Anton Dohrn Seamount and the evolution of the Rockall Trough

Atlantic
Basalts
Guyot
Rifting
Rockall

Atlantique
Basaltes
Guyot
Rifting
Rockall

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ABSTRACT

Seismic data from the flat-topped Anton Dohrn Seamount in the central Rockall Trough reveal that the feature is capped by a thin (~ 100 m) sedimentary layer which covers an extensive erosion surface lying approximately 800 m below sea level. The surface of erosion truncates a volcanic sequence that outcrops on the eastern side of the seamount to form a well-defined terrace from which alkali basalts and chalks of late Cretaceous age have been recovered. A refraction profile shot over the summit plateau and ultrasonic measurements on the basalts suggest that sedimentary and volcanoclastic units are abundant constituents of a low-velocity (3.69 km s^{-1}) volcanic core which persists to depths of over 1 500 m. The seamount differs from the shallow Cenozoic volcanic piles in the region where high seismic velocities (> 5 km s^{-1}) occur close to the sea bed. Minor element abundances and REE inversion indicate that the Anton Dohrn basalts have been generated as a result of within-plate igneous activity, with most melting taking place in the spinel-garnet peridotite transition zone. Pb-isotope ratios are consistent with eruption of the basalts in an oceanic rift. There is no evidence for contamination by continental crust. The presence of late Cretaceous sediments, the REE patterns and Nd- and Pb-isotope ratios suggest that the seamount is related to a distinct phase of igneous activity pre-dating the development of the main Iceland plume. The crestal erosion surface is probably of Paleocene age and directly associated with a broad regional uplift around Iceland. Its present depth is about one half of that predicted from subsidence models. The depth anomaly probably reflects continued dynamic support from the Iceland plume.

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RÉSUMÉ

Le mont sous-marin Anton Dohrn et l'évolution du bassin Rockall

Des données sismiques du plateau du mont sous-marin Anton Dohrn, dans la partie centrale du bassin Rockall, révèlent que cette structure est surmontée d'un mince horizon sédimentaire (~ 100 m) couvrant une vaste surface d'érosion développée à une profondeur d'environ 800 m. La surface d'érosion tronque un substratum volcanique qui affleure sur le côté oriental du haut-fond pour créer une terrasse nettement dessinée d'où les basaltes alcalins et les craies datant du Crétacé terminal ont été récupérés. Un profil de sismique-réfraction pris sur le plateau sommital et des analyses par ultrasons suggèrent que les unités sédimentologiques et volcanoclastiques sont les composants abondants d'une armature volcanique de petite vitesse (3,69 km s^{-1}), qui persiste jusqu'à une profondeur supérieure à 1 500 m. Le haut-fond se distingue des autres structures volcaniques tertiaires de la région, où de grandes vitesses sismiques (> 5 km s^{-1}) sont rencontrées à proximité du fond marin. Les teneurs en éléments-traces et l'inversion des lanthanides indiquent que les basaltes Anton Dohrn ont été créés à la suite d'une activité ignée intra-plaque, l'essentiel de la fusion ayant lieu dans la zone de transition péridotite à spinel-péridotite à grenat. Les rapports des isotopes Pb concordent avec l'hypothèse d'une éruption des basaltes dans un rift océanique. Il n'y a aucune évidence de contamination par la croûte continentale. La présence de sédiments crétacés, la distribution des lanthanides et un faible rapport $^{143}Nd/^{144}Nd$ suggèrent que le haut-fond est en relation avec une phase distincte d'activité ignée précédant le développement du plume principal de l'Islande. La surface d'érosion sommitale date probablement du Paléocène et serait associée à un large soulèvement régional autour de l'Islande. Sa profondeur actuelle est d'environ la moitié de celle prévue par les modèles de subsidence. Cette anomalie de profondeur a probablement rapport avec un support dynamique par le plume de l'Islande.

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INTRODUCTION

Anton Dohrn Seamount lies in the central part of the Rockall Trough, an elongated depression more than 2 000 m deep separating the continental shelf off Britain from the Rockall Plateau (Fig. 1). Early bathymetric surveys showed that it is a guyot with a summit level near 700 m (Dietrich and Ulrich, 1961). The origin of the feature and surrounding parts of the Rockall Trough has been the subject of much debate (Talwani and Eldholm, 1972; Roberts, 1975; Russell and Smythe, 1978; Roberts *et al.*, 1981; Scrutton, 1986; Megson, 1987; Smythe, 1989). Some authors have suggested that the seamount is situated in a continental rift; others have argued that it lies in an oceanic trough that developed as a result of a northward propagation of the Mid-Atlantic Ridge during the Mesozoic.

It is well established that the crust in the vicinity of Anton Dohrn Seamount is much thinner than beneath the Rockall Plateau and the continental shelf west of the British Isles. The Moho depth under seismic refraction line E10 in Figure 1 is about 14 km (Jones *et al.*, 1970), a figure which is consistent with free-air gravity anomalies recorded over the central Rockall Trough (Scrutton, 1972). By contrast, the continental crust beneath the Hebridean shelf to the east and the Rockall Plateau to the west is over 26 km thick (Scrutton, 1972; Bott *et al.*, 1979; Jones *et al.*, 1984). In both regions Precambrian Lewisian basement is exposed at the sea floor. Seismic refraction and wide-angle reflection measurements made with arrays of ocean bottom receivers and closely-spaced surface shots along lines G-H and I-J in Figure 1 also reveal a shallow Moho near Anton Dohrn Seamount and have been used to support the hypothesis that the region developed by asymmetrical stretching and thinning of continental crust (Roberts *et al.*, 1988). Further south, Makris *et al.* (1991) have derived the velocity structure along track L-M in Figure 1 using ocean

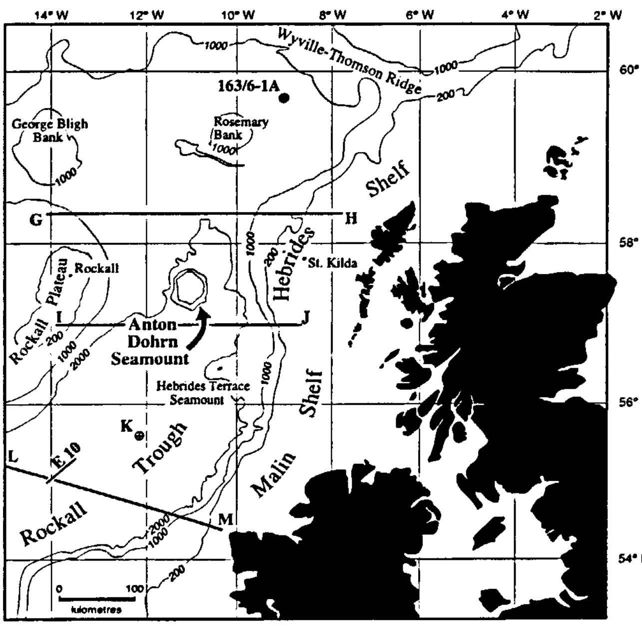


Figure 1

Location of Anton Dohrn Seamount in the Rockall Trough. Bathymetric contours in metres are taken from Roberts et al. *(1977). Positions of deep seismic profiles shot close to the seamount are labelled as follows: G-H and I-J (Roberts* et al.*, 1988); L-M (Makris* et al.*, 1991); E10 (Ewing and Ewing, 1959; Jones* et al.*, 1970). K is the centre point of a two-ship oblique reflection/refraction profile shot parallel to the axis of the Rockall Trough (Joppen and White, 1990). Drill-site 163/6-1A in the northern Rockall Trough is plotted from Morton* et al. *(1988).*

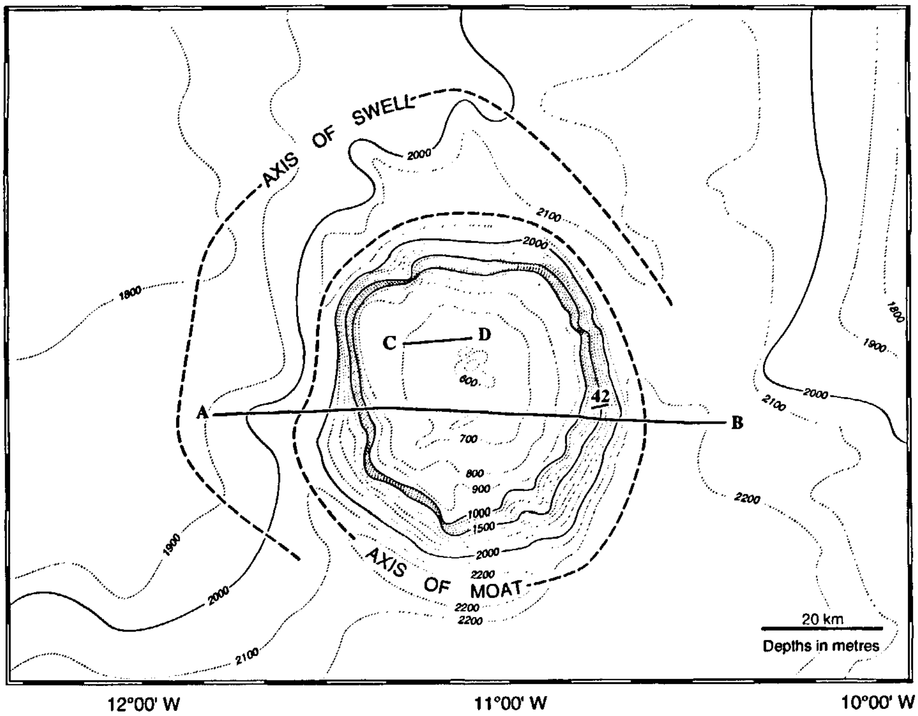


Figure 2

Bathymetry of Anton Dohrn Seamount (after Dietrich and Ulrich, 1961; Roberts et al.*, 1977). A-B is the location of an airgun reflection profile which is reproduced in Figure 3. C-D is an unreversed seismic refraction profile shot with a sonobuoy positioned at C; results are given in Figure 4. Basaltic rocks were recovered by dredging along the track labelled 42 on the eastern side of the seamount.*

bottom seismometers deployed at intervals of less than 10 km and shots fired at spacings of about 1 km. They conclude that this part of the Rockall Trough is also underlain by stretched continental crust. In the same area, however, Joppen and White (1990) found that the crustal structure cannot be interpreted so unambiguously. Seismic results from a two-ship expanding spread profile along the axis of the trough centred on point K in Figure 1 are consistent with the presence of oceanic crust or thinned continental crust heavily injected with basaltic material. In this region Roberts *et al.* (1981) have reported NNE-trending magnetic lineations in a zone about 120 km wide, which they believe reflect the presence of oceanic crust created by sea-floor spreading between Albian and Maastrichtian time. Other interpretations are possible, including ones invoking spreading during an earlier interval (Smythe, 1989) or the occurrence of swarms of linear basic intrusions separating strips of highly stretched continental crust.

Although Cenozoic sediments have been sampled from the deeper parts of the Rockall Trough by shallow coring and drilling (Latouche and Parra, 1976; Faugères *et al.*, 1981; Masson and Kidd, 1986), basement rocks have been drilled at only one deep-water site, which lies north of Rosemary Bank (163/6-1A; Fig. 1). At this location over 1 000 m of basalts and dacites were recovered below Upper Paleocene-Recent sediments. Morton *et al.* (1988) suggest on isotopic evidence that the basaltic rocks may have been contaminated with continental material, thus adding some support for the presence of stretched continental crust north of Anton Dohrn Seamount.

To investigate the origin of Rockall Trough further we have examined seismic data and rock samples collected from the crestal region of Anton Dohrn Seamount by the vessels R.R.S. *John Murray* and R.R.S. *Shackleton.* The seismic observations consist of a single-channel reflection recording along line A-B in Figure 2 and a refraction profile which was shot over the summit plateau on line C-D. The rocks were obtained by dredging the eastern side of the seamount along the short track labelled 42 in Figure 2. They show close similarities in composition and were found in association with chalks of Maastrichtian age which have been described earlier (Jones *et al.*, 1974). The suite of rocks is small but has proved important to study because it comes from one of the few accessible basement windows in the axial region of the Rockall Trough.

SEISMIC DATA

Airgun reflection profile A-B in Figure 3 shows a capping of sediments up to 0.1 s thick on the summit of the seamount. The sedimentary layer consists of a succession of reflectors resting on a strongly reflecting interface labelled X, which dips gently outwards from the central region. The sediment cover terminates near the outer rim of the summit plateau. On the eastern side, reflector X continues to form a prominent terrace about 2 km wide before plunging steeply into deep water. The region below X is characterized by many closely spaced reflectors forming an outward-dipping sequence that is most clearly recorded between kilometres 50-60, where it can be traced to a depth of 0.5 s below the sea floor.

There are no seismic indications of a sediment cover on the steep slopes between the rim of the crestal plateau and a water depth of about 1 500 m (~ 2 s of reflection time; Fig. 3). In deeper water, reflector X marks the top of a highly reverberant sequence which has been observed on seismic profiles further south and interpreted as igneous basement of Cretaceous age (Roberts *et al.*, 1981). The sediments above X are thicker on the western side of the seamount than on the east, a feature which probably

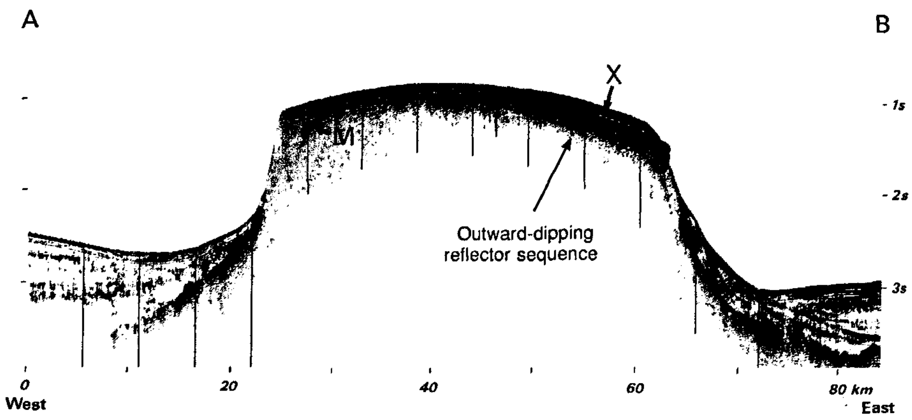


Figure 3

Single-channel reflection profile across Anton Dohrn Seamount recorded along track A-B in Figure 2. Two-way reflection time is shown in seconds. X: reflector marking an extensive erosion surface which is probably of Paleocene age; M: water layer multiple. Sediments on the summit plateau are up to 0.1 s (~ 100 m) thick. Near the base of the seamount the sediment cover thickens to over 0.8 s (~ 800 m).

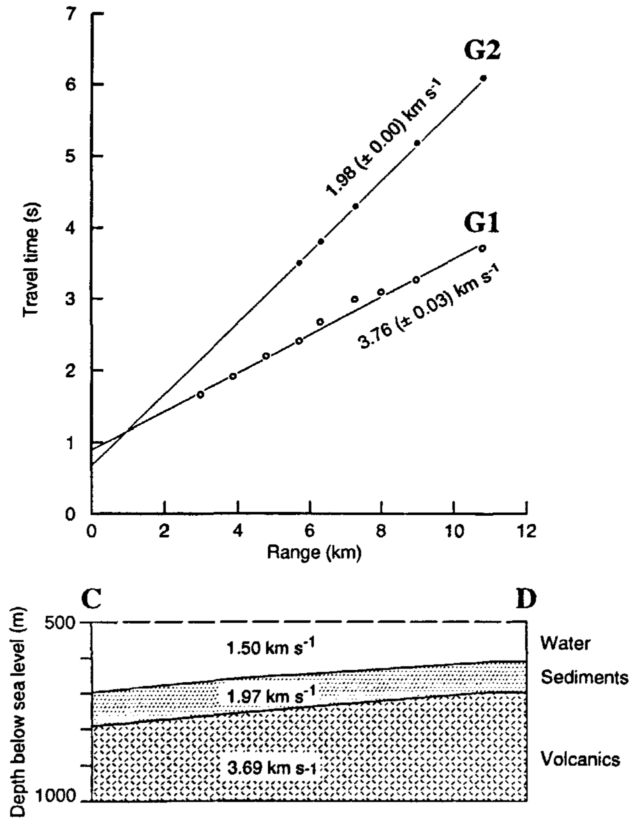


Figure 4

Results from seismic refraction profile C-D in Figure 2. G1: arrivals from the volcanic basement; G2: seabed arrivals. Velocities in the lower diagram are corrected for dip.

reflects the long-term influence of the seamount topography on bottom water flow and deposition rates (Roberts *et al.*, 1974).

The seismic velocity structure of the upper part of the seamount has been determined from an unreversed refraction profile which was shot along line C-D (Fig. 2) using a free-floating sonobuoy and small explosive charges spaced at intervals of about 1 km. During the recording period the buoy drifted approximately 300 m northwards over an area of almost flat sea floor; the end of the line at C indicates its position at the mid-stage of shooting. Shot-receiver ranges were calculated from direct water-wave arrivals using a horizontal sounding velocity of 1.489 km s^{-1} derived from water temperatures and salinities. The vertical sounding velocity is 1.501 km s^{-1}.

Figure 4 shows a plot of arrival times for shots out to a range of 10.8 km from the sonobuoy. Two clear sets of refractions were observed, with apparent velocities of 1.98 km s^{-1} and 3.76 km s^{-1}. The intercept time of the lower velocity line (G2) is consistent with propagation along the sea bottom; the velocity corrected for a low westward dip (0.4°) is 1.97 km s^{-1}. The same dip can be assumed for the second refractor (G1) since, with only a small difference (0.29 s) in intercept time, it must lie in the depth range of the shallow reflectors lying almost parallel to the sea floor on profile A-B; the dip-corrected velocity is 3.69 km s^{-1}. The thickness of the sediment cover on the nearest portion of profile A-B, assuming a velocity of 1.97 km s^{-1}, closely corresponds with that of the 1.97 km s^{-1} layer on the refraction line. The 3.69 km s^{-1} refractor is thus coincident with reflector X and marks a large increase in seismic velocity at the prominent crestal erosion surface.

DREDGED ROCKS

Four large (5-20 kg) blocks of basalt with thin ferromanganese oxide coatings were recovered by dredging the eastern side of the seamount where reflector X outcrops. The rocks are associated with basaltic breccias containing Maastrichtian chalks, which have been described elsewhere (Jones *et al.*, 1974), and with the reef-building coral *Lophelia prolifera*, fragments of which ranged from a few centimetres to more than half a metre. Calices of the terminal corallites still contained live tissue. The dredging track is shown in Figure 2.

Petrography

Samples were taken from the central part of each dredge block; these are designated 42A-D. In thin section, specimen 42A is a fine-grained, slightly vesicular rock showing a typical basaltic texture. It contains pseudomorphs after olivine phenocrysts, microphenocrysts and rare glomerocrysts of feldspar. The plagioclase is dominantly labradorite with occasional bytownite in the groundmass. The latter contains magnetite, Ti-augite and devitrified glass, together with low-temperature alteration products which include clay, Fe^{2+} and carbonate minerals. Carbonates also form the infillings of vesicles and veins. Sample 42B is an altered basalt having a more trachytic texture, with an alignment of fresh plagioclase laths and microphenocryts of labradorite. There are rare glomerocrysts present, also composed of labradorite, and clay and carbonate pseudomorphs after olivine phenocrysts. The groundmass is made up of plagioclase laths, Ti-augite, magnetite and secondary clays, carbonates and Fe^{2+} minerals. Vesicles and veins are filled with fibrous clay minerals and calcite.

Specimen 42C is a medium to fine-grained basalt with a sub-trachytic texture outlined by plagioclase laths, which are mainly labradorite. It contains numerous phenocrysts and microphenocrysts of clay minerals and carbonate pseudomorphs after olivine. The groundmass consists of plagioclase sub-ophitically enclosed by Ti-augite oikocrysts, as well as euhedral magnetite and rare devitrified glass. Secondary minerals are abundant. Fibrous clays form rosettes within interstices; Fe^{2+} minerals, carbonates and chlorite occur in the groundmass. The few vesicles present are generally filled with zeolites, while fibrous carbonate minerals are seen in veins. Sample 42D is a fine-grained basalt with a sub-trachytic texture. It contains many phenocrysts of olivine entirely replaced by serpentine. Labradorite occurs as small laths and microphenocrysts. Interstitial nepheline is present in a groundmass dominated by plagioclase. Magnetite in euhedral and skeletal forms and Ti-augite oikocrysts are common. Products of secondary alteration include clays, carbonates and Fe^{2+} minerals. Zeolites, carbonates and clay minerals occupy a small number of vesicles.

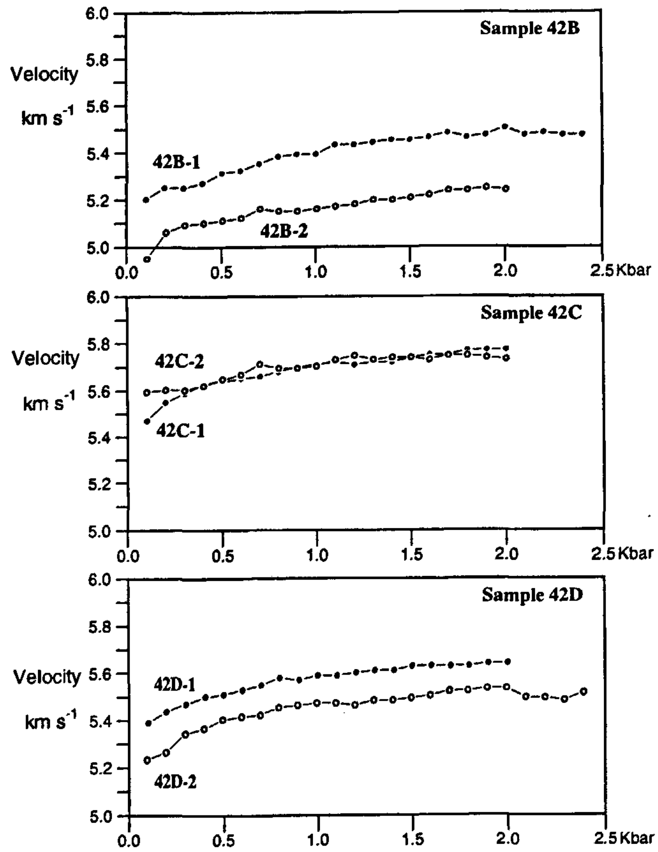


Figure 5

Ultrasonic (1.0 MHz) measurements of P-wave velocities in dredge samples 42B, 42C and 42D. Pore fluids were allowed to escape as confining pressures increased so pore pressures were effectively atmospheric. Plots for two core samples from each dredged block are shown, each point indicating the mean of velocities measured during increasing and decreasing parts of the pressure cycle. Velocities are not corrected for small dimension changes under loading.

Ultrasonic measurements

P-wave velocities were measured on 2.5-cm diameter cores taken from samples 42B, 42C and 42D, using a pulse-transmission method with PZT-5A transducers operating at 1.0 MHz. Measurements were made at confining pressures up to 2.4 kbar (0.24 GPa), with a vent allowing pore fluids to escape so that pore pressures were effectively atmospheric. Velocities were determined on both the increasing and decreasing parts of the pressure cycle but the difference was small; each point on the plot in Figure 5 is the mean of two values.

Velocities in the samples, 5.2-5.8 km s^{-1} at 2 kbar (0.2 GPa), are close to those predicted from their densities (2.68-2.74 Mg m^{-3}) using the relationships given by Christensen and Salisbury (1975). The small velocity-pressure gradients seen in Figure 5 (0.08-0.16 km s^{-1}/kbar; 0.8-1.6 km s^{-1}/GPa) have been observed in other studies of ocean floor basalts and indicate 'tight' rock specimens, with low porosities contained within low-aspect ratio cracks (*see*, for example, Toksöz *et al.*, 1976). Porosities of the Anton Dohrn core samples measured at atmospheric pressure are less than 2 %. The velocities throughout the pressure range are appreciably higher than the 3.69 km s^{-1} value obtained for the material below the sedimentary cover on refraction profile C-D (Fig. 4). Although refraction velocities are likely to be less because of the effects of large-scale fractures and joints which cannot be accounted for in our laboratory measurements, the large velocity difference is likely to reflect the inclusion of low-velocity pelagic deposits, such as the Maastrichtian chalks already sampled from the area, and thick volcanogenic sediments within the main basaltic sequence.

Geochemistry

Major element analyses of the basalts were carried out on a Philips PW 1480 X-ray fluorescence spectrometer using fused discs made from unwashed and unleached crushed samples from the interiors of the dredged blocks. In selecting the samples, care was taken to avoid any part affected by infiltration of ferromanganese oxides. Except for Co, Li and the rare earths, which were determined on a Philips PV8210 ICP atomic emission spectrometer, other elements were measured by XRF using pressed pellets with a matrix correction calculated from major element analyses. Major, minor and rare earth element

Table 1

Composition of basalts from Anton Dohrn Seamount.

Sample	42A	42B	42C	42D
SiO_2	42.94	42.26	43.47	44.27
Al_2O_3	16.93	17.44	16.21	16.88
Fe_2O_3	13.16	14.49	12.81	13.14
CaO	15.87	13.88	14.95	13.88
MgO	4.70	4.96	6.52	5.49
Na_2O	2.66	2.65	2.65	2.88
K_2O	1.453	1.442	1.006	1.239
TiO_2	1.787	1.833	1.747	1.856
P_2O_5	0.318	0.382	0.287	0.309
MnO	0.171	0.234	0.194	0.178
TOTAL	99.99	99.57	99.84	100.12
LOI	9.04	8.84	7.47	6.77
ppm				
Ba	175	179	157	166
Co	70	58	61	60
Cu	115	84	111	87
Li	49	52	54	50
Nb	14.7	14.8	14.2	14.8
Sr	328	334	320	337
V	330	369	324	369
Zn	136	129	114	115
Y	28.6	27.4	26.5	26.6
Zr	173	174	170	176
Sc	38	38	35	38
Cl	770	918	454	606
Ga	18	20	19	18
Pb	3.3	2.0	2.4	3.2
Rb	25.3	24.8	16.7	18.2
Th	1.4	0.6	1.3	1.6
La	19.3	19.0	20.0	18.9
Ce	30.9	30.8	30.7	31.4
Pr	4.2	3.8	3.8	4.0
Nd	20.8	19.9	19.1	19.3
Sm	4.5	4.6	4.4	4.6
Eu	1.6	1.6	1.5	1.6
Gd	5.3	5.2	4.9	4.9
Dy	4.7	4.7	4.5	4.6
Ho	1.0	0.9	0.9	0.9
Er	2.6	2.6	2.4	2.4
Yb	2.3	2.3	2.3	2.1
Lu	0.4	0.3	0.3	0.3

concentrations in the Anton Dohrn basalts are listed in Table 1. Errors are typically less than 1 % or 1 ppm (2 S.D.) except for Nb, Rb, Y (0.3 ppm; 2 S.D.) and Cl (± 50 ppm). Following conventional ion exchange separation, Nd- and Pb-isotope ratios have been determined with a VG 354 mass spectrometer (Tab. 2), Nd being measured using the method of Thirlwall (1991). The Nd-isotope ratio for sample 42C is corrected for machine fractionation with a value of 0.7219 for $^{146}Nd/^{144}Nd$; Pb-isotope ratios are normalized for mass fractionation using results obtained on NBS SRM 981. Sr isotope data were not obtained because of the limited preservation of primary igneous phases; insufficient augite is present to permit concentration by leaching.

Table 2

Pb- and Nd-isotope ratios in basalts from Anton Dohrn Seamount.

Sample	Isotopes	Measured ratio	Initial ratio (70 Ma)[a]
42B	$^{206}Pb/^{204}Pb$	18.027	17.922
42B	$^{207}Pb/^{204}Pb$	15.448	15.443
42B	$^{208}Pb/^{204}Pb$	37.989	37.920
42C	$^{206}Pb/^{204}Pb$	18.197	18.111
42C	$^{207}Pb/^{204}Pb$	15.495	15.491
42C	$^{208}Pb/^{204}Pb$	38.162	38.040
42C	$^{143}Nd/^{144}Nd$	0.512871[b] (± 0.000011)	

[a] Initial Pb isotope ratios calculated using Th and Pb from Table 1 and assuming U ~ 0.3 ppm.

[b] Gives ε_{Nd} = + 4.9 at 70 Ma, using Sm/Nd = 0.23 from Table 1.

On the Ti-Zr-Y diagram in Figure 6 the four dredge blocks fall in the within-plate basalt field and are quite distinct from the basalts of Rosemary Bank and drill-site 163/6-1A in the northern Rockall Trough (Fig. 1). The Anton Dohrn samples exhibit similar patterns on the chondrite-normalized multi-element plot in Figure 7, each showing a moderate enrichment in more incompatible elements. For comparison, Figure 7 also includes plots for MORB, ocean island basalts and Hebridean Skye lavas. Ce/Pb ratios (9-16) are higher than in continental crust (~ 4) but lower than in most oceanic volcanics (~ 25; Hofmann *et al.*, 1986). These lower values may imply crustal contamination or simply Pb addition during alteration. A Nb anomaly is lacking but there is a strong positive K anomaly, which again might be due to alteration or contamination by continental crust. The Pb-isotope ratios in blocks 42B and 42C (Tab. 2) are, however, more consistent with an oceanic origin for the seamount; both samples lie within the North Atlantic MORB field on a $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ plot (Fig. 8). There is no evidence for contamination by continental crust as seen, for example, in the early Cenozoic lavas on the Isle of Skye in the Hebrides, where Pb-isotope ratios form a linear array that indicates mixing of Archaean (Lewisian) continental basement and 60 Ma mantle-derived Pb (Moorbath and Welke, 1969; Dickin, 1981). Average Pb-isotope ratios given by Dickin (1981) for Lewisian granulites and amphibolite gneiss are plotted in Figure 8 *a*, together with his estimated composition of the sub-Hebridean mantle.

REE patterns in Figure 9 reveal the distinctive character of the Anton Dohrn lavas compared with N-type MORB and basalts associated with the Iceland plume at drill-site 163/6-1A and DSDP site 336. The seamount samples also differ from the Jurassic lavas of the North Sea Forties Field which are related to an enriched upper mantle at the

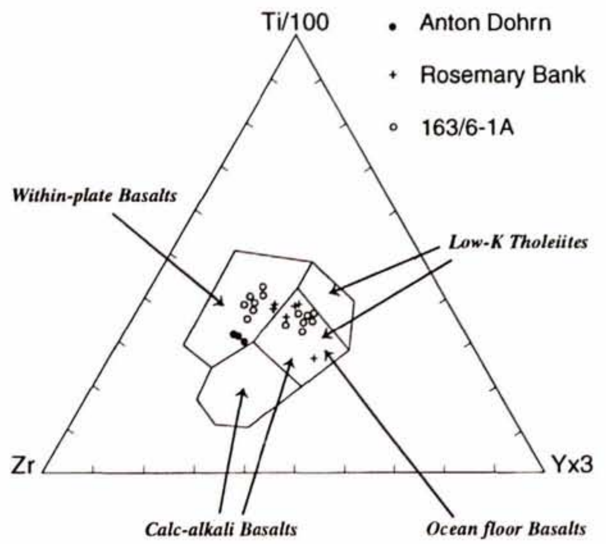


Figure 6

Basalts from Rockall Trough plotted on a Ti-Zr-Y diagram. Points for Rosemary Bank and drill-site 163/6-1A are taken from Dietrich and Jones (1980) and Morton et al. *(1988), respectively. Compositional fields are given in Pearce and Cann (1973).*

confluence of three continental rift zones (Latin, 1990; McKenzie and O'Nions, 1991); higher REE concentrations in the range La-Dy are found in the Forties volcanics. Differences between the Anton Dohrn basalts and products of the Iceland plume are also evident from the Pb-isotope data (Fig. 8 *a*) and the $^{143}N/^{144}Nd$ ratio of 0.512871 in sample 42C (Tab. 2), which is appreciably lower than in Icelandic basalts (O'Nions *et al.*, 1977; Zindler *et al.*,

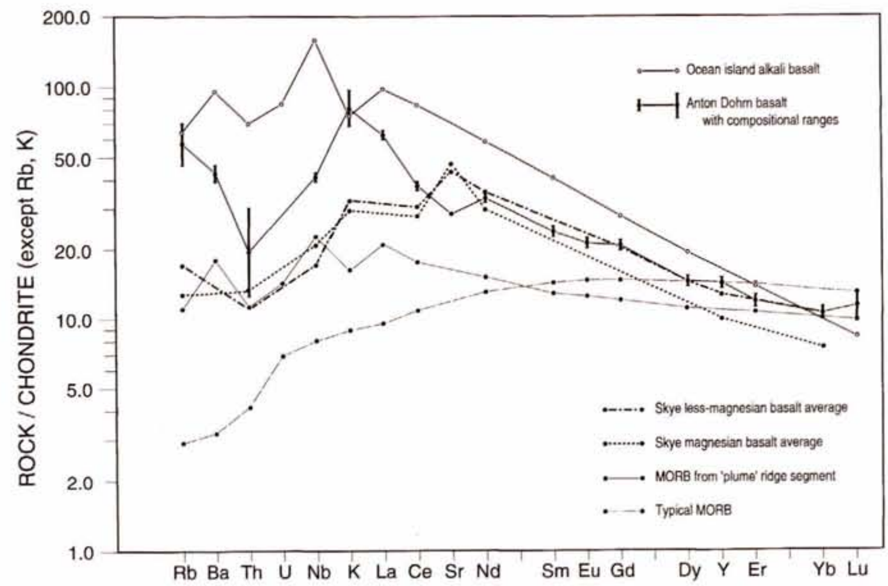


Figure 7

Chondrite-normalized multi-element plot of lavas from Anton Dohrn Seamount, shown with average compositions of basalts from the ocean basins (Sun, 1980) and the Isle of Skye in the Cenozoic volcanic province of northwest Scotland (Thompson et al.*, 1980).*

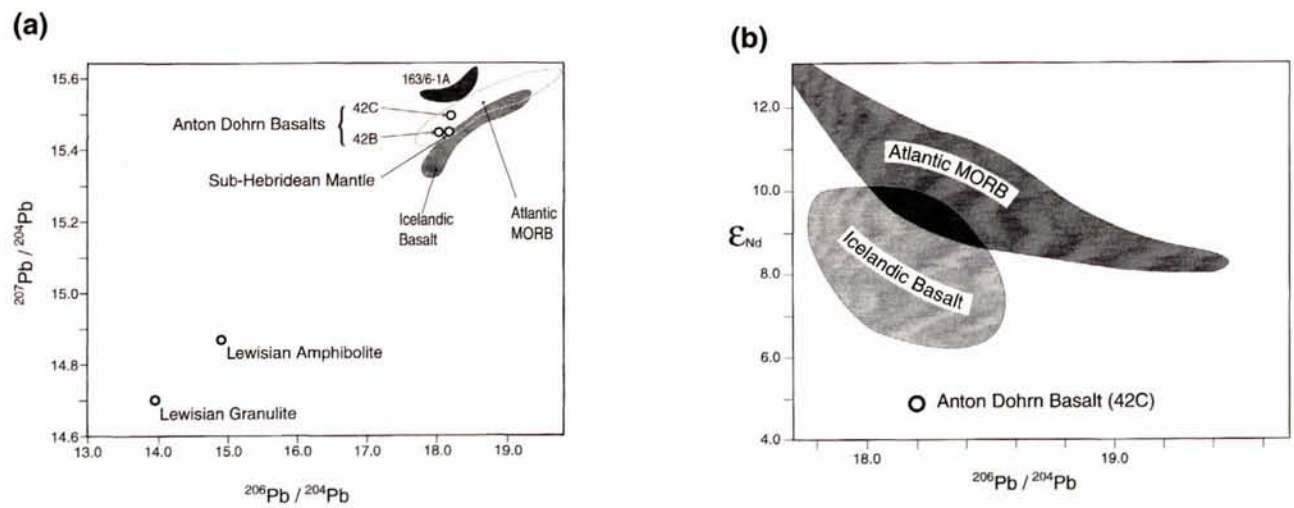


Figure 8 *a*

Age-corrected Pb-isotopic composition of dredge samples from Anton Dohrn Seamount compared with Atlantic MORB and Icelandic basalts (Dupré and Allègre, 1980; Cohen and O'Nions, 1982; Dosso et al.*, 1991), and basalts from drill-site 163/6-1A in the northern Rockall Trough (Morton* et al.*, 1988). Points showing the mean compositions of Lewisian granulite-facies gneiss and amphibolite-facies gneiss, and an estimated composition for the sub-Hebridean mantle are taken from Dickin (1981).*

Figure 8 *b*

Anton Dohrn basalts shown on a ε_{Nd} - $^{206}Pb/^{204}Pb$ plot. Compositional fields of MORB and Icelandic basalts are taken from Staudigel et al. *(1984) and references cited therein.*

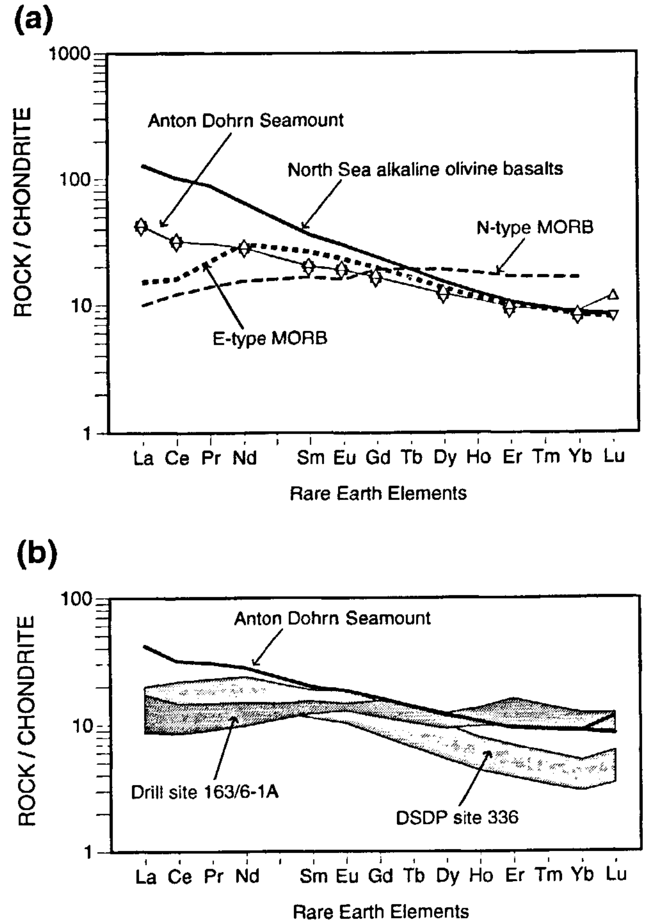


Figure 9 *a*

Chondrite-normalized REE plot of Anton Dohrn basalts (Δ - 42A; ∇ - 42B). Variations for N-MORB, E-MORB and alkaline olivine basalts from the North Sea are drawn from analyses listed in Table 4 of McKenzie and O'Nions (1991). The North Sea lavas come from the Forties Field and are of Jurassic age. Normalization coefficients are taken from Thompson (1982).

Figure 9 *b*

Chondrite-normalized REE plot of basalts from Anton Dohrn Seamount, drill-site 163/6-1A (Morton et al.*, 1988) and DSDP site 336 on the Faeroe-Iceland Ridge (Talwani* et al.*, 1976).*

1982). Anton Dohrn Seamount may therefore represent a small but distinct precursory plume to Iceland. The combined Pb-Nd isotope composition of its lavas (Fig. 8 *b*) is unusual for North Atlantic basalts (Cohen and O'Nions, 1982; Condomines *et al.*, 1983; Elliot *et al.*, 1991; Sun and Jahn, 1975). Some older Icelandic basalts (*e. g.* I-13 of Cohen and O'Nions, 1982) approach the combination of low ε_{Nd} and low $^{206}Pb/^{204}Pb$; a few Hawaiian lavas also have similar characteristics (Staudigel *et al.*, 1984). Overall, the Pb-Nd isotopes suggest enriched mantle as a minor component of the Anton Dohrn mantle source.

DISCUSSION

Seismic profiles A-B and C-D show that the crest of Anton Dohrn Seamount is covered by up to 100 m of sediments which bury an almost flat erosional surface marking the top of the volcanic basement. The basement velocity of 3.69 km s^{-1} (Fig. 4) differs little from that in the Upper Basalt Series of the Faeroes (~ 3.9 km s^{-1}; Palmason, 1965), but is appreciably lower than in the basaltic sequence exposed on Faeroe Bank (4.2 km s^{-1}; Jones and Ramsay, 1982). Beneath the Faeroes seismic velocities increase from ~ 3.9 km s^{-1} near the surface to 4.9-5.3 km s^{-1} at a depth of 300 m. Such an increase is not observed on Anton Dohrn Seamount; the line of 3.76 km s^{-1} first arrivals on profile C-D extends out to the furthest shot without evidence of a break to higher velocities (Fig. 4). If material with velocities exceeding 5 km s^{-1} is present then it must lie at least 1.8 km below the crest to account for the head-wave arrival time at the longest range. Much of the seamount is therefore made up of low-velocity volcanics, in marked contrast to the early Cenozoic basaltic accumulations associated with the Iceland plume further north.

The composition of the Anton Dohrn basalts is distinctly different from the Cenozoic lavas of the Faeroe-Iceland Ridge and at drill-site 163/6-1A in the northern Rockall Trough (Fig. 8, 9). The recovery of Maastrichtian chalks from the seamount (Jones *et al.*, 1974) indicates that it belongs to a phase of volcanic activity that preceded the eruption of the thick lava sequences to the north and the start of sea-floor spreading between Rockall and Greenland. Pb-isotope ratios in samples 42B and 42C are consistent with the conclusion of Roberts *et al.* (1981) that a narrow oceanic rift extended into the Rockall Trough during the Cretaceous. There is no evidence for continental contamination in the small suite of samples available to us. Pb-isotope ratios in basalts from site 163/6-1A fall above the MORB field (Fig. 8 *a*) which, according to Morton *et al.* (1988), may reflect addition of continental material. If this interpretation is correct, then a strip of oceanic basement extending along the axial region of the Rockall Trough from the south terminates against stretched continental crust between the Anton Dohrn Seamount and the lower flank of the Wyville-Thomson Ridge (Fig. 1).

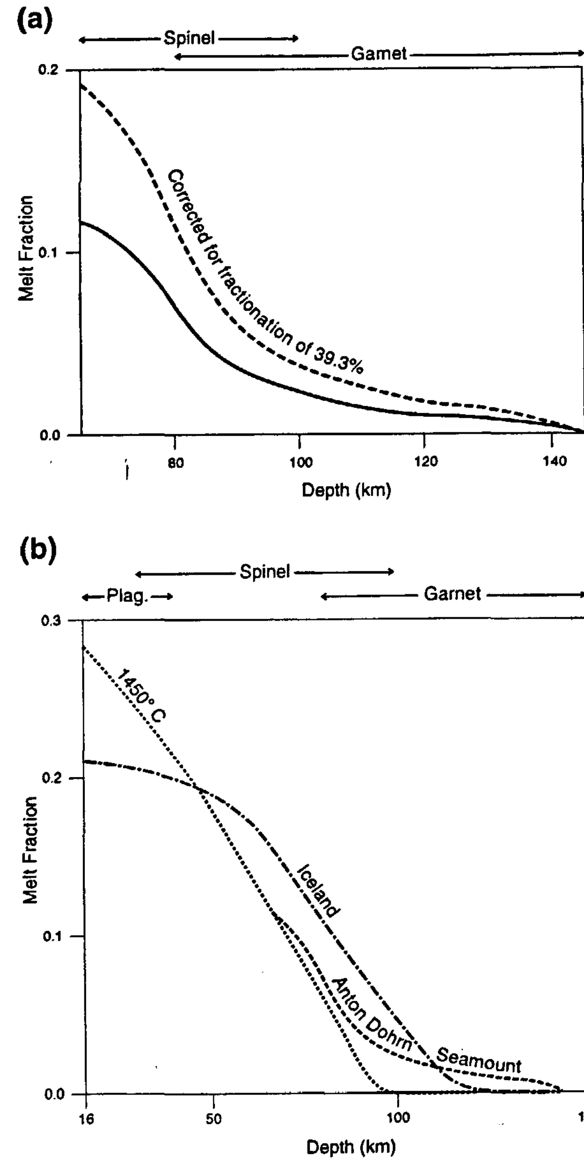
Variations in the melt fraction with depth below Anton Dohrn Seamount have been derived from REE concentrations (Tab. 1) using the inversion method of McKenzie and O'Nions (1991); a 65 km-thick lithospheric cap to melting is assumed. The two curves in Figure 10 *a* suggest a large proportion of melt was generated in the depth and temperature range of the transition from a spinel to a garnet peridotite mantle. The calculated thickness of melt is approximately 2.5 km (D.P. McKenzie, personal communication, 1993). In Figure 10 *b* the dotted line shows melting caused by adiabatic decompression with a mantle potential temperature, T_p, of 1 450° C (McKenzie and Bickle, 1988). The close fit of the curves for fractions exceeding 0.04 implies that the underlying mantle was some 150° C hotter than beneath a normal oceanic ridge (T_p ~ 1 300° C). Melting beneath Anton Dohrn Seamount extended much deeper into the mantle (> 110 km) than

Figure 10 *a*

Depth distribution of melt fraction by weight beneath Anton Dohrn Seamount from REE inversion (solid line), assuming that the melt is derived from a primitive upper mantle with a composition given by McKenzie and O'Nions (1991). The dashed curve shows the melt distribution after correction for crystal fractionation. The top of the melting zone lies at a depth 65 km.

Figure 10 *b*

Distribution of melt fraction beneath Anton Dohrn Seamount and Iceland. The dotted line shows the melting profile computed using the method of McKenzie and Bickle (1988), which assumes that melting is due to adiabatic decompression. The mantle potential temperature is 1 450° C and the entropy of melting, ΔS, is 400 J/(kg °C). Also included in the computation is a correction for compaction of the residue as the melt is extruded (D.P. McKenzie, personal communication, 1993).



under normal ridge crests, where it is largely confined to levels above 75 km (White *et al.*, 1992). High mantle temperatures in this part of the Rockall Trough during the late Cretaceous may have influenced the maturation and migration rates of hydrocarbons in the Mesozoic basins beneath the adjacent continental margins.

Comparison of the morphology of Anton Dohrn Seamount with other volcanic features indicates that during the late Cretaceous it stood at least 2 000 m higher than at present (Jones *et al.*, 1974). The intense erosion that led to the formation of its striking summit plateau is likely to have taken place in the Paleocene when large areas of western Britain were uplifted and deeply denuded (Hall, 1991). At this time, some 2 000 m of roof and cover formations, comparable in thickness to those eroded from Anton Dohrn Seamount, were stripped from the major igneous centres of Northwest Scotland, including Skye, Mull and Arran (George, 1966). The erosion was rapid. In the Hebrides, for example, roughly 2 000 m of lavas were removed from Mull during the interval 58-56 Ma BP (Curry *et al.*, 1978). The uplift and denudation were probably related closely to the development of the Iceland plume.

Since the extensive planation of its summit Anton Dohrn Seamount has sunk approximately 800 m. This is about 800 m less than predicted from the subsidence curves of McKenzie (1978) for a feature formed on Cretaceous (~ 70 Ma) ocean floor. Further south, basement depths are also smaller than those calculated from subsidence models. Near point K in Figure 1 Joppen and White (1990) have found basement to be about 700 m shallower than expected from an observed minimum stretching factor of 6. Dynamic support of the lithosphere by the Iceland plume is the most plausible explanation for the shallowness of Anton Dohrn Seamount and adjacent parts of the Rockall Trough. Buoyancy forces associated with the plume appear to have caused uplift in regions as far as 1000 km from Iceland (White and McKenzie, 1989). Strong evidence for similar dynamic support of anomalously shallow regional topography has also been found around the Cape Verde hotspot in the Equatorial Atlantic (Courtney and White, 1986).

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