Robertson, A.H.F., Emeis, K.-C., Richter, C., and Camerlenghi, A. (Eds.), 1998
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 160

53. ERATOSTHENES SEAMOUNT: THE POSSIBLE SPEARHEAD OF INCIPIENT CONTINENTAL COLLISION IN THE EASTERN MEDITERRANEAN[1]

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ABSTRACT

We compare earlier works, based on available geophysical data and plate kinematic considerations, about the origin and evolution of the Eratosthenes structure within the Eastern Mediterranean tectonic framework, with data from Ocean Drilling Program (ODP) Leg 160. The model under discussion is supported by the ODP data regarding the late evolution of the Eratosthenes Seamount; however, deeper drilling is needed for better understanding of the early history of this structure.

Analysis of the available seismic reflection, seismic refraction, and magnetic data in view of the regional geologic history suggests that the deep structure of the Eratosthenes Seamount originated in early Mesozoic time. The ODP data confirm that the Eratosthenes structure, which was located a few hundred kilometers away from the Late Cretaceous/early Tertiary active plate boundary, was not affected by the major tectonic events of that period. The data also reflect the existence of the Eratosthenes structural high already in Late Cretaceous and Eocene times. The ODP data corroborate that the Africa-Anatolia plate boundary was reactivated as the Cypriot Arc, between Cyprus and the Eratosthenes structure, in the late Miocene, through subduction of remnant oceanic lithosphere of the Mesozoic Neotethys beneath Cyprus.

The absence of Messinian evaporites on the Eratosthenes Seamount and within the surrounding depression was confirmed by Leg 160 data. Similar data led us to infer that this area formed a Messinian island, which subsided in post-Messinian time. The post-Messinian subsidence shaped the seamount and surrounding natural moat, which in turn are superimposed on the Eratosthenes structural high. The Miocene–Pliocene subduction along the Cypriot Arc changed into collision between Cyprus and the Eratosthenes structure after the elimination of oceanic lithosphere from this junction. The Cyprus-Eratosthenes collision triggered the extreme uplift of southern Cyprus at about 1.5–2 Ma. Pulsed uplift of Cyprus, apparently accompanied by pulsed subsidence of the Eratosthenes area, marks incipient continental collision in the Eastern Mediterranean. The Eratosthenes Seamount, therefore, is the possible spearhead of incipient continental collision and is the best candidate for the study of collisional processes in this area.

INTRODUCTION

The Eratosthenes Seamount, located between Cyprus and the Nile Cone, is one of the more prominent physiographic features in the southeastern Mediterranean (Fig. 1; Kempler and Ben-Avraham, 1987a). It is an elevated structure, which rises more than 1500 m above its surroundings, surrounded by a deep natural moat. Seismic refraction reveals that the Eratosthenes Seamount is underlain by a continental crust greater than 20 km thick, which is comparable to that of Cyprus and the southern Levant coast. The thickness of the Eratosthenes crust, which includes a significant layer with seismic velocities below 6.7 km/s, is in contrast to the thinned, high-velocity crust that occurs elsewhere in the southeastern Mediterranean (Makris et al., 1983). Although the lack of pronounced Bouguer gravity expression may rule out a lower crust root or flexural response to the topographic load (Woodside, 1976; Woodside et al., 1992; Makris and Wang, 1994), the differences in the velocity structure and thickness suggest a continental block within a zone of thinned-continental or oceanic crust (Garfunkel and Derin, 1984; Kempler and Ben-Avraham, 1987a). The Eratosthenes structure is also associated with a distinct magnetic anomaly that covers a larger area than that of the seamount (Fig. 2). The origin, detailed structure, and evolution of the Eratosthenes Seamount have not been fully understood to date.

Reviews of earlier works about the Neogenean Cypriot segment of the Africa-Eurasia plate boundary include those by Kempler (1986), Anastasakis and Kelling (1991), and others. Kempler and Ben-Avraham (1987a; 1987b) proposed that collision between the Eratosthenes Seamount and the central segment of the Cypriot Arc interrupts the process of subduction south of Cyprus. This concept was further integrated into the regional tectonic scheme by Robertson (1990). Several studies have suggested different tectonic models of the Eratosthenes Seamount and have shown that drilling on the seamount has become indispensable to gain further progress in this field (e.g., Hsü, 1992; Kempler and Garfunkel, 1992; Mart et al., 1992; Robertson, 1992). The orthodox view of the Eratosthenes Seamount as a part of the African plate that subducts northward beneath the Anatolian plate and collides with Cyprus, became the working assumption for Ocean Drilling Program (ODP) Leg 160.

The evaporite-free Eratosthenes Seamount has been considered a natural dipstick, which recorded the geologic history of the Eastern Mediterranean basin in a sedimentary succession that corresponds to a much thicker sedimentary section elsewhere in the basin, and a possible window for pre-Messinian rocks of the southeastern Mediterranean. Leg 160 provided a unique opportunity to examine the upper part of this sedimentary succession. The data largely support the model under discussion here, regarding the late evolution of the Eratosthenes Seamount. Nevertheless, deeper drilling is needed to better understand the early history of this structure.

THE BACKGROUND MODEL

Our earlier studies of the Eratosthenes Seamount and the Eastern Mediterranean tectonic history were based on available seismic reflection data from the Eratosthenes area, namely, the *Geol 1* multichannel seismic reflection profiles from a 1976 consortium of the Bureau d'Études Industrielles et de Cooperation de l'Institute Français du Petrol (BEICIP), Geophysical Offshore Exploration, Canada, and

[1]Robertson, A.H.F., Emeis, K.-C., Richter, C., and Camerlenghi, A. (Eds.), 1998. *Proc. ODP, Sci. Results*, 160: College Station, TX (Ocean Drilling Program).
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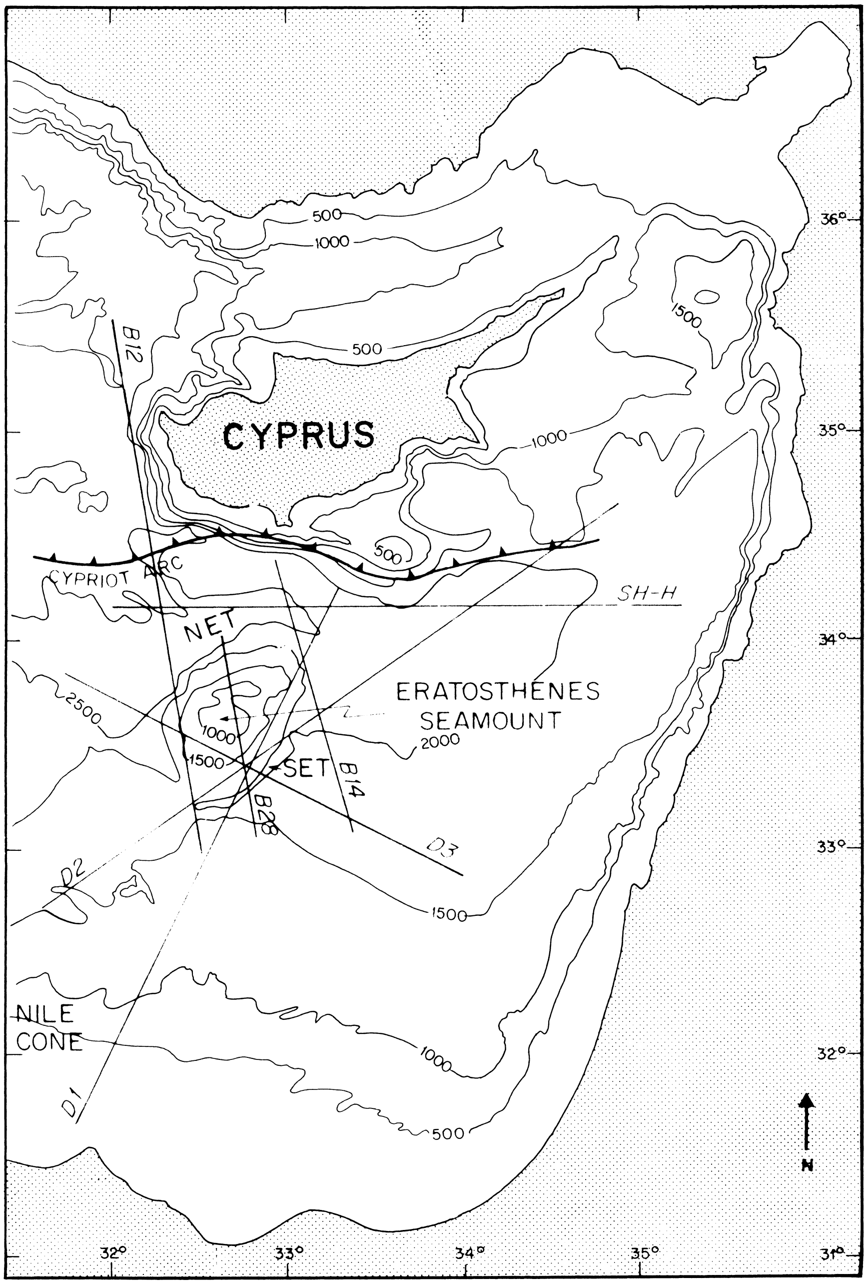


Figure 1. Bathymetry of the Eratosthenes area, simplified after Hall (1980, 1981), with location of sections and line drawings of BEICIP-GEO-RRI (B) and Shackleton (SH) seismic reflection profiles, and compiled cross sections (D). The natural moat around the Eratosthenes Seamount comprises the North Eratosthenes Trough (NET) and the South Eratosthenes Trench (SET).

Robertson Research International Ltd., United Kingdom (Kempler, 1986; 1994b); the *Shackleton* (Cambridge) profiles (Woodside and Williams, 1977); the *Chain* (Woods Hole) profiles (Ross and Uchupi, 1977); and the *Akademik Nikolaj Strakhov* (Russian Academy of Sciences) profiles (Kempler, 1994a). Combined with other geophysical data and with plate kinematic considerations, their analyses enabled us to identify major structural elements of different ages and to suggest a composite model for the origin and evolution of the Eratosthenes structure within the Eastern Mediterranean geologic framework (Kempler and Ben-Avraham, 1987a; Kempler, 1994b; Kempler and Garfunkel, 1995). This model is presented and later examined here in view of the data from Leg 160.

Indications for a Mesozoic Origin

The thick Messinian (late Miocene) evaporite sequence in the Mediterranean largely masks deeper structures. Nevertheless, analysis of the available seismic reflection, seismic refraction, and magnetic data in reference to regional geologic history suggests that the deep structure of the Eratosthenes Seamount originated in early Mesozoic time. The most prominent reflector in the Eastern Mediterranean is the top of the Messinian evaporite sequence (e.g., Ryan et al., 1971; Finetti and Morelli, 1973). However, although this reflector is the deepest one recorded in most of the available seismic reflection data, mainly the single-channel seismic reflection profiles (e.g., Ross and Uchupi, 1977), deeper reflectors appear in other surveys (e.g., Woodside and Williams, 1977) and the multichannel seismic reflection BEICIP profiles). Among these, we recognize a prominent reflector that rises several kilometers from beneath the base of the Messinian evaporites and from all directions toward the seamount (Figs. 3, 4). This reflector has been identified by Finetti and Morelli (1973, their fig. 40) and by Garfunkel and Almagor (1987). However, its age and its relation with more nearshore reflectors remain obscure.

The sedimentary section of the seamount is visible in the multichannel seismic reflection profiles to a depth of 5–6 s two-way traveltime (7–8 km). A few subparallel reflectors appear at various

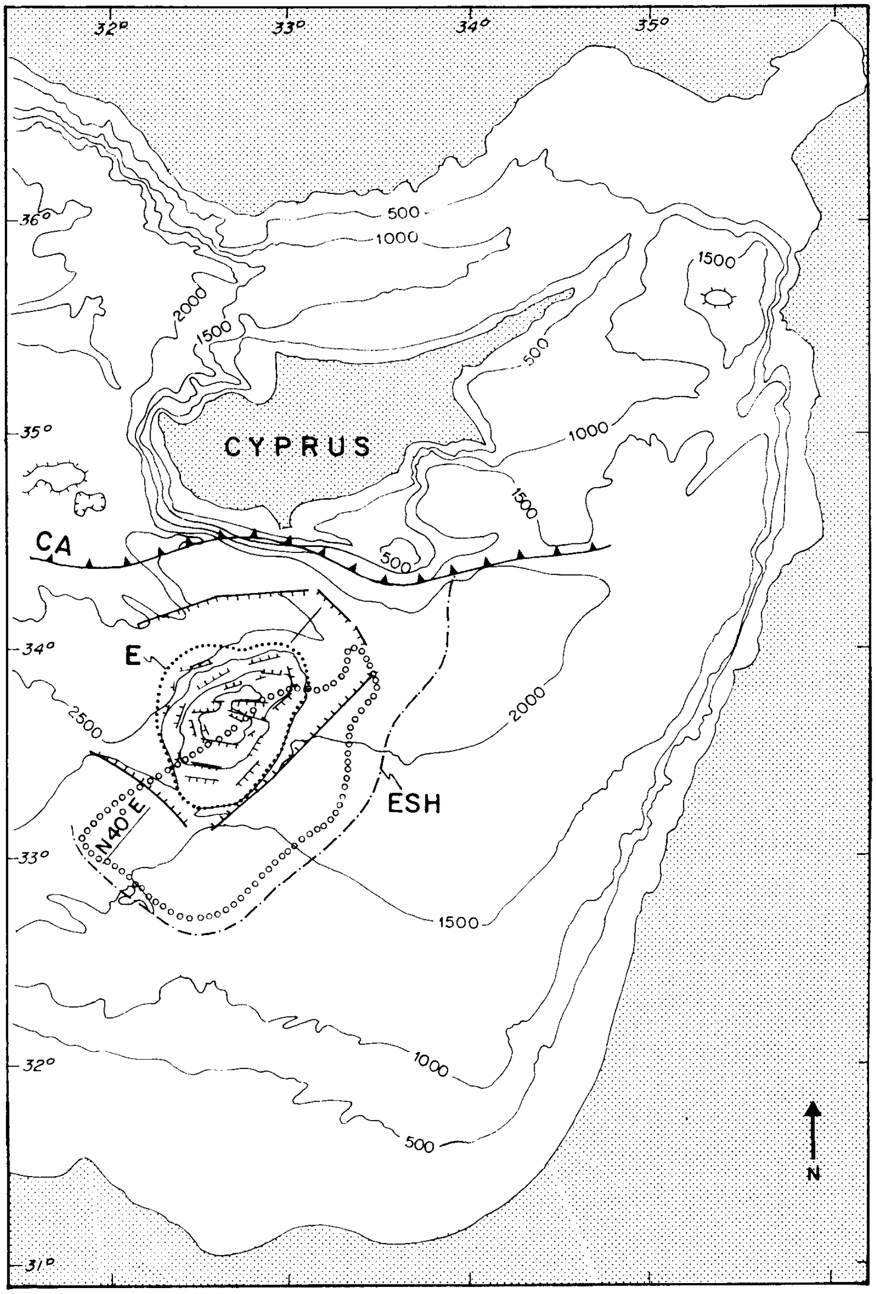


Figure 2. Structural elements in the Eratosthenes area. The Eratosthenes Seamount, E (dotted line) forms the central part of the larger Eratosthenes structural high, ESH (dots and dashes), on the southern side of the Cypriot Arc (CA; line with triangles). The superimposed quadrilateral depression is surrounded by steep faults (lines with tick marks). Note the good correlation between the ESH and the zero contour of the magnetic anomaly (line of circles). Bathymetry simplified after Hall (1980, 1981).

depths, dipping to the sides beneath the seamount flanks (Figs. 3, 4). The deepest reflector identified beneath the summit seems to be the continuation of the deep reflector that rises toward the seamount, although it is separated from the latter by steep faults along the outer rim of the surrounding natural moat. This reflector delineates a large, deep-seated structure, named here the Eratosthenes structural high (ESH in Fig. 2). The elevated part of this feature, elongated in a northeast–southwest direction, roughly coincides with the zero contour of the adjacent magnetic anomaly (Figs. 2, 3).

Based on modeling, Ben-Avraham et al. (1976) suggested that the significant magnetic anomaly in the vicinity of the Eratosthenes Seamount reflects a large, deep-seated, basic crustal structure on which the seamount is superimposed. Its magnetic characteristics, $D \approx 340°$ and $I \approx 46°$ (Ben-Avraham et al., 1976), yield a paleomagnetic pole at about 70°N, 290°E remarkably close to the $\alpha = 95\%$ field of the middle to late Triassic paleomagnetic poles of Africa (Fig. 5; Piper, 1988). Because late Triassic–Liassic times were periods of widespread volcanism on the adjacent lands (Delaune-Mayère et al., 1977; Robertson and Woodcock, 1980; Bonen, 1980; Garfunkel, 1989), the causative body of the Eratosthenes magnetic anomaly might well consist of volcanics of this age. Thus, we infer that the magnetized body formed in early Mesozoic time at the northern margin of the African plate and moved little relative to the plate since then. The proximity of the paleomagnetic poles indicates that the deviation of the magnetic vector from the north is a result of the overall motion of Africa since early Mesozoic time rather than local rotation. The location and dimensions of the Eratosthenes structural high coincide with both the continental block in the seismic refraction profile and the estimated magnetized body beneath the Eratosthenes Seamount (Ben-Avraham et al., 1976; Makris et al., 1983). Therefore, we suggest that this structure represents the Mesozoic basement of the complex Eratosthenes structure. The present seamount was apparently shaped by later tectonics.

After Garfunkel and Derin (1984), we suggest that the Eratosthenes structural high is partly a volcanic block, which formed at the Afroarabia continental margin during the early Mesozoic rifting

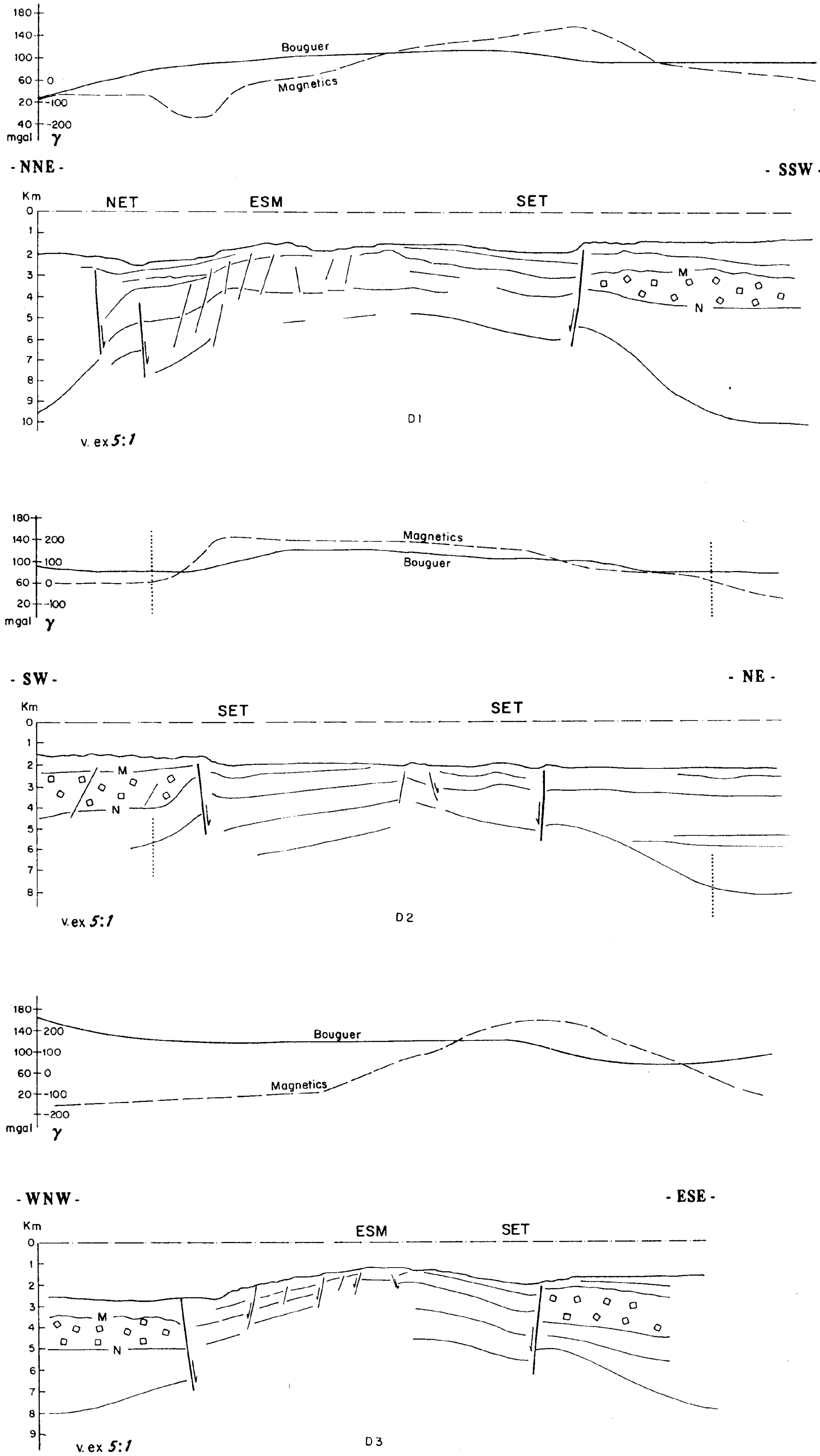


Figure 3. Compiled cross sections. ESM = Eratosthenes Seamount; NET = North Eratosthenes Trough; SET = South Eratosthenes Trench. For location, see Figure 1.

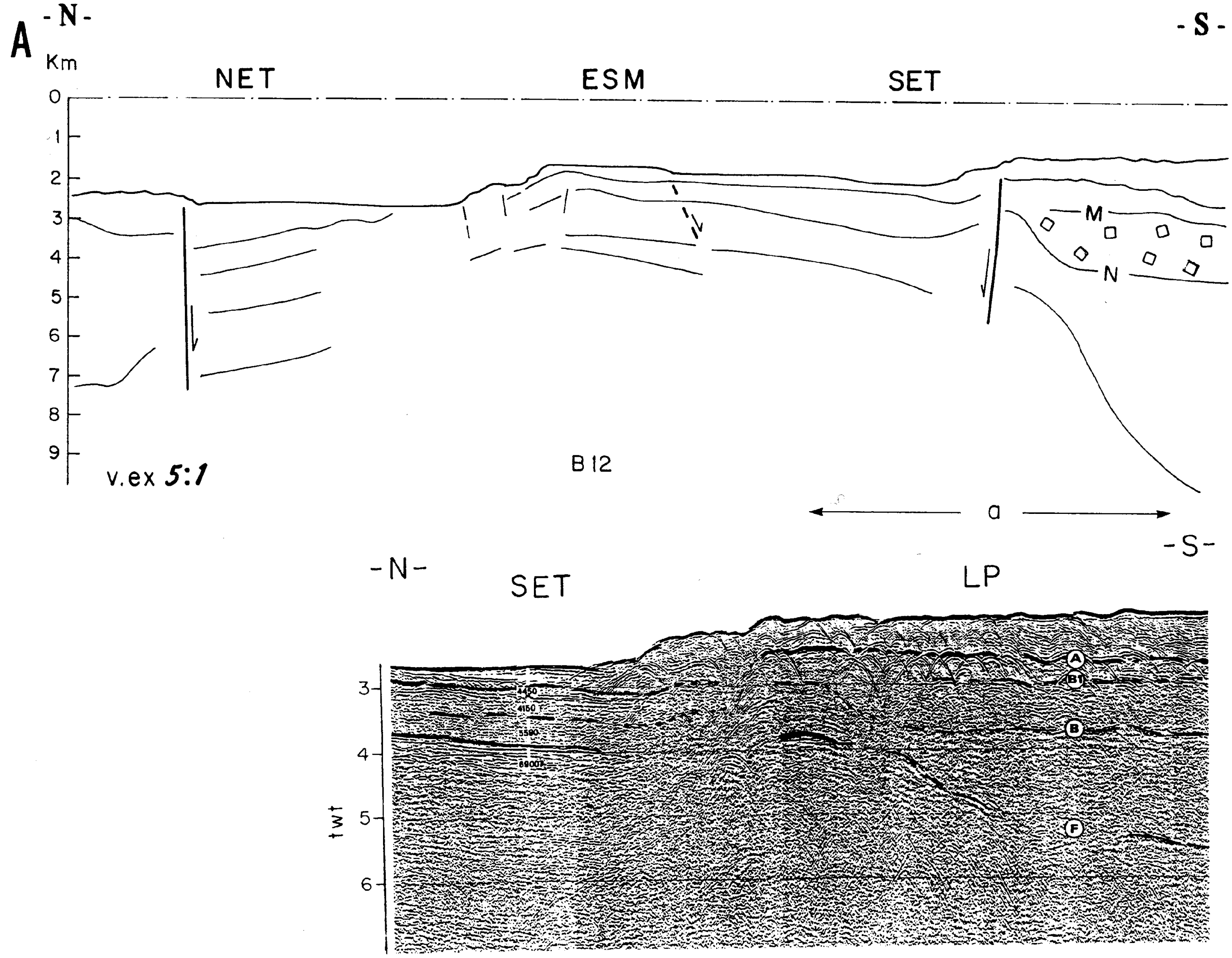


Figure 4. Line drawings of three BEICIP seismic reflection profiles (**A** = line 12, **B** = line 14, **C** = line 28) with sections of the seismic record (← a → indicates location along each line drawing). The available version includes BEICIP original interpretation, which was not always accepted by the author. ESM = Eratosthenes Seamount; NET = North Eratosthenes Trough; SET = South Eratosthenes Trench; LP = Levant Platform. For location, see Figure 1.

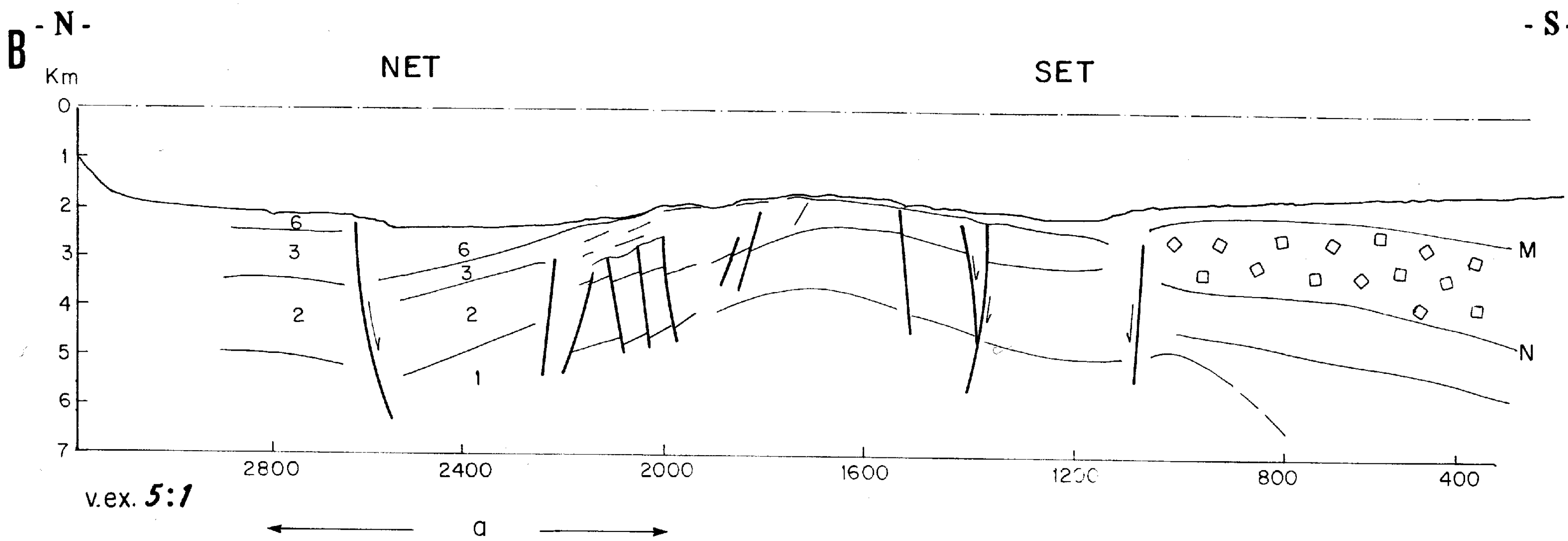
of this margin. Following further stretching and thinning of the area, it was stranded in the Eastern Mediterranean (cf. Krasheninnikov et al., 1994). During the Late Cretaceous and early Tertiary period, it was located a few hundred kilometers from the then-active plate boundary (Fig. 6; Kempler, 1994b; Kempler and Garfunkel, 1995). Therefore, the effect of the early stages of Africa-Eurasia convergence on this structure was practically insignificant.

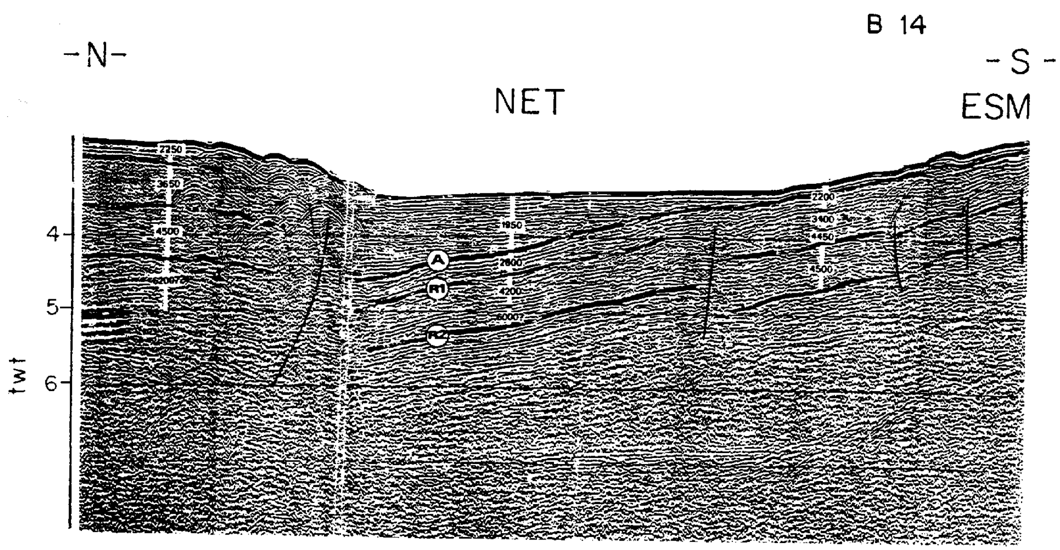
Tertiary Evolution

Significant influence of the regional tectonics on the Eratosthenes structure resumed with the Miocene formation of the Cypriot Arc along the Late Cretaceous plate convergence boundary. The approach of the Eratosthenes structure to the Cypriot Arc led to a change from subduction to collision along the reactivated plate boundary.

Africa-Eurasia plate convergence in the Eastern Mediterranean region was restricted to north of Cyprus throughout early Tertiary time (Kempler, 1994b; Kempler and Garfunkel, 1995). A dramatic change in the regional tectonic regime was associated with the development of major strike-slip systems around the Eastern Mediterranean, first the Dead Sea Transform, in Oligocene/Miocene time, and then the Anatolian Transform Fault System, in late Miocene time (Ketin, 1948; Freund et al., 1968, 1970; Garfunkel et al., 1981; Şengör et al., 1985; Barka, 1992). The westward escape of the Anatolia plate along the Anatolian Transform Fault System began in Serravalian time (Şengör et al., 1985). Because the Neogene to present plate boundary in the Eastern Mediterranean is found between Cyprus and the Eratosthenes Seamount, we suggested that the Late Cretaceous suture between the Troodos-Baer-Bassit ophiolite belt and the Levant basin was reactivated in relation to this motion of the Anatolian plate (Fig. 6; Kempler and Garfunkel, 1995). Plate convergence resumed along this segment of the Cypriot Arc through left-lateral oblique relative motion (Kempler and Garfunkel, 1994).

A strip of about 100 km of remnant Neotethys oceanic lithosphere, which probably persisted south of the Troodos massif since Late Cretaceous time, was subducted along the plate boundary in the late Miocene, and mostly in Pliocene time (Kempler, 1994b). Geologic evidence from Cyprus suggests that the process changed to underthrusting of thinned continental crust, which was related to serpentinite diapirism and pulsed uplift of the Troodos massif, in Pleistocene time (McCallum and Robertson, 1990; Robertson, 1990). Therefore, it seems that the Eratosthenes-Cyprus collision, which followed the elimination of oceanic lithosphere from this junction, trig-





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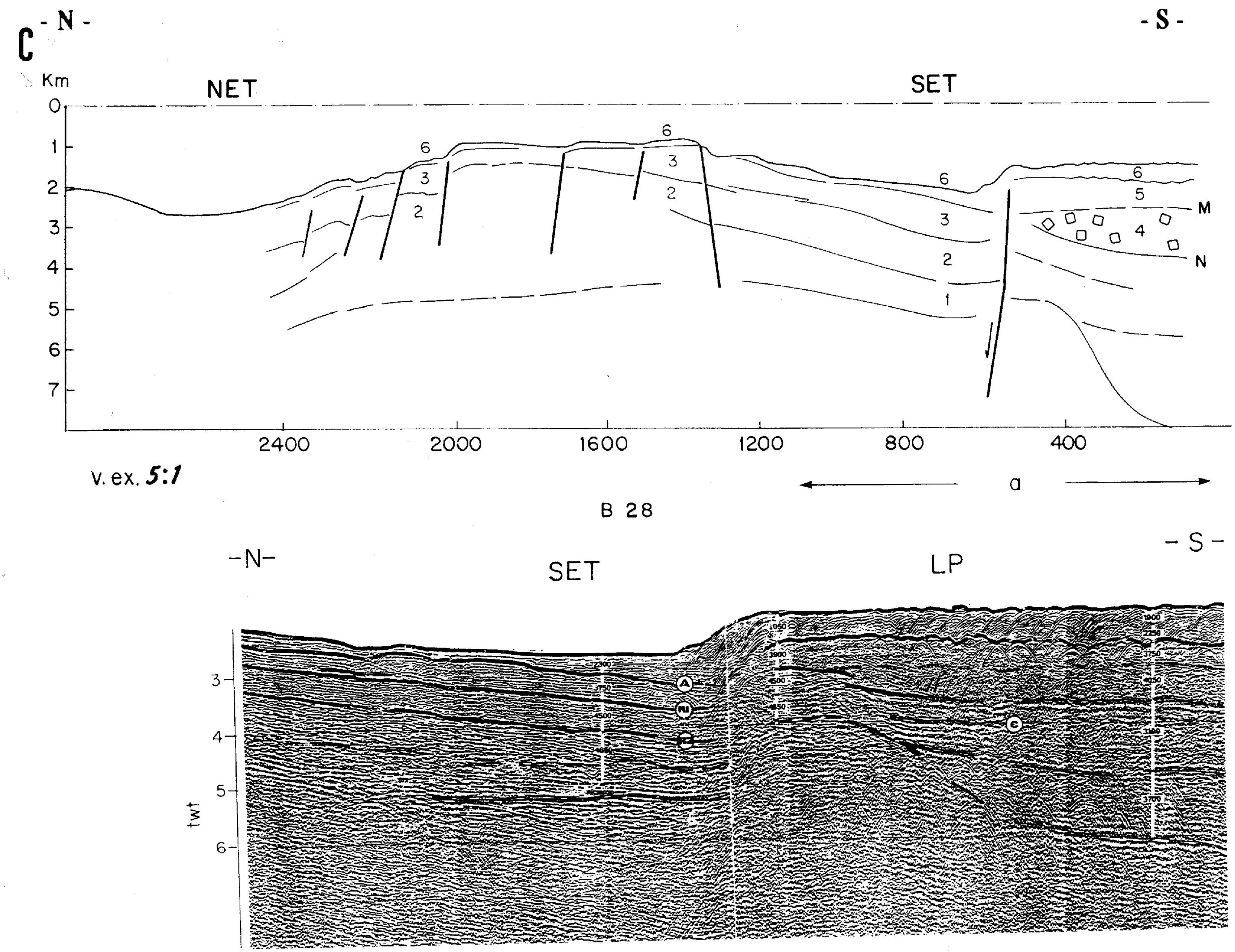

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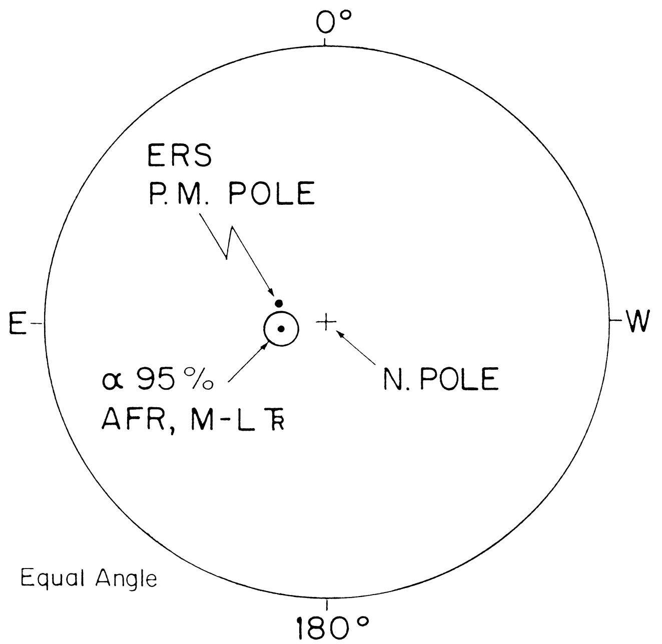

Figure 5. The Eratosthenes palaeomagnetic pole, calculated after Ben-Avraham et al. (1976), is adjacent to the α = 95% field of the middle to late Triassic palaeomagnetic poles of Africa, after Piper (1988).

gered the extreme uplift of southern Cyprus some 1.5–2 Ma. (Robertson, 1990; Kempler, 1994b; Kempler and Garfunkel, 1995).

The natural moat around the Eratosthenes Seamount comprises a rather narrow trench in the southeast and a relatively wide trough in the north. The latter widens to merge into the abyssal plain to the west. On the multichannel seismic reflection profiles, the deep structure of the moat seems to have been formed by downfaulting of the area enclosed by the steep faults at the outer rim. These faults displace the Eratosthenes basement reflector with a vertical throw of over 500 m (Figs. 3, 4). The inner side of the moat is continuous with the flanks of the seamount. Pinching out of the Messinian evaporites toward the outer rim of the southeastern trench causes a false picture of thrusting, which was widely accepted in earlier studies (e.g., Kempler, 1986). In fact, the steep faults delimit a large area with the seamount at its center in a quadrilateral depression elongated in a N40°E direction, which is superimposed on the Eratosthenes structural high (Fig. 2). The steepness and prominence of the faults that now surround this depression suggest that strike-slip motions were important at an early stage of the evolution of at least part of these faults as well.

The Eratosthenes Messinian Island

The central, upper part of the Eratosthenes structure lies above the evaporite deposition depth and actually formed an island in the Messinian sea. Post-Messinian subsidence of this area created the seamount with a surrounding natural moat. The Messinian evaporite sequence, up to 1500–2000 m thick in the Eastern Mediterranean, pinches out toward the outer rim of the quadrilateral depression verging on and above the steep faults that surround it. The absence of this sequence within the depression and on top of the seamount indicates that the area enclosed by the faults was above the Messinian sea level or evaporite deposition depth (Figs. 2, 3; Neev et al., 1976; Montadert et al., 1978; Sonnenfeld and Finetti, 1985; Kempler, 1994b). Given that a significant sea-level drop occurred during the Messinian (Hsü et al., 1973, 1977; Ryan, 1978; Cita, 1982), it follows that the subsidence of the Eratosthenes Seamount and surrounding depression, which were above their surroundings throughout the Messinian event, occurred in post-Messinian time. This subsidence of the present seamount relative to the peripheral part of the Eratosthenes structural high occurred in addition to the regional subsidence caused by rapid sea-level rise in early Pliocene. Though the cause of the seamount subsidence is not fully clear, we suggest that it occurred mainly through normal displacement on the steep faults that surround the complex. Normal faulting could be related to subduction-related bulging of the area.

According to this model, the presently submerged seamount was exposed above the Messinian sea with its peak, now about 700 m below sea level, standing some 1800 m above the evaporites, now some 500 m below the 2000-m-deep sea bottom. The base of the few hundred-meters-thick, post-Messinian sediments in the surrounding natural moat, at a present depth of about 2500 m, was also above the level of Messinian sea evaporite deposition. Therefore, the rim of the present depression approximately outlines the Messinian coast line around an exposed Eratosthenes mountain, or Messinian island (Fig. 7A). The present outer shoulders of the quadrilateral depression were below the Messinian sea level and were covered by evaporites. Uplift of the Eratosthenes Seamount above sea level at the end of the Miocene is also compatible with the finding of preserved pelagic oozes, which would otherwise be destroyed (Krasheninnikov et al., 1994). In this context, it is worthwhile to note Tanner and Williams' (1984) view of the Eratosthenes as a mount in the sea rather than as a seamount. This scenario is also compatible with Miocene formation and strike-slip motions on the steep faults, followed by their reactivation as dip-slip or oblique faults in post-Messinian times (Fig. 7B). The vertical motion that superimposed the quadrilateral depression over the Eratosthenes structural high is possibly a net displacement rather than the only vertical motion that has occurred on the steep faults.

We conclude that the absence of Messinian evaporites on the Eratosthenes Seamount and the surrounding depression indicates that the area enclosed by the steep faults was above the Messinian sea level (or evaporite deposition depth) and subsided in post-Messinian time, most probably through normal displacement on the faults. The rim of the present depression approximately outlines the coast line around the Eratosthenes Messinian island. This interpretation of the seismic reflection profiles does not rule out the possibility that non-evaporite Messinian sediments exist on the Eratosthenes Seamount and in the surrounding depression, similarly to Messinian dolomites and sabkha anhydrites on the continental shelf of Israel. Such rocks were drilled on that continental shelf at present depths of about 700 m, which is comparable to the Eratosthenes summit depth (Gvirtzman and Buchbinder, 1976; Kempler, 1994b). If found, Messinian rocks on the Eratosthenes Seamount would be expected to have derived from refilling stages in a deep-dry basin, a peripheral facies of a shallow, permanent basin, or a barred basin (e.g., Hsü et al., 1977; Gvirtzman and Buchbinder, 1977; Sonnenfeld, 1985).

Holocene Tectonic Framework

Incipient collision between the Eratosthenes structure and Cyprus probably began in Pleistocene time. As the dominant process in the recent tectonics of the Eastern Mediterranean, this collision affects the late evolution of both Cyprus and the Eratosthenes Seamount.

The central segment of the Cypriot Arc, between Cyprus and the Eratosthenes Seamount (Kempler and Ben-Avraham, 1987a; Anastasakis and Kelling, 1991), is located in a transition zone between active compression and probable subduction west of Cyprus, and diffuse transtension east of this island (Kempler, 1994a; 1994b). Collision between Cyprus and the Eratosthenes structure is marked by the seismic activity, and clearly affects the shape of the Cypriot Arc (Fig. 2; Kempler, 1986). Despite being a convergence zone, this segment of the plate boundary lacks the typical structure of other subduction zones. It shows compression in a north-south direction and some

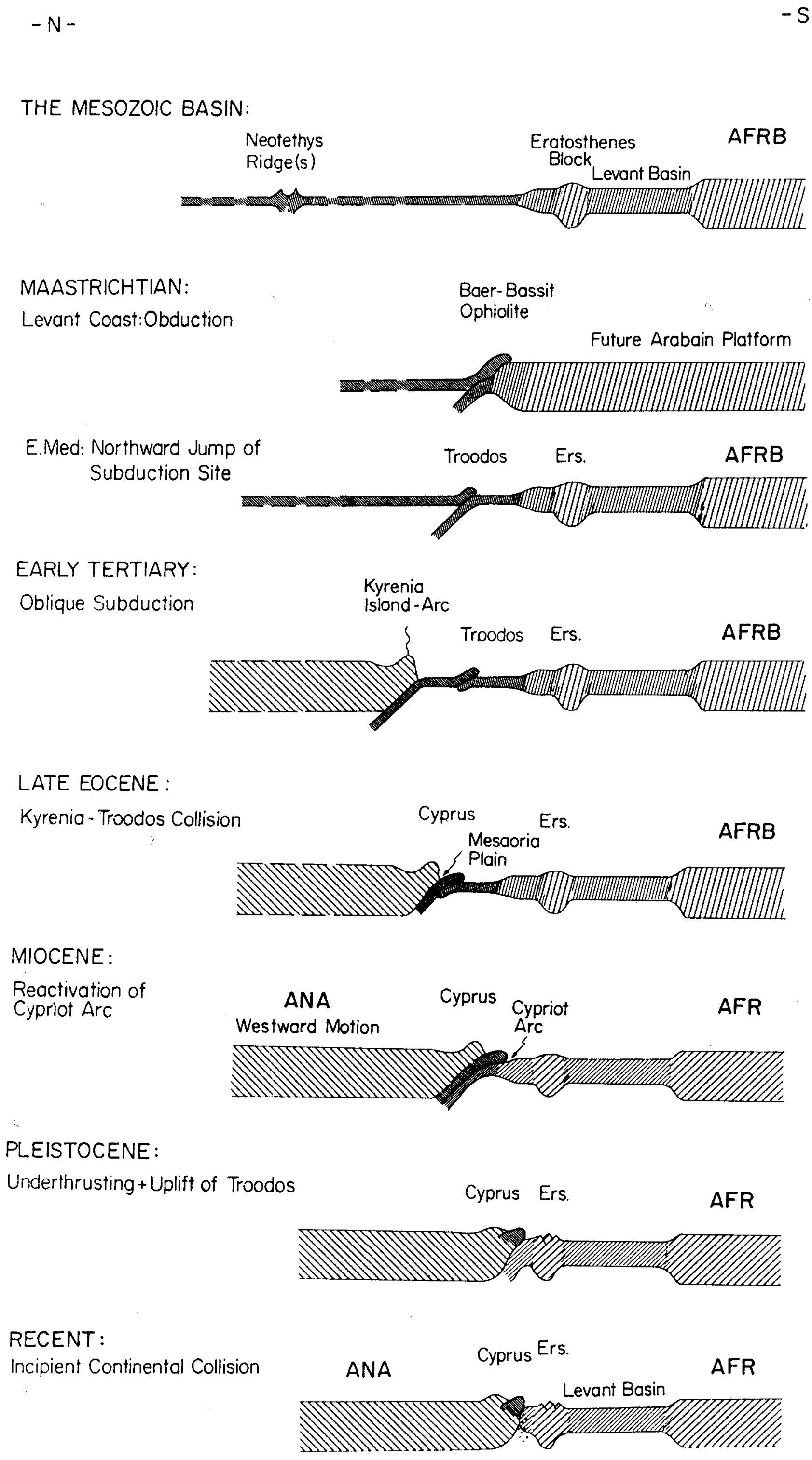

Figure 6. Schematic model of the tectonic evolution of the Eastern Mediterranean, after Kempler and Garfunkel (1995). The first stage of the Mesozoic Neotethys lithosphere consumption terminates with the emplacement of the East Mediterranean ophiolites onto the northern edge of the Afroarabia plate. Later lithosphere consumption was restricted to north of the ophiolite belt until the Troodos and Kyrenia complexes joined into a single structure, Cyprus, in late Eocene/Oligocene time. AFRB = Afroarabia, changes to AFR = Africa after the separation of the Arabia Plate from the Africa Plate. The Cypriot Arc was reactivated south of Cyprus in the late Miocene, in relation to the Anatolia (ANA) westward motion. Subduction along the Cypriot Arc changed into underthrusting of thinned continental crust in Pleistocene time. This process is currently interrupted by the approach of the Eratosthenes structure (ERS) to its location south of Cyprus, which has caused incipient continental collision.

shear, which is probably caused by a sideways escape of crustal blocks because of the Eratosthenes-Cyprus collision (Salamon, 1993). The collision is considered an interruption to the Africa-Anatolia convergence south of Cyprus, caused by the arrival of the relatively thick and buoyant Eratosthenes block to its present location south of Cyprus in Holocene time (Fig. 6; Kempler and Ben-Avraham, 1987a; Robertson, 1990; Kempler, 1994b; Kempler and Garfunkel, 1995).

The relatively flat summit of the Eratosthenes Seamount is delimited by scarps of normal faults that form a series of terraces around the summit. The faults produce a small east-west graben on the summit (Kempler, 1986). The effect of the graben on the bathymetry is especially prominent because of the thin sedimentary cover on the seamount. However, the normal faults on the Eratosthenes summit do not displace the sedimentary fill in the surrounding moat and are probably not active at present.

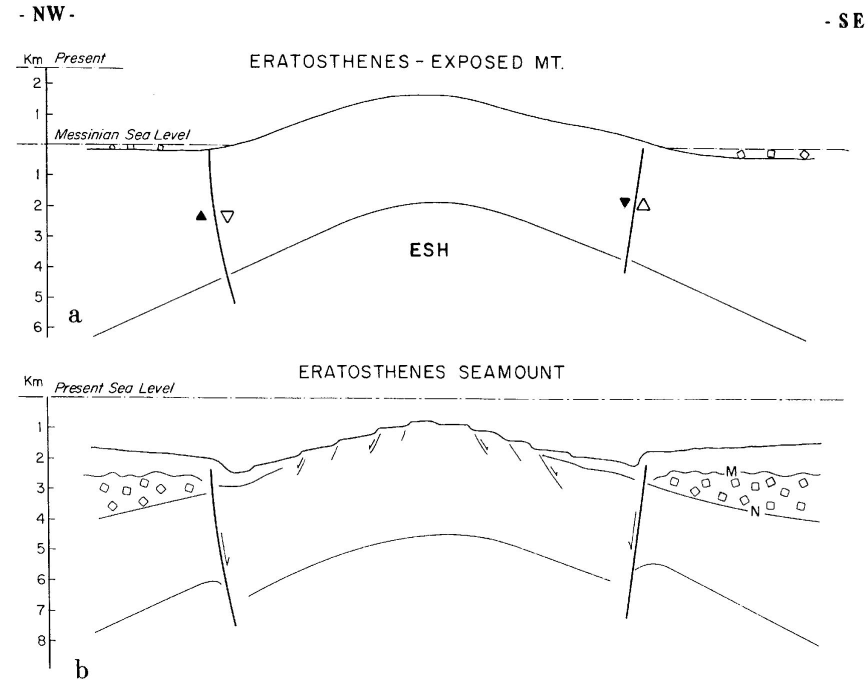

Figure 7. Schematic model of the evolution of the Eratosthenes Messinian island into the present seamount, after Kempler (1994a). **A.** The upper part of the Eratosthenes structural high (ESH) is exposed above the Messinian sea level/evaporite deposition depth. The steep faults probably formed as strike-slip faults (triangles symbolize speculative left-lateral motion). **B.** The present seamount and surrounding moat are separated from the area covered by over 1 km of Messinian evaporites (M = top, N = base of Messinian), by the steep faults, which functioned as dip-slip faults only in post-Messinian time.

Kempler and Ben-Avraham (1987a) suggested that the Eratosthenes-Cyprus collision, which causes cessation of northward subduction at the Cypriot Arc, may result in southward migration of the plate boundary. Polarity reversal at the new plate boundary was expected to take place through southward subduction of remains of Neotethys oceanic lithosphere south of the Eratosthenes structure and beneath the northern edge of the Levant Platform, or the hitherto passive continental margin of the Africa Plate. However, our recent analysis of the available seismic reflection profiles does not support this assumption, nor does the sparse seismic activity south of the Eratosthenes Seamount.

EXAMINATION OF THE FOREGOING MODEL

Only one of the four sites along the Eratosthenes–Cyprus transect of Leg 160 was drilled to Cretaceous rocks. The location of Site 967 is presently near the foot of the Eratosthenes Seamount northern flank. Before the Late Cretaceous, it was located in a shallow-water environment on a carbonate platform, similar to Turkey and the Levant (Robertson and Shipboard Scientific Party, 1996). During the late Mesozoic, it was covered by deep-water pelagic sediments in a stable tectonic setting adjacent to the passive continental margin of North Africa. There is no evidence at Site 967 for the Late Cretaceous tectonic events that occurred farther north, or for any ophiolitic material that could mark tectonic activity along any nearby southern boundary of the Troodos complex. The Late Cretaceous to middle Eocene rocks at Site 967 were affected merely by normal microfaulting and intense fracturing, indicating only minor tectonic movement and failure in different orientations. The lack of turbidites in the Late Cretaceous and Eocene successions suggests that the Eratosthenes area was already elevated above the seafloor during those intervals (Robertson and Shipboard Scientific Party, 1996).

The data thus confirm that the Eratosthenes structure, which was located a few hundred kilometers away from the Late Cretaceous–early Tertiary active plate boundary (Kempler and Garfunkel, 1995), was not affected by the major tectonic events of that period. Moreover, it reflects the existence of the Eratosthenes structural high—a stranded, continental block in the otherwise thinned continental or oceanic lithosphere of the Eastern Mediterranean—before its central part was shaped and sank. This sequence created the Eratosthenes Seamount with its unique, surrounding topographic low.

Tectonic activity resumed near the Eratosthenes structure by Miocene time. The locations of the southern sites, Sites 966 and 965, were uplifted and attained shallow-marine conditions during the Miocene, but subsided again in late Miocene. On the other hand, the location of Site 967 went through extensive faulting—both steep, normal faults and shallow-dipping normal and reverse faults—in Miocene time, but its Oligocene and Miocene sediments were removed because of tectonic uplift and erosion by the late Miocene. The Leg 160 Shipboard Scientific Party estimated that the Miocene uplift was more than could be accounted for by eustatic sea-level changes or flexural faulting related to incipient collision, but was subduction related (Robertson and Shipboard Scientific Party, 1996). The location of Site 968, on the southern Cyprus margin, went through some tectonic uplift, probably related to that of Cyprus itself, during the late Miocene. The contrast between the Miocene occurrences in the site locations probably indicates the formation or reactivation of the tectonic boundary between the African plate, with the Eratosthenes structure at its northern edge, and the Anatolian plate, including Cyprus (cf. Kempler, 1994a). These occurrences may also mark the development of the upper part of the vast Eratosthenes structure as a distinct feature.

The data confirm that the Africa-Anatolia plate boundary developed between Cyprus and the Eratosthenes in the late Miocene, through subduction of remnant oceanic lithosphere of the Mesozoic Neotethys beneath Cyprus. Regional considerations suggest that the Cypriot Arc is an inherited and reactivated structure (Kempler, 1994b; Kempler and Garfunkel, 1995). No conclusion whatsoever of Leg 160 sheds new light on the importance of strike-slip in the Miocene evolution of the Eratosthenes area.

The absence of Messinian evaporites on the Eratosthenes Seamount and within the surrounding depression was confirmed by Leg 160 data. These findings, and the identification of a Messinian erosive surface across the entire seamount plateau in the site-survey data (Robertson et al., 1995), support the existence of the Eratosthenes

Seamount and immediate surrounding area as a Messinian island. The findings further imply that the whole complex subsided after Messinian time. Integrating the site-survey data with the drilling data may help to map the coast line around the Messinian island. At Site 968 on the southern Cyprus margin, an upper Miocene turbidite succession includes material from the Miocene Pakhna Formation of southern Cyprus and detrital gypsum from late Messinian small, silled basins on the upper paleoslope, which formed following initial uplift of southern Cyprus.

Episodes of both extension and tectonic uplift occurred at all four site locations in post-Messinian times. However, the general trend was one of subsidence in the southern (Eratosthenes-related) Sites 965, 966, and 967 vs. uplift in the northern (Cypriot) Site 968. Strong, rapid, tectonic subsidence accompanied by increasing water depth of deposition affected the Eratosthenes area in early Pliocene time. The location of Site 967 subsided more, and probably earlier, than at Sites 965 and 966. The latter two went first through some tectonically induced compression. Site 968 area had still been in a deep basinal setting in Messinian/early Pliocene time, before it was tectonically uplifted to its present position on the lower slope of the Cyprus margin. This information is compatible with post-Messinian subsidence of the whole area around the Eratosthenes Seamount while subduction caused the uplift of Cyprus and its margin.

Tectonic instability increased in mid-late Pliocene although the general trend of subsidence persisted, which led to the present morphology. Angular unconformities and evidence for syndepositional compression close to the Pliocene/Pleistocene boundary in the location of Site 966 (Emeis, Robertson, Richter, et al., 1996) may indicate pulsed subsidence. Minor uplift of the small ridge on which Site 967 is located locally interrupted its otherwise continuous subsidence. The water depth at Site 967 was by late Pliocene shallower than at present, and reached the present water depth, about 2500 m, by early Pleistocene. Several hiatuses in the drilled sections may point to regional disturbances in the ordinary sediment deposition. Particularly significant is a hiatus in late Pliocene/early Pleistocene time that appears at all four sites, except in Hole 967C. The lack of hiatus evidence there suggests a local rather than regional process. However, the coincidence of the tectonic instability and the hiatus with extreme, simultaneous uplift of Cyprus as a first time single amalgamated tectonic unit (Robertson, 1990) supports its relationship with the initiation of the Eratosthenes-Cyprus collision.

Both the site-survey data (Robertson et al., 1995) and Leg 160 data show evidence for significantly more extension at the northern edge of the Eratosthenes plateau (Site 966) and its mid-northern slope (Site 965) than was previously expected. The fact that the rate of subsidence of the natural moat is higher than that of the southern Eratosthenes slopes (Robertson et al., 1995) indicates some northward tilting of the seamount within the overall subsiding depression. A big variation in the sedimentation rates near the foot of the Eratosthenes Seamount northern flank probably indicates enduring pulsed subsidence, which can be related to the pulsed uplift of Cyprus.

The site-survey data collected during the *Gelendzhik* cruise in 1993 (Robertson et al., 1995) appear compatible with southward migration and polarity reversal of the plate boundary south of Cyprus (Kempler and Ben-Avraham, 1987a). However, southward underthrusting below the Levant Platform is shown only at the upper 1.5-s two-way traveltime of the sedimentary section—a depth of less than 2 km (Limonov et al., 1994). Therefore, the significance of the apparent underthrusting should still be examined in additional surveys.

CONCLUSIONS

The first ODP leg to focus on the Eratosthenes Seamount and its immediate surroundings provided a unique opportunity to examine the foregoing model in regard to the Tertiary evolution of this conspicuous feature. However, Leg 160 was restricted to shallow drilling and could not resolve some fundamental questions regarding the Eratosthenes origin and early history. We, therefore, suggest to adopt those components of the foregoing model that could not be examined during this leg as the working assumption for further data collection and deeper drilling of the Eratosthenes structure. Accordingly, the Eratosthenes structure is considered partly a volcanic block, which formed at the Afroarabia continental margin during the early Mesozoic rifting of this margin, but was stranded in the Eastern Mediterranean following further stretching and thinning of the area. During Mesozoic time, it remained in a stable tectonic setting adjacent to the passive continental margin of North Africa. Located a few hundred kilometers from the Late Cretaceous/early Tertiary active plate boundary, it was not affected by the early stages of Africa-Eurasia plate convergence.

Leg 160 data confirm that an Eratosthenes structural high, although not necessarily a distinct seamount, was already elevated above the seafloor in Late Cretaceous/Eocene times, and that the area was not affected by the major tectonic events of that period. The upper part of the Eratosthenes structure developed as the Eratosthenes Seamount since Miocene time. Its Miocene uplifting was followed by subsidence, which in post-Messinian times affected a vast area around the Eratosthenes Seamount. This area includes the seamount and the surrounding natural moat, which is enclosed by a series of steep faults. The latter displace a deep reflector that marks the present shape of the Eratosthenes structural high. The importance of strike-slip in the Miocene evolution of these faults, expected on the basis of their steepness and prominence, integrated with the regional information, remains obscure. The Cypriot Arc, an inherited structure located along the Late Cretaceous plate convergence boundary, was reactivated by Miocene time and accommodated northward subduction of remnant oceanic lithosphere of the Mesozoic Neotethys beneath Cyprus.

During the Messinian period, the area enclosed by the steep faults formed an island above the Messinian evaporite deposition depth. The post-Messinian subsidence of this area has shaped the Eratosthenes Seamount and surrounding depression, which are superimposed on the Eratosthenes structural high. While this subsidence has basically continued throughout post-Messinian times, Cyprus and its margin were uplifted. The Miocene–Pliocene subduction along the Cypriot Arc caused initial uplift of Cyprus and tectonic instability. However, a more drastic uplift of Cyprus less than 2 Ma. is interpreted to be the result of underthrusting of thinned, continental lithosphere along the Cypriot Arc after the remains of the Mesozoic Neotethys lithosphere had been fully consumed. Pulsed uplift of Cyprus has been accompanied by pulsed subsidence and significant extension in the Eratosthenes area. Both vertical motions probably mark incipient continental collision in the Eastern Mediterranean. The Eratosthenes Seamount, therefore, is the possible spearhead of incipient continental collision and the best candidate for the study of collisional processes in the area.

The significance of the Leg 160 data to unfolding the Tertiary evolution of the Eastern Mediterranean is particularly important because the thickness of the sedimentary cover elsewhere in this basin is at least 15 km, including 1–1.5 km of Messinian evaporites. The drilling data have confirmed that the regional tectonics did not affect the Eratosthenes area between Late Cretaceous and Miocene times, and only Miocene renewal of the convergence between the Eratosthenes and Cyprus began to influence the evolution of both structures. However, this phase of shallow drilling should lead to further, deeper drilling, of the Eratosthenes structure and other sites around Cyprus, which are indispensable for the geological study of the Eastern Mediterranean. Two other factors that may greatly improve our understanding of the evolution of this area are the exact sea-level changes in the Eastern Mediterranean since the Miocene, and the flexural subsidence of the basin because of Pliocene–Pleistocene sediment loading. A special emphasis should be given to the relative motions between the Eratosthenes structure and its surroundings, which are probably underlain by different basement rocks and thus react in different ways to both flexural and tectonic types of subsidence.

ACKNOWLEDGMENTS

I greatly appreciate the contribution of Zvi Garfunkel to my understanding of the Eratosthenes structure and its Eastern Mediterranean tectonic framework. Sharing the preparation work for the Eratosthenes ODP proposal with Yossi Mart and Floyd W. McCoy added much to clarify the picture. Helpful reviews by T. McGee and A. Barka, and remarks by John Woodside, are kindly acknowledged. P. Grossman and H. Bernard prepared the figures.

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Date of initial receipt: 1 January 1997
Date of acceptance: 23 August 1997
Ms 160SR-031

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