Ophiolites
and Oceanic Lithosphere

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Preface

The proposal that ophiolites are on-land fragments of oceanic lithosphere has been with us for over 20 years and has been widely accepted by the Earth Sciences' community. Despite this, many oceanographers are reluctant to use ophiolite data. Their argument (and it comes largely from the geological rather than geophysical oceanographers) is that 'Even if ophiolites *are* on-land fragments of oceanic lithosphere, they must be atypical for otherwise they would have been subducted and not obducted'. So they conclude that, although the study of ophiolites is perfectly acceptable in its own right, its results should not be used in the investigation of present-day, *in-situ* oceanic lithosphere—i.e. the invoking of 'reversed uniformitarianism' is not acceptable. However using uniformitarian principles to interpret ophiolites from present-day oceanic lithosphere studies is equally problematical for (i) petrological/geochemical studies of ocean-floor rocks are based on widely spaced boreholes of limited depth and dredge-haul sampling, (ii) geophysical data can only detect large-scale phenomena and are open to various interpretations, and (iii) direct observations from submersibles are still very limited. Such circumstances should have drawn the two groups of workers closer together.

We believe that the deliberate ignoring of ophiolite evidence has, at best, slowed down our understanding of processes by which oceanic lithosphere is produced. Two examples to illustrate this will suffice: in the early 1970s, studies on ophiolite metamorphism indicated that hot seawater passed through the uppermost 4 km of the oceanic crust soon after it was generated at a constructive plate margin. These hot brines enriched in transition metals emerged from the oceanic crust to react with cold seawater to produce metal-enriched muds that with time became massive sulphide deposits. It was not until later in the decade when the thermal budget imbalance was identified by heat-flow studies on the East Pacific Rise, that oceanographic investigations into the possibility of seawater circulation through oceanic crust adjacent to present-day constructive margins took place with the subsequent location of black smokers where metal-enriched brines emerge from the ocean crust. Similarly, there has been much nonsense talked about magma chambers beneath constructive margins. The presence of a crustal magma chamber is implicit in all ophiolite-based models and most workers accept that magma chambers exist in the present-day oceanic crust; indeed they have been identified geophysically beneath the fast-spreading East Pacific Rise (see Orcutt *et al.*). However, because none have been seismologically detected beneath the slow-spreading Mid-Atlantic Ridge, serious (*sic*) proposals on how oceanic crust could be produced without involving magmatic processes have been made at oceanographic conferences despite the fact that no ophiolite has yet been described that could be produced by anything other than magmatic processes.

The notable exception to this negative attitude was the Ophiolite Conference held in Nicosia, Cyprus, during April 1979 when many oceanographers took the opportunity to study the outcrops on the classic Troodos ophiolite; much invaluable discussion and productive research collaboration resulted. Our proposal to the Geological Society to hold an international conference entitled 'Ophiolites and Oceanic Lithosphere' was specifically intended to encourage and stimulate oceanographic-ophiolite research recognition and collaboration. By and large it failed, for although some 200 participants from eighteen countries attended the conference held in the apartments of the Geological Society in Burlington House, London on the 17–19 November 1982, only seven of the fifty-seven papers presented were on oceanic studies, three compared oceanic and ophiolitic data and the remaining forty-seven were entirely concerned with ophiolites. Most papers were well presented and lively discussions, regrettably not published here, ensued. The ophiolite-oceanographic imbalance occurred despite canvassing by the organizers to encourage greater oceanographic participation and is reflected in these proceedings. (Of the thirty-three papers presented here twenty-six are on ophiolites, two compare oceanographic or ophiolitic data and only five are oceanographic.)

The papers in this volume fall into two categories. In the first section the nature and formation of oceanic lithosphere is discussed from integrated and individual studies of the present ocean crust and ophiolite complexes. The second section contains both review and original articles on the emplacement (obduction) of ophiolites and the use to which they can be put in understanding the processes of plate collision. The nineteen papers in Section I can be further subdivided into five groups on (i) magma chambers, their products and processes, (ii) fracture zones, (iii) mantle structures, (iv) lavas and sediments, and (v) isotope studies and metamorphism.

Magma chambers: products and processes: Orcutt, McClain & Burnett, in reviewing and updating seismic studies across the East Pacific Rise, confirm the presence of extensive shallow magma chambers but dispute the commonly held view that oceanic crust thickens with increasing age. *Fisk* uses petrological arguments to limit the depths and temperatures of magma chambers beneath constructive margins and concludes that for the Galapagos Rise and Mid-Atlantic Ridge basalts, the reservoirs were located at about 3 km below the ridge crest and had temperatures of 1150–1270°C. *Flower* discusses the dependence of basalt petrology and geochemistry on spreading rates, postulating that slow-spreading ridges are characterized by polybaric fractionation and fast-spreading ones by low-pressure isobaric systems. Peculiarities of magma compositions of intermediate-rate spreading ridges are attributed to a combination of slow- (plagioclase accumulation) and fast-spreading (open magma supply) characteristics.

In contributions to magma-chamber products and processes from ophiolites, *Smewing* et al. describe the cumulate sequence gabbros of the northern Oman ophiolite and suggest that these were formed in a series of elongate magma chambers along the constructive margin at which the ophiolite developed. In separate papers, *Gregory, Pallister* and *Browning* discuss mantle-melt reactions, parental magma compositions and crystallization sequences in the Oman ophiolite. Variations in these features over short along-strike distances indicate that melts of varying composition and degree of fractionation are transferred into the crust during spreading processes. *Elthon, Casey & Komor* identify the early crystallization of Mg-rich pyroxenes in the basal cumulates of the Bay of Islands, Newfoundland ophiolite and propose that they crystallized at high pressures (>10 kb) and were tectonically transported to the base of the crust. This interpretation is in conflict with Browning's Oman evidence which suggests that the early crystallization of clinopyroxene results from magma compositions that differ from MORB-type liquids.

Fracture zones: White, quoting seismic data, describes the anomalously thin and deformed oceanic crust in and adjacent to the Mid-Atlantic Ridge fracture zones and discusses its influence on the structure of slow-spreading ridges. Atlantic fracture-zone rocks and structures studied from submersibles and dredge hauls are described by the CYAGOR II group and *Honnorez, Mével & Montigny*. From ophiolite studies comes *Karson*'s paper which describes a fossil transform fault in the Coastal Complex of Newfoundland.

Mantle structures: This topic has only two contributions from ophiolite studies. *Smewing* et al. mentioned earlier under magma chambers, describe the mantle foliations and lineations and the layering in gabbros from the northern part of the Semail ophiolite. They show that the stress field, which produced the mantle foliation, also affected the lowermost

2 km of the crustal sequence indicating an effective coupling between crust and mantle during sea-floor spreading processes. *Nicolas & Rabinowicz* present a model for asthenospheric flow beneath ocean ridges based on their study of mantle tectonite fabrics.

Lavas and sediments: Two papers, both based on studies of the classic Troodos ophiolite, fall in this category. *Malpas & Langdon* describe the komatiitic mafic and ultramafic lavas that occur near the top of the Troodos lava sequence and conclude that they are products of off-axis magmatism. *Boyle & Robertson* studying the metallogenic sediments occurring above and within the Troodos eruptive sequence, compare them to those associated with present-day ridges and conclude that the Troodos ophiolite was produced at a fairly fast-spreading constructive margin.

Isotope studies and metamorphism: Five papers fall into this category. *Elthon* et al. discuss the processes of hydrothermal metamorphism of the oceanic crust based on a study of the Sarmiento ophiolite in S Chile, whereas *Stakes, Taylor & Fisher* describe oxygen-isotope and geochemical characterization based on the study of specimens from both the present oceanic crust and the Oman ophiolite. In particular, they show how water/rock ratios and magmatic *v.* seawater influences can be calculated. *Thirwell & Bluck* present an Sr–Nd-isotope study on the eruptive rocks of the Caledonian ophiolite at Ballantrae, SW Scotland which, they suggest, were formed in a variety of tectonic settings and not in a simple, single ophiolite sequence. *Menzies* shows that the majority of diopsides separated from orogenic and ophiolitic tectonite peridotites have Sr and Nd isotope composition close to MORB. He suggests that the orogenic lherzolites represent a source of MORB liquids whereas the ophiolite harzburgites represent a depleted residium after extraction of such a liquid. *Ahmed & Hall* provide evidence suggesting that serpentinization and rodingitization in the Sakhakot-Qila ophiolite of Pakistan took place whilst the ophiolite was still an *in-situ* part of the oceanic crust.

We have divided the papers in the second part of the volume into two categories. Those concerned with (i) ophiolite emplacement and obduction and (ii) regional studies.

Ophiolite emplacement and obduction: Of the papers in this section, two (*Spray* and *Casey & Dewey*) deal with the detachment of the potential ophiolite from its *in-situ* oceanic lithosphere setting, whereas *Ogawa & Naka, Searle & Stevens* and *Woodcock & Robertson* are concerned primarily with the emplacement of oceanic crust onto arc or continental margins. *Spray*, drawing attention to the elongate form of most ophiolites (length > breadth > thickness) and the fact that the igneous crystalline ages are very close to those given by the metamorphic soles that mark the initial detachment of the ophiolite from its oceanic setting, concludes that this happened to young, hot oceanic lithosphere close to its associated constructive margin. *Casey & Dewey* discuss the relation between the initiation of subduction and ophiolite obduction as a consequence of change in plate movement. *Ogawa & Naka* describe forearc ophiolites in Japan and the Western Pacific and conclude that much of their mélangic structure results from deformation in a fracture zone prior to emplacement on a forearc margin. *Searle & Stevens* are concerned with the origin and emplacement of the Newfoundland, Oman and Spontang (Himalayan) ophiolites as forearc continent collisions and identify modern analogues for this process from the Western Pacific. The account of the Spontang ophiolite is particularly interesting as it is, so far as we are aware, the first account of this remote complex to appear in Western literature. *Woodcock & Robertson* discuss contrasting styles of ophiolite nappe emplacement in various Tethyan ophiolites.

Regional studies: Seven papers are included under this heading although the article by

Rothery, describing the use of satellite imagery in the investigation of the Oman ophiolite, does not realistically fall in this, or any other, category in this volume. *Colley*'s account of a possible ophiolite from Fiji gives a new interpretation to this essentially volcanic complex. *Davies & Jaques* and *Milsom* provide new geological and geophysical data on Papua–New Guinea ophiolites whilst *Coleman, Wadge, Draper & Lewis* and *Sturt, Roberts & Furnes* review ophiolite complexes in Arabia, the Caribbean and the Scandinavian Calidonides respectively. *Hall*, in a controversial paper, claims that the well-known ophiolites of the Middle East, and notably the Oman, are virtually autochthonous being formed by intracontinental rifting of a passive continental margin.

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I. NATURE AND FORMATION OF OCEANIC LITHOSPHERE

MAGMA CHAMBERS: PRODUCTS AND PROCESSES