HEAT

by

X. Le Pichon and K.J. Hsü

The Hellenic Arc and Trench Program (HEAT) is a coordinated international multidisciplinary program investigating subduction tectonics in the Eastern Mediterranean. This article outlines the scientific rationale for initiating the program, highlighting in particular the precision-oriented studies that are being carried out under the sea and the impressive results of the recent preliminary structural investigation made by the R.V. Jean Charcot in the Hellenic Trench.

Introduction

Ten years ago, when one of the authors of this article (Hsü) was co-chief scientist on the D.V. Glomar Challenger during her thirteenth leg in the Mediterranean Sea, three sites of the leg were devoted to studying the Hellenic Trench. Sites 127 and 128 were drilled in the southern Matapan Trench (on the southwest Hellenic Trench) and Site 129 in the southeastern Strabo Trench (see Fig. 1). At Sites 127 and 129, a well-defined stratigraphic inversion was drilled at the foot of the inner trench wall and was interpreted by Hsü and Ryan (1974) to be an effect of subduction. While relatively few accepted this evidence as being clearly related to subduction, most recognized the many similarities between the Hellenic Trench and a typical consuming plate boundary: active underthrusting of the arc, intermediate seismicity with a spatial arrangement suggesting that it belongs to a slab dipping away from the boundary, topography of the

trench, large negative free-air anomaly, active volcanic arc (Ryan, 1970).

This first attempt to study a trench with the Glomar Challenger was followed by several more recent drilling legs devoted entirely to the study of the Pacific subduction complexes. Preliminary reports indicate, however, that the investigations are incomplete and some data quite puzzling. For example, the evidence obtained during leg 60 on the Marianas Trench slope suggests that the entire subduction region is dominated by normal faulting and tensional strain, and that the overriding plate is being tectonically eroded. No direct evidence for subduction has been obtained, and nowhere has deep-sea drilling penetrated a tectonic mélange or a subduction-complex (R. von Huene, personal communication, November 1978).

Figure 1. Sketch map of Hellenic Arc - Trench region showing sites surveyed (1 to 4) in September, 1978. Arrows indicate the relative motion between the African and the Aegean Plates.

We believe this is because limited, relatively shallow drilling cannot by itself resolve the structural complexity of the processes involved in subduction and give a complete picture of the tectonic pattern of outer rise, trench and inland slope.

If the tectonic pattern is so complex and if the evidence for overthrust only affects a very narrow region at the foot of the slope (as suggested, for example, by the late B.C. Heezen from observations of the bottom of the Middle America Trench), then it is unlikely that we will ever be able to decipher the pattern completely using the standard oceanographic techniques from surface ships. We need high resolution detailed geological and geophysical surveys of the trench floor and lower trench slope region. Sophisticated new technology has now made these types of surveys possible, with a resolution comparable to the one obtained in geological studies on land. In particular, one should note the Seabeam, a set of multiple, narrow-beam echo-sounders, the deep-tow fishes, the submersibles, and the numerous sampling instruments which can be precisely (within 10 m) positioned on the sea bottom using acoustic navigation. Up to now, these new technologies have been used almost exclusively for the study of accreting plate boundaries, where new oceanic lithosphere is being formed (for example: Project FAMOUS, Heirtzler and van Andel, 1977; Le Pichon, 1975).

Subduction and Hellenic Trench

Unfortunately, studies using these technologies are relatively costly and can only take place within the framework of large programs. Is subduction, then, a sufficiently high priority in science to be the object of a large program and if so, is the Hellenic Trench a good place to study subduction?

During the last few years, the international geological community has realized more and more that among the major dynamic processes now affecting the lithosphere, the study of subduction of oceanic lithosphere should be given high, if not top, priority. Although subduction had specifically been included in the seafloor spreading scheme of Harry Hess nearly 20 years ago, most of the research effort had gone into the study of the oceanic ridges. The majority of the models used for the evolution of mountain belts supports the theory that they are the end products of plate-interaction along consuming margins, where crustal shortening is caused by the subduction of oceanic lithosphere in a first phase, and eventually, by crustal collision in a second phase. Thus, as Jean Aubouin recently wrote "A la coupe tectonique des Alpes, référence du passé, se substituera de plus en plus la coupe mer marginale-arcs insulaires, fossé, océan en tant que modèle de référence d'où partiront les idées nouvelles." In addition, it is often suggested that the only efficient means of transferring matter from the oceanic to the continental lithosphere is along subduction zones.

Nevertheless, it is fair to say that models which produce mountain belts by plate interaction along consuming boundaries are mostly hypothetical: they are based on inferences rather than on hard facts. It cannot be otherwise since we do not as yet know the style of deformation along a consuming place boundary. We have few indications of the relative importance of the accreting and erosional mechanisms active along this boundary. The preliminary results of the Glomar Challenger's latest legs have placed the role and even the existence of the sedimentary accreting wedge in question. The only definite proof of compression and thrusting along the trenches lies in the earthquake fault-plane solution studies. Obviously then, any program capable of giving a complete tectonic and stratigraphic section across the deepest part of a trench deserves priority consideration.

But why choose the Hellenic Trench? There is still no clear consensus either on the nature and amount of relative motion

occurring along this boundary or on its evolution. Some scientists doubt that the relatively shallow 3 km-deep Mediterranean basin, which is choked up with sediments (up to 10 km), is of oceanic origin (Makris, 1976). They point out that the small size of the arc, its high curvature, the large amount of extensional tectonics behind it in the whole Aegean area, all suggest that the Hellenic Trench Arc is not strictly comparable to Pacific Island Arcs.

The important point, however, is the extraordinary phenomenological similarity between the Hellenic Arc and other active consuming plate boundaries. In particular, studies of earthquakes clearly show that the whole Hellenic Arc is overthrusting the floor of the Mediterranean Sea toward the southwest. The much shallower water depth of the Hellenic Trench (3 to 5 km instead of 7 to 10 km), is an advantage, as it allows us to obtain data of a higher resolution than in a very deep trench. The greater thickness of sediment is also very interesting to those studying the problem of disposal of huge amounts of sediments. Finally, there are the Messinian evaporites, deposited about five million years ago, which record in their morphology the stresses affecting the sea floor.

The HEAT Program

This, then, is the rationale for initiating the Hellenic Arc and Trench Program. A group of scientists met in Athens during the sixth Aegean Colloquium in September 1977 and proposed "to promote a coordinated multidisciplinary program of study of the Hellenic Arc and Trench in order to discover the geodynamic processes at work". In addition to advocating the study of detailed geology and geophysics of the Trench using sophisticated techniques such as manned submersibles, the group insisted on a global study of the Arc, under the sea as well as on land, with detailed surface studies and deep-sea investigating techniques. This paper concentrates primarily on the studies currently being carried out under the sea.

Since the FAMOUS (French American Mid-Ocean Undersea Study) program, American and French teams have been able to routinely conduct detailed stratigraphic and tectonic traverses of the deep-sea floor (see Fig. 2 and ARCYANA, 1975). Detailed investigations of the continental slope using submersibles have shown that it is possible to find large outcrop areas where the sub-bottom stratigraphic section can be observed, even in areas of high sedimentation. For example, a study of the steep Stoechades and Saint Tropez canyons on the Provence continental slope (between 1000 and 2500 m) showed that the stratigraphic section could be examined and sampled (Groupe Estocade, 1977) in an area where current sedimentation rates are tens of centimeters per thousand years.

But the area which can be investigated with such a high resolution is extremely small. In a single dive, a submersible can cover, on the average, about 2 km of the sea bottom and obtain four or five samples of rocks. In a one-month cruise one can hope to complete 15 to 20 dives covering about 30 to 40 km of a traverse 10 to 20 m wide. Any dive which is started in a quiet area of heavy sedimentation may very well turn out to be useless. Thus it is essential to use the submersible only for obtaining critical information in key areas previously defined by other means.

The basis for establishing a preliminary structural interpretation is a detailed morphologic framework. This interpretation may then be tested by investigations from a surface ship using high accuracy acoustic navigation. Cores, dredges, and camera stations can give essential information if they are located within a few tens to hundreds of meters within this detailed structural morphologic framework. They will confirm the presence of suspected outcrops and establish

Figure 2. Pillow lavas in FAMOUS area.

a preliminary stratigraphy; they may eventually indicate the presence of fault scarps. A deep-tow fish study helps to refine this intermediate scale investigation. The most important data generally include detailed, well positioned photographic coverage and deep-towed sub-bottom acoustic profiles of the first few meters of sediment.

Site Survey by R.V. Jean Charcot

A preliminary structural investigation has just been made in the Hellenic Trench. The R.V. Jean Charcot, equipped with a multi-narrow beam sounder, the Seabeam, made high resolution bathymetric maps of the four key areas shown in Figure 1. The maps were made at a scale of 1:20 000 with a 20 m contour interval. The Seabeam actually consists of the equivalent of 16 narrow beams sampling the bottom over an angular width of about 42° , that is, over a width equivalent to about three quarters of the water depth. Each traverse is made in such a way that it covers a lane immediately adjacent to the preceding one. Thus there is no interpolation in the compilation of the map, which results from a complete sounding of the bottom charted. The result is a real-time, high accuracy contoured map of the sea-floor which can be produced quite rapidly. The four surveys of Figure 1 were obtained in a total of 10 days of continuous mapping. We consider that the multi-narrow beam sounder will be for marine geology what aerial photography is now for land geology.

The Seabeam surveys established that the Hellenic Trench on the southwest side is morphologically very different from the Pliny and Strabo Trenches. Both sets of trenches are affected by intense tectonics, which can be deciphered in the

detailed morphology. Both sets show extremely steep, quasi vertical scarps and some well-developed, presumably active canyons. Thus, it now seems possible to observe and sample the stratigraphic section in place.

Studies of the fault-plane mechanisms of thrust type surface-earthquakes along the Hellenic Arc indicate that the motion is roughly SW-NE (McKenzie, 1972) and is almost perpendicular to the southwest Hellenic Trench, but approximately parallel to the southeast Pliny and Strabo Trenches. Furthermore, Le Pichon and Angelier (1978) have proposed that the rotation pole of the Hellenic arc with respect to the Mediterranean sea-floor is situated northwest near 40°N , 18°E . As a result, the direction of underthrusting turns progressively counterclockwise to the northeast along the Pliny and Strabo Trenches. The Jean Charcot cruise revealed that the Pliny and Strabo Trenches actually consist of short, narrow V-shaped en-echelon troughs within the main trench depression, the troughs being everywhere parallel to the average direction indicated by the earthquake fault-plane mechanism. This direction changes from about $\text{N}50^\circ\text{E}$ south of Crete to $\text{N}30^\circ\text{E}$ - $\text{N}20^\circ\text{E}$ south of Rhodes.

The survey results suggest that the morphology closely reflects the tectonic pattern and shows a striking difference between the Hellenic and the Strabo and Pliny Trenches. The first seems to be dominated by thrusting, whereas the latter probably represents transform trenches. One can consequently hope to decipher the major tectonics and structural differences between the two types of trenches through future investigations. Meanwhile, dredged samples obtained by British and French ships have confirmed that there are outcrops of Pliocene and Miocene rocks on the scarps of the

trenches. The results of recent deep-tow studies by a U.S. group confirm the presence of rugged relief. Clearly, a precise understanding of the tectonics of the Hellenic Arc and Trench may be obtained by geologists through direct observation in submersibles.

Future Plans

We are planning to make a number of dives with the French submersible *Cyana* in 1979, going down as deep as 2000 m to study the geological sections outcropping on the steep walls of the Hellenic, Pliny and Strabo Trenches. If the preliminary results prove fruitful, we hope to dispatch a bathyscaphe to make studies at a greater depth. Meanwhile, discussions with the JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) Active Margin Panel have led us to conclude that the lower reaches of the inland slope of the trenches south of the Hellenic Arc are sites where thick sections of tectonic mélanges might be reached by deep-sea drilling with the present capabilities of drilling technology.

The French submersible Cyana. (Photo courtesy E. Kristof of National Geographic)

The next obvious step is to investigate, with similar precision, a deep Pacific trench. While some drilling has already been done and relatively detailed surface ship studies have been carried out, the international scientific community has yet to concentrate its efforts on a well defined target and to fully utilize the potential of new, sophisticated techniques for sea bottom studies.

References

- ARCYANA, 1975, Transform fault and rift valley from bathyscaphe and diving saucer, *Science*, v. 190, p. 108-116.

- Groupe Estocade, 1977, Etude par submersible des canyons des Stoechades et Saint-Tropez, *C.R. Séan. Acad. Sci.*, Paris, t. 284, Sect. D, p. 1631-1634.

- Heirtzler, J.R. and van Andel, T.H., 1977, Project FAMOUS: Its origin, programs, and setting, *Geol. Soc. America Bull.*, v. 88, p. 481-487.

- Hsü, K.J. and Ryan, W.B.F., 1974, Deep-sea drilling in the Hellenic Trench, *Geol. Soc. Greece*, v. 10, p. 81-89.

- Le Pichon, X., 1975, Le projet FAMOUS: Pour quoi faire? *La Recherche*, v. 47, p. 674-677.

- Le Pichon, X. and Angelier, J., 1978, The Hellenic Arc and Trench System: a key to the neotectonic evolution of the Eastern Mediterranean area (in press).

- McKenzie, D.P., 1972, Active tectonics of the Mediterranean region, *Geophys. J.R. Astr. Soc.*, v. 30, p. 109-185.

- Makris, J., 1976, A dynamic model of the Hellenic Arc deduced from geophysical data, *Tectonophysics*, v. 36, p. 339-346.

- Ryan, W.B.F., 1970, The floor of the Mediterranean Sea, Ph.D. Thesis, Columbia Univ., New York, 196 p.

ABOUT THE AUTHORS:

Xavier Le Pichon, now professor at the Université Pierre et Marie Curie in Paris, France, first worked at the Lamont Doherty Geological Observatory, then moved to Brest where he founded the Scientific Department of the Centre Océanologique de Bretagne. He was scientific director of the French team of the FAMOUS expedition to the Mid Atlantic Rift and has since served as coordinator of the French scientific submersible program.

Professor K.J. Hsü, Chairman of the Geological Institute, Federal Institute of Technology, Zurich, Switzerland, is also President of the International Association of Sedimentologists (one of IUGS' affiliated associations). During the past ten years, Professor Hsü has concentrated his research work on elucidating the sedimentology of deep and shallow water sediments in the Eastern Mediterranean.