Cretaceous tectonic setting of Eratosthenes Seamount in the eastern Mediterranean Neotethys: initial results of ODP Leg 160

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Abstract Recent ODP traverse of boreholes on the northern flank of Eratosthenes Seamount in the eastern Mediterranean Sea encountered shallow marine carbonates of mid-Cretaceous (?) age, overlain first by bathyal chalks of Coniacian-Maastrichtian and Eocene ages, then by shallow-marine limestones of Miocene age. The succession is similar to that of the southern Levant, but is markedly different from southern Cyprus. The results suggest that Eratosthenes Seamount formed part of the divergent African margin during the Mesozoic. It was submerged in the Late Cretaceous, then uplifted by the Miocene. Neogene subduction along the Cyprean active margin brought the Eratosthenes Seamount into incipient collision with Cyprus.

Keywords: Neotethys, Eastern Mediterranean, Southern Levant, Eratosthenes Seamount, Cyprus, Tectonics, Geodynamics.

Résumé

Tectonique néotéthysienne crétacée de mont Eratosthène en Méditerranée orientale : premiers résultats du Leg ODP 160

Les forages réalisés le long du flanc nord du mont Eratosthène au cours de la récente campagne ODP entreprise en Méditerranée orientale, ont rencontré des carbonates à faciès peu profonds d'âge probable Crétacé moyen, surmontés successivement par des craies bathyales du Coniacien-Maastrichtien et éocènes, puis par des calcaires peu profonds d'âge miocène. Cette succession est semblable à celle rencontrée dans la partie méridionale du Levant, mais est sensiblement différente de celle de la partie méridionale de Chypre. Ces résultats impliquent que le mont Eratosthène faisait partie intégrante, au cours du Mésozoïque, de la marge divergente africaine. Il fut ensuite submergé à la fin du Crétacé, puis soulevé au cours du Miocène. La subduction néogène le long de la marge active de Chypre, a conduit à un début de collision avec l'île de Chypre.

Mots clés : Néotéthys, Méditerranée orientale, Sud Levant, Mont Eratosthène, Chypre, Tectonique, Géodynamique.

Version française abrégée

La marge continentale sud-levantine et le bassin adjacent de la Méditerranée sud-orientale (**fig. 1**) représentent des reliquats bien conservés de la marge continentale méridionale de la Néotéthys centrale. Cette région a fonctionné comme une marge divergente depuis le Trias et elle représente encore de nos jours une zone de transition entre le domaine continental et le domaine océanique. En bordure NW du bassin méditerranéen sud-oriental, se trouvent l'île de Chypre et le mont Eratosthène. Au sein de l'ensemble sud-levantin, l'île de Chypre se singularise par ses caractéristiques géologiques particulières, et la frontière géologique entre les plaques tectoniques africaine et eurasiatique est localisée entre cette île et le Sud Levant. Le mont Eratosthène, qui n'a été affecté ni par l'épais-

Note

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se couverture sédimentaire du cône profond du Nil, ni par la couche d'évaporites messinienne, semble constituer un point-clé pour ce qui est de la détermination de la frontière de plaque en Méditerranée orientale. Située à quelque 100 km au sud de Chypre, cette structure de forme elliptique s'allonge sur près de 100 km et est large de 60 km (**fig. 1**). Elle repose sur des fonds de l'ordre de 2 500 m et culmine à 600 m de profondeur. Elle est ceinturée par des dépressions tectoniques, qui tendent à s'élargir vers l'ouest jusqu'à devenir ce qui fut considéré comme une plaine abyssale aux dimensions réduites. Les profils de sismique réfraction suggèrent que le mont Eratosthène se situe à l'aplomb d'une croûte continentale amincie, semblable à la croûte de l'île de Chypre, alors qu'une portion de croûte océanique le sépare du Sud Levant (Makris *et al.*, 1983). L'Arc de Chypre, qui représente l'expression incurvée d'une grande faille de chevauchement à pendage nord, sépare l'île de Chypre du mont Eratosthène. Un transect de forages profonds a été réalisé sur le mont Eratosthène en avril 1995, au cours du Leg ODP 160 (Emeis *et al.*, 1996).

Le forage ODP 967, implanté sur le versant nord du mont Eratosthène par des fonds de 2 500 m, a atteint 600 m de profondeur. Après avoir traversé près de 100 m de sédiments plio-quaternaires et 25 m de carbonates micritiques d'âge fini-miocène, le forage a rencontré, jusqu'au niveau -446 m, des craies bathyales d'âge Crétacé moyen (Albien ?) et Coniacien-Maastrichtien, l'ensemble reposant sur des calcaires marins de caractère peu profond. Aucun fossile datable n'ayant été trouvé dans cette couche calcaire caractérisant la partie inférieure du forage, son attribution au Crétacé moyen constitue une hypothèse de travail (**fig. 2**). La possibilité d'une séquence marine peu profonde d'âge Crétacé moyen, ainsi que l'absence d'ophiolites, illustrent la similitude géologique de cette structure avec le Sud Levant et la différence d'avec Chypre.

Les découvertes du Leg ODP 160 suggèrent que le mont Eratosthène représentait, au Crétacé moyen, une structure marine peu profonde située au large de l'Afrique, et ayant subsidé jusque dans les fonds bathyaux au cours du Sénonien (Dubertret, 1955; Delaune-Mayere *et al.*, 1976). Ce mont a conservé sa position bathyale pendant l'Eocène, mais ensuite, tandis que l'Afrique et l'Anatolie dérivaient l'une vers l'autre, le bassin de Chypre-Eratosthène s'est refermé. Le bloc d'Eratosthène a alors été éjecté sous le bloc chypriote, probablement au cours des temps pliocènes, entraînant le dernier soulèvement de l'île de Chypre (Robertson et al., 1995a). Les fossés tectoniques ceinturant le mont Eratosthène peuvent être considérés comme l'expression de sa subsidence quaternaire. La faille inverse à pendage nord entre Chypre et Eratosthène pourrait représenter la trace de la subduction vers le nord qui consuma les fragments de croûte néotéthysienne.

INTRODUCTION

The continental margin of the southern Levant, namely Israel and northeastern Egypt, and the adjacent marine basin of the southeastern Mediterranean Sea, are well-preserved remnants of the southern continental margin of the central Neotethys (**fig. 1**). The region has existed as a divergent margin since the Triassic, and even today it represents an important geomorphic and tectonic feature separating land and sea. The southeastern Mediterranean Sea includes the island of Cyprus and the Eratosthenes Seamount. The main purpose of this paper is to highlight the principal features of the Cretaceous – Early Tertiary sequence of the northern slope of the Eratosthenes Seamount, and to contrast it with contemporaneous sedimentary successions of the southern Levant and southern Cyprus. A Mid-Late Cretaceous to Early Tertiary succession was encountered only in hole 967, while two other holes, 965 and 966, recovered mainly Miocene and Plio-Quaternary sediments, and are discussed elsewhere (Robertson *et al.*, 1995 a, Emeis *et al.*, 1996).

Located some 100 km south of Cyprus, the Eratosthenes Seamount is elliptical, nearly 100 km long and 60 km wide (**fig. 1**). It rises from depths of approximately 2,600 m to a maximum of ca. 600 m below sea level. It is surrounded by a series of faulted troughs, which widen westwards to become a small abyssal plain (Emery *et al.*, 1966; Krasheninnikov and Hall, 1994). The geophysical characteristics of the seamount were explored by Woodside (1977), and subsequent extensive geological and geophysical surveys were reported by Sage *et al.* (1988), Sage and Letouzey (1990), Krasheninnikov and Hall (1994), Limonov *et al.* (1994), and Robertson *et al.* (1995b). A north–south transect of holes was drilled by the Ocean Drilling Program (Leg 160) in April 1995 (Robertson *et al.*, 1995 a; Emeis *et al.*, 1966).

REGIONAL GEOLOGICAL SETTING

Cretaceous geology of the southern Levant

The geological sequence of the southern Levant is floored by Precambrian series of the Arabo-Nubian Massif overlain by a Palaeozoic sedimentary cover. This succession underwent extensive erosion in the Jurassic (Weissbrod, 1981; Garfunkel and Derin, 1984). The Mesozoic is dominated by shallow-marine sediments, including limestones, dolomites, marls, shales, sandstones, and minor evaporites. Coastal and continental shelf exploration boreholes reveal sedimentological evidence of northwestward deepening of the marine environment (Bein and Gvirtzman, 1977). Seismic surveys across the distal continental margin off Israel further indicate that the Early. Mid-Cretaceous depositional environment was hemipelagic (Mart, 1994). On land there was then a switch to pelagic chalk that was deposited in the Coniacian to Middle Eocene. These sediments contain palaeontological evidence of upwelling in a bathyal environment, and reflect abrupt tectonic subsidence (Garfunkel and Derin, 1984; Almogi-Labin *et al.*, 1993). A regional depositional hiatus separates Middle Eocene siliceous chalk from Late Eocene to Miocene argillaceous chalks, and is associated with a strong seismic reflector (Gvirtzman, 1970). Seismic data show a westward thickness increase of the Senonian and Eocene sequences from 0.5 to 3 km (Mart, 1994).

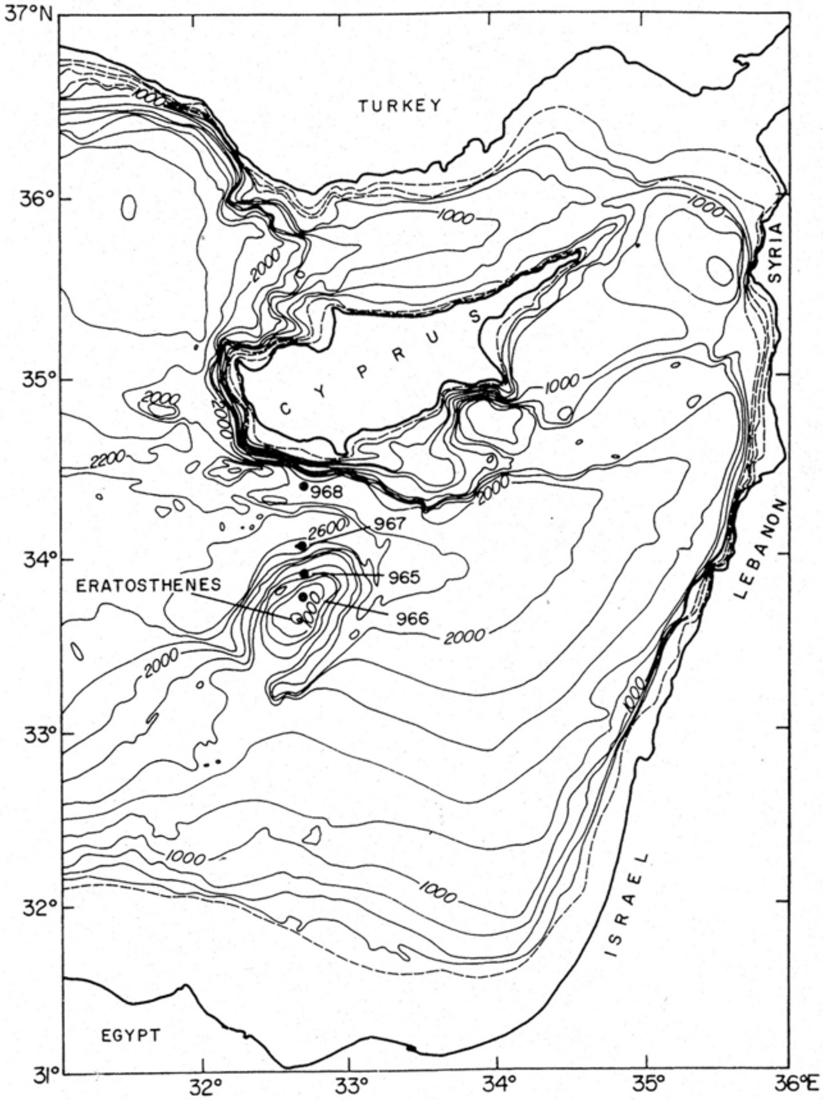

Fig. 1 Bathymetric chart of the eastern Mediterranean Sea, showing the location of the ODP drill sites.

Carte bathymetrique de la Méditerranée orientale, montrant l'emplacement des forages du leg ODP 160 de mont Eratosthène.

The structural setting of the southern Levant during the Late Mesozoic and Early Cenozoic is characterized by a series of asymmetrical anticlines and synclines, known as the 'Syrian Arc', that forms an elongate structural zone, ca. 1,000 km long and 150 km wide, from northern Sinai to southern Syria. Typically, an individual anticline is about 100 km long × 30 km wide, and had an original structural relief of 1,500–2,500 m. The Syrian Arc is interpreted as the product of regional tectonic compression that occurred in the late Turonian, and inverted a series of pre-existing normal faults and regional rifts at the margin of Neotethys (Cohen *et al.*, 1990). Freund *et al.* (1975) suggested that the Syrian Arc inversion reactivated Late Jurassic – Early Cretaceous faults, whereas Garfunkel and Derin (1984) suggested that the rifting occurred in the late Triassic – Early Jurassic, coevally with extensive volcanic activity (Steinitz *et al.*, 1982). Garfunkel (1991) associated Mid-Cretaceous volcanism in the Levant with a hot spot, while Freund *et al.* (1975) noted a southward increase of the K_2O/SiO_2 ratio, and associated the Early Cretaceous volcanism with possible Tethyan southward subduction. A Syrian Arc anticline that was discovered in the Mediterranean basin off northern Israel was folded during the Turonian. It was eroded in a shallow-marine or subaerial environment, then it subsided abruptly to basinal depths. The anticline was then covered by undeformed Senonian and Tertiary strata (Mart, 1994). This sequence of events suggests subsidence, which is consistent with the deposition of the bathyal Senonian chalk, and is probably coeval with genesis of ophiolites to the north, in Hatay and Baer-Bassit (Dubertret, 1955; Delaune- Mayere *et al.*, 1976; Whitechurch *et al.*, 1984). The abrupt change from Turonian tectonic compression to tectonic extension in the Senonian along the southern margin of the central Neotethys is apparently of regional significance.

Eratosthenes Seamount in the Cretaceous and Early Tertiary

The geophysical characteristics of the Eratosthenes Seamount are emphasized by its large underlying elliptical magnetic anomaly, nearly 200 km across (Woodside, 1977), which may relate to the existence of a magmatic body located at a depth of 2–4 km (Ben-Avraham *et al.*, 1976). Furthermore, seismic refraction data suggest that the seamount is founded on continental crust, which may be similar to the seismic characteristics of the continental crust which underlies southern Cyprus. Crust with seismic velocities of 6.7 km/s separates the seamount from the southern Levant (Makris *et al.*, 1983). Several seismic reflection surveys across Eratosthenes Seamount show a large, northward-dipping reverse fault between the seamount and Cyprus, along the Cyprean Arc (Biju-Duval *et al.*, 1979; Kempler and Ben-Avraham, 1987; Limonov *et al.*, 1994; Robertson *et al.*, 1995b). The Seamount is associated with a large magnetic and free-air gravimetric anomalies, but, surprisingly, it lacks a clear Bouguer gravimetric signature (Woodside, 1977).

Of the four ODP Leg 160 holes that were drilled between the Eratosthenes Seamount and Cyprus, one, hole 967, was drilled on the lower northern slope of Eratosthenes Seamount at a water depth of 2,500 m, and reached a depth of 600 m. This hole drilled under nearly 100 m of hemipelagic Plio-Quaternary sediments, and 25 m of latest Miocene-Early Pliocene micritic and recrystallized carbonates and gypsum. The borehole encountered bathyal pelagic chalks, first of Eocene, and then of Coniacian–Maastrichtian ages, down to 446 m below the sea floor. Micropalaeontological evidence indicates a depositional hiatus during the Palaeocene to middle Eocene (S. Spezaferri, Pers. Comm., 1996). Finally, the bit penetrated 154 m of shallow-marine limestones, probably Mid-Cretaceous (**fig. 2**), which could be Albian in age (S. Spezaferri, Pers. Comm., 1996). Our current interpretation is that after a period of shallow-marine deposition in the Mid-Cretaceous, the seamount was affected by a relative sea-level rise in the Senonian, and remained in bathyal depositional environment until the Miocene (Emeis *et al.*, 1966; Robertson *et al.*, 1995a).

Southern Cyprus in the Cretaceous

The Cretaceous history of southern Cyprus was dominated by the genesis of the Troodos ophiolite at ca. 92–88 Ma. Geochemical evidence indicates that the ophiolite formed by crustal accretion above a subduction zone (Pearce *et al.*, 1984). Recent work provides no support for an earlier concept of the ophiolite as a grossly allochthonous thrust sheet derived from the north, and most workers now assume (Robertson and Xenophontos, 1994) that the ophiolite formed and has remained in the southernmost Neotethys near its present position in the eastern Mediterranean. Notably, the Late Cretaceous metalliferous and pelagic sedimentary cover of the Troodos ophiolite is tectonically undisturbed in many areas, and there is no evidence that could reflect regional thrust emplacement. During the Late Cretaceous, the Troodos ophiolite docked with a contrasting litho-tectonic terrane, the Mamonia Complex of SW Cyprus. The latter unit is dominated by disrupted Mesozoic Neotethyan continental margin sediments, together with volcanics that represent remains of late Triassic marginal (*i.e.* near continental margin) oceanic crust, including MORB-type basalts (Malpas *et al.*, 1992). The ophiolite is depositionally overlain by metalliferous sediments ('umbers') of Cenomanian-Turonian age, that, in turn, pass upwards into radiolarites of Campanian age. Overlying these sediments are pelagic chalks of Maastrichtian to late Oligocene–Early Miocene age (Lefkara Formation) (Robertson *et al.*, 1991). Southern Cyprus was uplifted mainly in the Plio-Quaternary (Poole *et al.*, 1990). The succession in southern Cyprus therefore contrasts strongly with that of the Eratosthenes Seamount at ODP Hole 967. Notably, evidence of ophiolite formation and tectonic deformation, as recorded in SW Cyprus, is absent from Eratosthenes Seamount: there are no late Cretaceous radiolarian deposits. Pelagic carbonates are present in both areas, but the timing is different. Deposition between the Palaeocene and the Early Eocene was effectively continuous in southern Cyprus, while a major hiatus existed on the Eratosthenes Seamount.

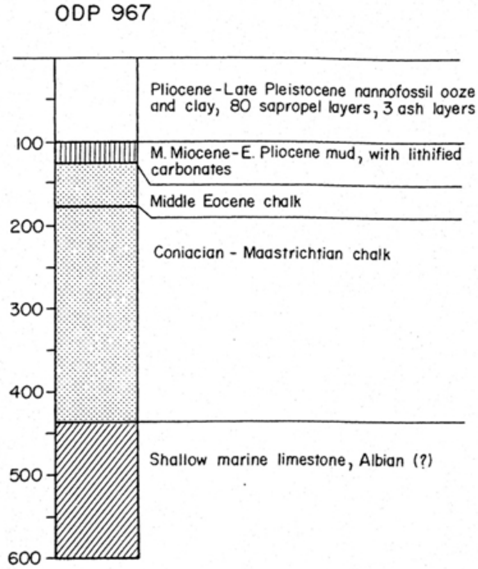

Fig. 2 Generalized log of ODP hole 967.

Log généralisé du forage ODP 967.

DISCUSSION AND CONCLUSIONS

The initial palaeogeography and tectonic setting of the Eratosthenes Seamount are obscure. The large magnetic anomaly of the Eratosthenes Seamount could suggest the existence of a magmatic intrusion in the basement, which is larger in diameter than the bathymetric feature (Ben-Avraham *et al.*, 1976). However, rocks related to the magnetic anomaly have not been recorded. The drilled lithology of the seamount indicates that after a period of shallow-marine limestone deposition in the Mid-Cretaceous, the seamount was affected by abrupt subsidence in the Senonian, and deposition of chalk occurred both then, and in the Maastrichtian and the Eocene. The palaeogeographic significance of the hiatus during the Palaeocene–Early Eocene is yet to be explored, but either slight tilt, which could have led to mud slumping, or deep-water current erosion of the soft sediments, seem plausible. The Eratosthenes Seamount was uplifted by the Miocene, and subsided again in the Pliocene (Robertson *et al.*, 1995a; Emeis *et al.*, 1996).

In the past, doubt has persisted as to the exact location of the tectonic plate boundary between Cyprus and Israel. Suggestions have included topographic lineaments within Cyprus (e.g. McKenzie, 1970; North, 1974); between Cyprus and the Eratosthenes Seamount (e.g. Dewey *et al.*, 1973; Biju-Duval *et al.*, 1977; Sengör *et al.*, 1984; Dercourt *et al.*, 1986, 1993), and even south of the Seamount (Ross and Uchupi, 1977). Some studies doubted whether any plate boundary actually exists near the Eratosthenes Seamount (e.g.

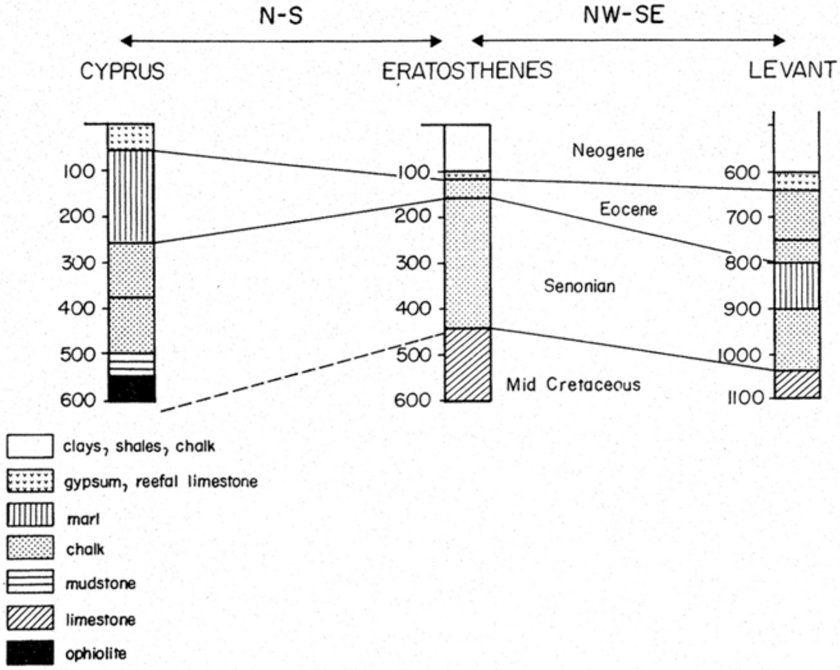

Fig. 3 Correlation of hole 967 with composite stratigraphic sections of southern Cyprus (after Robertson *et al.*, 1991) and northwestern Israel.

Corrélations du forage 967 avec les coupes stratigraphiques composites du sud de Chypre (d'après Robertson *et al.*, 1991) et du nord-ouest d'Israël.

Malovitsky *et al.*, 1975; Neev *et al.*, 1976). Makris *et al.* (1983) showed seismic refraction data supporting the existence of a segment of oceanic crust between Israel and the Eratosthenes Seamount. These authors also inferred that the continental crust underlying the Eratosthenes Seamount and Cyprus was continuous. Ben-Avraham *et al.* (1976) associated the large magnetic anomalies of the Eratosthenes Seamountwith magmatic rocks, correlated them with the Troodos ophiolites, and suggested that both originated as parts of the same tectonic feature.

If the Africa–Anatolia plate boundary did not exist between Cyprus and the Eratosthenes Seamount, then the sedimentary successions of the Eratosthenes Seamount and southern Cyprus would be expected to be similar. However, drilling at site 967 showed that the Late Cretaceous and Early Tertiar history of southern Cyprus do indeed differ drastically from that of Eratosthenes. Furthermore, the sedimentary succession of the Seamount is similar to that of the southern Levant, in that shallow-marine carbonates of mid-Cretaceous age are overlain by Senonian and Eocene pelagic chalks in both areas (**fig. 2**). The Palaeocene–Early Eocene hiatus, encountered in hole 967, is consistent with a Pre-Late Eocene regional unconformity encountered in the southern Levant (Gvirtzman, 1970). By contrast, noticeably absent from Eratosthenes Seamount is any evidence of ophiolitic lithologies, unlike southern Cyprus. The Eratosthenes Seamount is therefore assumed to be part of the African plate.

During the Late Cretaceous, a subduction zone separated the Eratosthenes Seamount from Cyprus, which, by then, already effectively formed part of the Eurasian plate (Kempler and Ben Avraham, 1987). It is possible that the present northward-dipping subduction zone was essentially a reactivation of this earlier, Late Cretaceous Benioff zone, which could also have been associated with the genesis of the Troodos as a supra-subduction zone ophiolite. The Plio-Quaternary uplift of southern Cyprus is believed to relate to its collision with the Eratosthenes Seamount (Gass and Masson-Smith, 1963; Robertson, 1990). Furthermore, the absence of a Bouguer gravimetric anomaly from the Eratosthenes Seamount could indicate that it is not gravimetrically compensated in the deeper crust, but it could instead have been dynamically supported as Africa and Anatolia began to undergo forceful collision (Limonov *et al.*, 1994, Robertson, 1995b). The seismic refraction evidence that the continental crust between Eratosthenes and Cyprus is continuous resulted from Plio-Quaternary thrusting of Eratosthenes under Cyprus.

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(1) K. C. Emeis, C. Richter, M. M. Blanc-Valleron, 1. Bouloubassi, H. J. Brumsack, A. Cramp, G. J. de Lange, E. Di Stefano, R. Flecker, E. Frankel, M. W. Howell, T. R. Janecek, M. J. Jurado-Rodriguez, A. E. S. Kemp, I. Koizumi, A. Kopf, C. O. Major, D. F. C. Pribnow, A. Rabaute, A. Roberts, J. H. Rullkötter, T. Sakamoto, S. Spezzaferri, T. S. Staerker, J. S. Stoner, B. M. Whiting.

REFERENCES

ALMOGI-LABIN, A., BEIN, A. and SASS, E., 1993. Late Cretaceous upwelling system along the southern Tethys margin (Israel): interrelationship between productivity, bottom water environments, and organic matter preservation, *Paleoceanography*, 8, pp. 671-690.

BEIN, A. and GVIRTZMAN, G., 1977. A Mesozoic fossil edge of the Arabian plate along the Levant coastline and its bearing on the evolution of the Eastern Mediterranean, *In*: BIJU-DUVAL, B. and MONTADERT, L., Eds., *Structural History of the Mediterranean Basins*, Technip, Paris, pp. 95-109

BEN-AVRAHAM, Z., SHOHAM, Y. and GINZBURG, A., 1976. Magnetic anomalies in the eastern Mediterranean and the tectonic setting of the Eratosthenes Seamount, *Geophys. J. Roy. Astr. Soc.*, 45, pp. 313-331.

BIJU-DUVAL, B., DERCOURT, J. and LE PICHON, X., 1977. From the Tethys ocean to the Mediterranean Sea: a plate tectonic model of the evolution of the western Alpine system. *In*: BIJU-DUVAL, B. and MONTADERT, L., Eds., *Structural History of the Mediterranean Basins*, Technip, Paris, pp. 143-164.

BIJU-DUVAL, B., LETOUZEY, J. and MONTADERT, L., 1979. Variety of margins and deep basins in the Mediterranean. *In*: WATKINS, J. S., MONTADERT, L. and DICKERSON, P. W., Eds., *Geological and Geophysical Investigations of Continental Margins*, Am. Assoc. Petrol. Geol. Mem., 29, pp. 293-318.

COHEN, Z., FLEXER A. and KAPTSAN, V., 1990. The tectonic mosaic of the southern Levant: implications for hydrocarbon prospects, *J. Petrol. Geol.*, 13, pp. 437-462.

DELAUNE-MAYERE, M., MARCOU, J., PARROT, J. F. and POISSON, A., 1976. Modèle d'évolution mésozoïque de la paléo-marge téthysienne au niveau des nappes radiolaritiques et ophiolitiques du Taurus Lycien d'Antalya et du Baër-Bassit. *In*: BIJU-DUVAL, B. and MONTADERT, L., Eds., *Structural History of the Mediterranean Basins*, Technip, Paris, pp. 73-77.

DERCOURT, J., ZONENSHAIN, L. P., RICOU, L. E., LE PICHON, X., KNAPPER, A. L., GRANDIAIAQUET, C., SBORTSHIKOV, I. M., GEYSSANT, J., LEPVRIER, C., PECHERSKY, D. H., BOUYLIN, J., BAZHENOV, M. L., LAUER, J. P. and BIJU-DUVAL, B., 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. *Tectonophysics*, 123, pp. 241-315.

DERCOURT, J., RICOU, L. E. and VRIELYNCK, B., Ed., 1993. *Atlas Tethys, Palaeoenvironmental Maps, Explanatory Notes*, Technip, Paris.

DEWEY, J. F., PITMAN, W. C., RYAN, W. B. F. and BONIN, J., 1973. Plate tectonics and the evolution of the Alpine system, *Geol. Soc. Am. Bull.*, 84, pp. 3137-3180.

DUBERTRET, L., 1955. Géologie des roches vertes du nord-ouest de la Syrie et du Hatay (Turquie), *Notes Mém. Moyen-Orient*, 6, 227 pp.

EMEIS, K. C., ROBERTSON, A. H. F. and RICHTER, C. and the Shipboard Science Party, 1996. *Proceedings of the Ocean Drilling Program*, 160, Initial Reports, ODP College Station, TX, 972 p.

EMERY, K. O., HEEZEN, B. C. and Allan, T. D., 1966. Bathymetry of the eastern Mediterranean Sea, *Deep-Sea Res.*, 13, pp. 173-192.

FREUND, R. GOLDBERG, M. WEISSBROD, T., DRUCKMAN, Y. and DERIN, B., 1975. The Triassic Jurassic structure of Israel and its relation to the origin of the eastern Mediterranean, *Geol. Surv. Israel Bull.*, 65, pp. 1-26.

GARFUNKEL, Z., 1991. Darfur-Levant array of volcanics – a 140-Ma-long record of a hot spot beneath the African–Arabian continent, and its bearing on Africa's absolute motion, *Israel J. Earth Sci.*, 40, pp. 135-150.

GARFUNKEL, Z. and DERIN, B., 1984. Permian – Early Mesozoic tectonism and continental margin formation in Israel and its implications for the history of the eastern Mediterranean. *In*: DIXON, J. E. AND ROBERTSON, A. H. F., Eds., The *Geological Evolution of the Eastern Mediterranean*, Blackwell, Oxford, pp. 187-201.

GASS, I.G. and MASSON-SMITH, D., 1963. The geology and gravity anomalies of the Troodos Massif, Cyprus, *Phil. Trans. Roy. Soc. London*, 255, pp. 417-467.

GVIRTZMAN, G., 1970. The Saqiye Group (late Eocene to early Pleistocene) in the Coastal Plain and HaShephela regions, *Geol. Surv. Israel Bull.*, 51, pp. 1-180.

KEMPLER, D. and BEN-AVRAHAM, Z., 1987. The tectonic evolution of the Cyprean arc, *Ann. Tectonicae*, 1, pp. 58-71.

KRASHENINNIKOV, V. A. and HALL, J. K., Ed., 1994. *Geologic Structure of the Northeastern Mediterranean*, Historical Productions-Hall Ltd., Jerusalem, 396 p.

LIMONOV, A. F., WOODSIDE, J. M. and IVANOV, M. K., Ed., 1994. Mud volcanism in the Mediterranean and Black Seas and shallow structure of the Eratosthenes Seamount, UNESCO Reports in Marine Science, 64, Paris, 173 p.

MAKRIS, J., BEN-ABRAHAM, Z., BEHLE, A., GINZBURG, A., GIESE, P., STEINMETZ, L., WHITMARSH, R. B. and ELEFTHERIOU, S., 1983. Seismic refraction profiles between Cyprus and Israel and their interpretation, *Geophys. J. R. Astr. Soc.*, 75, pp. 575-591.

MALOVITSKY, Y. P., EMELYANOV, E. M., KAZAKOV, O. V., MOSKALENKO, V. N., OSIPOV, G. V., SHIMKUS, K. M. and CHUMAKOV, I. S., 1975. Geological structure of the Mediterranean sea floor (based on geological and geophysical data), *Mar. Geol.*, 18, pp. 231-261.

MALPAS, J., XENOPHONTOS, C. and WILLIAMS, D., 1992. The Ayia Varvara formation of SW Cyprus: a product of complex collisional tectonics, *Tectonophysics*, 212, pp. 193-211.

MART, Y., 1994. The tectonic origin of the Senonian marine basin underneath the southeastern Mediterranean Sea, *Tectonophysics*, 234, pp. 5-18.

MCKENZIE, D.P., 1970. The plate tectonics of the Mediterranean region, *Nature*, 226, p. 239.

NEEV, D., ALMAGOR, G., ARAD, A., GINZBURG, A. and HALL., J.K., 1976. The geology of the southeastern Mediterranean. *Geol. Surv. Israel Bull.*, 68, 51 pp.

NORTH, R. G., 1974. Seismic slip rates in the Mediterranean and Middle East, *Nature*, 252, pp. 560-563.

PEARCE, J. A., LIPPARD, S. J. and ROBERTS, S., 1984. Characteristics and tectonic significance of supra-subduction zone ophiolites, *Spec. Publ. Geol. Soc. London.*

POOLE, A. J., SHIMMIELD, G. B. and ROBERTSON, A. H. F., 1990. Late Quaternary uplift of the Troodos ophiolite, Cyprus: uranium-series dating of Pleistocene coral, *Geology*, 18, pp. 894-897.

ROBERTSON, A. H. F., 1990. Tectonic evolution of Cyprus. *In*: MALPAS, J. *et al.*, Eds., *Ophiolites and Oceanic Lithosphere*, Cyprus Geological Survey Department, Nicosia, pp. 235-252.

ROBERTSON, A. H. F. and XENOPHONTOS, C., 1994. Development of concepts concerning the Troodos ophiolite and adjacent units in Cyprus, *In*: PRICHARD, H. M. *et al.*, Eds., *Magmatic Processes and Plate Tectonics*, Geol. Soc. London Spec. Pub., 76, pp. 85-119.

ROBERTSON, A. H. F., CLIFT, P. D., DEGNAN, J. and JONES, G., 1991. Palaeogeographic and Palaeotectonic evolution of the eastern Mediterranean Neotethys, *Palaeogeogr., Palaeoclim., Palaeoecol.*, 87, pp. 289-343.

ROBERTSON, A. H. F., EMEIS, K. C., RICHTER, C. and the Shipboard Science Party, 1995a. Evidence of collisional processes associated with ophiolitic obduction in the eastern Mediterranean: results from Ocean Drilling Program Leg 160, *GSA Today*, 5, pp. 213, 219-221.

ROBERTSON, A. H. F., KIDD, R. B., IVANOV, M. K., LIMONOV, A. F., WOODSIDE, J. M., GALINDO-ZALIVAR, J. and NIENTO, L., 1995b. Eratosthenes Seamount, easternmost Mediterranean: Evidence of active collapse and thrusting beneath Cyprus, *Terra Nova*, 7, pp. 254-264.

ROSS, D.A. and UCHUPI, E., 1977. Structure and sedimentary history of southeastern Mediterranean Sea, *Am. Assoc. Petrol. Geol. Bull.*, 61, pp. 872-902.

SAGE, L. and LETOUZEY, J., 1990 Convergence of the African and Eurasian Plate in the eastern Mediterranean, *In*: LETOUZEY, J., Ed., Petroleum and Tectonics in Mobile Belts; *Proceedings of the IFP Exploration and Production Research Conference*, Technip, Paris, France, pp. 49-68.

SAGE, L., LÈTOUZEY, J. and MONTADERT, L., 1988. Geological structure of the deep eastern Mediterranean Sea (east of 250E), Rapp. Comm. Int. Mer Medit., 3, 1, p. 103 (abstract).

SENGÖR, A.M.C., YILMAZ, Y. and SÜNGÜRLÜ, O., 1984. Tectonics of the Mediterranean Cimmerides: nature and evolution of the westem termination of the Paleo-Tethys, *In*:. DIXON, J. E. and ROBERTSON, A. H. F., Eds., *The Geological Evolution of the Eastern Mediterranean*, Geol. Soc. London, Spec. Pub. 17, Blackwell, Oxford, pp. 77-112.

STEINITZ, G., GVIRTZMAN, G. and LANG, B., 1982. Evaluation of K-Ar ages of the Asher volcanics, Current Research 1982, Geological Survey of Israel, pp. 34-38.

WEISSBROD, T., 1981. The Paleozoic of Israel and adjacent countries, Geol. Surv. Israel Report MP 600/81, 276 pp (in Hebrew, abstract in English).

WHITECHURCH, H., JUTEAU, T. and MONTIGNY, R., 1984. Role of the eastern Mediterranean ophiolites (Turkey, Syria, Cyprus) in the history of the Neo-Tethys, *In*: DIXON, J. E. and ROBERTSON, A. H. F., Eds., *The Geological Evolution of the Eastern Mediterranean*, Geol. Soc. London Spec. Pub 17, Blackwell, Oxford, pp. 301-318.

WOODSIDE, J. M., 1977. Tectonic elements and crust of the eastem Mediterranean Sea, *Mar. Geophys. Res.*, 3, pp. 317-354.