Trabajos de Geología, Universidad de Oviedo, 29 : 45-50 (2009)

Tectonic evolution of the Mediterranean: a dame with four husbands

A. M. C. Şengör*

İTÜ Avrasya Yerbilimleri Enstitüsü, Ayaza a Istanbul 34469, Turkey.

**e-mail: sengor@itu.edu.tr*

Abstract: The tectonics of the Mediterranean Region since the end of the Hercynian orogeny in Europe has been dominated successively by four major developments largely outside it, whose effects interacted in the Mediterranean to give it its extremely complicated geology. The first influence was that of the consumption of the Paleo-Tethys under Gondwanaland in regions east of the present-day Bulgaria. A second concurrent influence was the right-lateral transpression along the Scythides as far west as the North Dobrudja: this led to the Triassic extension and partial ocean-floor generation in the Carpathians, the Alps and the Pyrenees. These two influences were still active when the Central Atlantic began opening, adding a third influence. This rifted new oceans in the Betics, the Atlas Mountain complex, the Apennines and the Alps. When Gondwanaland began rifting in Late Jurassic, its extensional tectonics began influencing places as far into the Mediterranean as the northern African continental margin east of Libya and parts of the Arabian Peninsula, adding a fourth influence. The Aptian-Albian opening in the South Atlantic finally halted the extension in these areas, but it imposed on Africa a northerly drift component with respect to Laurasia. This led to the generation of new subduction zones and the obduction of giant ophiolite nappes. In the northern African continental margin east of Libya, aborted ophiolite obduction led to the generation of the Syrian Arcs orogen, a foreland fold/thrust system with no corresponding internides. Major continental collisions began in the Eocene, but the final pinching of the Mediterranean basin at both ends was a Miocene affair.

Keywords: Mediterranean, Scythide shear zone, Paleo-Tethys, Central Atlantic Ocean, South Atlantic Ocean, Gondwanaland, Syrian Arcs orogen.

The Mediterranean area is tectonically one of the most complicated regions in the world. It includes today the seismically most active region in the world and its past seems to have been equally stirring. With the advent of plate tectonics it became clear that the opening of the Atlantic Ocean had been the controlling factor of the overall kinematic framework of Mediterranean tectonics. On the basis of this recognition, Hsü (1971), Smith (1971) and Dewey *et al.* (1973) provided syntheses of the Mediterranean tectonic development immediately after the widespread recognition of the plate structure and the great horizontal mobility of the lithosphere. Common to all these syntheses was a central kinematic problem: how to maintain extension on both sides of Argand's African promontory during Triassic and Liassic? The usual answer given was to assume subduction somewhere farther east, where the geology was less known than in any west European country. Only in 1979 did the discovery of the Paleo-Tethyan suture (Şengör, 1979) put flesh on the bones of this hypothesis. However, it was later recognised that the Paleo-Tethyan subduction was highly oblique and

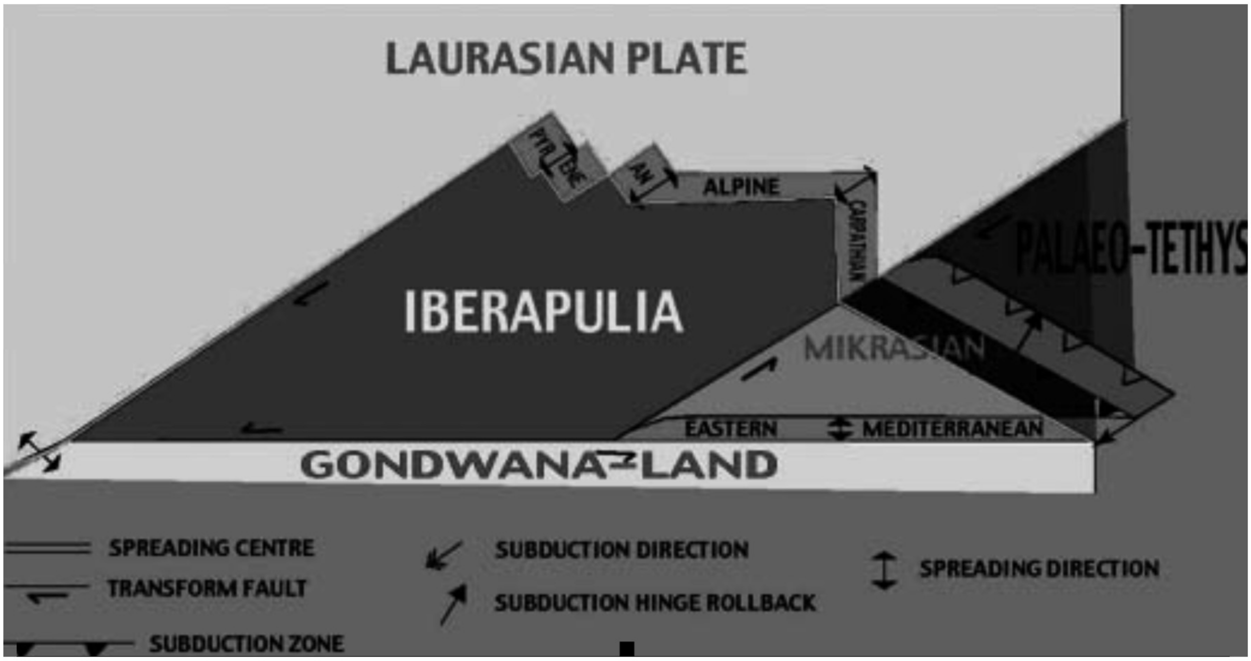

Figure 1. Tentative kinematic model showing the relationships between different plate boundaries.

that a serious component of strike-slip characterised the tectonic evolution of its northern margin well into the Mesozoic (Natal’in and engör, 2005). This discovery made it clear that not one, but two Paleo-Tethyan subduction zones were necessary: one dipping under Laurasia and the other under Gondwanaland.

The question then became how many such strike-slip convergent motions were absorbed within the Paleo-Tethys and how much was transferred farther west into the Mediterranean realm. If any was transferred into the Mediterranean, how did it interfere with the Atlantic opening kinematics? Figure 1

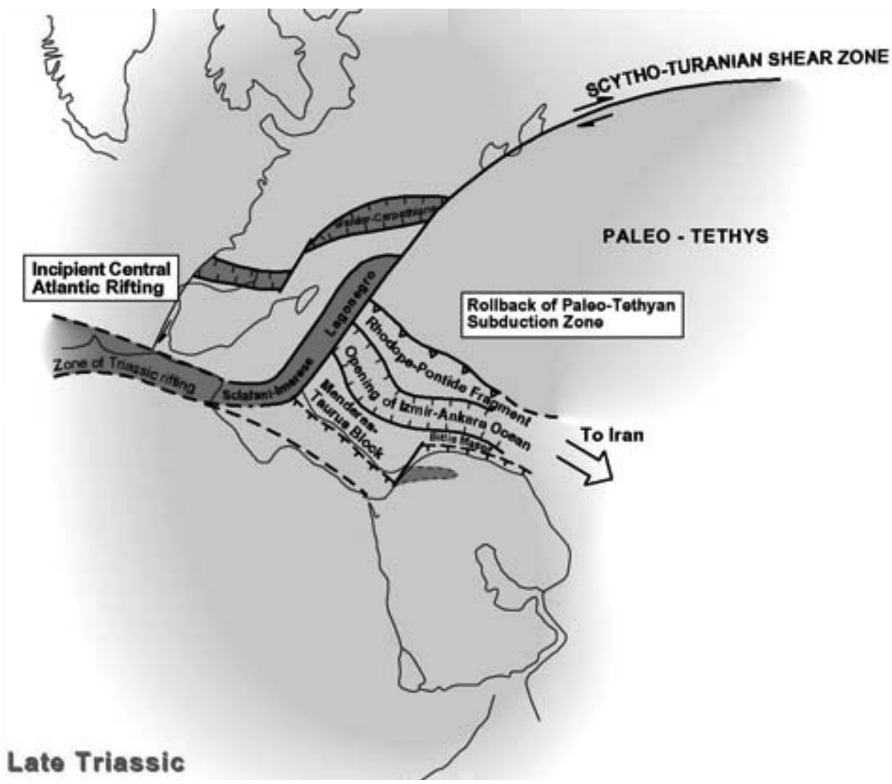

Figure 2. Tectonic map of the Mediterranean region during the Late Triassic showing the location of the main faults.

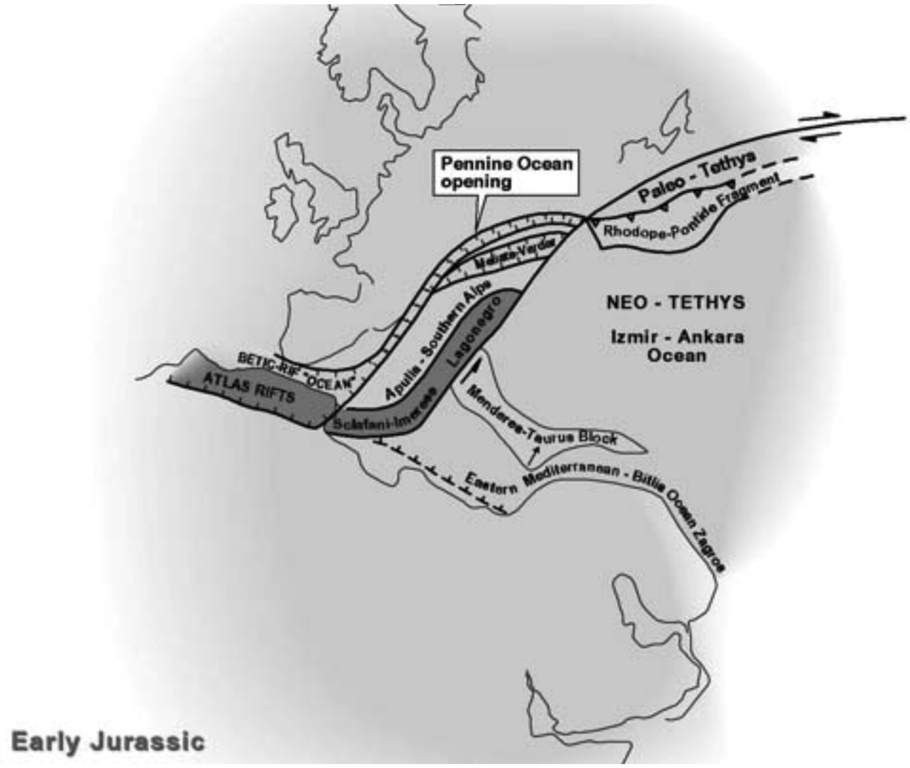

Figure 3. Tectonic map of the Mediterranean region during the Early Jurassic showing the location of the main faults.

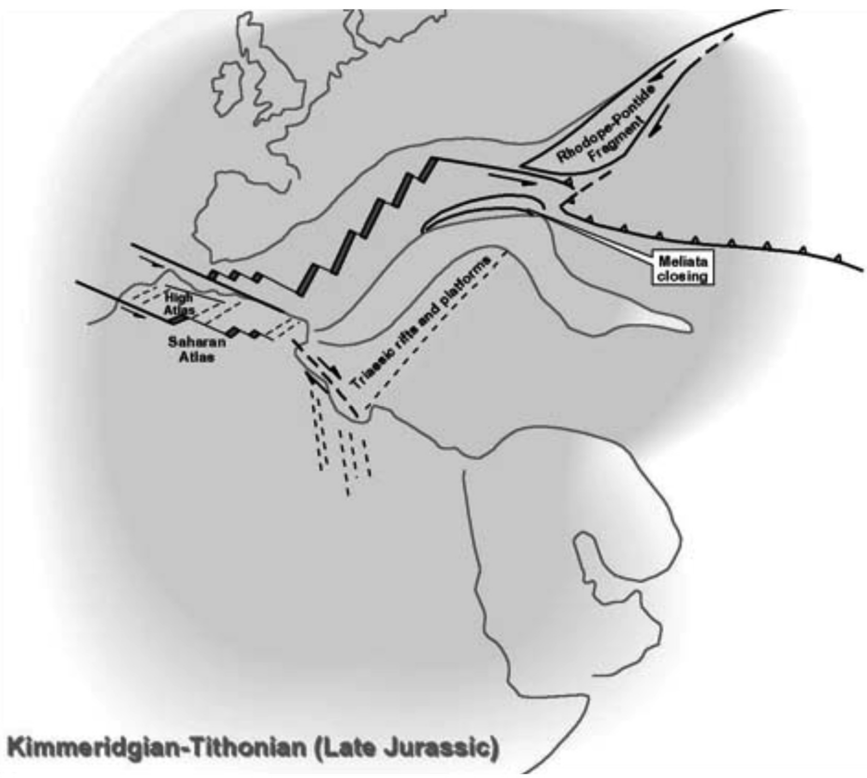

Figure 4. Tectonic map of the Mediterranean region during the Kimmeridgian-Tithonian (Late Jurassic) showing the location of the main faults.

shows a tentative kinematic model to answer these questions. It shows the northern margin of the Paleo-Tethys as a pure strike-slip system (a keirogen), although there was also much subduction. I drew it here as a pure strike-slip to emphasise that it is the strike-slip component that is of significance for the Mediterranean tectonics farther west. The diagram also shows that there was much dis-

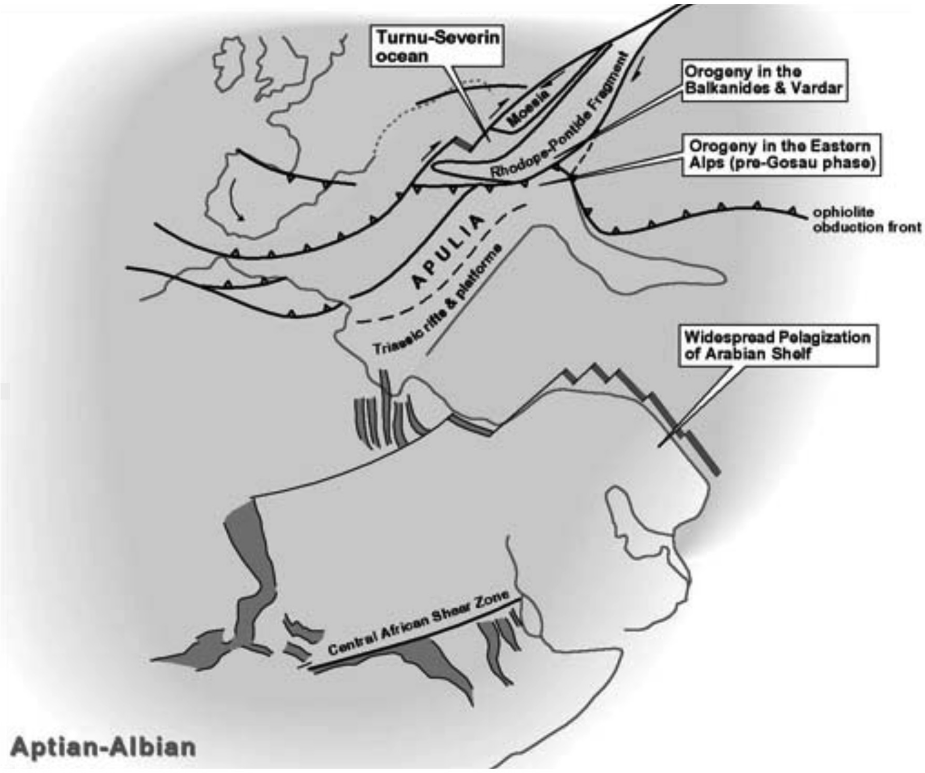

Figure 5. Tectonic map of the Mediterranean region during the Aptian-Albian showing the location of the main faults.

placement and strain partitioning amongst various plate boundaries and plate boundary zones.

The basic tenet of this model is to assume that not all of the strike-slip along the northern margin of the Paleo-Tethys (along the Scythides) was consumed by the subduction zone, but a very insignificant part was partitioned to impose extension along the future Carpathians, Alps and the Pyrenees. The presence of strike-slip in the Scythides is based entirely on geological data as no part of Paleo-Tethyan ocean floor is now extant. This accounts for the Triassic extensional phases of extension in the Mediterranean mountain ranges that were independent of the later Jurassic extension. Figure 2 shows what the Mediterranean area may have looked like during the Late Triassic.

As early as during the Hettangian/Sinemurian, the Mediterranean area was feeling the effects of the Central Atlantic opening. This is the time of the major rifting in the future Mediterraenan Tethyside chains (Fig. 3) and the time of the opening of the main Pennine Ocean in the Alps. In Kimmeridgian/Tithonian times, ocean opening continued, except for the Meliata Ocean in the eastern Alps and the Carpathians, that was consumed (Fig. 4).

During the Hauterivian, the Mediterranean area was already beginning to feel the influence of a third player outside its area, namely the initial rifting in the South Atlantic. The South Atlantic rifting was a part of a much larger area of the inner-Gondwanaland rifting field that extended from the present-day Gulf of Guinea all the way into southeastern Turkey and the Zagros in Iran. It created the major basins within the Chad basement and the ones farther to the northwest such as the Marmarica taphrogen in Libya and Egypt (Fig. 5).

In the Aptian-Albian, a number of subduction zones were already active in the Mediterranean area. However, a period of rifting characterised the periphery of the Arabian promontory and the Sirte Basin in Libya.

In the Late Cretaceous, major ophiolite obduction characterised the eastern part of the Mediterranean. Until now it was always assumed that the Turkish ophiolites were the westernmost representatives of this episode of widespread obduction. Recently, however, it was recognised that a double thickness oceanic crust characterises the oceanic basement just offshore of Cyrenaica, whereas onshore Cyrenaica is characterised by intense, foreland-type folding and thrusting of Senonian age. This episode of deformation had long been known, but its cause had remained enigmatic. It now seems as if the westernmost Late Cretaceous obduction event was actually in Libya, but it was aborted before the ophiolite nappe could fully overthrust the continental margin. This attempted obduction put the entire northern margin of Africa under compression and the effects of it were felt as far away as the Benue aulacogen in Nigeria, which at this time experienced shortening. By contrast, the Sirte basin continued expanding.

A string of granite intrusions cut through the obducted ophiolite nappes in Turkey, close to their root zones. This has been interpreted as a result of decompression melting, but it is possible that a subduction zone flip may also have occurred and created a short-lived continental margin arc system north of the Menderes-Taurus block in Turkey.

Since the Cretaceous, the history of the Mediterranean has been one of continuous orogeny (Fig. 6). Major collisions happened mainly in the Eocene, but both to the east (in SE Turkey) and to the west (Gibraltar arc) collisions were delayed as late as Miocene (Fig. 7).

As early as in the Oligocene, major extensional subduction zones began creating oceanic basins, a process that continues today. It is unclear how much of the extension in the Aegean is a result of orogenic collapse (Suess' Rule) and how much of it a consequence of roll-back of subduction hinge. It is also unclear when the subduction under the Hellenic arc may have commenced. It seems clear from the available kinematic constraints that spreading in the eastern Mediterranean must either have been uncommonly slow, or it must have been accommodated by corresponding subduction under the Hellenic/Tauric system or was episodic with long intervals of repose.

The final act of the Mediterranean orogeny was the closure of the Gibraltar arc and the collision in southeastern Turkey. The collisional area in southeastern Turkey is very peculiar, because the high plateau there is underlain by a continental crust only 40 km thick! It seems that it consists entirely of subduction-accretion material and that once the subducting oceanic slab was lost, the accretionary complex was underplated by hot asthenospheric material. This led to rapid uplift and very widespread alkalic volcanism.

The tectonic evolution of the Mediterranean was thus the result of four factors: firstly, the subductive removal of the Paleo-Tethys under Pangea along future eastern Mediterranean mountain belts; secondly, the opening of the Central Atlantic;

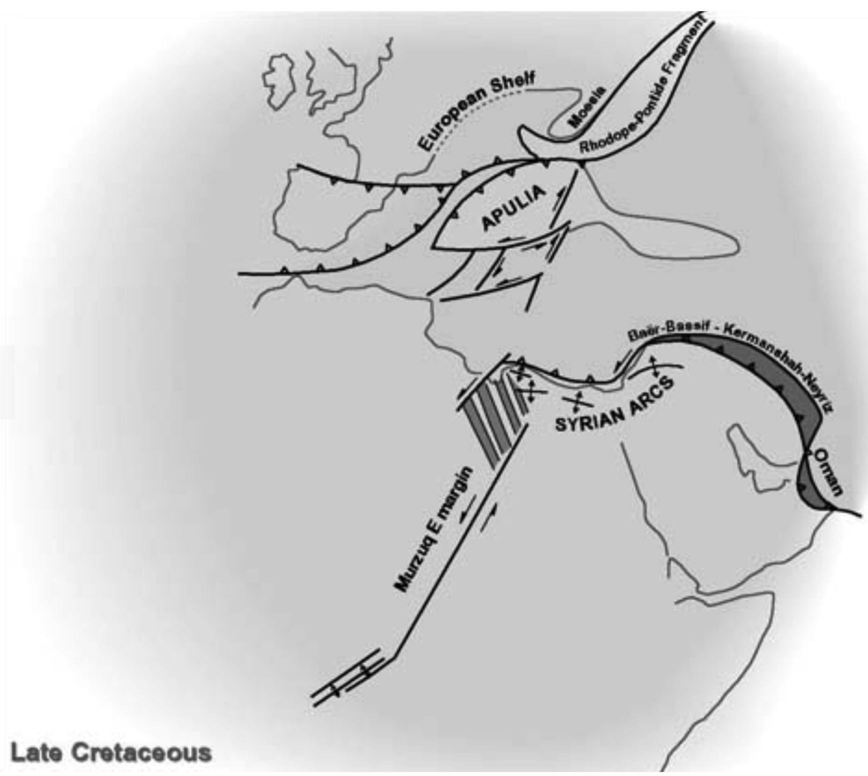

Figure 6. Tectonic map of the Mediterranean region during the Late Cretaceous showing the location of the main faults.

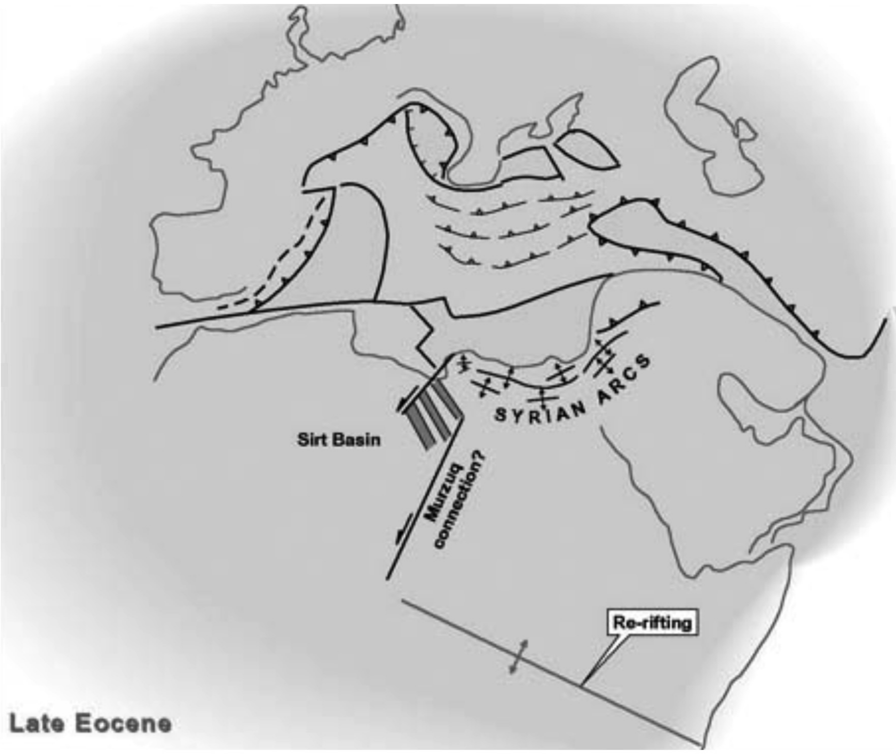

Figure 7. Tectonic map of the Mediterranean region during the Late Eocene showing the location of the main faults.

thirdly, the opening of the South Atlantic and, finally, the opening of the North Atlantic. It looks as if the Mediterranean was a dame with four succesive husbands who dictated her life and in the process managed to give birth to possibly the most beautiful sea and its surroundings in the world. Little wonder that it also was the cradle of human civilisation and grew hand in hand with the idea of human freedom.

Acknowledgements

I am grateful to the organisers of the YORSGET-08 Symposium for inviting me for a keynote address in one of the most beautiful and culturally pivotal places in the world. No honour can be higher than being valued by one's younger colleagues and hardly any place more exciting for an Earth scientist than Spain, where the revival of curiosity about our beautiful planet began more than half a millennium ago that has given us our modern scientific society.

References

DEWEY, J. F., PITMAN, W. C., RYAN, W. B. F. and BONNIN, J. (1973): Plate tectonics and the evolution of the Alpine System. *Geol. Soc. Am. Bull.*, 84: 3137-3180.

HSÜ, K. J. (1971): Origin of the Alps and western Mediterranean. *Nature*, 233: 44-48.

NATAL'IN, B. A. and ŞENGÖR, A. M. C. (2005): Late Palaeozoic to Triassic evolution of the Turan and Scythian platforms: The pre-history of the Palaeo-Tethyan closure. *Tectonophysics*, 404: 175-202.

ŞENGÖR, A. M. C (1979): Mid-Mesozoic closure of Permo-Triassic Tethys and its implications. *Nature*, 279: 590-593.

SMITH, A. G. (1971): Alpine deformation and the oceanic areas of the Tethys, Mediterranean and Atlantic. *Geol. Soc. Am. Bull.*, 82: 2039-2070.