SEISMOTECTONIC IMPLICATIONS OF RELATIVE MOTIONS BETWEEN THE AFRICAN ARABIAN AND TURKISH PLATES

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Abstract
The nature of the Turkish-African plate boundary is investigated on the basis of the existing seismologic and tectonic data. Current knowledge on seismicity and neotectonics is condensed in a seismotectonic map encompassing the assumed southern margin of the Turkish plate. From the seismotectonic evidences it is concluded that consumption of African lithosphere beneath Turkey is not a suitable model to explain present plate interaction in this area. The observed relationship between extensional, compressional, and strike-slip deformation is likely to be characteristic for convergent strain within a broad diffuse zone in the Mediterranean.

1. INTRODUCTION

The concepts of plate configuration in the Eastern Mediterranean implicate considerable motions of the intervening small plates relative to the Eurasian and Afro-Arabian plates (e.g. McKENZIE 1972, DEWEY et al. 1973, BIJU-DUVAL et al. 1977, SENGOER 1979). The Turkish microplate is wedged between the Arabian and Eurasian plates and moves westward in order to avoid excessive crustal thickening along the collision front. The motion is evident from tectonic and seismic activity along wrench-type major lineaments acting as transform faults, namely the Dead Sea Rift (DSR), the East Anatolian Fault (EAF), and especially the North Anatolian Fault (NAF). Conversely, the assessment of type of deformation and nature of plate interaction along the assumed convergent Turkish-African plate boundary appears to be rather difficult. As a matter of fact, this boundary was delineated and characterized rather tentatively on the basis of a general plate concept, without sufficient corroboration by seismologic and/or geologic-tectonic arguments. The following seismotectonic considerations may illustrate to what extent the available data are relevant for interpretation of the nature of plate convergence between Turkey and Africa.

2. SEISMICITY

The general seismicity, epicentral and focal depth distribution, strong shock characteristics and solutions of focal mechanisms are suitable contributions for the determination of the neotectonic situation over a regional scale. However, these data have to be considered in the context of geology in order to be interpreted properly. Information on seismicity within the region bounded by longitudes 29°-37° E and latitudes 33°-39° N is based on a completely revised earthquake catalogue compiled by ERGIN & BUEYUEKASIKOGLU (1978), covering the historical period with strong shocks of the 18th and 19th century, and the instrumental period 1901 - 1976. The reliably located events with $M \geq 5{,}1$ and $I_0 \geq$ VII are depicted on the seismotectonic map (Fig. 1), together with information on focal depth.

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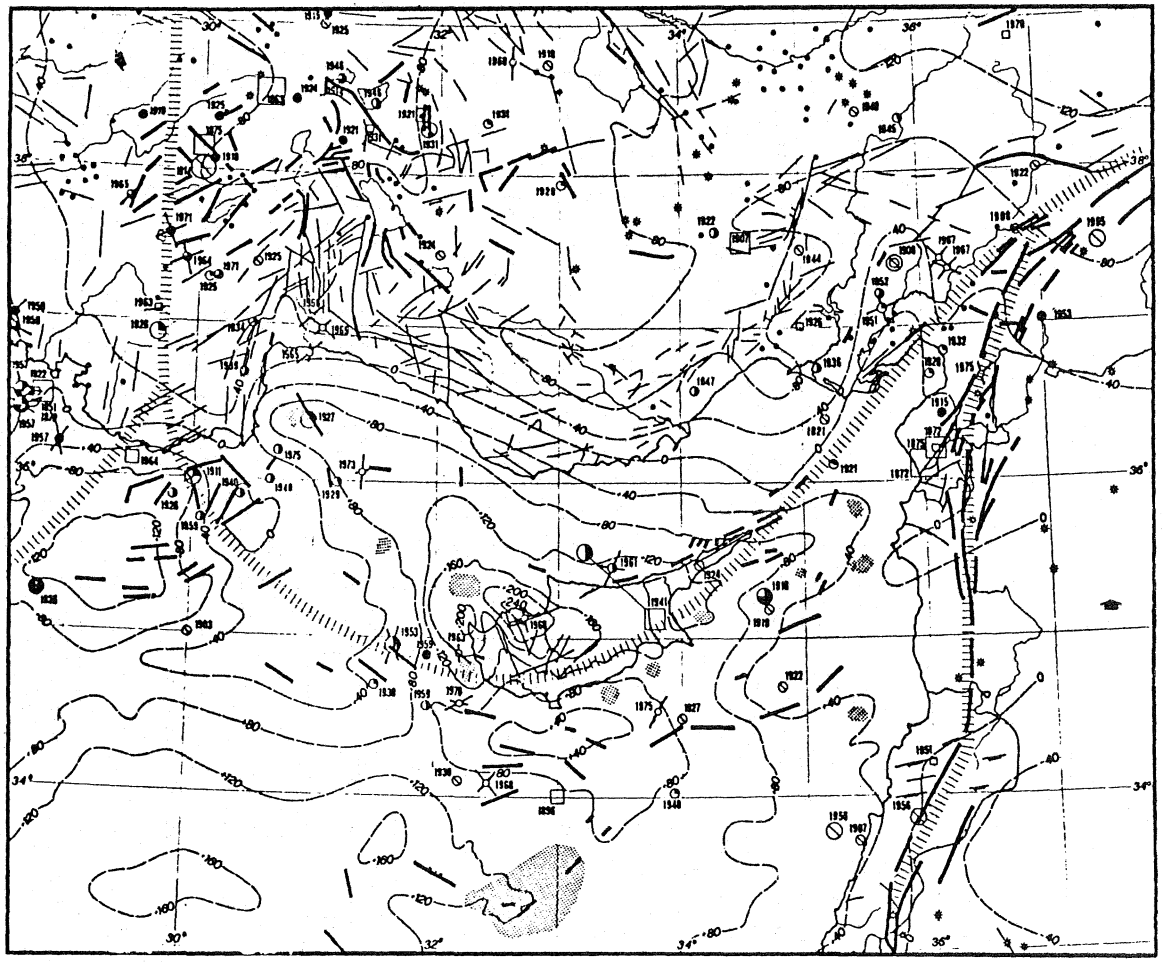

Seismotectonic Map

Explanation

Earthquake epicenter (period 1850 - 1975) with year of occurrence

Magnitude	Focal depth in km: unknown	1-30	31-60	61-120	≥121
5,1 - 6,0	○	●	◕	◑	◔
6,1 - 7,0	⊘	●	◕	◑	◔
7,1	⊘				

MM - Intensity: VII, VIII, IX, ≥X

- computed epicenter with corresponding macroseismic epicenter
- horizontal components of P- and T- axes, unit vector
- Plate boundary after McKenzie 1972
- relative plate motion
- Tectonic lineament or fault: age of activity

pre-Quaternary	until present

- relative sense of motion

Center of volcanic activity:
- extinct
- active in historic times
- hot and/or mineral water spring (data only for Turkey available)

Bouguer anomaly:
- 40 — contour interval: 40 mgal, density: 0,267 kN/m³

Magnetic anomaly:
- positive anomaly ≥ 100 γ

FIG. 1

The following regional and spatial distribution is recognized: Earthquakes with shallow focal depths are widespread on the Turkish and Levante mainland and in the offshore region. Events with intermediate focal depths ($60 \leq h \leq 250$ km) are accumulated in the region of the Antalya Basin, in the Adana and Iskenderun basins, and in southern Central Anatolia; the latter is the region of Neogene - Early Quaternary volcanism. A seismically active region with shallow and intermediate foci is also discernible to the SW and S of Cyprus, whereas the large area of the Mut Platform is obviously aseismic.

The fault plane solutions provided by ALPTEKIN (1973), CANITEZ & UECER (1967), and ALPTEKIN & EZEN (1978) reveal a rather complex picture of deformation along the assumed Turkish-African plate boundary.

The horizontal components of the P-axes of focal solutions in Fig. 1 indicate a basically compressional stress regime along the Cypriot Arc. In Fig. 2 two N-S vertical sections of earthquake foci may elucidate in some more detail the tectonic significance of the seismic activity. The section across the western wing of the Cypriot Arc (Fig. 2a) shows the foci with intermediate depth scattered over a broad zone beneath the Gulf of Antalya. This picture hardly allows for the identification of a subduction zone according to pacific models or also according to the section across the Hellenic Arc (PAPAZACHOS 1973, PAPAZACHOS & COMNINAKIS 1977). This spatial array is not substantially changed if the section is perpendicular to the Florence Rise (BUEYUEKASIKOGLU 1980). Moreover, there is a gap of seismic activity observed exactly in the region where the downward bending of a subducted lithosphere would be expected, namely to the S of Florence Rise. Finally, from the projection of the available fault plane solutions no depth dependence of the focal mechanism is observed, i.e. no down-dip tensional stress release of the intermediate earthquakes as it was found to exist along dipping slabs by ISACKS & MOLNAR (1971) using worldwide data.

The perpendicular section across Cyprus (Fig. 2b) evokes to some extent the idea of shallow underthrusting of the island. This is, however, not supported by the available fault plane solutions, which exhibit different fault types with subhorizontal directions of T-axes. Taking into account the lateral distance exceeding 300 km it is neither conceivable to postulate a relationship of the intermediate foci beneath Central Anatolia with those beneath Cyprus.

Thus, in spite of the apparent compression between Turkey and Africa and some fictitious arguments from the spatial distribution of earthquake foci there is virtually no striking seismologic evidence in favour of active subduction beneath the Cypriot Arc at present.

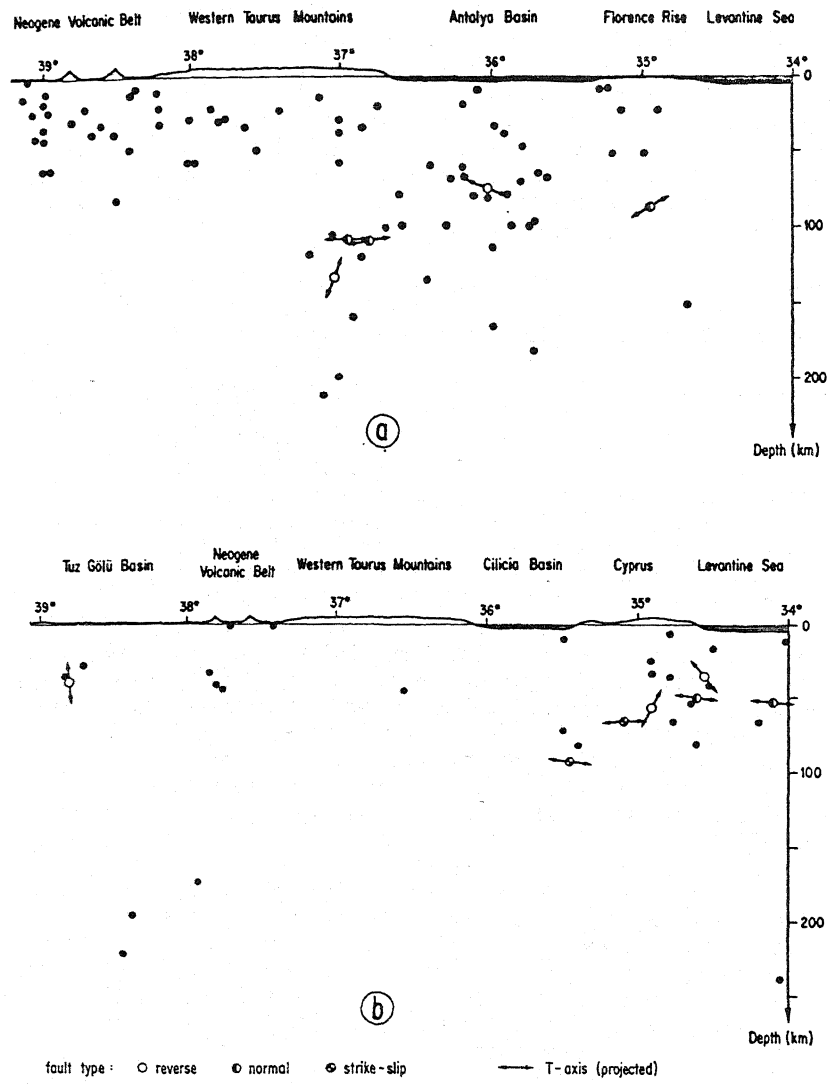

Fig. 2 : N-S vertical sections of earthquake foci with $M \geq 4,1$ and uncertainty on focal depth $\leq$ 30 km across the Cypriot-Tauride Arc. a : section 30^{o}-32^{o} E, b : section 32^{o}-34^{o} E.

3. GEOLOGY AND TECTONICS

The region under investigation is part of the Mediterranean sector of the Alpine orogenic belt, which in turn is considered to be the result of the Afro-Arabian-Eurasian collision and of the interaction with intervening smaller plates. The Late Mesozoic collision is indicated by the peri-Arabian ophiolite crescent (RICOU et al. 1975) which may extend along the Cypriot Arc (BIJU-DUVAL et al. 1976). Subsequent fracturation of continental margins and Late Alpine diastrophism obliterated the ophiolitic nappe front. The andesitic volcanism in Central Anatolia was probably related to continuous subduction of oceanic crust beneath South Anatolia. From the Miocene onward, compressive stress appears to be progressively replaced by differential tectonics as indicated by the evolution of intra-montaneous depressions onland and distinct salt basins within the Mediterranean (WOODSIDE 1977). This phase was associated with extensive blockfaulting which lasted until Pleistocene times. The change of composition of the volcanics in the Afyon-Kayseri area from calc-alkaline to more K-rich products during the Pliocene appears to be related to this change of the tectonic style, thus indicating that audesitic volcanism related to subduction was already in a final stadium at that time.Quaternary active faulting is especially observed in the Western Taurus,in Central Anatolia and along the Turkish-Arabian boundary (EAF). The large area of the Neogene Mut Platform is largely free of post-Miocene faulting (Fig. 1). The active faults offshore as inferred from seismic profiling are almost parallel to the Alpine structures. The still actively subsiding marginal basins (Finike, Antalya, Iskenderun) suggest a predominantly tensional stress field along the southern boundary of the Turkish plate. This is also confirmed by the growth faults bounding the island of Cyprus to the N and to the S. There are only minor geologic evidences testifying for the Turkish-African convergence, such as the Cyprus Outer Ridge (KENYON & BELDERSON 1977), and the continuous elevation of parts of the Florence Rise (Anaximander Mts., NESTEROFF et al. 1977). The extensional regime of Central Anatolia is much less pronounced than the stretching in the Aegean, which may in fact result in an overriding of the thinned northern margin of Africa. Thus, taking into account that the Turkish plate cannot be considered as a torsionally rigid block there is no geological evidence in favour of active subduction of African lithosphere beneath South Anatolia either.

4. CONCLUSIONS

Models of plate interaction involving subduction are largely based on the assumption that the consumed lithosphere is oceanic. Subduction of continental lithosphere has variously been found to exist as well (e.g. BIJU-DUVAL et al. 1977), but this implicates severe constraints such as buoyancy effects (e.g. MOLNAR & GRAY, 1979). Although it cannot be correlated with Arabia (BEIN & GVIRTZMAN 1977) the crust underlying the young sedimentary cover in the Eastern Mediterranean is considered to be continental rather than oceanic (FINETTI & MORELLI 1973, MORELLI et al. 1975, MALOVITSKIY 1975, WOODSIDE 1977, MORELLI 1978). From such geophysical evidence and by taking into account the seismological and geologic-tectonical arguments it is concluded that a subduction model - either oceanic or continental - is not suitable to characterize the assumed Turkish-African plate boundary. It is also not conceivable to assume a juxtaposition of different types of plate interaction with respect to the small radius of the Cypriot-Tauride arc. The observed

complex relationship between extensional, compressional, and strike-slip deformation in this area appears to be more characteristic for a continental zone along which plate convergent displacement is converted into convergent strain within a broad and diffuse zone. Likewise, the relative motion between Africa and the westward moving Turkish plate seems to be taken up by some sort of non-elastic creep within the zone as suggested by NORTH (1974 and 1977) and HARSCH et al. (1980).

REFERENCES

ALPTEKIN, O. (1973)
Focal mechanisms of earthquakes in western Turkey and their tectonic implications. - unpubl. Ph. D. thesis, New Mexico

ALPTEKIN, O. & EZEN, U. (1978)
Focal mechanisms of some earthquakes in the region surrounding the Akkuyu nuclear power plant site. - ITU report (unpublished)

BEIN, A. & 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. - Int. Symp. CIESM Split, 95-110

BIJU-DUVAL, B. LAPIERRE, H. & LETOUZEY, J. (1976)
Is the Troodos Massif (Cyprus) allochthonous? - Bull. Soc. geol. Fr. 18, 1347-1356

BIJU-DUVAL, B., DERCOURT, J. & LE PICHON, X. (1977)
From the Tethys ocean to the Mediterranean seas: a plate tectonic model of the evolution of the Western Alpine system. - Int. Symp. CIESM Split, 143-164

BUEYUEKASIKOGLU, S. (1980)
Eurasian-African plate boundary in southern Turkey and Eastern Mediterranean. - Proc. 7th WCEE, Istanbul

CANITEZ, N. & UECER, S.B. (1967)
Computer determinations for the fault plane solutions in and near Anatolia. - Tectonophysics 4, 235-244

DEWEY, J.F., PITMAN III, W.C., RYAN, W.B.F. & BONNIN, J. (1973)
Plate Tectonics and the Evolution of the Alpine System. - Bull. geol. Soc. Amer. 84, 3137-3180

ERGIN, K. & BUEYUKASIKOGLU, S. (1978)
Seismicity of Akkuyu nuclear power plant-site, final report. - ITU report (unpublished), 162 pp.

FINETTI, I. & MORELLI, C. (1973)
Geophysical Exploration of the Mediterranean Sea. - Boll. Geof. teor. appl. 15, 263-341

HARSCH, W., KUEPFER, T., RAST, B. & SAEGESSER, R. (1980)
Seismotectonic considerations on the boundary region between the Turkish and the African plates. - Geol. Rdsch. (in press)

ISACKS, B.L. & MOLNAR, P. (1971)
Distribution of stresses in the descending lithosphere from global survey of focal mechanism solutions of mantle earthquakes. - Rev. Geophys. Space Phys. 9, 103-174

KENYON, N.H. & BELDERSON, R.H. (1977)
Young compressional structures of the Calabrian, Hellenic and Cyprus Outer Ridges. - Int. Symp. CIESM Split, 233-240

McKENZIE, D.P. (1972)
Active tectonics of the Mediterranean region. - Geophys. J. Roy. Astron. Soc. 30, 109-185

MALCVITSKIY, Y.P., EMELYANOV, E.M., KAZAKOV, O.V., MOSKALENKO, V.N., OSIPOV, G.V., SHIMKUS, K.M. & CHUMAKOV, I.S. (1975)
Geological structure of the Mediterranean Sea floor (based on geological-geophysical data). - Marine Geology 18, 231-261

MOLNAR, P. & GRAY, D. (1979)
Subduction of continental lithosphere: some constraints and uncertainties. - Geology 7, 58-62

MORELLI, C. (1978)
Eastern Mediterranean: Geophysical results and implications. - Tectonophysics 46, 333-336

MORELLI, C., PISANI, M. & GANTAR, C. (1975)
Geophysical studies in the Aegean Sea and in the Eastern Mediterranean. - Boll. Geofis. teor. appl. 18, 127-168

NESTEROFF, W.D., LORT, J., ANGELIER, J., BONNEAU, M. & POISSON, A. (1977)
Esquisse structurale en Méditerranée orientale au front de l'Arc Egéen. - Int. Symp. CIESM Split, 241-250

NORTH, R.G. (1974)
Seismic Slip Rates in the Mediterranean and Middle East. - Nature 252, 560-563

NORTH, R.G. (1977)
Seismic Moment, Source Dimensions, and Stresses Associated with Earthquakes in the Mediterranean and Middle East. - Geophys. J.R. astron. Soc. 48, 137-161

PAPAZACHOS, B.C. (1973)
Distribution of seismic foci in the Mediterranean and surrounding area and its tectonic implication. - Geophys. J.R. astr. Soc. 33, 421-430

RICOU, L. -E., ARGYRIADIS, I. & MARCOUX, J. (1975)
L'axe calcaire du Taurus, un alignement de fenêtres arabo-africaines sous des nappes radiolaritiques, ophiolitiques et métamorphiques. - Bull. Soc. géol. Fr., 17, 1024-1044

PAPAZACHOS, B.C. & COMNINAKIS, P.E. (1977)
Modes of lithospheric interaction in the Aegean area. - Int. Symp. CIESM Split, 319-332

RAST, B. & SAEGESSER, R. (1980)
On the Systematics in defining Seismic Zones. - Proc. 7th WCEE, Istanbul

SENGOER, A.M.C. (1979)
The North Anatolian transform fault: its age, offset and tectonic significance. - J. geol. Soc. Lond. 136, 269-282

WOODSIDE, J.M. (1977)
Tectonic elements and crust of the Eastern Mediterranean sea. - Mar. Geophys. Res. 3, 317-354.