Geophys. J. Int. (2006) **164,** 176–181 doi: 10.1111/j.1365-246X.2005.02737.x

Seismotectonics of the Cyprian Arc

Shimon Wdowinski,[1,2] Zvi Ben-Avraham,[1] Ronald Arvidsson[3] and Goran Ekström[4]

[1] *Department of Geophysics and Planetary Sciences, Tel Aviv University, Tel Aviv* 69978, *Israel. E-mail: shimonw@bellsouth.net*
[2] *Also at Division of Marine Geology and Geophysics, University of Miami,* 4600 *Rickenbacker Causeway, Miami,* FL 33149-1098*, USA*
[3] *Department of Earth Sciences, Seismology, Uppsala University,* SE-752 36 *Uppsala, Sweden*
[4] *Department of Earth and Planetary Sciences, Harvard University,* 20 *Oxford Street, Cambridge,* MA 02138, *USA*

Accepted 2005 July 4. Received 2005 May 13; in original form 2004 September 15

SUMMARY

The Cyprian Arc forms the plate boundary between the Anatolian plate in the north and the Nubian and Sinai plates in the south. We examine the tectonic setting and seismic activity along the arc in light of new geodetic studies indicating relative NE–SW plate motions across the arc. The first-order tectonic variations are determined by the arc's geometry. The eastern arc, oriented subparallel to relative motion, is dominated by transcurrent tectonism. The western arc is oriented almost normal to relative plate motion and is subjected to convergent processes. Variations in the level and depth of seismic activity along the western arc suggest that the northwestern section of the arc represents a subduction boundary, whereas the southeastern section represents a collision boundary. The two tectonic domains of the western arc are separated by a NE–SW trending tear fault, which produces large earthquakes, such as the $M_W = 6.8$, 1996 Paphos earthquake. We compare the geometrically similar Cyprian and Hellenic Arcs and find significant differences in the rate, direction and type of convergence across the two arcs. The Hellenic Arc is subjected mainly to subduction, whereas the shorter Cyprian Arc is subjected to subduction, collision and transcurrent tectonic processes.

Key words: Eastern Mediterranean, plate motion, seismicity, tectonics.

INTRODUCTION

Tectonic plate motion between Nubia, Arabia and Eurasia becomes complex in the Eastern Mediterranean, due to independent motion of smaller blocks or subplates. The Anatolian block escapes the convergence between Eurasia and Arabia by moving southwestwards towards the Hellenic and Cyprian Arcs (Jackson & McKenzie 1984). The Sinai subplate partitions the motion between Nubia and Arabia into left-lateral horizontal motion along the Dead Sea Fault and divergence along the Gulf of Suez. (Although many studies refer to Anatolia as a block and Sinai as subplate, here for simplicity, we refer to both as plates).

The Cyprian Arc forms the plate boundary between the Anatolian plate in the north and the Nubian and Sinai plates in the south (Fig. 1). It is connected to the Hellenic Arc in the west and to the Dead Sea and the East Anatolian faults in the east. The arc has experienced little seismicity over the last century. Jackson & McKenzie (1984, 1988) suggested that the observed seismicity may not be representative of longer time periods.

Increased seismic activity during the second half of the 1990's provided new observations on active faulting along the arc, but introduced more questions than answers regarding the tectonic framework of the Cyprian Arc. The two largest earthquakes, the 1996 $M_W = 6.8$ Paphos and the 1998 $M_W = 6.2$ Adana earthquakes (Fig. 2a), were relatively deep (30–40 km) strike-slip events occurring near, but not on the plate boundary (Arvidsson *et al.* 1998; Aktar *et al.* 2000). Recently, Pilidou *et al.* (2004) re-examined the seismic data of the 1996 Paphos earthquake sequence and determined that their epicentres occurred at a depth of the 76–85 km. The 1996 Paphos earthquake is in particular puzzling, because it ruptured the lower crust in a NE–SW direction, perpendicular to the direction of the plate boundary in the western part of the arc (Arvidsson *et al.* 1998).

Recent space geodetic studies (McClusky *et al.* 2000, 2003; Wdowinski *et al.* 2004) reveal new observations on the current plate motion and crustal deformation in the Eastern Mediterranean, providing a quantitative framework of the relative motion between the Anatolia, Nubia and Sinai plates. In this study, we use this framework to analyse the seismic activity along the Cyprian Arc and to provide a new seismotectonic model for the region.

SEISMICITY

The easternmost Mediterranean (east of longitude 30°E) is characterized by low-to-moderate seismic activity. Jackson & McKenzie (1984, 1988) pointed out that the level of seismicity along the Cyprian Arc is rather low compared with the Hellenic Arc. Here we use the following three seismic data sets to infer the details of seismic activity along the Cyprian Arc:

(1) Harvard CMT solutions for the time period 1976–2004 with $m_b > 4.5$;

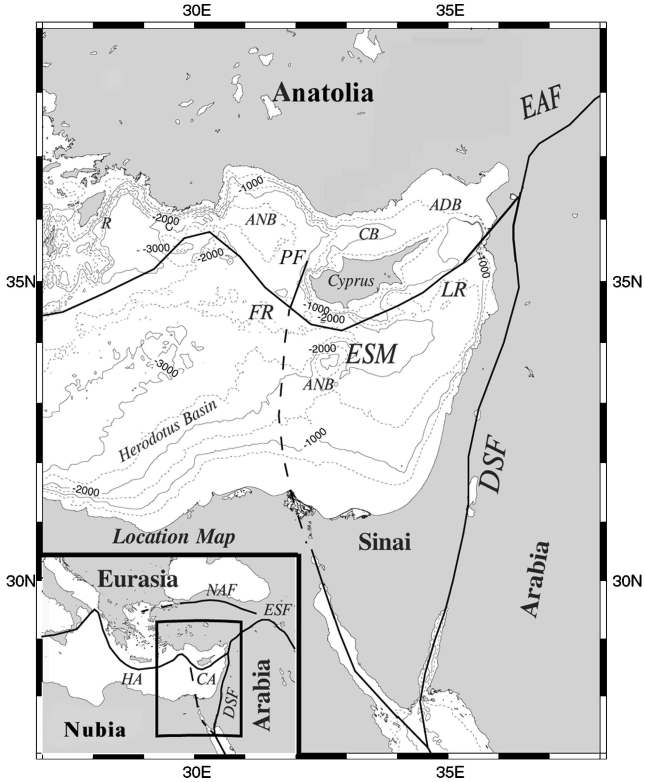

Figure 1. Bathymetric map of the eastern Mediterranean showing the seafloor morphology and major tectonic elements in the regions. The plate boundary along the eastern arc follows the linear trend of seismicity along the arc (Fig. 2). The boundary along the western arc, which lack seismic activity, is based on previous studies. DSF—Dead Sea Fault; EAF—Eastern Anatolian Fault; NAF—North Anatolian Fault; CA—Cyprian Arc; HA—Hellenic Arc; PF—Paphos Fault; ESM—Eratosthenes Seamount; FR—Florence Rise; ANB—Antalya Basin; CB—Cilicia Basin; ADB—Adana Basin; LR—Larnaka Ridge; R—Rhodes. Insert—location map showing the tectonic plates, subplates and their boundaries.

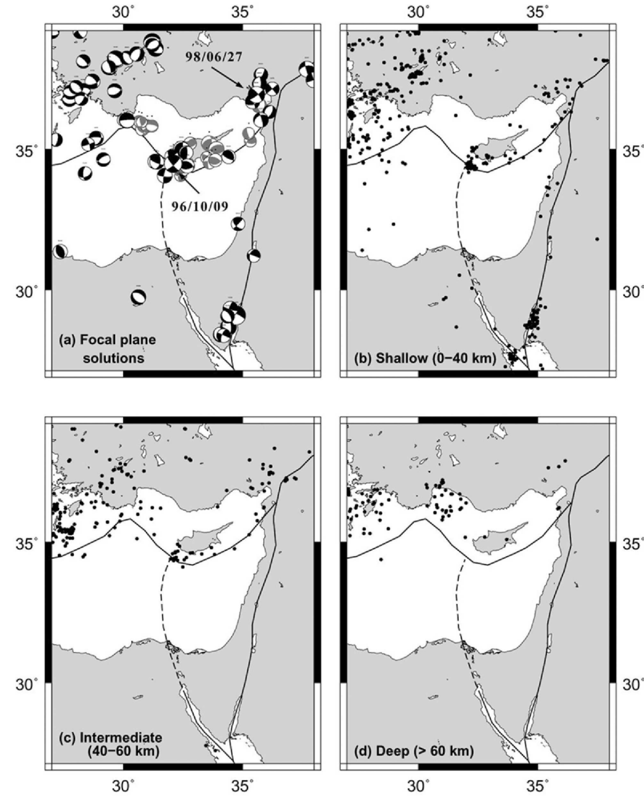

Figure 2. (a) Harvard CMT (black) and first *P*-wave arrivals fault plane (grey–Salamon *et al.* 2003) solutions for shallow earthquakes (depth 0–40 km). The marked dates denote the two recent significant seismic events in the northeastern Mediterranean, the 1996 $Mw = 6.8$ Paphos and the 1998 $Mw = 6.2$ Adana earthquakes. (b) Shallow seismicity with depth from 0–40 km based upon the Engdahl *et al.* (1998) relocated catalogue. (c) Same as (b), but for earthquakes with depth 40–60 km. (d) Same as (b), but for earthquakes with depths greater than 60 km.

(2) Salamon *et al.*'s (2003) fault plane solution of first *P*-wave arrivals for the time period 1940–2001 with $M_L > 4$ and

(3) Engdahl *et al.*'s (1998) relocated ISC and NEIC events with $M > 3$. The first two sets provide information on the faulting type and direction of the larger magnitude earthquakes, whereas the third data set provides accurate information on the location, in particular the depth of larger and smaller events ($M > 3$).

Using the CMT and first *P*-wave arrivals fault plane solutions (Salamon *et al.* 2003) we can determine type and direction of the larger magnitude events ($M > 4$) along the Cyprian Arc (Fig. 2a). However, before determining the type and direction of faulting, we can see that the larger events are distributed unevenly along the arc, in four clusters. The clusters are located, from left to right, in

(a) the northwestern corner of the arc,
(b) southwestern Cyprus,
(c) southeastern Cyprus, and
(d) eastern Turkey adjacent to the intersection between the Cyprian Arc, the Dead Sea Fault and the East Anatolian Fault.

The northwestern cluster consists of 6 small event ($M < 5$) showing all three faulting types (normal, reverse and transcurrent). The southwestern Cyprus cluster is characterized by strike-slip and thrust events reflecting a transpressional setting (Fig. 2a). The largest event in this cluster was the $Mw = 6.8$, 1996 Paphos earthquake, with a NW–SE strike-slip faulting (Arvidsson *et al.* 1998; Pilidou *et al.* 2004). The other solutions in this cluster correspond to smaller magnitude events ($M < 6$). The southeastern Cyprus cluster consists mainly of thrust events showing both N–S and NW–SE faulting direction of moderate size earthquakes ($M < =6$). Papazachos & Papaioannou (1999) provided a review of the seismic activity along the Cyprian Arc. They show that seven strong ($M > 6.0$) earthquakes occurred near or in Cyprus during the instrumental period (1901–1997) and about 15 known strong destructive earthquakes hit the island during historic time. The northeastern cluster, located northeast of the Adana Basin, is characterized by strike-slip and normal fault events (Fig. 2a). The largest event in this cluster was the $Mw = 6.2$, 1998 Adana earthquake, which was also a NW–SE strike-slip event with an epicentral depth of 30 km (Aktar *et al.* 2000). The other eight CMT solutions represent smaller event ($M < 6$) with shallow epicentral depth (<20 km).

The relocated earthquake catalogue of Engdahl *et al.* (1998) (Fig. 2) provides a larger set of seismic data ($M > 3$) and good control of the epicentral depth. Using this catalogue, we divide the Eastern Mediterranean data set into three subsets according to epicentral depth. The two seismic clusters of the larger magnitude earthquakes (CMT solutions, black balls in Fig. 2a) also appear in the shallow and intermediate depth events (Figs 2b and c), but not at the deep events (>60 km). Fig. 2(b) also shows seismic activity along the eastern trace of the Cyprian Arc, but not along the western part. The lack of shallow seismicity in the western segment of the arc was noted by Jackson & McKenzie (1984, 1988), Ambraseys & Adams (1993) and Engdahl *et al.* (1998). Jackson & McKenzie (1984, 1988) attributed the lack of seismicity to a very long recurrence time for large earthquakes, or to ductile aseismic slip on the interface between the subducting African plate and the Anatolian–Aegean plate. Arvidsson *et al.* (1998) pointed out the eastward decrease in seismic activity along the central and eastern segments of the Cyprian Arc. They suggested that the decrease in seismic level follows a similar decrease in the convergence rate between Anatolia and Africa, as their pole of rotation lies southeast of the arc.

Fig. 2(d) shows that deeper events (>60 km) occur mostly in the westernmost section of the arc beneath the Antalya Basin. The distribution of deep earthquakes suggests that subduction takes place west of Cyprus in the Antalya basin and below southern Turkey (Jackson & McKenzie 1984; Ben-Avraham *et al.* 1988; Ambraseys & Adams 1993). This region is also characterized by compressional deformation of shallow young sediments (Anastasakis & Kelling 1991).

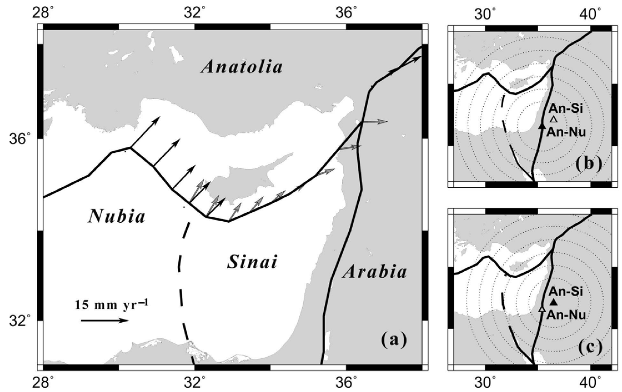

Figure 3. (a) Predicted motion along the Cyprian Arc as calculated from the An–Nu and An–Si poles (Table 1). The black arrows in the western arc show the relative motion between Anatolia (An) and Nubia (Nu) and the grey arrows show the relative motion between Anatolia and Sinai (Si). (b) Map showing the location of the An–Nu pole and small circles about the pole. (c) The same as (b) for the An–Si pole. The figure does not include confidence ellipses of the Euler poles nor of the velocity vectors, because some of the references (Table 1) used in the calculations provide only partial information of the uncertainty values.

GPS-DETECTED CURRENT PLATE MOTION AND CRUSTAL MOVEMENTS

Space geodetic monitoring of crustal movements in the eastern Mediterranean has been conducted over the past 15 yr, first with Satellite Laser Ranging (e.g. Smith *et al.* 1994) and since the early 1990's mostly with the Global Positioning System (GPS). McClusky *et al.* (2000) summarize decade-long GPS measurements across the Aegean, Anatolia and the Caucuses. Their land observations have limited direct applications to our offshore study, but provide an accurate tectonic framework for understanding current plate movements and crustal deformation in the Eastern Mediterranean. McClusky *et al.* (2003) used additional data from Nubia and Eurasia to constrain and improve the plate motion model for the area. Wdowinski *et al.* (2004) presented continuous GPS data for the Southern Levant (Israel, Jordan and Syria), providing additional kinematic constraints on the current motion of the Sinai plate.

McClusky *et al.* (2000) showed that central Turkey (Anatolia) moves in a coherent fashion with internal deformation <2 mm yr^{-1}. They also calculated Anatolia's pole of rotation and its relative motion with respect to Eurasia and Arabia (Table 1, Fig. 3a). In order to estimate the relative motion between the Anatolian and Sinai plates, we added the rotation vectors of the Anatolia–Eurasia relative motion (McClusky *et al.* 2000) with recent calculated Eurasia–Sinai rotation vector (Wdowinski *et al.* 2004) (Table 1, Fig. 3a). Using the GPS-determined Euler poles (Table 1), we calculated the expected motion along the Cyprian Arc. Along the western part of the arc, the Anatolian and Nubian plate converge in a NE–SW direction, perpendicular to the NW–SE orientation of the arc. The convergence rate increases northwestwards and is in the range of 9–14 mm yr^{-1} (Fig. 3). Along the southern section of the western side of the arc, Anatolia converges with Sinai at a slightly lower rate (7–8 mm yr^{-1}) and in a slightly more northern direction than the Anatolia–Nubian (An–Nu) convergence. This region, southwest of Cyprus, is seismically the most active region in the Eastern Mediterranean and is characterized by compressional and NE–SW right-lateral strike-slip faulting (Fig. 2a; Arvidsson *et al.* 1998; Pilidou *et al.* 2004).

Along the eastern part of the arc, the relative motion between Anatolia and Sinai is predominantly left-lateral with increasing extension towards the east. The calculated rates are in the range of 7–8 mm yr^{-1}. McClusky *et al.* (2003) derived higher rates (8–10 mm yr^{-1}) with a similar direction using An–Nu relative plate motion. Both the convergent motion in the western arc and tensional motion in the northeastern arc are consistent with the focal mechanism solution (Fig. 2a) (McClusky *et al.* 2003). East of the Cyprian Arc, relative motion along the EAF (Arabia–Anatolia) is predominantly left lateral at a rate of 9 ± 1 mm yr^{-1} (McClusky *et al.* 2003).

McClusky *et al.* (2000) showed that central Anatolia moves as a coherent block, but that eastern Anatolia moves northeastwards with respect to the central Anatolian block and is subjected to a left-lateral shear, especially near the EAF. Interestingly, they show that the only GPS site in Cyprus (NICO) also moves northeastwards with respect to the Anatolian plate, in a similar direction and magnitude to

Table 1. Relative angular velocities in geographic coordinates[a].

Plates	Latitude (°N)	Longitude (°E)	Ω deg Myr^{-1}	σ_{max}[b]	σ_{min}[b]	Azi[c]	σ_{Ω} deg Myr^{-1}	Reference
An–Eu	30.7	32.6	1.2	0.8	0.4		0.1	McClusky *et al.* (2000)
Eu–Nu	−0.95	−21.8	0.06	4.8	4.3		0.005	McClusky *et al.* (2003)
Si–Eu	23.14	16.62	0. 2242	18.1	0.74	58.5	0.147	Wdowinski *et al.* (2004)
An–Nu	31.58	35.40	1.171					This study
An–Si	32.11	35.89	1.175					This study

[a]Plate abbreviations are: An—Anatolia; Eu—Eurasia; Nu—Nubia; Si—Sinai.
[b]2-D 1-sigma lengths in degrees of the semi-major σ_{max} and semi-minor σ_{min} of the pole error ellipse.
[c]The azimuth (degrees) is the clockwise angle between north and the semi-major ellipse axis.

the GPS sites in central Anatolia. Although they did not discuss the tectonic setting of the Cyprian Arc, McClusky *et al.* (2000) present in their maps two arcs, one north and the other south of Cyprus, suggesting that Cyprus behaves as an independent block and moves independently from the Anatolian plate.

SEISMOTECTONICS OF THE CYPRIAN ARC

The new space geodetic studies of the eastern Mediterranean indicate that relative plate motions across the Cyprian Arc, between both Anatolia and Nubia and Anatolia and Sinai, occur in the NE–SW direction (Fig. 3). In light of this newly observed and well-determined direction of relative motion, we examine the tectonic setting along the arc according to the arc's geometry and seismic activity. We focus on the current plate motion and deformation processes (tens of years as determined from seismic and geodetic observations), which do not necessarily agree with the orientation of geological structures forming over millions of years.

The first-order tectonic changes along the Cyprian Arc are determined by the arc's geometry (Fig. 1). The eastern arc is oriented NE–SW, subparallel to the direction of relative plate motion, suggesting a predominantly transcurrent motion along the eastern arc. The western arc, however, is oriented almost normal to the direction of relative plate motion, in a NW–SE direction, indicating convergence.

Seismicity along the eastern arc is concentrated along a narrow belt (Fig. 2b), suggesting a narrow and well-defined plate boundary between Anatolia and Sinai. The faulting direction, as indicated by five focal plane solutions along the eastern arc, is roughly NE–SW, parallel to the direction of the relative plate motion. Three of the solutions indicate N–S, NE–SW and E–W thrust faulting, and the other two roughly NE–SW strike-slip faulting. Occurrence of dip-slip events adjacent to major strike-slip faults is a common phenomenon, which is often explained by segmentation and geometrical complexities of strike-slip fault systems. Marine geophysical studies show that the primary active structures along the eastern arc are NE–SW strike-slip faults distributed within a wide region (roughly 100 km), both north and south of the current arc location (Ivanov *et al.* 1992; Ben-Avraham *et al.* 1995; Vidal *et al.* 2000). These structural observations indicate that the eastern arc has been in a transcurrent tectonic setting since the Miocene (Ivanov *et al.* 1992), similar to the present-day setting, although the location of the plate boundary most likely migrated with time.

Seismicity along the western arc shows two distinct and very different environments. The southeastern segment, southwest of Cyprus, is characterized by a large number of shallow and intermediate events and the absence of deep events (Fig. 2). The northwestern segment, however, is characterized by the absence of shallow events and some intermediate and deep activity near and north of its northwestern section, beneath the Antalya Basin (Figs 1 and 2). Another significant difference between the two segments is the level of activity. The southeastern segment produces large events, such as the $Mw = 6.8$, 1996 Paphos earthquake, whereas the northwestern segment produces only small event ($M < 4$). The focal plane solutions of the large events, southwest of Cyprus, show predominantly the expected NE–SW faulting direction occurring by both thrust and strike-slip events. The thrust events are consistent with the expected convergence across the western arc. However, the larger magnitude strike-slip events (e.g. the 1996 Paphos earthquake), do not fit regular convergence models across arcs.

The irregular seismic activity along the western arc is explained by two possible mechanisms. Arvidsson *et al.* (1998) suggested that the strike-slip activity occurs along a NE–SW intermediate depth tear fault (>30 km) separating the subduction north of the tear fault from continental collision south of the fault. Papazachos & Papaioannou (1999) suggested that strike-slip activity occurs along a transform fault, which transfers the convergence in southwestern Cyprus to convergence in the Antalya Basin. According to their model, the western arc is segmented and its northwestern segment is located about 100 km northeast of the western arc assumed in this study. However, the transform fault model of Papazachos & Papaioannou (1999) fails to explain the depth distribution of the seismic events along the western arc. The recent study of Pilidou *et al.* (2004), which determine the epicentral depth of the 1996 events at a deeper level (76–85 km), further supports the tear fault model. Thus, we adopt the tear fault model of Arvidsson *et al.* (1998).

Recently, Woodside *et al.* (2002) suggested on the basis of a marine geophysical survey of the Florence Rise that relative motion between Anatolia and Nubia (Africa in their study) is accommodated by a NW–SE dextral wrench system. Although their model agrees with the geological observations, it contradicts the well-determined NE–SW current relative plate motion between the two plates. Possibly, the geological structures formed over several millions of years in a different tectonic environment to the present plate motion. The observed difference between the geologic and geodetic convergence direction suggests a geologically recent change in the tectonic setting of the western arc.

DISCUSSION AND CONCLUSIONS

The Cyprian Arc has a similar geometry to the Hellenic Arc and the two are often compared (e.g. Papazachos & Papaioannou 1999). However, the well-determined plate motion of the eastern Mediterranean and the observed sesimicity suggest that the two arcs are subjected to very different tectonic activity. The convergence across the Hellenic Arc is 20–40 mm yr^{-1}, about two to three times faster than across the Cyprian Arc. This higher rate yields a significantly higher level of seismicity and at much deeper levels (up to 300 km). The direction of relative plate motion along the two arcs combined with their geometries is also significantly different (Fig. 4). Along the Cyprian Arc, the direction of relative motion is either normal to the arc in the western side, or subparallel in the eastern side (Fig. 3). However, along the Hellenic Arc the direction of relative motion is normal to the central part of the arc in the vicinity of Crete and becomes partly oblique towards the eastern and western segments of the arc due to the arc's geometry. The nature of convergence also contrasts difference between the two arcs. The Hellenic Arc is subjected to subduction throughout its length, whereas the Cyprean Arc, which is almost half the length of the Hellenic Arc, is subjected to subduction, collision, and transcurrent motion. In summary, the two arcs show significant differences in their rate and direction of relative motion across the arcs.

Marine geophysical surveys south and west of the Cyprus Arc have mapped geological structures indicating N–S convergence across the arc (e.g. Robertson 1998; Woodside *et al.* 2002). The most prominent structures are located between Cyprus and the Eratosthenes Seamount, which is a continental fragment embedded within the oceanic crust of the eastern Mediterranean (Ben-Avraham *et al.* 1976; Kempler 1998; Mart & Robertson 1998; Robertson 1998). These structures indicate that the seamount began to thrust beneath the Cyprus active margin in the Late

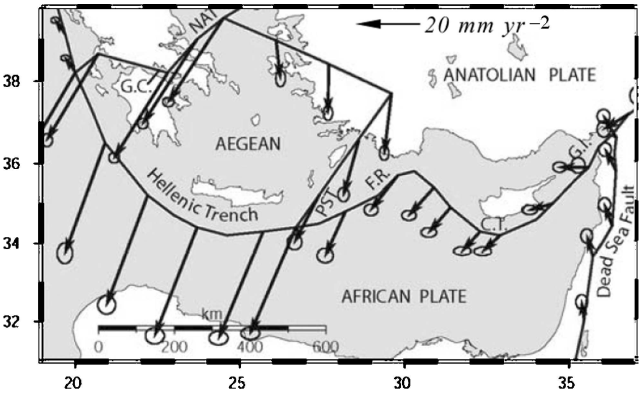

Figure 4. Relative motion along plate boundaries in the eastern Mediterranean based on McClusky *et al.* (2003). Motions around the Aegean and Anatolian plates show their motion relative to the bordering plates. Aegean–Nubian convergence is predominantly perpendicular to the orientation of the Hellenic Arc (trench), whereas the convergence direction across the Cyprian Arc is normal across the western arc and transcurrent in the eastern section. (Figure was modified from McClusky *et al.* 2003).

Miocene—Early Pliocene (∼5 Ma) (Robertson 1998). In the western arc, Woodside *et al.* (2002) found no geological structures indicating NE–SW convergence between Anatolia and Nubia. He interpreted the geological structures in the Florence Rise as a NW–SE dextral wrench system, formed during a N–S convergence between the two plates. The lack of recent geological structures south and west of Cyprus indicating present-day NE–SW convergence between Anatolia and Nubia, suggests a recent (geologically) change in the direction of plate motion across the Cyprian Arc. Due to the slow convergence rate and the short time since the change in the relative motion, no significant geological structure has been yet formed in the western arc. The region may still be adjusting to the new tectonic setting imposed by the recent change in plate motion from N–S convergence in the Miocene to NE–SW convergence at present.

The new GPS-determined plate motion calculations for the eastern Mediterranean indicate differences between An–Nu and Anatolia–Sinai (An–Si) rates and directions of convergence. Anatolia converges with Sinai at a slightly lower rate and in a slightly more northern direction to its convergence with Nubia (Fig. 3). The calculated difference between An–Nu and An–Si is small (7–8 mm yr^{-1} for An–Si and 8–9 mm yr^{-1} for An–Nu) and cannot explain the change of convergence style along the western arc. Furthermore, this small change most likely lies within the velocity uncertainties, which unfortunately we could not estimate (see caption of Fig. 3). However, if we consider this small difference in relative plate motion between An–Si and An–Nu, it adds a small compressional and right-lateral shear within the Anatolian plate at the vicinity of the triple junction. We speculate that strike-slip activity along the Paphos Fault marks the northern extent of the Sinai–Nubia plate boundary (its location is well determined only along its southern section, in the Gulf of Suez; Fig. 1). Our suggestion is also consistent with Salamon *et al.* (1996), who proposed on the basis of seismological evidence that the western boundary of the Sinai plate extends west of the Eratosthenes Seamount into the Cyprian Arc.

In summary, our seismotectonic analysis of the Cyprian Arc, which is based on current plate motion, arc geometry and seismic activity, reveals that the arc can be divided into three main segments (Fig. 5):

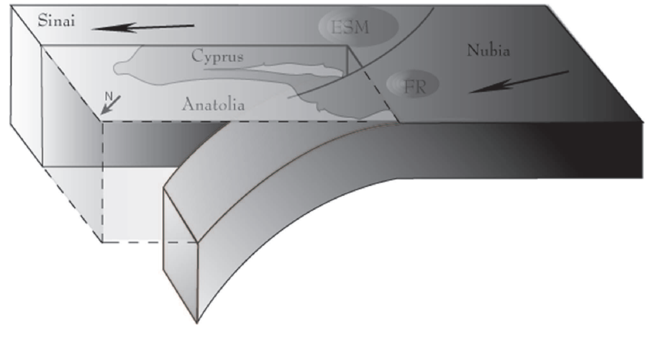

Figure 5. Schematic diagram showing the plate configuration and their relative motion along the Cyprian Arc. ESM—Eratosthenes Seamount; FR—Florence Rise.

(1) an eastern segment oriented parallel to the direction of the An–Si relative plate motion and characterized by transcurrent motion;

(2) a central segment located southwest of Cyprus, characterized by a NE–SW collision between Sinai and Anatolia and

(3) a western segment of normal subduction, where the Nubian plate subducts beneath the Anatolian plate. The transition between the central and western segments occurs along a NE–SW trending tear fault, which produces large strike-slip earthquakes.

ACKNOWLEDGMENTS

We are grateful to Amos Salamon for providing us his seismic data and for Tim Dixon and Giovanni Sella for their helpful comments on the manuscript. We thank Amotz Agnon, an anonymous reviewer, and the editor for their helpful reviews. The figures in this manuscript were produced using the public domain Generic Mapping Tools (GMT) software (Wessel & Smith 1995).

REFERENCES

Aktar, M., Ergin, M., Özalaybey, S., Tapirdamaz, C., Yörük, A. & Biçmen, F., 2000. A lower-crustal event in the northeastern Mediterranean: the 1998 Adana Earthquake ($M_w = 6.2$) and its aftershocks, *Geophys. Res. Lett.*, **27,** 2361–2364.

Ambraseys, N.N. & Adams, R.D., 1993. Seismicity of the Cyprus region, *TerraNova*, **5,** 85–94.

Anastasakis, G. & Kelling, G., 1991. Tectonic connection of the Hellenic and Cyprus Arcs and related geotectonic elements, *Mar. Geol.*, **97,** 261–277.

Arvidsson, R., Ben-Avraham, Z., Eckström, G. & Wdowinski, S., 1998. Plate tectonic framework for the October 9, 1996 Cyprus earthquake, *Geophy. Res. Lett.*, **25,** 2241–2244.

Ben-Avraham, Z., Shoham, Y. & Ginzburg, A., 1976. Magnetic anomalies in the eastern Mediterranean and the tectonic setting of the Eratosthenes Seamount, *Geophys. J. R. astr. Soc.*, **45,** 105–123.

Ben-Avraham, Z., Kempler, D. & Ginzburg, A., 1988. Plate convergence in the Cyprian Arc, *Tectonophysics*, **146,** 231–240.

Ben-Avraham, Z., Tibor, G., Limonov, A.F., Leybov, M.B., Ivanov, M.K., Tokarev, M. Yu. & Woodside, J.M., 1995. Structure and tectonics of the eastern Cyprian Arc, *Marine and Petroleum Geology*, **12,** 263–271.

Engdahl, E.R., van der Hilst, R.D. & Buland, R., 1998. Global teleseismic earthquake relocation with improved travel times and procedures for depth relocation, *Bull. seism. Soc. Am.*, **88,** 722–743.

Ivanov, M.K., Limanov, A.F. & Woodside, J. (eds), 1992. Geological investigations in the Mediterranean and Black Seas, *UNESCO Rep. Mar. Sci.*, **56,** p. 208.

Jackson, J.A. & McKenzie, D., 1984. Active tectonics of the Alpine-Himalayan Belt between western Turkey and Pakistan, *Geophys. J. R. astr. Soc.*, **77,** 185–264.

Jackson, J.A. & McKenzie, D., 1988. The relationship between plate motions and seismic moment tensors, and the rates of active deformation in the Mediterranean and Middle East, *Geophys. J.*, **93,** 45–73.

Kempler, D., 1998. Eratosthenes Seamount: the possible spearhead of incipient continental collision in the eastern Mediterranean, College Station, Texas (Ocean Drilling Program), *Proceedings of the Ocean Drilling Program*, Vol. 160, pp. 709–721. eds, Robertson, A.H.F., Emeis, K.-C., Richter, C. & Camerlenghi, A.

Mart Y. & Robertson, A.H.F., 1998. Eratosthenes Seamount: an oceanographic yardstick recording late Mesozoic-Tertiary geological history of the eastern Mediterranean, *Proceedings of the Ocean Drilling Project, Scientific Results*, Vol. 160, pp. 701–708 eds, Robertson, A.H.F., Emis, K.-C., Richter, C. & Camerlenghi, A., College Station, Texas, Ocean Drilling Program.

McClusky, S. *et al.*, 2000. Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus, *J. geophys. Res.*, **105,** 5695–5719.

McClusky, S., Reilinger, R., Mahmoud, S., Ben Sari, D. & Tealeb, A., 2003. GPS constraints on Africa (Nubia) and Arabia plate motions, *Geophys. J. Int.*, **155,** 126–138.

Papazachos, B.C. & Papaioannou, Ch.A., 1999. Lithospheric boundaries and plate motions in the Cyprus area, *Tectonophysics*, **308,** 193–204.

Pilidou, S., Priestley, K., Jackson, J. & Maggi, A., 2004. The 1996 Cyprus earthquake: a large, deep event in the Cyprean Arc, *Geophys. J. Int.*, **158,** 85–97.

Robertson, A.H.F., 1998. Tectonic significance of the Eratosthenes Seamount: a continental fragment in the process of collision with subduction zone in the eastern Mediterranean (Ocean Drilling Program Leg 160), *Tectonophysics*, **298,** 63–82.

Salamon, A., Hofstetter, A., Garfunkel, Z. & Ron, H., 1996. Seismicity of the eastern Mediterranean region: perspective from the Sinai subplate, *Tectonophysics*, **263,** 293–305.

Salamon, A., Hofstetter, A., Garfunkel, Z. & Ron, H., 2003. Seismotectonics of the Sinai subplate—the eastern Mediterranean region, *Geophys. J. Int.*, **155,** 149–173.

Smith, D.E., Kolenkiewicz, R., Robbins, J.W., Dunn, P.J. & Torrence, M.H., 1994. Horizontal crustal motion in the central and eastern Mediterranean inferred from satellite Laser ranging measurements, *Geophys. Res. Lett.*, **21,** 1979–1982.

Vidal N., Klaeschen, D., Kopf, A., Docherty, C., Von Huene, R. & Krasheninnikov, V.A., 2000. Seismic images at the convergence zone from south of Cyprus to the Syrian coast, eastern Mediterranean, *Tectonophysics*, **329,** 157–170.

Wdowinski, S., Bock, Y., Baer, G., Prawirodirdjo, L., Bechor, N., Naaman Knafo, S., Forrai, Y. & Melzer, Y., 2004. GPS measurements of current crustal movements along the Dead Sea Fault, *J. geophys. Res.*, **109,** doi:10.1029/2003JB002640.

Wessel, P. & Smith, W.H.F., 1995. New version of the generic mapping tools released, *EOS, Trans. Am. Geophys. Un.*, **76,** 329.

Woodside, J.M., Mascle, J., Zitter, T.A.C., Limonov, A.F., Ergun, M. & Volkonskaia, A., 2002. shipboard scientists of the PRISMED II Expedition, The Florence Rise, the western bend of the Cyprus Arc, *Mar. Geol.*, **185,** 177–194.