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PETROLOGY OF THE OCEAN FLOOR

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PREFACE

"Ocean floor petrology" is concerned primarily with the study of volcanism and related processes involving the creation and the transformation of crustal material which takes place at contact with seawater. The field of ocean floor petrology has developed and will continue to evolve rapidly with man's effort to penetrate and explore greater depths through the use of more sophisticated technology. The present work was initially intended to be a comprehensive review of the major mineralogical and geochemical investigations carried out in the study of oceanic crust. However, during the process of gathering the data together, new information has been added in order to further increment our knowledge of the oceanic crust.

It is not the pretense of this work to give a complete coverage of ocean-floor genesis, but to give insights into the compositional diversities of basement rock samples associated with various geological settings. Since the petrological studies of the ocean floor are interrelated with other disciplines, an attempt has been made throughout this work to cover some general aspects of the morphology and the structure of oceanic features for which data and samples are available. Both the sampling and the gathering of other geological data from the ocean floor have been found to be an expensive and difficult task. Submersibles and unmanned bottom-navigated instruments have demonstrated their efficiency and are prerequisites for sea-floor exploration in order to implement further detailed studies of magmatism, hydrothermalism and structural processes related to different types of geological features.

This book has been divided into twelve chapters which can be separated into two main parts. The first part, including Chapters 1 through 8, deals with the composition of the oceanic basement associated with the various types of structures thus far recognized and sampled. Since oceanic ridges are one of the main features and also the most accessible for sampling, they are the best known. Even so, we are far from having a clear picture of the deep-seated processes involved in the creation of new crust. Only a few segments of oceanic ridges have been studied in detail using advanced technology. The FAMOUS project (Franco-American Mid-Ocean Undersea Study) and project RITA (study of the *Ri*vera and *Ta*mayo Fracture Zones) provided new structural and petrological data for the understanding of plate boundaries accreting at different rates in the Atlantic and Pacific Oceans. Deep-sea drilling has proved to be invaluable in recovering samples in heavily sedimented areas hitherto inaccessible by other methods of sampling.

Other major oceanic structures such as aseismic ridges, which are thought to be chains of elevated edifices active during the early stage of the separation of the continental masses, are still inadequately sampled. The crustal composition of oceanic trenches is also poorly known. More sampling of the outer island arcs or ocean-side regions of the trenches is necessary in order to have more insight into crustal behavior prior to the plunging of the lithosphere.

Other poorly known regions, located at the plate boundaries and characterized by both extensional and compressional plate motions, have been tentatively called thrust-faulted regions and these are also discussed.

The aspect of subaerial ophiolites and their inferred occurrences in an oceanic environment has not been discussed in depth in this book. Obviously, this subject is of great interest in understanding the early emplacement of ocean-floor ultramafic and mafic complexes at accreting plate boundaries. The lack of a continuous section through layers 2 and 3 of the oceanic crust has, up to now, prevented marine geologists from making any meaningful correlation between subaerial ophiolites and similar oceanic types of rock associations.

The second part of the book (Chapters 9, 10, and 11) deals mainly with the alteration of oceanic crust after its creation when exposed to the progressive effects of weathering, hydrothermalism, and metamorphism.

So far, the economic aspects of deep-seated oceanic environments have been centered on the study of polymetallic manganese nodules (made up of Mn, Fe, Ni, Cu). However, the mineral wealth of the ocean floor is still not well assessed and it was only recently (1979) that massive sulfide deposits with higher metal concentrations than those of the manganese nodules were seen to be formed at depths of 2600 meters. It is necessary that future exploration be oriented towards a systematic interdisciplinary study of oceanic ridges and associated fracture zones in order to obtain more insight into the genesis of ore deposits in both oceanic and subaerial regions.

The last chapter (Chapter 12) deals with subcrustal and upper mantle processes related to accreting plate boundary regions. This chapter is based on inferences made from major experimental petrological work and geophysical investigations carried out on oceanic rocks and environments.

As we increase our knowledge in oceanic petrology, the questions become more complex, the problems more complicated. Oversimplification is replaced by a feeling of confusion, albeit closer to the "truth". It is essentially due to the increasing complexity of the field of oceanic petrology that an interdisciplinary approach is vital in future work.

ROGER HEKINIAN
St. Renan, 30 December 1980

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ABBREVIATIONS

DSDP	Deep Sea Drilling Project
FAMOUS	Franco American Mid-Ocean Undersea Survey
IPOD	International Phase of Ocean Drilling
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
RITA	An acronym derived from the names of the Rivera and Tamayo Fracture Zones on the East Pacific Rise
TAG	Trans-Atlantic Geotraverse
ALV	"Alvin" (submersible)
AR, ARP	"Archimède" (bathyscaphe)
CY, CYP	"Cyana" (diving saucer)

CONTENTS

CHAPTER 1

MINERALOGY AND CHEMISTRY OF OCEAN FLOOR ROCKS

ULTRAMAFIC ROCKS

Most of the ultramafic rocks found in the ocean floor are serpentinized to various degrees. It is also observed that in many cases the serpentinized peridotites collected from various structures of the ocean floor are accompanied by gabbros and sometimes by minor amounts of anorthosite. Basaltic rocks are also intermixed in various proportions within the dredge hauls, suggesting that some kind of interrelationship might exist between these different rock types. The distribution of ultramafics from the ocean floor is shown on a world map in Fig. 1-1.

Serpentinized peridotite

It is often difficult to establish the primary composition of altered peridotite. Assuming that the serpentinization of oceanic peridotite proceeds under isochemical conditions, we can therefore convert the silicate analyses to anhydrous residue in order to obtain the primary normative composition of the peridotitic material. Chemical analyses of some serpentinized peridotites are shown in Table 1-1.

Serpentinization is a process of alteration of an original mineral, usually pyroxene or olivine, which gives rise to different types of serpentine minerals and structures. Often the original rock structure and mineral outlines are preserved, and it is sometimes easy to reconstruct the ghost minerals. Two examples where these may be readily recognized are the formation of bastite from pyroxene and the preserved sharp outlines formed by Fe-oxide minerals replacing many olivine crystals.

The texture of serpentinized peridotite varies. There are massive varieties with allotriomorphs of polygonal olivine relics and crystals, and xenomorphic randomly oriented tabular pyroxene. Other textural features, such as linear orientation or a contorted appearance of mineral grains are often encountered in specimens of serpentinized material. Some pyroxene minerals show deformed twin lamellae and broken-up plagioclase crystals, and an effect of granulation on mafic minerals may also occur. These later textural features are attributed to cataclastic metamorphism (see Chapter 9).

Because of the different degrees of rock serpentinization, some authors (Dmitriev and Sharaskin, 1975) think that there are at least two stages of serpentinization. The first stage consists of uniform serpentinization of minerals (pseudomorphism) with no signs of alteration of the primary rock fabric, while the second stage consists of the formation of veins and veinlets plus many new mineral phases due to the recrystallization of serpentine.

TABLE 1-1

Chemical analyses of serpentinized peridotite from the Mid-Atlantic Ridge near 53°N and from 30°N (Hékinian and Aumento, 1973; Miyashiro et al., 1969a). The data from the Kane and from the Vema Fracture Zones are from Miyashiro et al. (1969a) and from Melson and Thompson (1971). Samples 97 and 93 are lherzolite from the Indian Ocean (C.G. Engel and Fisher, 1969)

	Mid-Atlantic Ridge, 53°N CM4-DR2-1	Mid-Atlantic Ridge, 30°N A150-6 AM-3	Kane Fracture Zone V25-8-T20	Vema Fracture Zone AII-20-9-1	Romanche Fracture Zone CH80-DR10-15	Rodriguez Fracture Zone 97-W	Mid-Indian Oceanic Ridge, 12°S 93-3
SiO_2 (wt.%)	37.80	41.76	40.68	39.71	43.00	4.5	38.29
Al_2O_3	3.75	2.30	2.86	2.59	1.08	3.59	2.74
Fe_2O_3	10.73*	5.66	4.69	7.31	10.29	1.60	4.65
FeO	—	3.14	3.43	1.30	1.12	5.23	2.25
MnO	0.10	0.11	0.10	0.12	0.12	0.10	0.06
MgO	32.29	33.83	33.20	33.15	31.87	34.84	35.32
CaO	1.87	1.53	2.05	1.52	0.08	5.50	3.75
Na_2O	0.21	0.23	0.12	0.28	0.29	0.19	0.20
K_2O	0.52	0.03	0.03	0.06	0.03	0.20	0.20
TiO_2	0.22	0.14	0.12	0.06	0.05	0.03	0.01
P_2O_5	—	0.02	0.01	0.02	0.08	—	—
H_2O	12.95	11.41	12.03	13.88	12.19	4.52	11.46
Total	100.44	100.16	99.32	100.00	100.20	98.78	98.75
Cr (ppm)	n.d.	3700	3600	3300	2520	6400	4800
Ni	n.d.	1500	2500	2300	2238	3500	3300
Co	n.d.						

n.d. = not determined.

*Indicates total Fe calculated as Fe_2O_3.

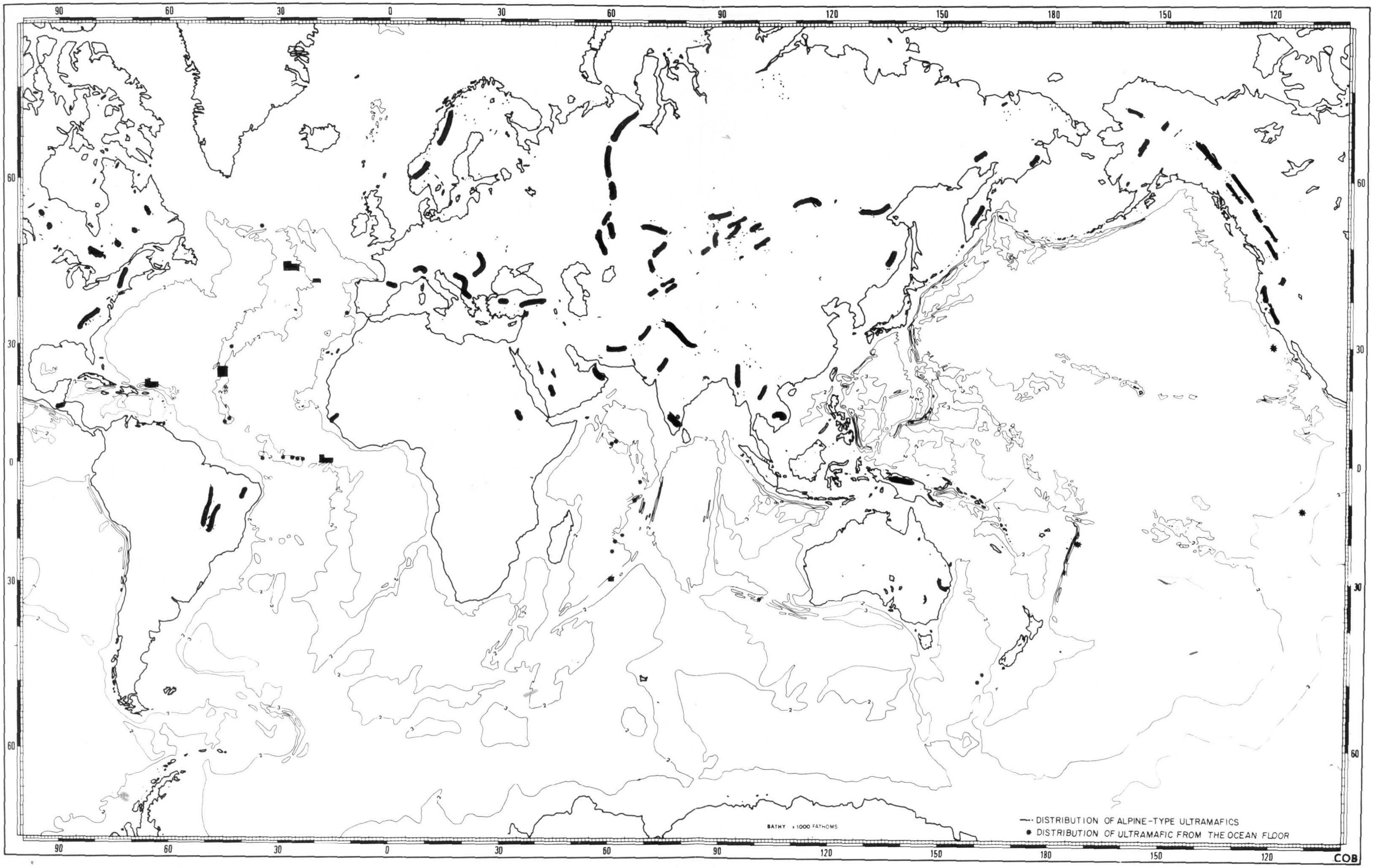

Fig. 1-1. Distribution of ultramafic rocks recovered from the ocean floor. The black dots and stripes plotted on the continental regions are the alpine type of ultramafics reported in Irwin and Coleman (1974).