Earth and Planetary Science Letters, 36 (1977) 297–300

[1]

THE GEOPHYSICAL SIGNIFICANCE OF OCEANIC PLAGIOGRANITE

NIKOLAS I. CHRISTENSEN

Department of Geological Sciences and Graduate Program in Geophysics, University of Washington, Seattle, Wash. 98195 (USA)

Received April 19, 1977
Revised version received June 13, 1977

Rocks ranging in composition from trondhjemite to diorite (plagiogranites) have been recovered from ocean ridges and are common constituents of ophiolites. Velocities and densities of diorite and trondhjemite from the Mid-Atlantic Ridge are shown to differ significantly from similar properties of metadolerite and gabbro. Compressional (V_p) and shear (V_s) velocities of plagiogranites are relatively low (V_p = 4.78–5.91 km/s at 1 kbar, V_s = 2.81–3.37 km/s at 1 kbar), as are densities (2.57–2.64 g/cm^3) and Poisson's ratios (0.24–0.27). These data lend strong support to the probable existence of a low-velocity/density zone within layer 3 of the oceanic crust. Based on observations in ophiolites, it is postulated that this zone can be up to 1 km in thickness and is laterally discontinuous.

1. Introduction

Recently, Coleman and Peterman [1] have emphasized the importance of leucocratic rocks within ophiolites and have collectively grouped albite granites, trondhjemites, tonalites and diorites into a general term, plagiogranite. A significant concentration of plagiogranite at any given level within the oceanic crust would likely influence many physical parameters, such as seismic, magnetic, thermal and electrical properties and density. Of these properties, seismic velocities are best known; in fact, the oceanic crust has been largely defined on the basis of seismic structure. The purposes of this paper are to present data on seismic velocities and densities of oceanic plagiogranites and discuss the geophysical significance of the measurements.

2. Velocity data

Four samples of oceanic plagiogranite were selected for velocity measurements. Two of the rocks (HU-159-34 and HU-159-38) recovered from the Mid-Atlantic Ridge at 45°N [2] contain approximately 15% hornblende, 2% biotite, 3% opaque, 10–15% quartz and 65–70% plagioclase (An_{20-40}). Based on the International Union of Geological Sciences Classification [3] these rocks are diorites. Samples AII-60-12-26 and AII-60-12-27 were dredged from the Mid-Atlantic Ridge at 22°S. Modal analyses are: 2% hornblende, 1% opaque, 10% quartz, 87% plagioclase (An_{30}) for sample AII-60-12-26 and 5% hornblende, 1% actinolite, 1% sphene, 3% opaque, 35% quartz, 55% plagioclase (An_{30-35}) for sample AII-60-12-27. The mineralogy of AII-60-12-26 is also that of a diorite, whereas, because of its higher quartz content, AII-60-12-27 is classified as a trondhjemite.

Compressional (V_p) and shear (V_s) velocities, which are given in Table 1, were measured in the laboratory under conditions of hydrostatic confining pressures to 6.0 kbars using a pulse transmission technique similar to that described by Birch [4]. The samples used for the measurements were cut in the form of right circular cylinders 1.30–2.54 cm in diameter and 3–5 cm in length. To check for possible anisotropy, velocities were measured in three mutually perpendicular directions from separate cores in diorite AII-60-12-26 and trondhjemite AII-60-12-27. Since both samples showed little anisotropy (at 6 kbars V_p varied from 6.25 to 6.31 km/s for AII-60-12-26 and from 5.11 to 5.19 km/s for AII-60-12-27) the reported velocities in Table 1 are simple means for

TABLE 1

Compressional and shear wave velocities, bulk densities and Poisson's ratios

Sample	Parameter	Pressure (kbar)						
		0.25	0.50	0.75	1.0	2.0	4.0	6.0
Diorite	V_p	5.12	5.20	5.27	5.33	5.47	5.72	5.86
HU-159-34	V_s	2.88	2.92	2.96	3.00	3.11	3.22	3.27
ρ = 2.637 g/cm^3	V_p/V_s	1.78	1.78	1.78	1.78	1.77	1.77	1.79
	σ	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Diorite	V_p	5.54	5.60	5.66	5.72	5.85	6.06	6.19
HU-159-38	V_s	3.12	3.16	3.19	3.23	3.32	3.42	3.49
ρ = 2.626 g/cm^3	V_p/V_s	1.78	1.77	1.77	1.77	1.77	1.77	1.77
	σ	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Diorite	V_p	5.53	5.75	5.84	5.91	6.04	6.19	6.26
AII-60-12-26	V_s	3.16	3.29	3.34	3.37	3.45	3.51	3.54
ρ = 2.572 g/cm^3	V_p/V_s	1.75	1.75	1.75	1.75	1.75	1.76	1.77
	σ	0.26	0.26	0.26	0.26	0.26	0.26	0.27
Trondhjemite	V_p	4.57	4.67	4.73	4.78	4.88	5.02	5.12
AII-60-12-27	V_s	2.65	2.74	2.78	2.81	2.87	2.95	3.01
ρ = 2.574 g/cm^3	V_p/V_s	1.72	1.70	1.70	1.70	1.70	1.70	1.70
	σ	0.25	0.24	0.24	0.24	0.24	0.24	0.24

three directions. The samples were water-saturated prior to the velocity measurements and pore pressures were maintained at values lower than external pressures during the runs by placing 100-mesh screens between the samples and copper jackets. The densities (ρ) of Table 1 were calculated from the mass and dimensions of the cores used for velocity measurements.

Values of the ratio of compressional to shear wave velocity (V_p/V_s) and Poisson's ratio (σ) calculated from the velocities are also given in Table 1 at selected pressures. Using an iterative technique and dynamically determined compressibilities [5] the velocities and Poisson's ratios have been corrected for length changes resulting from compression at elevated pressures.

3. Implications for the oceanic crust

Although a large number of measurements of velocity have already been made in the laboratory, prior to this study no velocities have been reported for plagiogranites dredged from oceanic regions and only limited data have been published for continental plagiogranites. The continental rocks which have been studied differ significantly from the oceanic rocks in velocity, density and mineralogy. Birch [4] reported compressional wave velocities ranging from 6.32 to 6.46 km/s at 1 kbar for two quartz diorites from Massachusetts and a tonalite from California. Simmons [6] has measured shear velocities of 3.69 km/s at 1 kbar in a quartz diorite from Massachusetts. These velocities are higher than the oceanic plagiogranite velocites of Tabel 1. The differences are apparently related to the reported higher plagioclase anorthite contents and the greater proportions of mafic minerals in the Massachusets and California rocks [4].

Within ophiolites, plagiogranites usually occur as dikes, sills and stocks which intrude gabbroic country rock near the gabbro-dolerite transition [7,8] and appear to be comagmatic with underlying gabbro [1,9]. The layer 2-3 seismic boundary lies above the plagiogranites within the dolerite section [10] and is related to increasing metamorphic grade [11]. Thus the plagiogranites are contained within seismic layer 3.

Velocities, densities and Poisson's ratios of plagiogranites are compared in Table 2 with similar prop-

TABLE 2

Properties at 1 kbar

Rock type	Number of samples	V_p (km/s)	V_s (km/s)	ρ (g/cm^3)	V_p/V_s	σ	Reference
Trondhjemite	1	4.78	2.81	2.57	1.70	0.24	Table 1
Diorite	3	5.65	3.20	2.61	1.77	0.27	Table 1
Metadolerite	15	6.73	3.72	2.93	1.81	0.28	[10]
Gabbro	11	7.07	3.70	2.95	1.91	0.31	[10]
Gabbro	10	7.19	3.79	2.96	1.90	0.31	[12]

erties of overlying metadolerite and underlying gabbro. The low densities of the plagiogranites are a consequence of the abundant sodic plagioclase and quartz and low contents of higher-density mafic minerals. The relatively low Poisson's ratios (Table 2) are related to high quartz contents, since, compared to most major rock-forming silicates, quartz has an extremely low Poisson's ratio [13]. Thus it is probable that a major low-velocity zone exists within layer 3.

The exact nature of the low-velocity channel depends on many variables. The results of this study show that composition is important; trondhjemites have lower velocities, densities and Poisson's ratios than diorites. The structure and seismic properties of the low-velocity channel will also be controlled by the ratio of plagiogranite to host rock and the thicknesss of the region containing the plagiogranite. Some ophiolites apparently contain only small quantities of plagiogranite, whereas others contain significant proportions. Thayer and Himmelberg [9] have described a steep-walled plug of trondhjemite 0.3 km in diameter occurring within gabbro at Canyon Mountain, Oregon. The Vourinos Complex of Greece contains a section of quartz diorite and diorite 0.85 km in thickness [14]. Trondhjemites in the Troodos Complex form a zone up to 1 km in thickness [8]. Williams [15] has described a section of quartz diorite with an apparent thickness of 1 km in the Bay of Islands Complex, Newfoundland. Thus, if these ophiolites are typical sections of oceanic crust, it is likely that the low-velocity channel may be a significant feature within layer 3.

Acknowledgements

I wish to thank K. Muehlenbachs and G. Thompson for providing the samples for this study. Financial support was provided by the Office of Naval Research Contract N-00014-0502.

References

1 R.G. Coleman and Z.E. Peterman, Oceanic plagiogranite, J. Geophys. Res. 80 (1975) 1099–1108.
2 F. Aumento, Diorites from the Mid-Atlantic Ridge at 45°N, Science 165 (1969) 1112–1113.
3 A. Streckeisen et al., Classification and nomenclature of plutonic rocks – IUGS Subcommission on Systematics of Igneous Rocks, Geotimes 18 (1973) 26–30.
4 F. Birch, The velocity of compressional waves in rocks to 10 kb, 1, J. Geophys. Res. 65 (1960) 1083–1102.
5 N.I. Christensen and G.H. Shaw, Elasticity of mafic rocks from the Mid-Atlantic Ridge, Geophys. J.R. Astron. Soc. 20 (9170) 271–284.
6 G. Simmons, Velocity of shear waves in rocks to 10 kilobars, 1, J. Geophys. Res. 69 (1964) 1123–1130.
7 C.H. Smith, Bay of Islands igneous complex, western Newfoundland, Geol. Surv. Can. Mem. 290 (1958) 1–132.
8 R.A.M. Wilson, The geology of the Xeros-Troodos area, Cyprus Geol. Surv. Dep. Mem. 1 (1959) 1–184.
9 T.P. Thayer and G.R. Himmelberg, Rock succession in the alpine-type mafic complex at Canyon Mountain, Oregon, 23rd Int. Geol. Congr. Rep. Sess. Prague 1 (1968) 175–186.
10 N.I. Christensen and M.H. Salisbury, Structure and constitution of the lower oceanic crust, Rev. Geophys. 13 (1975) 57–86.
11 N.I. Christensen, Composition and evolution of the

oceanic crust, Mar. Geol. 8 (1970) 139–154.
12 R.D. Hyndman and M.J. Drury, The physical properties of oceanic basement rocks from deep drilling on the Mid-Atlantic Ridge, J. Geophys. Res. 81 (1976) 4042–4059.
13 N.I. Christensen and D.M. Fountain, Constitution of the lower continental crust based on experimental studies of seismic velocities in granulite, Geol. Soc. Am. Bull. 86 (1975) 227–236.
14 E.M. Moores, Petrology and structure of the Vourinos ophiolitic complex of northern Greece, Geol. Soc. Am. Spec. Paper 118 (1969) 1–74.
15 H. Williams, Mafic-ultramafic complexes in western Newfoundland Appalachians and the evidence for transportation: a review and interim report, Proc. Geol. Assoc. Can. 24 (1971) 9–25.