Marine Geology, 19 (1975) M75—M80

Letter Section

POSSIBLE LOWER CRUSTAL ROCKS RECOVERED ON LEG 31 BY DEEP-SEA DRILLING IN THE PHILIPPINE SEA

DAVID M. FOUNTAIN[1], RICHARD L. CARLSON, MATTHEW H. SALISBURY[2] and NIKOLAS I. CHRISTENSEN

Department of Geological Sciences, University of Washington, Seattle, Wash. (U.S.A.)

(Received June 12, 1975)

ABSTRACT

Fountain, D.M., Carlson, R.L., Salisbury, M.H. and Christensen, N.I., 1975. Possible lower crustal rocks recovered on Leg 31 by deep-sea drilling in the Philippine Sea. Mar. Geol., 19: M75—M80.

Compressional wave velocities measured in gabbroic rocks and metabasites recovered from Site 293 of Leg 31 in the Philippine Sea (on the Central Basin Fault) are correlative with seismic velocities determined for Layer 3. The lower crustal origin for these rocks suggested by this data is further supported by the similarity between these samples, dredge haul samples from fracture zones in the main ocean basins and rocks found in ophiolite complexes. These plutonic rocks were possibly introduced to the sea floor by movements along the Central Basin Fault, a major tectonic feature in the Philippine Sea, or formed as part of new ocean crust within a leaky transform fault.

INTRODUCTION

Drilling at Site 293 of Leg 31 of the Deep Sea Drilling Project, located on the northwestern extension of the Central Basin Fault in the Philippine Sea (Fig.1), recovered volcanic, plutonic and metamorphic rocks which were incorporated within a tectonic breccia (Karig et al., 1975). These rocks, which are similar in petrology to igneous and metamorphic rocks dredged from the ocean floor and regarded as samples of Layer 3, may represent important constituents of the lower oceanic crust.

Compressional wave velocities for samples from this suite of rocks have been measured at confining pressures to 6 kbar. The velocities at appropriate pressures are compared to lower crustal seismic velocities determined by refraction profiling within the Philippine Sea and main ocean basins.

---

[1] Present address: Department of Geology, University of Montana, Missoula, Mont., 59801 (U.S.A.).

[2] Present address: National Science Foundation, Washington, D.C., 20550 (U.S.A.).

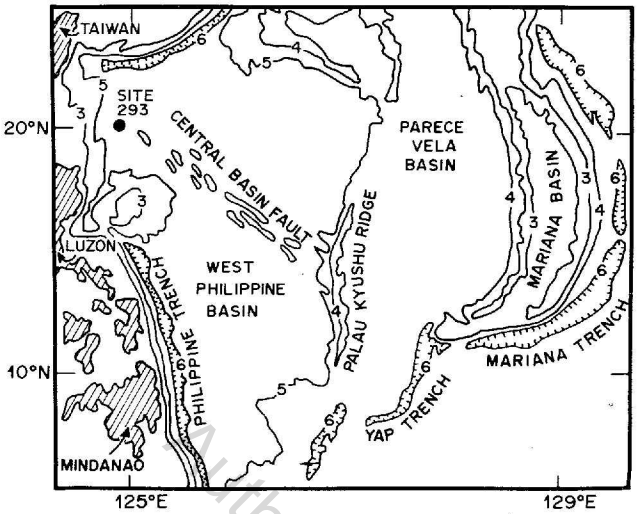

Fig.1. Generalized map of the Philippine Sea showing location of Site 293 of Leg 31. Contours are in kilometers below sea level.

DATA AND SAMPLE DESCRIPTIONS

Compressional wave velocities were measured in seven rocks recovered at Site 293. Four of these samples [31-293-20-1 (136—139 cm), 31-293-21-1 (5—8 cm), 31-293-21-1 (32—35 cm) and 31-293-21-2 (11—14 cm)] are gabbros and anorthositic gabbros exhibiting cumulate textures and, in some cases, strong preferred orientation of plagioclase crystals. In one sample [31-293-21-1 (32—35 cm)], there is partial alteration to actinolitic amphibole. No obvious evidence of deformation was observed in thin sections of these four samples, although they were recovered from a breccia unit. Unlike these plutonic rocks, the remaining samples exhibit abundant evidence of both metamorphism and deformation. Sample 31-293-18-1 (90—93 cm) is a metadiabase containing actinolitic amphibole after clinopyroxene. The thin section of this rock shows evidence of cataclastic textures. Cataclasis and granulation are also exhibited in sample 31-293-19-1 (108—111 cm), a chloritized gabbro with some epidote. Sample 31-293-20-1 (100—103 cm) is a hornblende metagabbro of amphibolite facies grade.

The samples were placed in water immediately following their recovery on ship and were subsequently stored in water until the compressional wave-velocity measurements were made in the laboratory. Each sample (in the shape of a right circular cylinder) was jacketed by placing a 100 mesh screen over the sample and a solid copper jacket over the screen. In this manner internal pore pressures were maintained at values between hydrostatic and lithostatic. The necessity of keeping samples retrieved from the ocean basins saturated in water prior to and during measurement of seismic wave velocities has been discussed extensively by Christensen and Salisbury (1975).

TABLE I

Compressional wave velocities for rocks recovered from Site 293

Sample	Bulk density (g/cm^3)	Velocity (km/sec) at varying pressures							
		0.2 kbar	0.4 kbar	0.6 kbar	0.8 kbar	1.0 kbar	2.0 kbar	4.0 kbar	6.0 kbar
293-18-1 (90—93 cm)	2.828	6.21	6.23	6.25	6.26	6.27	6.33	6.44	6.53
293-19-1 (108—111 cm)	2.848	6.51	6.53	6.55	6.57	6.58	6.63	6.70	6.74
293-20-1 (100—103 cm)	2.853	6.49	6.56	6.62	6.67	6.71	6.80	6.86	—
293-20-1 (136—139 cm)	2.832	6.80	6.85	6.89	6.93	6.95	7.02	7.10	7.16
293-21-1 (5—8 cm)	2.939	6.80	6.83	6.85	6.87	6.88	6.95	7.05	7.10
293-21-1 (32—35 cm)	2.938	6.77	6.82	6.85	6.88	6.91	7.00	7.07	—
293-21-2 (11—14 cm)	2.933	6.99	7.01	7.03	7.05	7.06	7.11	7.17	7.23

Bulk densities were determined and compressional wave velocities to 4 or 6 kbar were measured by the pulse transmission method (Birch, 1960). Densities and velocities are presented in Table I. Shear wave velocities were not determined for the rocks because of probable seismic anisotropy resulting from strong preferred mineral orientation. Seismic velocity and density data for volcanic rocks recovered during Leg 31 drilling can be found in a separate report (Christensen et al., 1975).

DISCUSSION

In Fig.2 the ranges of compressional wave velocities between 0.6 and 2 kbar confining pressure (pressures appropriate to Layer 3) are shown along with the frequency distributions of seismic velocities in Layer 3 for the main ocean basins and for the Philippine Sea. The range of V_p for these samples clearly corresponds to the range of Layer 3 velocities observed in the main ocean basins and the Philippine Sea (Murauchi et al., 1968; Christensen and Salisbury, 1975). This agreement suggests that the igneous and metamorphic rocks recovered at Site 293 are samples from the lower oceanic crust. From a comparison of Fig.2, Table I and the lithologies described above, it is also evident that velocities of the gabbroic rocks correspond to the high range of Layer 3 velocities, whereas velocities of the metamorphic samples are correlative with the lower range of Layer 3 velocities.

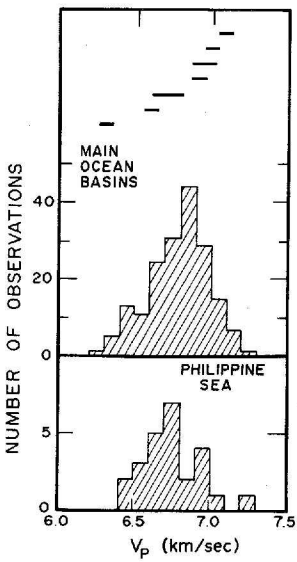

Fig.2. Range of compressional wave velocities (solid bars) for Site 293 samples between 0.6 and 2.0 kbar with histograms of lower crustal velocities for Philippine Sea (Murauchi et al., 1968) and main ocean basins of the world (Christensen and Salisbury, 1975). The 3 samples with lower velocities are metamorphic, whereas the others are gabbros and anorthositic gabbros.

Similar rock types to those studied here have been frequently dredged from fracture zones in the main ocean basins. In particular, gabbroic rocks exhibiting cumulate features similar to the igneous rocks from Site 293 have been recovered in oceanic dredge hauls (e.g., Engel and Fisher, 1969; Melson and Thompson, 1970). Metabasites are also commonly retrieved from the ocean floor and these often show the same metamorphic mineral assemblages observed in the metabasites recovered from Site 293 (e.g., Bonatti et al., 1970; Miyashiro et al., 1971). Metagabbros of a similar petrology also have been recovered by drilling during Leg 13 on the Gorringe Bank in the eastern Atlantic (Honnorez and Fox, 1973).

Not only are the rock types recovered from Site 293 similar to dredge samples, but they show remarkable similarities to rock types found in ophiolite complexes (e.g., Christensen and Salisbury, 1975). Gabbroic rocks, many with cumulate textures, are common in the lower portions of ophiolite complexes and are frequently equated, in whole or in part, with Layer 3. Above the thick sequence of cumulate and massive gabbros are sheeted dikes, which exhibit mineralogies and textures similar to those of the metabasites from Site 293. Rocks from sheeted dikes are often brecciated with actinolite commonly replacing pyroxene and have a grain size generally smaller than that of the underlying gabbros (Williams and Malpas, 1972). Using ophiolite complexes as an analog to oceanic crust, the metabasites from Site 293 could correspond to sheeted dike complexes, which form either the bottom portion of Layer 2 or the uppermost portion of Layer 3. This is consistent with the lower velocities of the metamorphic rocks and with the slightly lower velocities often observed for the top of the lower crust in detailed sonobuoy surveys (Hussong, 1972). Cumulate gabbros, with higher velocities, would be found at somewhat lower levels of Layer 3, a suggestion again consistent with results from sonobuoy measurements (Hussong, 1972).

The proximity of Site 293 to the Central Basin Fault suggests that the recovered igneous and metamorphic rocks were emplaced by tectonic activity along the fault. Alternatively, these samples may have formed in situ as new ocean crust within a leaky transform fault by mechanisms outlined by van Andel et al. (1969). Regardless of the mechanism of emplacement the direct correlation of seismic velocities in these rocks and the velocities of the lower oceanic crust provide strong evidence for a lower crustal origin for the metabasites and igneous rocks recovered at Site 293 in the Philippine Sea. The remarkable similarity between these rocks, rocks dredged from main ocean basin fracture zones and rocks observed as important elements of ophiolite complexes further strengthens this hypothesis.

ACKNOWLEDGMENTS

The samples were supplied by the Deep Sea Drilling Project which is funded by the National Science Foundation. We wish to thank Ian MacGregor for maintaining the samples in the saturated condition following shipboard

recovery. Tracy Vallier and Ian MacGregor provided helpful comments on the manuscript. This investigation was supported by the Office of Naval Research contract N-00014-67-A-0014 and the National Science Foundation grant GA-36138.

REFERENCES

Birch, F., 1960. The velocity of compressional waves in rocks to 10 kilobars, 1. J. Geophys. Res., 65: 1083—1102.

Bonatti, E., Honnorez, J. and Ferrara, G., 1970. Equatorial mid-Atlantic ridge: Petrologic and Sr isotopic evidence for an alpine type rock assemblage. Earth Planet. Sci. Lett., 9: 247—256.

Christensen, N.I. and Salisbury, M.H., 1975. Structure and constitution of the lower oceanic crust. Rev. Geophys. Space Phys., 13: 57—86.

Christensen, N.I., Carlson, R.L., Salisbury, M.H. and Fountain, D.M., 1975. Elastic wave velocities in volcanic and plutonic rocks recovered on DSDP Leg 31. In: J.C. Ingle Jr., D.E. Karig and others (Compilers), Initial Reports of the Deep Sea Drilling Project, XXXI. U.S. Government Printing Office, Washington, D.C., pp. 607—609.

Engel, C.E. and Fisher, R.L., 1969. Lherzolite, anorthosite, gabbro and basalt dredged from the Mid-Ocean Ridge. Science, 166: 1136—1141.

Honnorez, J. and Fox, P.J., 1973. Petrography of the Gorringe Bank "basement", In: W.B.F. Ryan, K. Hsü and others (Compilers), Initial Reports of the Deep Sea Drilling Project, XIII. U.S. Government Printing Office, Washington, D.C., pp. 747—749.

Hussong, D.M., 1972. Detailed Structural Interpretations of the Pacific Oceanic Crust using ASPER and Ocean Bottom Seismometer Methods. Thesis, University of Hawaii, Honolulu, 165 pp.

Karig, D.E., Ingle Jr. J.C., Bauma, A.H., Ellis, C.H., Haile, N., Koizumi, I., Ling, H.Y., MacGregor, I., Moore, J.C., Vjiie, H., Watanabe, T., While, S.M. and Yasui, M., 1975. Initial Reports of the Deep Sea Drilling Project, XXXI. U.S. Government Printing Office, Washington, D.C.

Melson, W.G. and Thompson, G., 1970. Layered basic complex in oceanic crust, Romanche Fracture, equatorial Atlantic Ocean. Science, 168: 817—820.

Miyashiro, A., Shido, F. and Ewing, M., 1971. Metamorphism in the Mid-Atlantic Ridge near 24° and 30 °N. R. Soc. London Philos. Trans., Ser. A, 268: 589—603.

Murauchi, S., Den, N., Asano, S., Hotta, H., Yoshii, T., Asanuma, T., Hagiwara, K., Ichikawa, K., Sato, T., Ludwig, W.J., Ewing, J.I., Edgar, N.T. and Houtz, R.E., 1968. Crustal structure of the Philippine Sea. J. Geophys. Res., 73: 3143—3171.

Van Andel, Tj.H., Phillips, H. and von Herzen, R.P., 1969. Rifting origin for the Vema Fracture in the North Atlantic: Earth Planet. Sci. Lett., 5: 296—300.

Williams, H. and Malpas, J., 1972. Sheeted dikes and brecciated dikes within transported igneous complexes, Bay of Islands, western Newfoundland. Can. J. Earth Sci., 9: 1216—1229.