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Several dredge samples from within the Vema, Romanche, and Chain fracture zones which cut across the Equatorial Mid-Atlantic Ridge were selected for detailed petrologic study in order to gain further insight into the relationship of these rocks with Alpine-type rock assemblages. Samples representative of the peridotite, gabbro, basalt, and alkalic suites, as defined by Bonatti and Honnorez (1970), were selected for study. Lherzolites and harzburgites from the peridotite suite were found to have similar characteristics. Primary textures, as observed through the serpentinization, are coarsely granoblastic. Olivine is $Fo_{89.3-91.6}$, opx $En_{87.0-88.8}$, cpx $Ca_{38.4-49.0}$, $Fe_{4.0-6.1}$ $Mg_{46.4-55.5}$, and spinel is enriched in Cr and Al. Large exsolved relict subcalcic pyroxenes (Ca36 Fe6Mg58) are present in one sample studied; they are deformed, and contain kink bands. Relict pyroxene indicates an earlier history of equilibration at about 1300°C, and recrystallized pyroxene indicates later recrystallization at about 1000°C. Ilmenite-rich norites (TiO2, 4.00-5.88%) are among the most Fe-rich (FeO + .9 Fe2O3 17.3 - 18. 2%) members of the gabbroic group and are late stage differentiates. Opx is En58-70, cpx is Ca40-44, Fe41-43 Mg15-17 in samples where pyroxenes are preserved, and plagioclase is An37-68. Low-K high alumina tholeiite from the basaltic group is similar to that reported by others. One sample in the alkalic suite which is of most interest is a teschenite. Cpx is high in CaO (20.3-22.2%) and Al2O3 (2.9-6.8%) and the trend (Ca46-48 Fe15-31Mg23-32) is similar to that of teschenites in the Black Jack and Shiant Isle sills. Plagioclase is An 10-75, analcite and zeolites are present but not olivine. The petrologic characteristics of the entire suite, except for the alkalic members, are consistent with those of the Alpine-type assemblage and is further evidence of their genetic relationship.

Evidence From Ophiolites

CONSTITUTION OF OCEANIC CRUST AND UPPER MANTLE AND SOME CONSTRAINTS ON ITS GENERATION

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An integrated study of the lithologies, layering and structure of the oceanic crust and of well-preserved ophiolite complexes has been made using direct observations of ophiolite complexes, dredge hauls and bottom observations in the ocean, seismic refraction studies of gross oceanic crustal layering, sound velocity measurements of both oceanic dredge haul and ophiolite complex samples, and magnetic anomaly observations. We propose that the oceanic crust and upper mantle consists of the following sequence: Layer 2a--thin 0.5 km. extrusive and shallow intrusive fresh basalt; Layer 2b--0.5 to 1 km. greenschist facies metabasalt; Layer 3a--about 1 km. greenschist facies sheeted metadolerite dykes; Layer 3b--2 to 5 km. of gabbroic rocks with not more than 1 km. of cumulate pyroxene-rich rocks at the base and minor trondhjemitic bodies at the top; Layer 4 (mantle)--mainly depleted Mg-rich harzburgite with minor dunite, at least 8 km. thick; upper 1 km. may be mainly cumulate dunite. It is clear that hornblende amphibolites and serpentinites are not found in oceanic crust apart from in transform and fracture zones. There are several problems in directly correlating velocity measurements with lithology. In the few well preserved ophiolite complexes there is a lack of any section of pyroxene-rich cumulates thick enough to match the substantial layer with V_p 7.4 km./s reported in many recent refraction profiles. Gabbros (from some ophiolite complexes) containing fresh pyroxene but with fine-grained zoisite/clinozoisite pseudomorphs after plagioclase have high (7.1-7.4 km./s) V_p, but seem unlikely to be the cause of the high velocity layer 3b. Also, problematical is the similarity in velocities of metadolerites to some fresh and altered gabbros. Basic constraints on a model for the generation of oceanic crust and mantle are as follows. Ophiolite complexes show that (a) at least 1 km. of cumulate gabbro overlies 0.5-1 km. of cumulate pyroxene-rich ultramafic rocks; (b) depleted Mg-rich non-cumulate harzburgite underlies the cumulates; (c) cross-cutting gabbroic bodies are extremely uncommon or absent from both the cumulate and non-cumulate ultramafic rocks; (d) pervasive gneissic foliations in the non-cumulate ultramafic rocks (and locally in gabbros) are sub-parallel to the cumulate layering and were therefore originally flat-lying; (e) the differential stress responsible for this gneissic fabric was low (10-100 bars) but significant; (f) diabase dikes diminish in overall proportion downwards into gabbro over about 1 km. thickness. Simple inferences derived from these observations are (1) A significant thickness of gabbro (and minor trondhjemite) is "plated" on a roof of sheeted dykes; (2) The cumulates require and will form a flat floor on which to accumulate; (3) Basaltic partial melt separates from olivine-eustatite-chromite residuum as far up as the level of the basal cumulates (not more than 6 km. below the ocean floor); (4) The zone supplying the partial melt must be very narrow (probably less than a few hundred meters wide); (5) Ultramafic cumulates underlying gabbroic cumulates require a zoned magma chamber if there is a large one continuously maintained during spreading, or requires smaller "pockets" that form and solidify episodically; (6) An elementary bending stress calculation shows that a continuously maintained magma chamber cannot have a large aspect ratio in section; (7) Magnetic anomaly integrity, FAMOUS observations and ophiolite dyke chilling statistics show that the zone of magma injection and hence the width of the under-lying magma chamber cannot be more than a few kilometers and may be merely a few hundred meters; (8) The narrower the zone of injection, the thinner the pillow lava layer will be. A model accommodating these constraints probably cannot have a continuously maintained large magma chamber. The presence of a linear welt of mantle material under the zone of extrusion and its rapid subsidence away from this zone may help to account for the gneissic fabrics observed and the existence of a thick section of cumulates in the absence of a large magma chamber. Likely transform fault/fracture zone evolution requires appallingly complex relationships between mylonitised to brecciated crustal materials, serpentinite diapirism, local sediment distribution, basaltic intrusion and extrusion, and simple shear to extensional or compressional tectonics. Many apparent anomalies in the local constitution of the oceanic crust may be due to such effects, especially since it has been recognized that small transform faults are abundant along present-day ridges. Well-documented local rearrangements of plate boundary configuration along ridges are also likely to be responsible for complex igneous, metamorphic and sedimentary relationships, in places superimposed on ordinary transform-fracture zone effects.

THE PETROLOGIC NATURE OF THE TRANSITION BETWEEN LOWER OCEANIC CRUST AND UPPER MANTLE

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The Mohorovičić discontinuity under oceanic basins has been well defined by detailed seismic refraction studies and more recently by reflection profiling using multichannel techniques. Velocities generally recorded for the lower portion of layer 3 (7.0 to 7.6 km/sec) agree with laboratory measurements at elevated temperatures and pressures in dredge samples of gabbro, norite, anorthosite and olivine gabbro. Studies of the dredge rocks and rocks from ophiolite complexes show that the lower crustal gabbros are often anisotropic due to preferred olivine and plagioclase orientation. Thus the lower oceanic crust is likely to be anisotropic with the anisotropy pattern controlled by preferred mineral orientation within cumulate layering.

Upper mantle velocities agree well with laboratory measurements in peridotites and dunites. Of significance is the anisotropy almost universally observed in detailed upper mantle refraction studies in which velocities are high normal to ridge crests. The magnitude of upper mantle anisotropy is consistent with field and laboratory studies of some ophiolites. For example, within the Newfoundland Bay of Islands ophiolite upper mantle velocities vary with azimuth by an average of 0.5 km/sec. The magnitude of this anisotropy is in excellent agreement with detailed seismic refraction studies and suggests that the Bay of Islands ultramafic represents oceanic upper mantle. Petrofabric studies show that preferred olivine orientation is clearly responsible for the observed anisotropy.

ON THE COMPOSITION OF THE OCEANIC LITHOSPHERE

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The composition and elastic properties of the earth's lithosphere beneath the sea floor are fundamental to our understanding of the mechanism of seafloor spreading and continental drift. New experimental information of the elastic properties, as a function of temperature, pressure and petrology, of eclogite and peridotite are presented. The density and seismic wave velocities in peridotite simulated in the laboratory for the oceanic lithosphere of the first 15 to 20 km depth match with results of recent seismic investigations very well. However, the elastic properties of olivine eclogite describe the seismic structure of the remaining lithosphere. The present study favors the idea of a chemical change within the lithosphere, and our laboratory results tend to favor $\bar{m} \sim 22$ for the oceanic crust. Of modelling the structure in terms of temperature and pressure coefficients, the surface wave studies introduce two complications: first, since partial melting is required by very low shear wave velocities of the asthenosphere, some consistent and sensible way of treating velocities in mush must be used; second, the mantle is definitely anisotropic, therefore a systematic crystal orientation has to be considered rather than just the average Vp and Vs for the mantle constituents. The seismic anomalies of azimuth-dependent fluctuations in the velocity of P waves along the base of the oceanic crust are as much as 8%; the high velocity tends to be parallel to the direction of seafloor spreading. A consistent explanation of this effect would be the presence of a sustained extensional strain rate in the spreading direction, applied at the base of the oceanic lithosphere. It would appear that the anisotrophy vanishes near the surface of oceanic plate.

THE NATURE AND ORIGIN OF THE OCEANIC CRUST - RARE EARTH AND MORPHOLOGICAL EVIDENCE FROM OPHIOLITES

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Despite the various arguments against the comparison of ophiolites and oceanic crust on the basis of thickness, and the many discussions concerning the true genetic environment of ophiolites, certain lithological, morphological and chemical similarities may be of assistance in the interpretation of DSDP cores and dredge hauls. The more important morphological features are: Layer 1-a variety of sediments, cherts, tuffs, limestones etc, occurring above or within the volcanic pile, and which decrease in abundance with depth; Layer 2-pillowed and massive volcanic lavas displaying an increase in metamorphic grade with depth. The pillows vary in size, shape etc. and display aphyric margins and coarser, sometimes columnar jointed, interiors. Larger pillows contain concentrically oriented vesicles and a minor amount of crystal layering is observed in the more phenocrystal lavas. Amongst the more common meta-basalts (tholeiites, alkalic and andesitic basalts) one encounters felsic and ultramafic (picrites and komatiites) horizons or flows. Layer 2 changes from a pillowed top to a base characterised by abundant dikes seen in places to crosscut or feed the volcanic pile. This transition is marked by a gradual loss of interpillow sediment and interdike pillows. Breccias and screens of pre-existing crust are associated with the mafic dikes which display irregular, complexly brecciated, chilled margins. The dike textures vary from ophitic to aphanitic and tend to be dominantly mafic in type. Lower in layer 2 one encounters complex crosscutting relationships, multiple phases of intrusion and perhaps multiple episodes of alteration from above and below. Lower layer 2 grades into the plutonic assemblage via a mafic dike-felsic screen transition. The felsic screens occur as slivers of trondjhemite, epidosite, diorite and gabbro between or within the mafic dikes. Mutually contradictory intrusive relationships within the mafic and felsic rocks greatly complicate the transition. In certain Californian ophiolites a sill complex occurs between the pillows and the plutonic assemblage. Layer 3-the upper portion of the plutonics contains sporadic mafic dikes cutting the magmatic felsic differentiates and occasional felsic dikes containing felsic screens. Textures and lithologies vary from vari-textured trondjhemites, diorites and gabbros (sporadic volatile distribution) through a cyclically layered sequence of gabbros displaying

International Conference on the Nature of the Oceanic Crust

The AGU sponsored International Conference on the Nature of the Oceanic Crust was held in La Jolla, California, December 4–6, 1975, more than 2 years after the first general meeting on rocks recovered by the Deep Sea Drilling Project (DSDP). A summary of the first meeting ('Deep Sea Drilling Project: Properties of Igneous and Metamorphic Rocks of the Oceanic Crust') appeared in the November 1973 E⊕S. Because at that time (through leg 31 of DSDP) only shallow (<100 m) penetrations had been achieved, few generalizations on the nature of the oceanic crust could be made on the basis of results presented at the first conference. However, it was evident that a diversity of basaltic rocks had been recovered during the first 31 legs of DSDP and that altered tholeiitic basalt was the dominant rock type cored.

Phase 3 of DSDP, whose objectives were outlined in the September 1973 *Geotimes*, concluded in November 1975. Among later phase 3 legs, most notable from the hard rock point of view were two relatively deep holes (leg 34 at site 319 and leg 37 at site 332, with 59 m and 583 m of hard rock penetration, respectively). Undoubtedly, the information obtained from these hard rock cores will be extremely useful in increasing our understanding of the nature of the oceanic crust and the mechanisms of its formation. As phase 3 of DSDP concluded and the International Phase of Ocean Drilling (IPOD) commenced, late 1975 was an opportune time to assess our level of understanding of the nature and development of the oceanic crust and to identify major oceanic crust related questions and objectives which can be solved during the IPOD phase of DSDP.

Although DSDP has been instrumental in rapidly increasing our knowledge of the oceanic crust over wide geographic regions, it is only part of the overall scientific effort associated with the hard rock oceanic crust; thus this second AGU sponsored meeting 'International Conference on the Nature of the Oceanic Crust' was not confined to results on DSDP sites and cores. This 3-day meeting was divided into five sessions: (1) vertical structure of the oceanic lithosphere; (2) characteristics and implications of the magnetic properties of ocean floor rocks; (3) petrogenesis of oceanic basalts; (4) correlations between basalt compositions and tectonic environment; and (5) metamorphism and alteration of the oceanic crust and the role of hydrothermal circulation.

In addition, a session was devoted to a discussion of the organizational structure of DSDP and the advisory Joides panels and the objectives and plans of the oceanic crust portion of the IPOD phase of DSDP. There were 128 scientists registered for the meeting including 21 foreign scientists. Although over 50 papers were presented (the abstracts follow this conference summary), the format of the meeting left ample time for discussion of each paper, and many papers generated considerable discussion. Approximately 30 papers presented at this meeting will be published in the *Journal of Geophysical Research* during the summer of 1976. The following discussion is a summary of the major features of each session.

Vertical Structure of the Oceanic Lithosphere

The first session on the vertical structure of the oceanic lithosphere was divided into three main approaches: (1) geophysical evidence, where oceanic crust structure is deduced by coupling data from seismic refraction studies at sea with sound velocity measurements on rock samples recovered from the sea floor; (2) evidence from fracture zones, where information obtained from rock distributions in sections exposed at fracture zones is utilized to infer the nature of the oceanic lithosphere; and (3) evidence from ophiolites, where data obtained from ophiolite complexes are used to model the oceanic crust and upper mantle on the assumption that ophiolites represent uplifted fragments of oceanic lithosphere.

On the basis of data obtained in seismic refraction experiments utilizing ocean bottom seismographs (OBS), three geophysical papers presented evidence of oceanic structure along and adjacent to accreting plate margins. On the flank of the mid-Atlantic ridge (MAR) in the French-American Mid-Ocean Undersea Study (Famous) area (37°N), McCamy and Rowlett determined a 4.0-km/s layer overlying a 6.2- to 6.5-km/s layer (mantle was not observed), a shear velocity of about 3.6 km/s for the lower layer, and a systematic velocity variation with azimuth which implies a regional dip to the northwest. Seismic refraction data and interpretations for the eastern Pacific rise (EPR) were reported by researchers from the Scripps Institution of Oceanography and the University of Hawaii. An important conclusion resulting from the data inversion of Dorman et al. was that along the crest of the EPR a low-velocity crustal zone overlies a mantle with V_p = 7.8 km/s. Rosendahl et al. emphasized that major crustal changes occur from the ridge crest to the flank. In particular, at or near the crest, crustal velocities are 5.2, 6.0, and 7.0 km/s, and a low-velocity crustal zone overlies anomalously

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Cover. The deep sea drilling from the *Glomar Challenger* provides the motif for this month's cover. The report of the International Conference on the Nature of the Oceanic Crust begins on page 393. Photos courtesy of the International Program of Ocean Drilling, National Science Foundation.

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