990), Renner *et al.* (1985), Guterch *et al.* (1985, 1990, 1991).

the South Shetland Islands crustal block. By contrast, the Antarctic Peninsula and its adjacent shelf have a typical continental crustal thickness of 40—45 km. The Moho depth beneath the Bransfield Trough is about 28—30 km. High velocities of P-waves of 7.2—7.6 km/s were found in the depth interval 10—25 km (Guterch *et al.* 1985, 1990, 1991; Birkenmajer *et al.* 1990; Grad *et al.* 1992, 1993). Recent geophysical and geological investigations in West Antarctica confirm that the Bransfield Strait is an active rift. The last eruptions of 1967, 1969 and 1970 at the Deception Island (Baker *et al.* 1969; Birkenmajer 1987; Smellie 1988, 1989), as well as permanent seismic activity (Pelayo and Wiens 1989) prove that the tectono-volcanic activity along Bransfield Strait is still developing.

More disscusion of geological and tectonic data from the region of the Antarctic Peninsula can be found e.g. in papers by Dalziel and Elliot (1982), Barker (1982), Barker and Dalziel (1983), Macdonald *et al.* (1988), Birkenmajer *et al.* (1990), Henriet *et al.* (1992), Acosta *et al.* (1992).

Data and interpretation

In the years 1979–1991, the Polish Geodynamical Expeditions to West Antarctica carried out, in the Antarctic Peninsula region, an extensive project of seismic refraction studies into the deep structure of the crust and lower lithosphere with explosion seismology methods. In the area of the Bransfield Strait, deep seismic sounding measurements were made along a number of profiles, from which the results from profiles DSS-1, DSS-4, DSS-17 and DSS-19 are discussed in this paper. The layout of profiles is shown in Fig. 3. The shots were detonated in the sea along the profile lines at about 70 m depths, using dynamite charges from 50 to 100 kg TNT each (in the case of DSS-19, the charges of 24 kg TNT only were used). Seismic waves from explosions were recorded by three- and five-channel analog and/or digital seismic instruments with vertical seismometers on five land stations in the South Shetland Islands

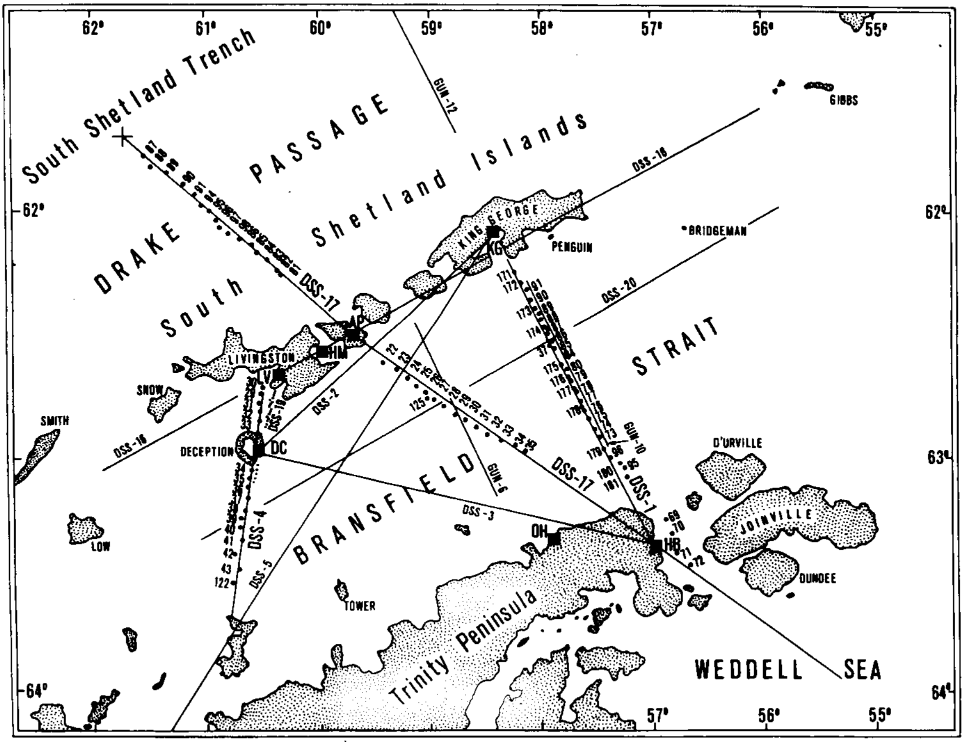

Fig. 3. Location of seismic profiles DSS-4, DSS-19, DSS-17 and DSS-1 in West Antarctica. Dots — shot points and their consecutive numbers; points — small shot (24 kg TNT) on the profile DSS-19; black squares — seismic stations: KG — at King George Island, AP — Arturo Prat, HM — at Half Moon Island, LV — at Livingston Island, DC — at Deception Island, OH — O'Higgins, HB — Hope Bay. The cross marks the beginning of the DSS-17 profile with coordinates $\lambda = 61.719$ W, $\varphi = 91.703$ S; the thin lines indicate the selected reflection (GUN) and deep seismic sounding (DSS) profiles discussed in the text.

(KG — the station on the Keller Peninsula at King George Island, AP — the Arturo Prat station at Greenwich Island, HM — the station at Half Moon Island, LV — the station at Livingstone Island, DC — the station at Deception Island) and two stations at the Antarctic Peninsula (HB — at the Hope Bay, OH — station O'Higgins).

Examples of seismic record sections from the study area are presented in Figs. 4–7. All recordings were filtered in the 2–15 or 2–10 Hz band, and the amplitudes were normalized. Distances between shot points were usually 4–6 km, the distances between seismic channels being 100–200 m. Five- or three-channel recordings make it possible to perform a much more accurate correlation of waves than that attainable with single channels. With a view to the clarity of seismic sections, however, we had to spread the channels, and the corrections of time were fitted to preserve the apparent velocities of the first arrivals. Because of this, for the other waves the local apparent velocities in individual recordings were deformed. Only distance and time for the central channel were not deformed, and these were the values used in modelling.

For the studied sections (Figs. 4–7), apparent velocities of the main wave trains occurring in first arrivals were determined. Both the seismic wave field and the wave velocities point to large structural differences of the crustal blocks of the South Shetland Trench, South Shetland Islands, Bransfield Strait and Antarctic Peninsula.

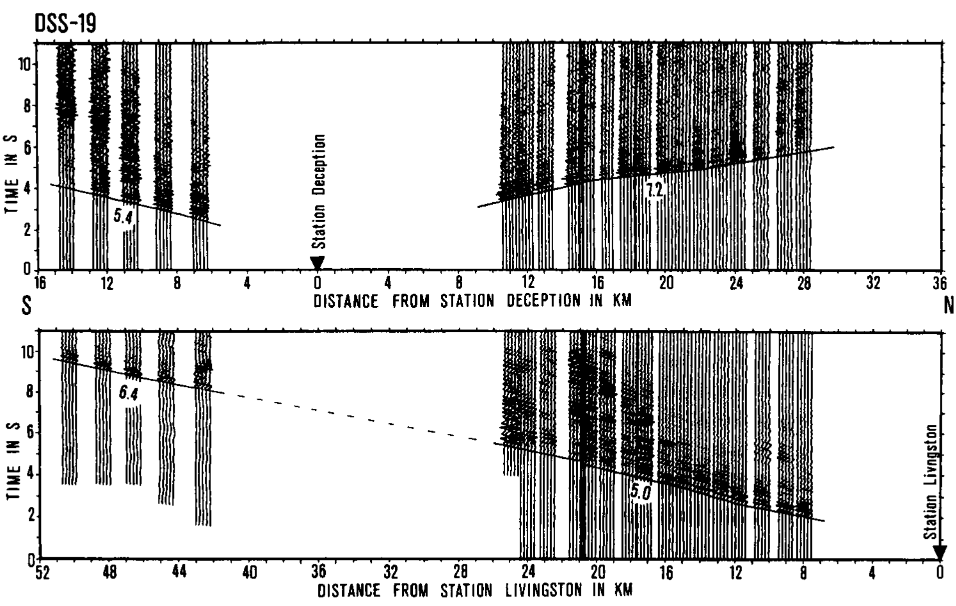

Fig. 4. Seismic record sections for profile DSS-19, stations Deception and Livingston. Non-reduced time, apparent velocities of first arrivals in km/s.

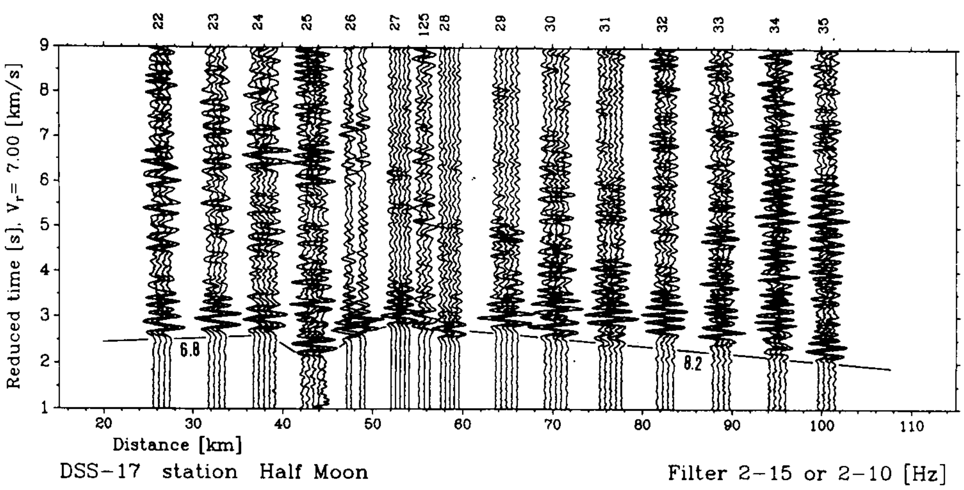

Fig. 5. Seismic record section for profile DSS-17, station Half Moon, part SE, shots 22–35. Apparent velocities of first arrivals in km/s.

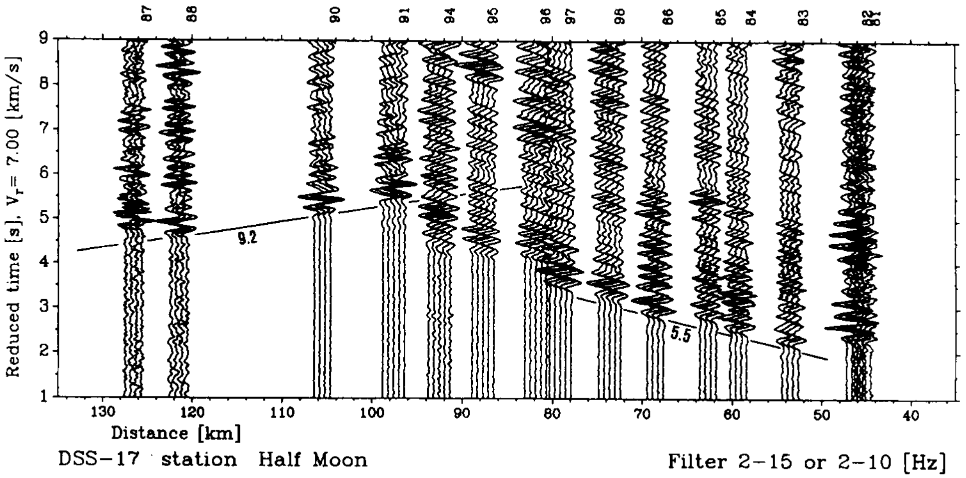

Fig. 6. Seismic record section for profile DSS-17, station Half Moon, part NW, shots 81–98. Apparent velocities of first arrivals in km/s.

Three refraction profiles, each about 10 km long, were shot in the area of Deception Island using an airgun array with a total capacity of about 30 l as a source. Two of them, profiles DEC-2 and DEC-3, were shot across the Port Foster to investigate the structure of the caldera (Grad *et al.* 1992). In the distance range of 2-7 km, waves with apparent velocities of 2.2–2.3 and 4.2–4.4 km/s were recorded. Seismic record sections from profile DSS-19, recorded at stations on Deception and Livingston islands, are presented (Fig. 4). The apparent velocities of first arrivals measured from shots in the

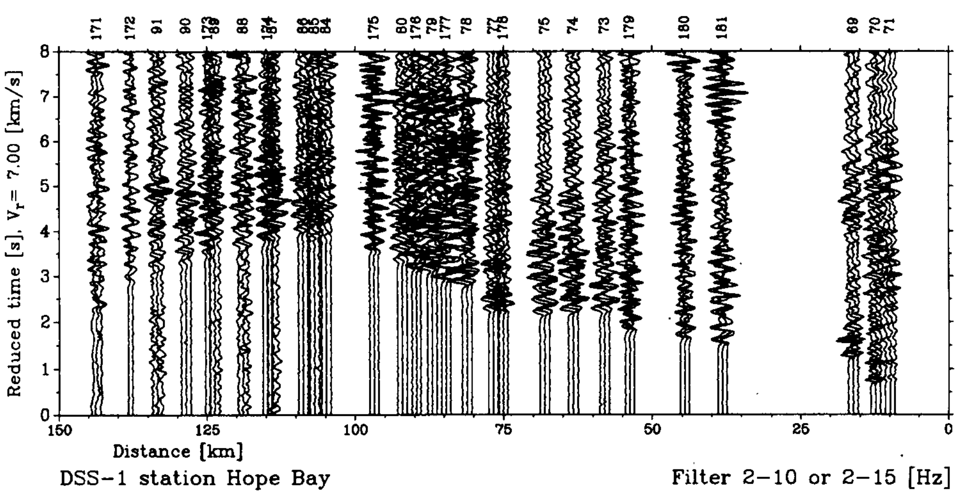

Fig. 7. Seismic record section for profile DSS-1, station Hope Bay. Apparent velocities of first arrivals in km/s.

c. 15 km long interval between the Deception Island and Livingston Island are 7.2 and 5.0 km/s for stations Deception and Livingston, respectively. This is a clear indication of a strong inclination of the seismic boundary, for which the real velocity of P-waves is of the order of 6.0 – 6.2 km/s. A similar wave field is observed for shots along profile DSS-4 recorded at station Deception. Some of the data from other profiles in the vicinity of Deception Island were published in earlier papers (Guterch *et al.* 1985, 1990, 1991; Grad *et al.* 1992).

On the record sections of shots along profiles DSS-17 and DSS-1 in the Bransfield Strait (recorded by stations Arturo Prat, Half Moon and King George) we observe relatively large apparent velocities, ranging from about 6.8 km/s in the 20 – 40 km interval of epicentral distances to some 8.2 – 9.7 km/s in the 60 – 100 km interval (Figs. 5 and 7). At 60 – 100 km distances we also observe a distinct reflected wave, arriving some 1 – 2 s after the first arrivals. It is located in the 165 – 185 km distance range along the profile, i.e. in the central part of the Bransfield Strait. Apparent velocities at sections recorded at stations O'Higgins and Hope Bay at Antarctic Peninsula are much lower: about 6.9 km/s in the 70 – 110 epicentral distance interval and 7.4 – 7.6 in the 140 – 160 km interval. Of influence on such a large differentiation in apparent velocities was the topography of the bottom (from some 100 m on the shelves to 1500 m in the central part of Bransfield Strait) and the inclination of seismic boundaries in the upper crust. The apparent velocities of more than 8.3 km/s and 6.9 km/s of reversed system of travel time branches give evidence for high real velocities in the medium, exceeding 7.0 km/s. A characteristic feature of all sections from profile DSS-17 is the occurrence of strong disturbances in correlation of the first onsets. A distinct travel time advance in this area by some 0.5 s points to the presence of a body of high seismic velocities in the upper Earth's crust.

The form of seismic record sections from the Drake Passage (the northwestern part of the profile DSS-17) is quite different (*see* e.g. Fig. 6). Of decisive influence on their form is the increase in the bottom depth, from some 100 m in the South Shetland Islands Shelf to over 5000 m in the South Shetland Trench. The observed apparent velocities range from 5.5 – 5.7 km/s to 9.2 – 10.4 km/s. Such large apparent velocities (despite the opposite influence of changes in the bottom topography) point to the presence of seismic boundaries that strongly dip from the Drake Passage under the South Shetland Islands.

The complicated pattern of the seismic wave field of the study area is indicative of the complicated structure of the crust and lower lithosphere. Bearing in mind the large variations in the bottom depth, velocity differences in the medium, intrusions and dipping boundaries, one-dimensional modelling is of very limited validity. In so complicated structures, with large vertical and horizontal inhomogeneities, two-dimensional modelling is necessary. In the present work we used the method of seismic ray tracing in two-dimensional models with curvilinear boundaries and complex velocity distribution (Červený and Pšenčík 1981, 1983). The depths and shapes of boundaries and the velocity distribution were chosen and corrected by comparing the experimental and calculated travel times of refracted and reflected waves. Theoretical travel times were recalculated for successive versions of the model for all seismic sections until a good agreement, of the order of 0.2 s, between the travel times was obtained. In the last step of the modelling of P-waves we also made slight corrections in the velocity distribution and the shape of the boundaries to obtain a better agreement between the relative amplitudes of refracted and reflected waves. Finally, the synthetic seismograms show good agreement with the observed wave field.

Model of the uppermost crustal structure

In modelling the structure on profiles DSS-1, DSS-4, DSS-17 and DSS-19 we used not only the seismic sections discussed above but some other data as well. The bottom depth along the profile was determined for each shot point, and a bathymetric map was applied in other places. In constructing the sedimentary complex model, the use was made of the results of earlier surveys in the Bransfield Strait region (Ashcroft 1972; Jeffers and Anderson 1990; Grad *et al.* 1992).

Profiles DSS-4 and DSS-19

The results of the upper crustal studies along this line are based on the 2-D interpretation of travel times of refracted waves recorded at the Deception and Livingston stations from profiles DSS-4, DSS-19 and DEC-3 (Grad *et al.* 1992). In the model (Fig. 8), two sedimentary layers with velocities of 1.9 – 2.2 and 4.0 – 4.2 km/s were distinguished mainly using data from profile DEC-3 and Ashcroft (1972). The uppermost layer, corresponds to unconsolidated and poorly consolidated young sediments, probably containing considerable

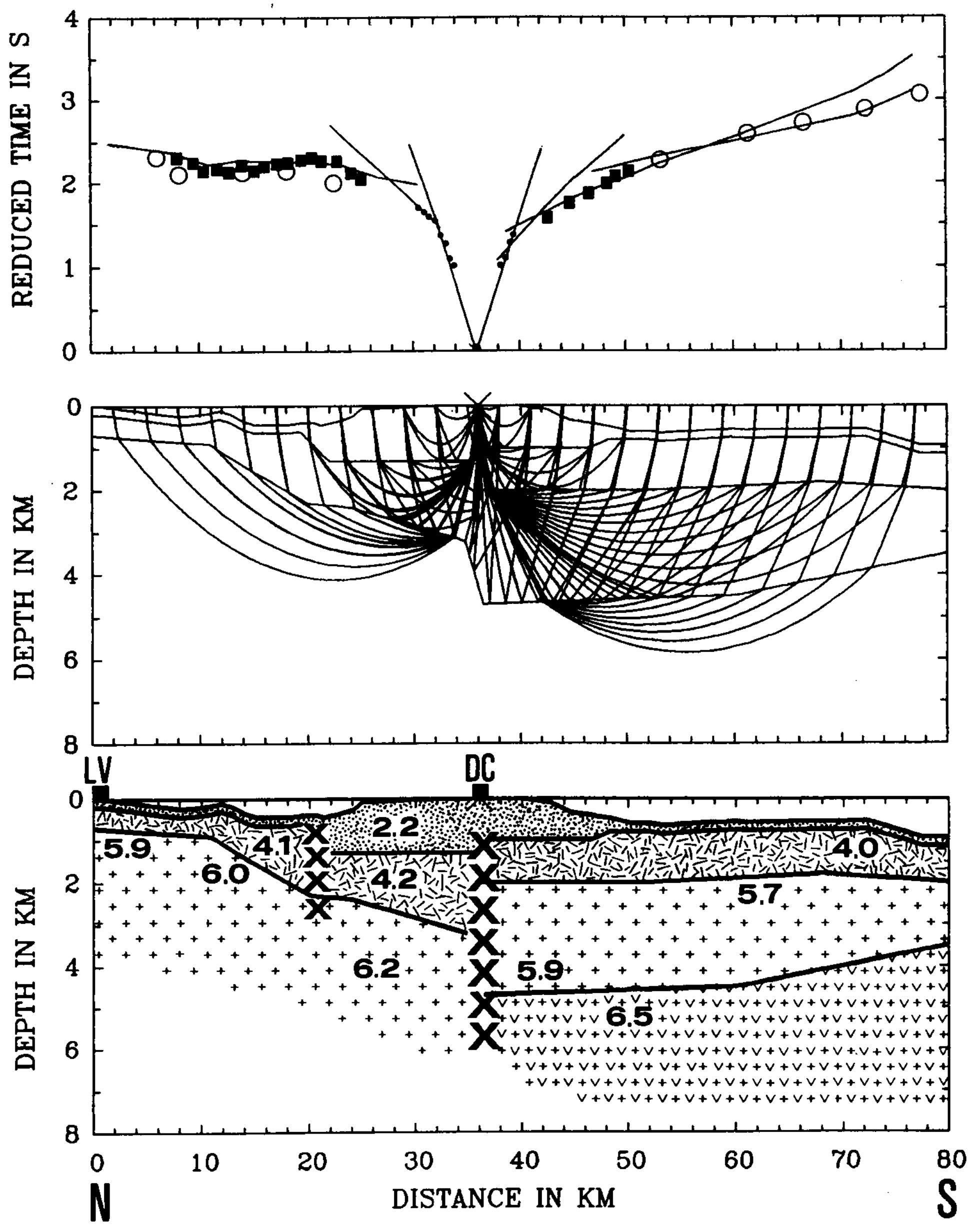

Fig. 8. Modelling of shallow structure of the Bransfield Strait along profiles DSS-4 and DSS-19. Comparison of theoretical and observed travel times of first arrivals (above), ray diagram (middle) and seismic model with v_p velocities in km/s (below). For the travel time diagram: solid line — theoretical travel time; observed times for profile DSS-4 (open circles), profile DSS-19 (black squares) and profile DEC-1 (points); reduction velocity 8.0 km/s. See text for more explanation.

amounts of lava and tuff. The underlying layer probably composed of older and better consolidated sediments and lavas. The southern and northern parts of the model differ. To the south, two layers with velocities of 5.7 – 5.9 and about 6.5

km/s are present, whereas in the north there is an inclined basement boundary, where velocities increase with depth from 5.9 to 6.2 km/s. The 5.7 and 6.2 km/s layers are in faulted contact beneath the Deception Island. The velocities observed beneath the sedimentary cover of 5.5–5.7 km/s are typical of acid crystalline or metamorphic rocks. In the area between the Deception and Livingston islands the 6.1 km/s velocity of an inclined boundary is typical of the continental crystalline basement. The results presented here allow as to distinguish different geotectonic units on either side of the Deception Island. This suggests that the location of Deception Island is controlled by the position of a major volcanic fault zone separating these different crustal blocks.

Profile DSS-17

Along profile DSS-17 in the Bransfield Strait a body of high seismic wave velocities ($v_p > 7.0$ km/s) was detected; the body is overlain by a sequence of

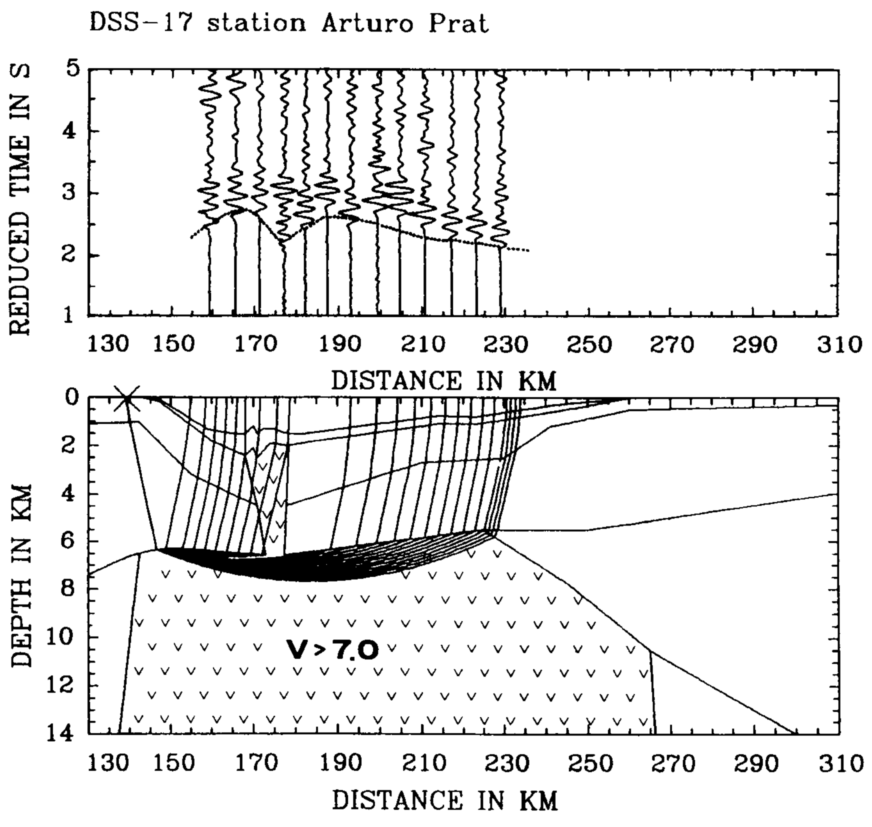

Fig. 9. Modelling of shallow structure of the Bransfield Strait along profile DSS-17. Fragment of seismic record section with a theoretical travel time of first arrivals and ray diagram for station Arturo Prat. Reduction velocity 7.0 km/s.

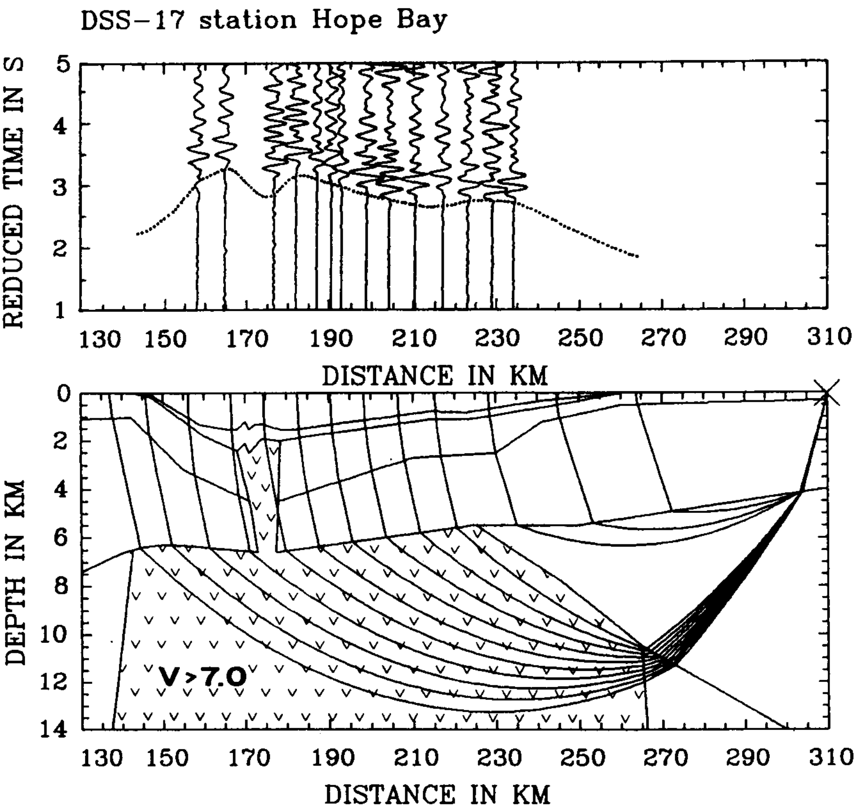

Fig. 10. Modelling of shallow structure of the Bransfield Strait along profile DSS-17. Fragment of seismic record section with a theoretical travel time of first arrivals and ray diagram for station Hope Bay. Reduction velocity 7.0 km/s.

layers with velocities of about 2.5, 4.2 and 5.6 km/s. In spite of a šcanty seismic measurement system along profile DSS-17, it was possible to localize in the 2 – 7 km depth range an approximately 10 km wide body of unusually high velocities (v_p = 6.8 km/s) as compared to the ambient medium. A comparison of fragments of seismic record sections with theoretical travel times and ray diagrams is shown in Figs. 9 – 12. The site of intrusion corresponds to the location of the axial ridge in the Bransfield Basin. A similar structure was identified on a nearby reflection profile GUN-6 (Figs. 3 and 13).

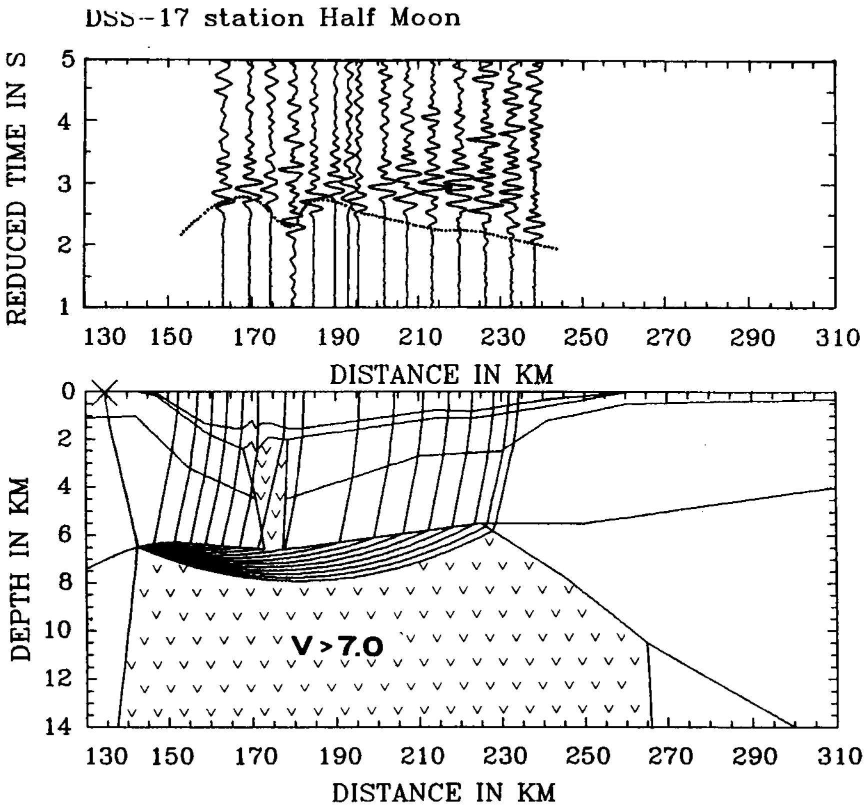

Fig. 11. Modelling of shallow structure of the Bransfield Strait along profile DSS-17. Fragment of seismic record section with a theoretical travel time of first arrivals and ray diagram for station Half Moon. Reduction velocity 7.0 km/s.

Profile DSS-1

The crustal structure beneath profile DSS-1 in the Bransfield Strait is highly anomalous. The results relating to the shallow structure are consistent with those obtained along other deep seismic profiles in the Bransfield Strait (Ashcroft 1972; Guterch *et al.* 1985, 1990, 1991; Grad *et al.* 1992). In the uppermost 10 km or so, sequences of layers with velocities of about 2.9, 4.0, 5.7 and 6.4 km/s were distinguished. Seismic velocities of 7.0 – 7.2 km/s were found at a depth of 10 – 12 km and a velocity of 7.6 km/s was found at a depth of about 25 km.

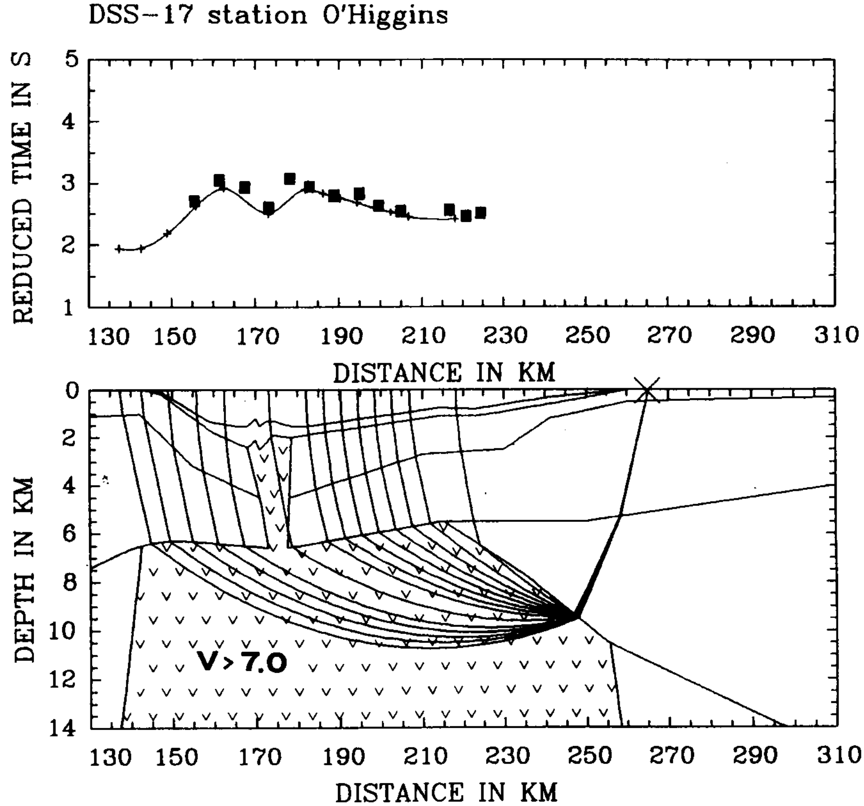

Fig. 12. Modelling of shallow structure of the Bransfield Strait along profile DSS-17 for station O'Higgins. Comparison of experimental (black squares) and theoretical (solid line) travel times of first arrivals (above) and ray diagram (below). Reduction velocity 7.0 km/s.

Reflection profiles (GUN)

For the uppermost crust, a qualitative comparison was made between the results from the reflection profiles (GUN) and deep seismic sounding profiles (DSS). On the time section from profile GUN-6 in the central part of the Bransfield Strait, a relatively homogeneous intrusion is surrounded by basins in which sedimentary sequences can easily be singled out (Fig. 13). In the transition zone from the South Shetland Shelf to the South Shetland Trench a qualitative comparison (with respect to the largedistance between the profiles) was made between the results from the reflection profile GUN-12 and deep seismic

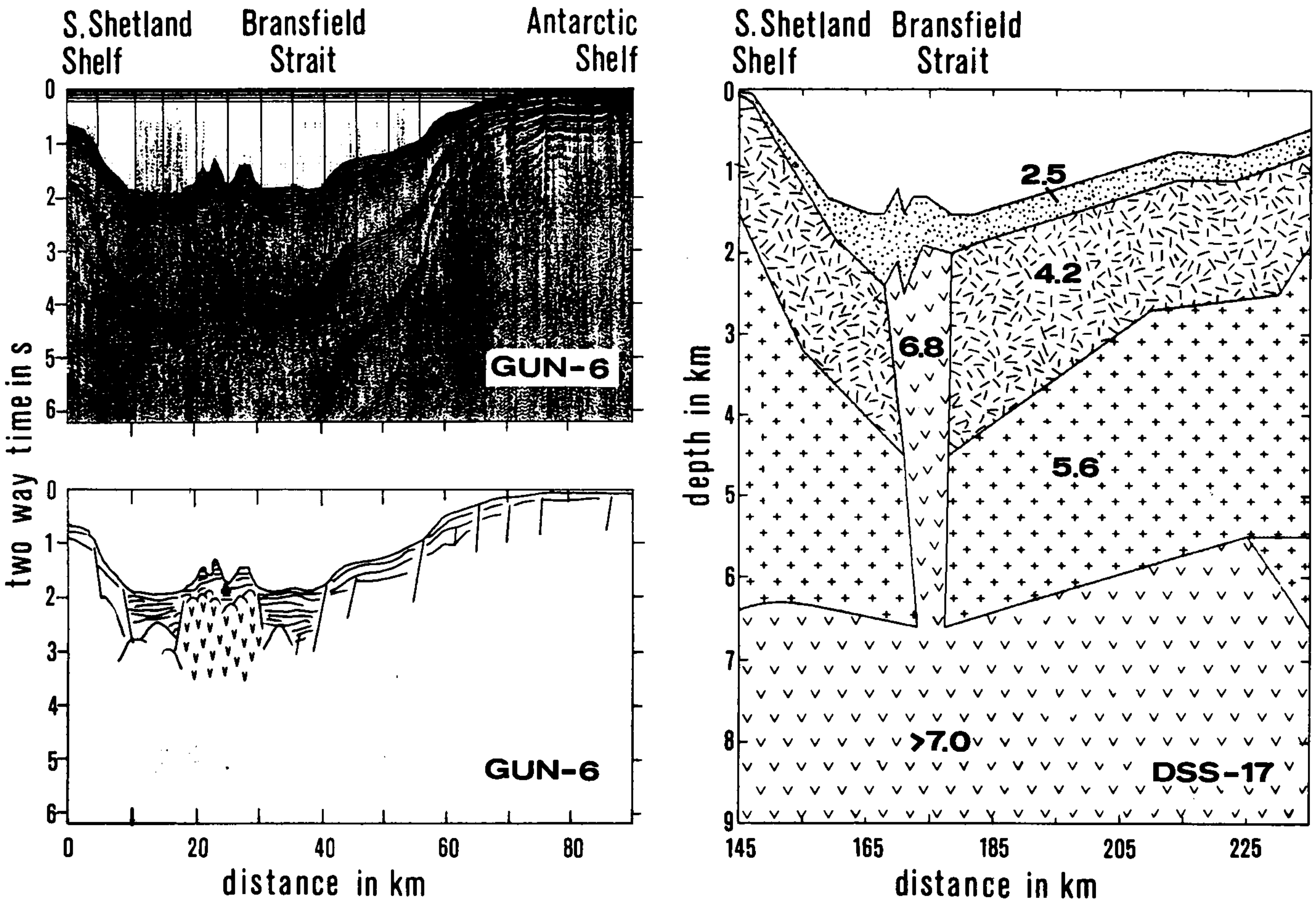

Fig. 13. Shallow structure of the Bransfield Strait as obtained on the basis of data from reflection profile GUN-6 (seismic section and cartoon) and modelling from profile DSS-17 (seismic model of the upper crust with v_p velocities in km/s). See text for discussion and Fig. 20 for more explanation.

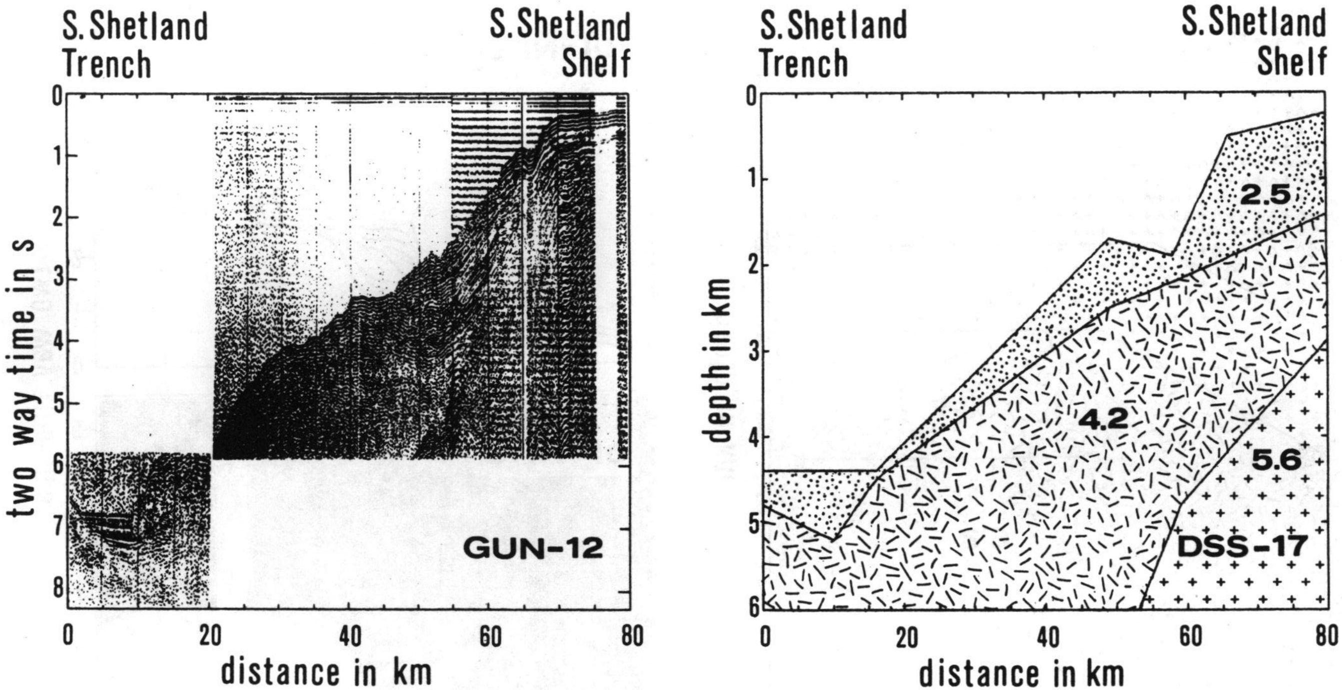

Fig. 14. Shallow structure of the South Shetland Trench and South Shetland Shelf as obtained on the basis of data from reflection profile GUN-12 (seismic section) and modelling from profile DSS-17 (seismic model of the uppermost crust with v_p velocities in km/s). See text for discussion and Fig. 20 for more explanation.

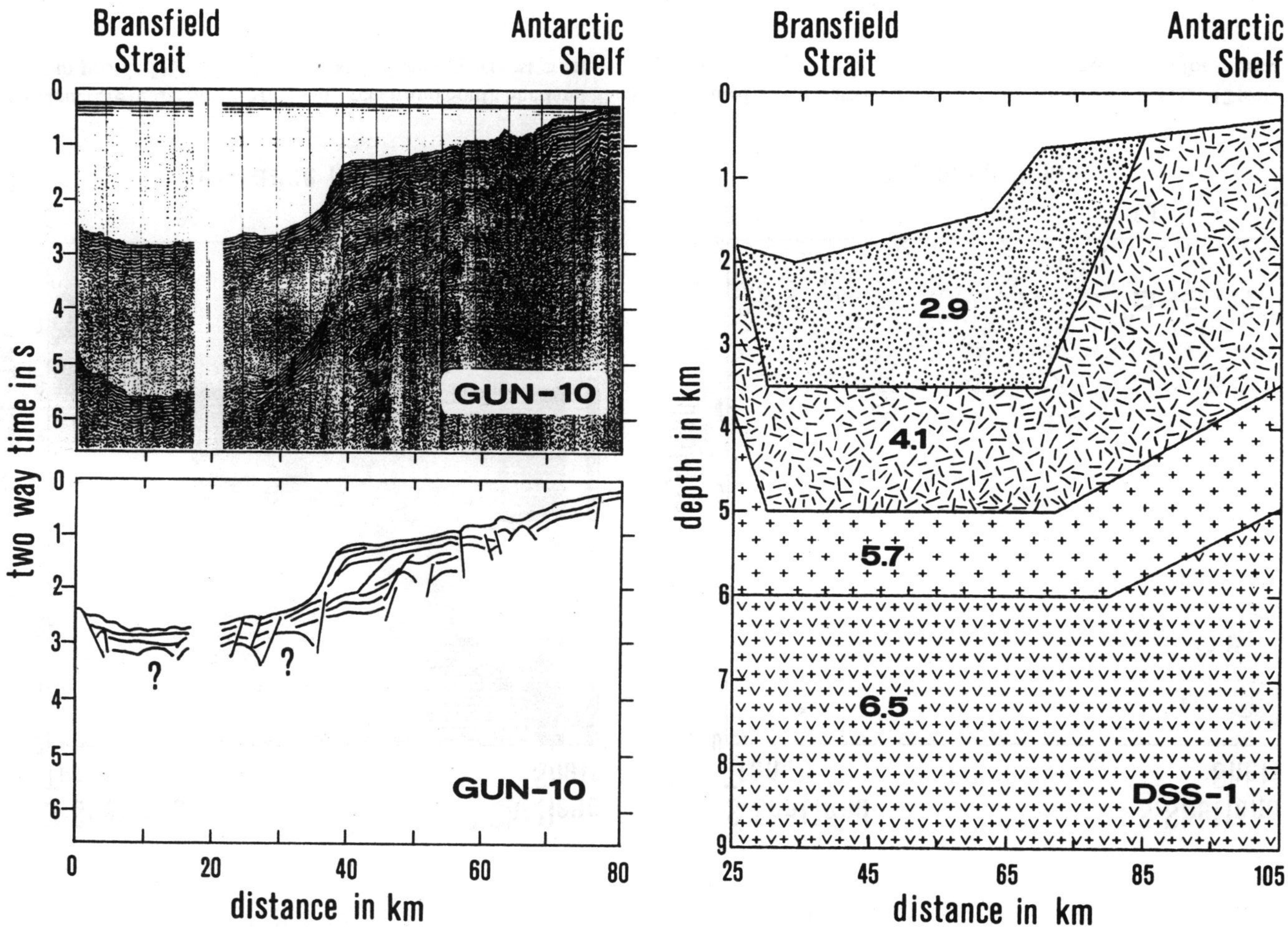

Fig. 15. Shallow structure of the Bransfield Strait as obtained on the basis of data from reflection profile GUN-10 (seismic section and cartoon) and modelling from profile DSS-1 (seismic model of the upper crust with v_p velocities in km/s). See text for discussion and Fig. 20 for more explanation.

sounding profile DSS-17 (Fig. 14). Of particular interest is the sequence of horizontalsedimentary layers in the central part of the South Shetland Trench, at times exceeding 7 s TWT. The dip of the substratum points to the subduction of the oceanic crust under the South Shetland Islands block. A comparison of results from profile GUN-10 and the uppermost crustal model for profile DSS-1 is shown (Fig. 15).

Structure of the crust and lower lithosphere

The results of modelling the crustal structure in the Bransfiel Strait along profiles DSS-1 and DSS-17 are shown in Figs. 16 – 17. The main element of both models is a high velocity body ($v_p > 7.0$ km/s), which was found at depths of 6 – 12 km. At greater depths an increase in the velocity was observed: in the area of profile DSS-1 the 7.6 km/s velocity was found at depth of about 25 km, whereas in the area of profile DSS-17 the 7.4 km/s velocity was found at depth of about 28 km. The depth of the Moho boundary in the cental part of the Bransfield Strait was determined only beneath profile DSS-17. The crustal thickness in Bransfield Strait is about 28 – 30 km, and the velocity underneath the Moho ranges from 8.1 to 8.2 km/s. The Moho depths of the neighbouring blocks of the Antarctic Peninsula and the South Shetland Islands are 40 – 45 and 30 – 35 km, respectively.

The modelling of the lower lithosphere was made only along profile DSS-17. The results are presented in Figs. 18 – 19. For clarity of seismic sections, only single channels out of the recorded five ones are depicted. A comparison of theoretical travel times, synthetic seismograms and the observed wave field together with ray diagrams provide a good documentation of the main elements of the model. The Moho boundary depth ranges on the 310 km long profile in a very broad interval: from 10 km for the oceanic crust at Drake Passage to 40 km under the Antarctic Peninsula. We also observe differentiation in the velocity distributions within individual blocks of the crust. In the oceanic crust the sequence of layers of velocities from 2.0 to 5.6 km/s overlies the 4 – 5 km thick main layer of approximately 6.9 km/s velocities. In the South Shetland Islands block under the low-velocity complex (2.0 – 4.0 km/s) there are three crystalline crust complexes with velocities of 5.6 – 6.1 km/s, 6.4 – 6.8 km/s and about 7.2 km/s. In the Bransfield Strait, the main element of the crust is the high velocity body of $v_p > 7.0$ km/s. In the Antarctic Peninsula crust one can single out a relatively thin sedimentary cover and consecutive layers of about 5.6, 6.6, and 7.2 km/s velocities. These results corroborate the former ones obtained for the South Shetland Islands and Antarctic Peninsula blocks along profiles DSS-1, DSS-2, DSS-3, DSS-4 and DSS-5 (Guterch *et al.* 1985, 1990, 1991).They also provide confirmation for the results obtained on profiles DSS-16 and DSS-20, in preparation for publication. In particular, the data from profile DSS-20 give evidence for the crustal thickness in Bransfield Strait, which is about 28 – 30 km.

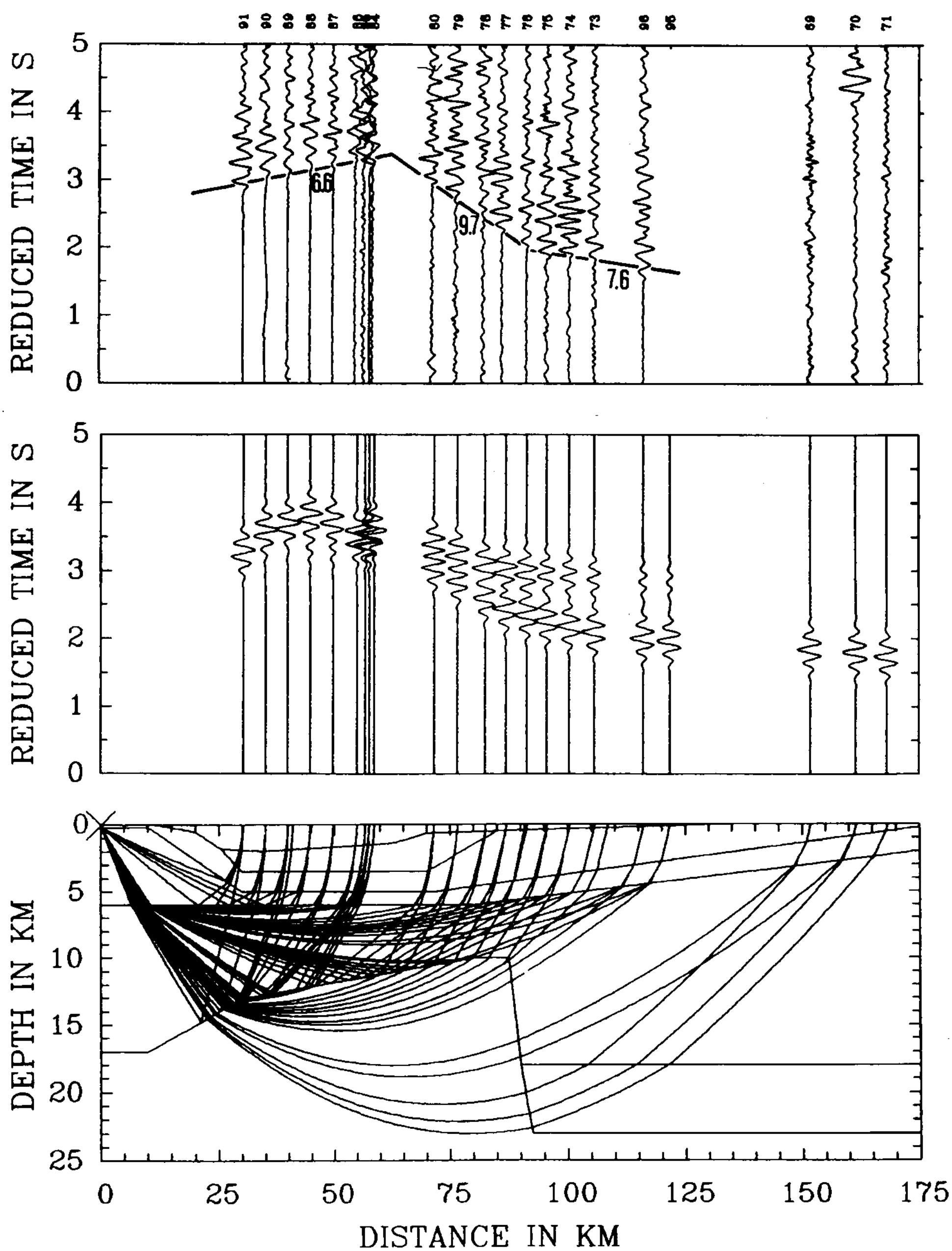

Fig. 16. An example of the results of crustal structure modelling along profile DSS-1. Seismic record section with theoretical travel time of the first arrivals (upper diagram), synthetic seismograms (middle) and model of the structure with seismic rays (bottom) for the station at King George Island. Reduction velocity 7.0 km/s.

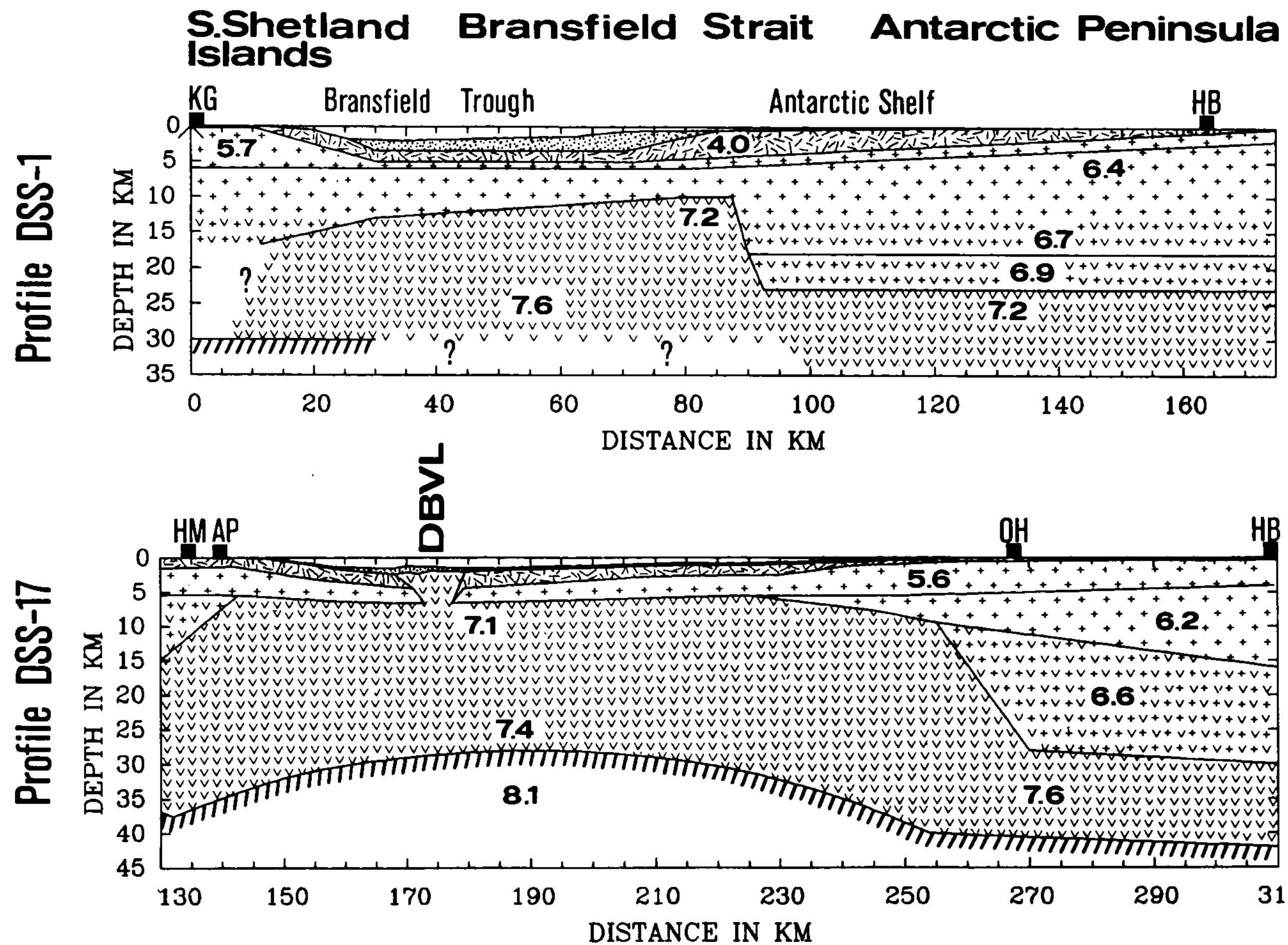

Fig. 17. Crustal models of the Bransfield Strait between the South Shetland Islands and Antarctic Peninsula for profiles DSS-1 and DSS-17. DBVL = Deception — Bridgeman volcanic line; numbers are v_p velocities in km/s. KG — the station on the Keller Peninsula at King George Island, AP — the Arturo Prat station at Greenwich Island, HM — the station at Half Moon Island, HB — station at the Hope Bay, OH — station O'Higgins.

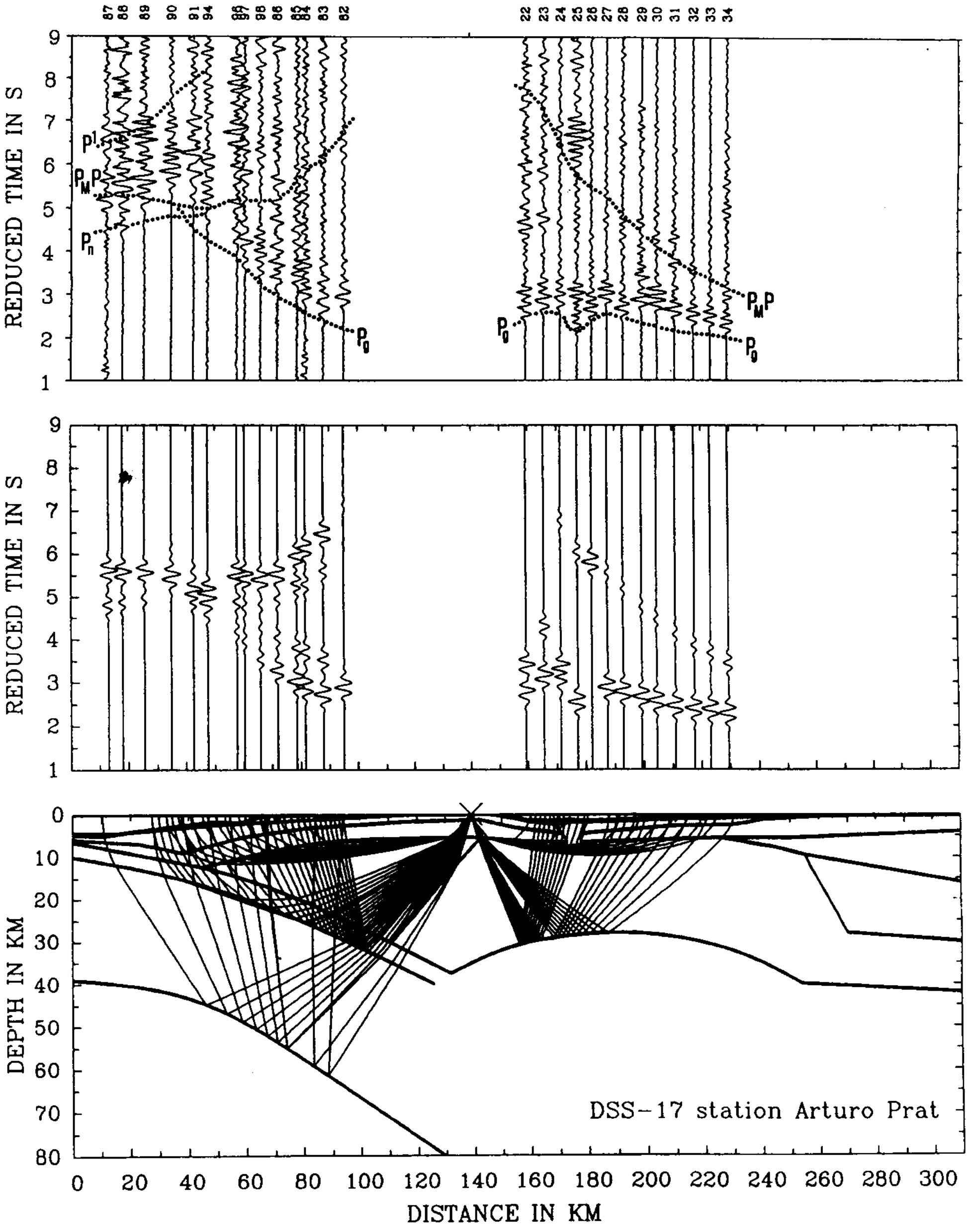

Fig. 18. An example of the results of lithosphere structure modelling along profile DSS-17. Seismic record section with theoretical travel times of the main waves (upper diagram), synthetic seismograms (middle) and model of the structure with selected rays (bottom) for station Arturo Pratt. Reduction velocity 7.0 km/s.

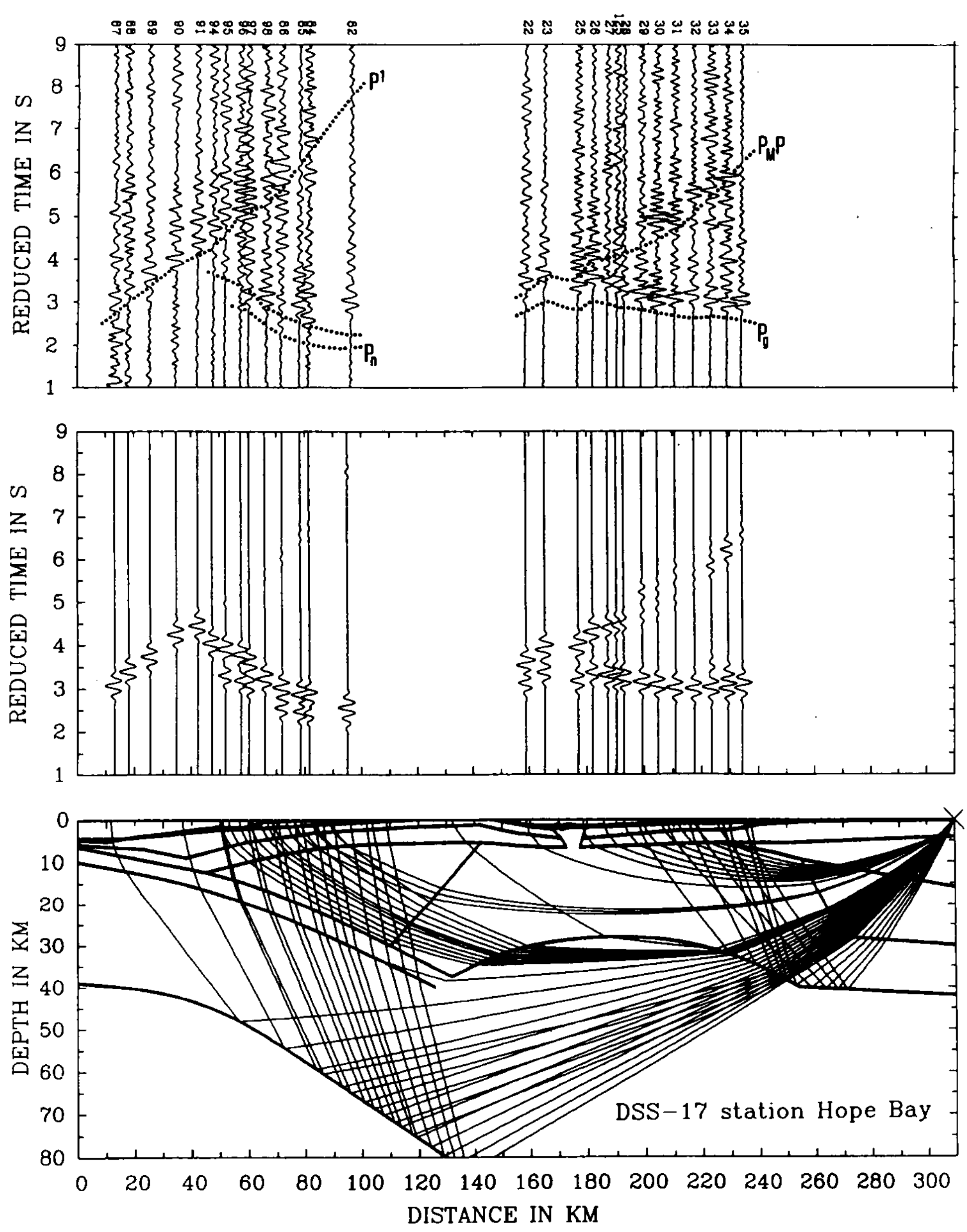

Fig. 19. An example of the results of lithosphere structure modelling along profile DSS-17. Seismic record section with theoretical travel times of the main waves (upper diagram), synthetic seismograms (middle) and model of the structure with selected rays (bottom) for station Hope Bay. Reduction velocity 7.0 km/s.

The velocity underneath the Moho ranges along profile DSS-17 from 8.1 to 8.2 km/s. In the transition zone from the South Shetland Trench to the South Shetland Islands, another boundary occurs under the Moho, at a depth growing from 35 to 80 km. The dip of the Moho, and also of the reflecting boundary in the lower lithosphere, is about 25°. The lithosphere structure model is shown in Fig. 20.

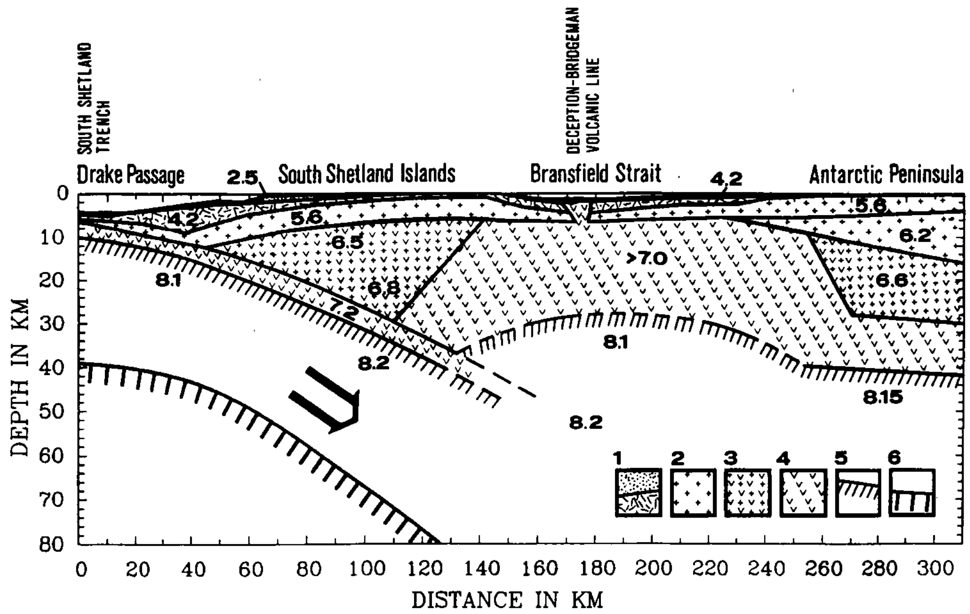

Fig. 20. Seismic model of the lithosphere along profile DSS-17 between the Drake Passage and Antarctic Peninsula. 1 = sediments, v_p = 2.5–4.2 km/s; 2 = upper crust, v_p = 5.4–6.3 km/s; 3 = middle crust, v_p = 6.4–6.8 km/s; 4 = the lower crust and high velocity body in the Bransfield Strait, $v_p > 7.0$ km/s; 5 = the Moho boundary, $v_p > 8.0$ km/s; 6 = the reflection boundary in the lower lithosphere.

Discussion of the results

The deep seismic sounding materials from profile DSS-17, with recordings up to about 300 km distances, made it possible to determine the structure of the lithosphere in the transition zone from the Drake Plate to the South Shetland Microplate, down to a depth of 80 km.

The results relating to the shallow structure are consistent with those obtained with the reflection profiling method by various expeditions (e.g., Meissner *et al.* 1988; Henriet *et al.* 1989, 1992; Jeffers and Anderson 1990; Gambôa and Maldonado 1990; Jeffers *et al.* 1991). This is especially true for Bransfield Strait (structure of the central sub-basin axial ridge) and Drake Passage (axial part of the South Shetland Trench). We also observe a close similarity to Ashcroft's models of the upper crust, at depths of 10–15 km

(Ashcroft 1972), but discrepancies occurr with the Moho boundary. Depths of 15 – 20 km for the South Shetland Islands and Bransfield Strait were obtained by Ashcroft on the basis of relatively short travel time branches — up to 80 – 100 km. The results from profile DSS-17 (and also DSS-1, DSS-5, and DSS-20) show that the Moho boundary is situated much deeper (in Bransfield Strait at a depth of 28–30 km), and the observed high values of apparent velocities result from inhomogeneity and inclination of the boundaries within the crust.

Comparing the lithosphere model with Bouguer anomalies (Figs. 2 and 20) one can notice that the positive anomaly of values in excess of +100 mgls correlates with the anomalous structure of Bransfield Strait and the South Shetland Islands block. The aeromagnetic anomaly observed in Bransfield Strait (Fig. 2; some 180 km along the profile) coincides closely with the position of the axial ridge in central sub-basin and also with the zone of basic intrusive and volcanic rocks (González-Ferrán 1991). Less explicit are relations to anomalies on a regional scale (Garrett 1990, 1991).

In the presented lithosphere model, in the contact zone of the Drake Plate and South Shetland Microplate, the dip of the subducting plate is about 25°. Similar figures were also obtained with the deep seismic sounding method in other regions of the circum-Pacific zone: about 10° in Southern Alaska (Fuis *et al.* 1991), 8 – 17° in Vancouver Island (Hyndman *et al.* 1990; Green *et al.* 1990; Morgan and Warner 1990), 8 – 15° in New Zealand (Davey and Smith 1983), 7° in Kuril Trench and 11° in Ryukyu Trench (Iwasaki *et al.* 1989).

The inclination of subducting plate determined from the distribution of the earthquake foci usually reached higher values, but they are related to greater depths. For the Kuril and Ryukyu trenches they are 50° – 55° and 40° – 50°, respectively (Cohn 1975; Veith 1974; Katsumata and Sykes 1969), and for Chile and Peru trench they are from 15° to 40° – 60° (Barazangi and Isacks 1976).

The modelling of the crustal structure of the transition zone between the South Shetland Island and Bransfield Strait indicates that the tectonic underplating has played a major role in the process of accrection and formation of the crustal blocks. The seismic wave fields change along the profile. Physical properties of the upper, midlle and lower crust are different from block to block.

The details of velocity structure in the lower crust in Bransfield Strait, which we have tested, are uncertain, because a high-velocity layer in the upper crust (v_p > 7.0 km/s at a depth of 6 – 10 km) masks observations of the lower crust. From our previous refraction works (Guterch *et al.* 1991) it was known that seismic velocity of about 7.6 km/s does exist at 20 – 25 km depth. In the present paper we have initial data about the Moho discontinuity (about 8.0 km/s), which is situated at a depth of 28 – 30 km in the Bransfield Trough. The recent detailed deep refraction study in the Bransfield Strait by the use of sensitive ocean bottom seismographs (Guterch and Shimamura 1991) will shed more light on the interpretation of the transition from the lower crust to the upper mantle in the Bransfield Trough.

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Streszczenie

Podczas Polskich Antarktycznych Ekspedycji Geodynamicznych w latach 1979–91 zrealizowany został obszerny program badań sejsmicznych Antarktyki Zachodniej. Głębokie sondowania sejsmiczne oraz sejsmiczne sondowania refleksyjne wykonane zostały na obszarze kontaktu mikropłyty Drake'a i Szetlandów Południowych oraz płyty Antarktycznej (fig. 1–3). Dla Cieśniny Bransfielda opracowano materiały z profili DSS-1, DSS-4, DSS-17 i DSS-19. Rejestracje fal sejsmicznych prowadzono w stacjach lądowych na Szetlandach Południowych i Półwyspie Antarktycznym. W oparciu o sekcje sejsmiczne (fig. 4–7) przeprowadzono dwuwymiarowe modelowanie sjsmiczne skorupy ziemskiej i dolnej litosfery do głębokości ok. 80 km. Górne piętro skorupy ziemskiej tworzą nieskonsolidowane i słabo skonsolidowane osady (v_p 1,9–2,9 km/s) pokrywające kolejne warstwy o prędkościach 4,0–4,2 i 5,6–5,9 km/s. Struktura skorupy Cieśniny Bransfielda jest wysoce anomalna. Stwierdzono tu występowanie ciała o wysokich prędkościach fal sejsmicznych (v_p > 7,0 km/s) w przedziale głębokości 6–30 km. Ciało to interpretuje się jako intruzję związaną z linią wulkaniczną Deception – Bridgeman (fig. 9–12). Dla górnego piętra skorupy ziemskiej dokonano jakościowego porównania wyników z profili refleksyjnych (GUN) i głębokich sondowań sejsmicznych (DSS) – (fig. 13–15). Na badanym obszarze głębokość granicy Moho zmienia się od 10 km w rejonie rowu Szetlandów Południowych do 40 km pod Półwyspem Antarktycznym (fig. 16–17). W strefie przejścia od Cieśniny Drake'a do Szetlandów Południowych stwierdzono istnienie granicy sejsmicznej na głębokości rosnącej od 40 do 80 km (fig. 18–19). Nachylenie tej granicy, jak również granicy Moho wynosi ok. 25° i wskazuje kierunek subdukcji litosfery mikropłyty Drake'a pod płytę Antarktyczną (fig. 20).

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