The contribution of scientific ocean drilling to the exploration of the Mediterranean

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The Ocean Drilling Program (ODP) is an international basic research program of scientific ocean drilling funded by 20 countries. Five of these countries border the Mediterranean: Spain, France, Italy, Greece and Turkey. Since the seagoing phase of ODP began in 1985, the drilling research vessel *JOIDES Resolution* has occupied some 250 sites, drilled about 600 holes and recovered about 70 km of core from all the major oceans of the world. ODP is the successor to the Deep Sea Drilling Project (DSDP) which ran from 1968 to 1983.

During the 25 years since the start of DSDP, only three DSDP/ODP legs have been dedicated to the Mediterranean Sea. As one would expect, the first leg, Leg 13 in 1970, was exploratory in its nature, comprising a dozen sites scattered throughout the region, from the Alboran Sea in the west to the Nile Cone in the east. Most of the holes drilled were quite shallow; at only two of the 12 sites did holes penetrate deeper than 500 m. Nevertheless, the recovery of Messinian evaporites gave birth to dramatic discoveries about the desiccation of the Mediterranean basins and to the hypothesis of the Gibraltar water fall. The fact that such major discoveries were possible with shallow drilling is essentially because these events occurred very recently in geological time.

Leg 42, in 1975, consisted of a similar number of sites to Leg 13. Again they were scattered throughout the region, including eight sites in the Mediterranean proper and three in the Black Sea. The holes drilled generally penetrated deeper than on Leg 13 and included a 1073 m hole in the Black Sea which bottomed in black shales.

By contrast, ODP Leg 107 was much more focussed, all the sites being located in the Tyrrhenian Sea. The primary thematic objective was to understand the evolution of a backarc basin in a continental setting. But since this was also the only leg to date in which hydraulic piston coring had been carried out in the Mediterranean, it was also possible to address several paleoceanographic objectives.

The present situation of scientific drilling in the Mediterranean is thus one in which a broad-brush regional coverage has been obtained, whilst thematically-focussed drilling has only been conducted in the Tyrrhenian Sea. APC/XCB coring, promising high recovery and undisturbed cores from the upper part of the sediment column, has not yet been attempted in most of the region. Furthermore, many of the holes drilled on Legs 13 and 42 were only spot cored.

The water depth in the Mediterranean is on average about a kilometer less than that in the major ocean basins. This could contribute to the operational efficiency of drilling deep holes. Deeper holes require the setting of re-entry cones, running casing, pipe trips to change drilling bits, in addition to wireline time to retrieve core barrels and make downhole measurements. The shallower the water, the less time all of these operations take.

Since Leg 42 there have been substantial improvements in the way scientific ocean drilling is conducted. Even since Leg 107 in 1986, there have been major improvements to downhole coring and logging equipment and to the equipping of the shipboard laboratories of the *JOIDES Resolution*. For example:

• The Adara device, located in the shoe of the APC, provides accurate in situ temperature measurements for heat flow determination.

• The Pressure Core Sampler (PCS) has been developed to bring cores with their contained gases back to the surface at ambient pressures. The PCS could be used, for example, to recover some of the very gassy sediments that were encountered on Leg 42B in the Black Sea.

• All good quality cores are routinely scanned with the MultiSensor Track (MST), measuring magnetic susceptibility, sonic velocity and density.

• The Formation MicroScanner (FMS) downhole logging tool is now regularly used to produce electrical resistivity images of the borehole wall.

• The shipboard computing system has been substantially upgraded to improve data transfer and assimilation. Further upgrades are in process.

The increasing range of physical property measurements made on cores in the shipboard laboratory is pushing ODP towards core-log integration. Comparison of shipboard measurements on cores with those obtained by downhole logging tools will eventually allow the two data sets to be fully integrated and core to be located at its proper place in the sediment column. By the time the drillship returns to the Mediterranean, possibly as soon as 1994, core-log integration should be far advanced.

At the roundtable workshop on "Focussing scientific objectives for deep drilling in the Mediterranean", a fuller presentation of ODP's technical and scientific capabilities will be made.

Tectonic Facies Concept Applied to Interprete the Geology of Cyprus

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Mountains formed by plate collision are exemplifed by the West Alps. Rock formations of the colliding plates are (1) overthrust, (2) underthrust, or (3) pushed out onto foreland. The three modes of deformation correspond respectively to those of (1) the Austro-alpine rigid basement nappes, (2) the Penninic melanges and mobilized basement nappes, and (3) the Helvetic cover nappes of the Swiss Alps. HSU and BRIEGEL (1991) proposed to consider the Austro-Alpine, Penninic, and Helvetic three major tectonic facies, and interprete the genesis of less well-known mountain belts of the world through comparison with the Alps.

The present Benioff zone under the Hellenic Arc dips to the north, and the Neogene tectonics of the eastern Mediterranean is commonly considered to have a southward vergence. Extrapolating from the Holocene to Miocene, the structural deformation of Cyprus has also been assumed to be a southward continuation of structures in Anatolia, characterized by a southward vergence; the Troodos ophiolites has thus been considered a fragment of ocean crust thrust up- and southward along one or more north-dipping thrust faults (e.g., BIJU-DUVAL and MONTADERT, 1978; ROBERTSON, 1990; 1991).

Two major tectonic units are present on the Island of Cyprus. The Kyrenia Range is underlain mainly by upper Mesozoic and Cenozoic formations, forming disharmonic folds and decollement thrusts. This style of deformation is typically that of a peeled-off passive-margin sequence. The southern half of the island is underlain mainly by the Troodos Ophiolite and by the Monia Melange.

That the Troodos represents ancient ocean crust is a concensus interpretation; the ophiolite complex is considered a huge slab in a tectonic melange. That the Monia Melange represents a tectonic melange now sandwiched in the suture zone between colliding plates is also a concensus interpretation. The question is the vergence of the deformation. Assuming that the Benioff Zone south of Cyprus dipped to the north during the Miocene as the Benioff Zone under the Hellenic Arc, the orthodox interpretation is to assume that a micro-continent, called by ROBERTSON (1990; 1991) the Monia Microcontinent has been underthrust beneath Cyprus. The orthodox model assumes thus that the Kerenia formations belonged to an overriding block.

The theoretical model for collision tectonics predicts, however, that a tectonic melange is the accretional wedge on an active margin, formed by shearing within a Benioff Zone which dips under the overriding block; the Saas-Zermatt and Arosa ophiolite melanges dip under the Austro-Alpine nappes. The Kerenia style of deformation is, however, not comparable to the rigid-basement thrusting of the AustroAlpine nappes; the style is more analogous to the tectonics of the Helvetic nappes. Considerations of comparative tectonics require that the Kerenia is a foreland deformed belt, formed by the plunger action of a *traineau écraseur* of an overriding plate.

HSU suggested in a memorandum to JOIDES drilling in 1989 that the Miocene Benioff Zone south of Cyprus may have dipped south, not to north. According to this model, the Troodos ophiolite underlies a back-arc basin which had its origin in Late Cretaceous back-arc seafloor-spreading. The Upper Cretaceous-Tertiary sedimentary sequence of the Kerenia Range is that of a passive-margin behind, i.e., north of the backarc basin. The frontal arc should then be located under the Eratosthenes Seamount! Such a paleogeographic interpretation suggests that the tectonics of the Cyprus deformation is typically that of a back-arc basin collapse. The ocean lithosphere under a back-arc basin, like that under the South China Sea today, dips under a frontal arc, causing the elimination of the basin and an arc-continent collision. The suture zone of such a collision is located on the back side of the arc, exemplifed by the Lichi Suture of the Mio-Pliocene arc-continent collision in Taiwan. The Monia Melange was the accretional wedge under the Eratosthenes Arc. The melange, including the Troodos slab of ocean lithosphere, was then sandwiched in the suture. The plunger action of the overriding arc and the melange caused the decollement deformation of the Kerenia-Range sequence.

This interpretation of the Cyprus tectonics presents an alternative to the current orthodoxy. Ocean- drilling south of Cyprus should yield data to discriminate the two working hypothesis. If the vergence of the Miocene deformation was directed southward, drilling south of Cyprus should penetrate a foreland deformed belt, similar to that of the Helvetic Alps, or that of the Appalachian Valley and Ridge. If, however, the vergence of the deformation caused by the Miocene collision was directed northward, ocean drilling should penetrated an island arc sequence (volcanic or non-volcanic) under the upper Neoene sediments of the Eratosthenes Seamount.

The settlement of the question of the Cyprus tectonics might help resolve the controversy on the tectonics of the Antalya Melange. RICOU and others (1979), the "super-nappists" suggested a southward thrust of the ophiolites from northern Turkey during the suturing of Anatolia. ROBERTSON (1990; 1991), on the other hand, considered the Antalya Ophiolite the lithosphere under a small ocean basin, the Isparta Angle; the ophiolite, according to this model, was emplaced "outward" from the Isparta Angle and onto the adjacent, relatively autochthonous carbonate platforms." My interpretation of the Cyprus geology supports the postulate by ROBERTSON. In the scheme of a back-arc basin complex, the continental crust under the Kerenia Range (and under the Troodos Ophiolite) could be interpreted as the foundation of a remnant arc, similar to the KyushuPalau Ridge of West Philippine Sea. The Kerenia passive-margin sequence was laid down on the south side of this remnant arc. That Antalya and Troodox ophiolites were, according to this model, the ocean lithosphere under the two back-arc basins north and south of the remnant arc respectively; those basins were eliminated by the mechanism of back-arc basin collapse, and the ophiolite nappes were thrust northward onto carbonate platforms.

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