Reports

Diorites from the Mid-Atlantic Ridge at 45°N

Abstract. *Diorites, associated with basalts, basalt breccias, and serpentinized peridotites, occur* in situ *on the faulted scarps of two seamounts from the western High Fractured Plateau of the Mid-Atlantic Ridge at 45°N.*

Igneous and metamorphic rocks of intermediate to acid composition have often been dredged from the slopes of seamounts of the mid-oceanic ridges (*1*). These rocks have been discarded and interpreted as being erratics ice-rafted from the continents during Pleistocene ice ages. Indeed, these rocks often show rounding, polishing, and striations which can be attributed to subaerial ice action. In addition, whenever dredge hauls contain appreciable concentrations of these rock types, they are usually petrologically unrelated to one another and are characteristically lacking in, or have a very thin coating of, ferromanganese crust, indicative of relatively brief contact with the ocean waters.

Table 1. Dredge station data for the diorite occurrences.

Station	Specimen yield (No.)				
	Basalt breccias	Basalt	Serpentinites	Diorites	Erratics
HU-120*	4	7	0	3	8
HU-159†	0	8	17	19	10
HU-165‡	0	5	29	1	17

* HU-120: 45°42′N, 28°56′W; 1680 to 1454 fm (1 fm = 1.8 m). † HU-159: 45°46′N, 28°59′W; 1460 to 1290 fm. ‡ HU-165: 45°13′N, 29°52′W; 1390 to 1230 fm.

Table 2. Composition (percentage of oxides) of two diorites from station 159 and averaged compositions of three tholeiites and four serpentinites from the same area; n.d., not determined; nil, not found. The serpentinite total includes concentrations of Cr and Ni expressed as oxides.

Oxide	Oxide content (%) in			
	Diorites AG-159-35	Diorites AG-159-39	Tholeiites (av. of 3)	Serpentinites (av. of 4)
SiO_2	61.97	72.47	50.53	37.47
TiO_2	.94	.33	1.22	.05
Al_2O_3	16.00	14.17	15.17	2.76
Fe_2O_3	3.22	1.85	.89	6.89
FeO	3.57	1.19	8.20	.66
MnO	.09	.08	.13	.12
MgO	2.43	1.39	8.65	36.67
CaO	3.24	1.48	11.6	.22
Na_2O	5.55	5.55	2.4	.18
K_2O	.75	.24	.24	.06
H_2O	1.28	.90	.49	12.93
CO_2	< .1	< .1	n.d.	.20
P_2O_5	.22	.06	.11	.02
Total	99.26	99.71	99.6	98.9

Granites, granodiorites, granite gneisses, and amphibolites dredged from the Mid-Atlantic Ridge at 45°N in 1966 (*2*) show the above-mentioned characteristics; K-Ar determinations of the age of biotites from these rocks revealed middle Precambrian ages (*3*), completely outside the limits suggested by the ages of the associated basalts (*4*, *5*). Furthermore, determinations of the ratios of oxygen isotopes (*6*) indicated that the oxygen compositions were consistently heavier than those of the associated ocean-floor basalts, and they were more in keeping with known ratios from continental material. Therefore, their roundness, striations, lack of ferromanganese coating, complete diversity of rock types, discordant ages, and isotopic compositions were taken as indications of an ice-rafted origin (*2*).

In the summer of 1968, one dredge station in the western High Fractured Plateau approximately 96 km west of the axis of the Mid-Atlantic Ridge (Fig. 1) recovered a major, homogeneous yield of dioritic rocks, and two other dredges (one from the same seamount) yielded minor amounts of similar rock types. The specimens were angular, showed outer weathering zones, and had thick ferromanganese crusts. The diorites occurred on the steep eastern slopes of two seamounts elongated from north to south; the latter are thought to be upthrusted blocks, and the slopes sampled are probably fault scarps (*6*). Associated with the diorites were concentrations of basalts, basalt breccias, completely serpentinized gabbros and peridotites, and a number of diverse rock types showing the ice-rafted characteristics mentioned earlier (Table 1).

The diorites show a considerable range in color index, even within individual hand specimens, as a result of variations in hornblende concentration. Some specimens contain more basic tear-shaped inclusions (xenoliths) composed both of aggregates of very fine grained hornblende and minor plagioclase, and coarse aggregates of olivine, ortho- and clinopyroxenes. These coarse aggregates are enveloped by well-developed amphibolitic coronas.

Plagioclase, the main constituent of the diorites, shows complex zoning from 40 to 20 percent anorthite (An_{40} to An_{20}) in the more melanocratic specimens, and from An_{20} to An_5 in those poorer in hornblende. Two of the larger plagioclase crystals examined contain distinct cores of K-feldspar (*6*). In most of the specimens plagioclase crystals are often enveloped by ragged borders of a second generation of feldspar; although these borders are in optical continuity with the core crystals, they exhibit different refractive indices. X-ray diffractograms and electron-probe analyses reveal either pure albite or thin lamellar alternations of albite and orthoclase in these borders. Distinct grains of orthoclase have been found in only one specimen.

Dark green hornblende is the main mafic mineral; large hornblendes rarely

Table 3. Composition (trace elements) of two diorites from station 159 and averaged compositions of three tholeiites and four serpentinites from the same area; n.d., not determined; nil, not found.

Element	Elemental composition (ppm) in			
	Diorites Ag-159-35	Diorites Ag-159-39	Tholeiites (av. of 3)	Serpentinites (av. of 4)
Sr	140	89	100	< 20
Ba	260	200	66	20
Cr	< 20	< 20	40	3000
Zr	760	200	115	< 30
V	38	22	376	70
Ni	46	22	170	1000
Cu	24	30	132	100
Co	< 20	< 20	44	100
Sc	< 10	< 10	58	< 10
Zn	52	27	82	n.d.
Pb	2.2	1.8	1.6	n.d.
Ga	32	40	40	n.d.
B	2.2	1.7	nil	n.d.
Rb	< 30	< 30	nil	nil
U	n.d.	n.d.	0.2	n.d.

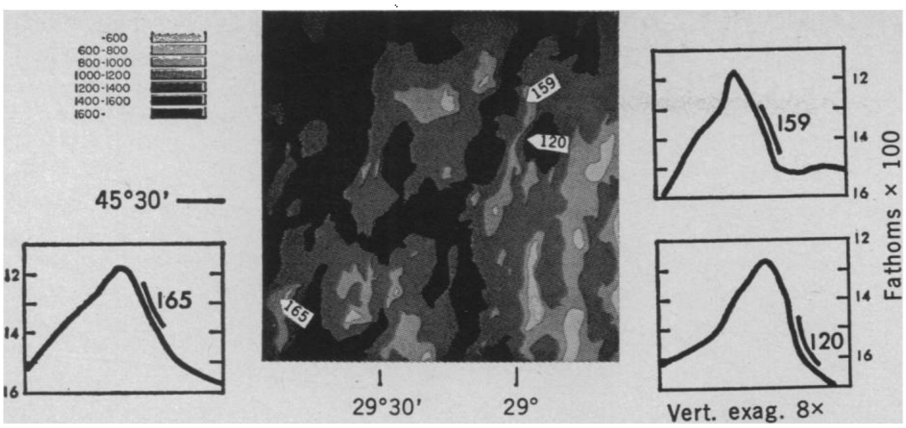

Fig. 1. Simplified bathymetric chart of the western High Fractured Plateau at 45°N, contoured at 200-fathom (365.6-m) intervals, showing station locations and vertical profiles of the dredging operations.

envelop relict cores of pyroxene and olivine. Biotite is only of secondary importance, but occurs in higher concentrations within the tear-shaped xenoliths, where it is associated with pale green hornblende differing in optical characteristics from the large crystals in the host rocks. Accessory minerals include magnetite, chrome spinel, apatite, sphene, and allanite.

Specimen AG-159-35 represents one of the more melanocratic rocks containing numerous basic xenoliths, whereas AG-159-39 is one of the more leucocratic, xenolith-free specimens (Tables 2 and 3). Both diorite analyses show unusually high ratios of soda to potash, which, together with the albite borders on some of the plagioclases, are reminiscent of the albitized diorities characteristic of alpine ultramafic intrusive complexes (*7*). Thus, the more melanocratic specimens are similar to the quartz-diorites of the alpine ultramafic association, and the leucocratic specimens are similar to trondhjemites of these environments.

The ferromanganese coating on the diorites is about 5 mm thick, less than that on the associated serpentinites and basalts (up to 15 mm); from previous calibration of the rate of ferromanganese deposition in the area (*5*) one can estimate that the diorites were first exposed to the ocean water some 3 million years ago (well before the Pleistocene ice ages), probably at the time of the final upthrusting of the seamount blocks. Relatively recent vertical movements of the oceanic crust may therefore have taken place in these areas of the High Fractured Plateau quite remote from the axis of the ridge. Basalts in the vicinity of the major diorite occurrences have been dated by whole rock K-Ar and by fission-track techniques to be from 8 to 12 million years old (*5*). Two K-Ar dates on the hornblendes from the diorites gave an average age of 9 ± 1.3 million years (*6*). In addition, oxygen isotopic compositions (*6*) place the diorites within the range obtained for the associated basalts and serpentinites.

The concordant ages and isotopic compositions and the chemistry and physical appearance of the diorites are strong indication that they occur *in situ* on the faulted scarps of the seamounts sampled, and that they are directly related to the basalt, metabasalt, serpentinized gabbro, and peridotite association found in the area at 45°N. Their *in situ* occurrence on these seamounts is proof that magmatic differentiation has progressed farther than is generally thought possible in mid-oceanic ridge environments. It also suggests that strong similarities may exist between the oceanic ridges and the synorogenic igneous complexes of the Alpine or Ophiolitic type. Forty-five dredge stations were established in a relatively small area (150 by 250 km) before these diorites were detected. They are obviously not common mid-oceanic rock types, but neither are they abundant in alpine complexes; however, since they do occur, it is possible that other magmatic derivatives may also have been collected in the past, but were promptly discarded as ice-rafted erratics (*2*, *6*).

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References and Notes

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Hydrothermal Ore Deposits in the Western United States: A New Concept of Structural Control of Distribution

Abstract. *Empirical plotting of four sets of equidistantly spaced shear stress trajectories, based on regularities in distribution of actual faults and ore veins in the continental area and on the landward prolongation of the big fracture zones of the northeastern Pacific, gives rise to a prospecting net for the western United States. Preferential accumulation of big ore deposits (including such deposits as Bingham and Tintic) along landward prolongation of the main fracture zones of northeastern Pacific, in the vicinity of intersections of four systems of trajectories, and along boundaries of crustal blocks suggests several possibilities for prospecting for unknown hydrothermal deposits in the Cordilleran part of the United States.*

The method of constructing empirical prospecting nets, which I described previously (*1*, *2*) has been put to practical application in the silver, lead, and zinc Pribram ore field, Czechoslovakia (*3*). The existence of a north-northwest set of faults empirically derived for a part of Scotland (and previously not known in geological maps of that area), as a complementary set to the well-known northeast-trending wrench-faults of the "Great Glen" strike, was ascertained by a recent geophysical survey (*4*). The Tyndrum district lies exactly at one of the intersections of these faults [Fig. 7 in (*2*)].