

# The Aegean: plate tectonic evolution in Mediterranean

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Field course "Naxos" in September 2014, Group B

## Abstract

The Mediterranean Sea, as known today, resulted from various geological processes starting in the late Paleozoic, where rifting caused the opening of the Neotethys Ocean, which represents today's area of the Mediterranean. During the Mid-Cretaceous, the separation of the African and American continents led to the eastward movement of the African plate. The rotation of the African plate, triggered by this separation then led to the closure of the Tethys Ocean, and the collision of Eurasia and the Arabian part of the African plate nearly stopped the rotation and formed today's area of the Mediterranean. The Aegean region significantly changed with the formation of the Mediterranean, as an ocean basin, the Pindos basin closed and other isotopic zones and massifs were piled up as a result of the subduction of the African plate alongside the Hellenic trench. The post-orogenic extension, starting 30 million years ago was due to the back arc extension, caused by the roll back of the African plate and led to the formation of metamorphic core complexes and the landscape we can see in the region today.

## 1. Introduction

The Mediterranean Sea, nowadays located between the European mainland and North Africa and the Middle East is a result of several geological processes, which can mainly be attributed to the movements of the underlying plates and the interaction between them. In this paper, the evolution of plate tectonics in this area will be discussed. A special focus will be on the Aegean region, which is located between the east of the mainland of Greece and west of Turkey, and the interaction of the plates there. In the end, the present day constellation of the plates in the Aegean will briefly be presented.

## 2. Plate tectonic evolution of the Mediterranean

As a result of a great number of internal forces the Mediterranean has a complicated geological history. Thus, it is difficult to reconstruct reliable plate movements for geologic times earlier than the Mid-Jurassic time, 190 million years ago (Higgins & Higgins, 1996). Nevertheless, there is evidence that the eastern Mediterranean Neotethys Ocean opened following the rifting of the north margin of Gondwanaland from the late Paleozoic on (Robertson et al., 1991). In the Early-Jurassic the North Atlantic Ocean did not yet exist and a super continent, named Pangea was formed by Gondwanaland and Eurasia connected with the North-American continent. An ocean, called Tethys existed between Africa and Eurasia. In Mid-Jurassic time the North Atlantic Ocean began to form due to a new plate margin, which caused rifting of the continent along enormous normal faults (see Figure 1). The production of new crust in the rift then formed the North Atlantic. The rifting was initiated in the south and led to the separation of Africa from North America and the movement of Africa to the east. In the Mid-Cretaceous, 110 million years ago the separation of Eurasia and North America took place. In the following the rotation of the African plate in clockwise direction was triggered by the faster formation of the southern parts of the Atlantic Ocean in comparison to the northern parts. This rotation then led to the closure of the Tethys Ocean, but it slowed down, when the Arabian part of the African continent collided with Eurasia forming today's mountains of Turkey. Nowadays this rotation has nearly stopped (Higgins & Higgins, 1996).

Six millions years ago the straits of Gibraltar were closed due to tectonic forces, which resulted in the drying out of the Mediterranean, as rivers were unable to keep up the water level. This event is called the Messinian Salinity Crisis (Higgins & Higgins, 1996).

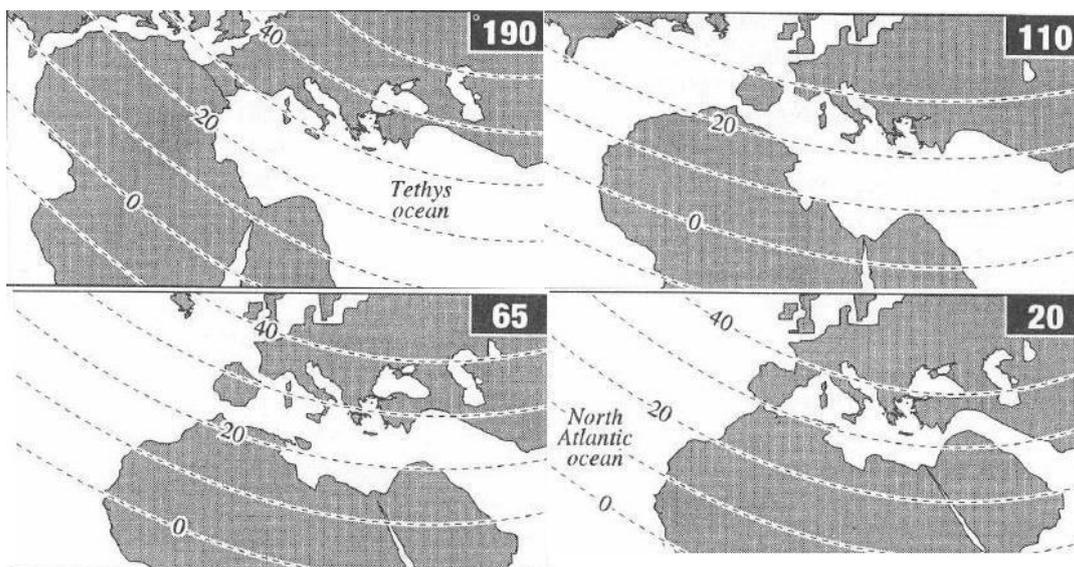
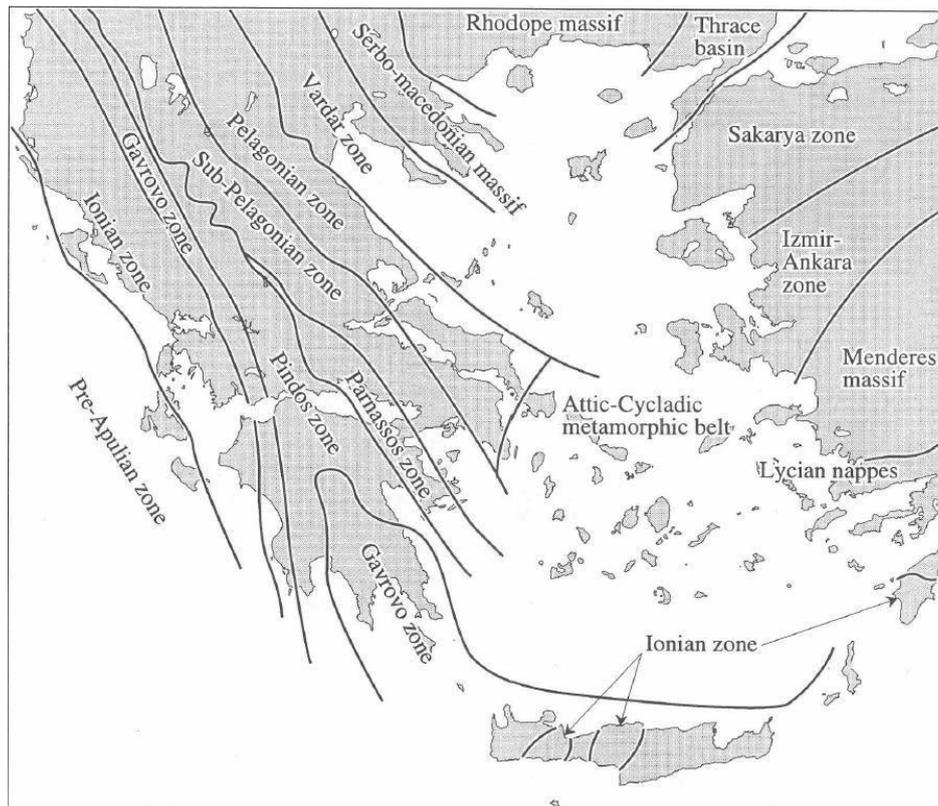


Figure 1: Evolution of the continents in the last 190 million years (Higgins & Higgins, 1996)

### 3. Plate tectonic history of the Aegean

The geology of the Aegean today comprises isotopic zones and massifs. Isotopic zones can be described as clusters of rocks sharing a history in terms of depositional environment and tectonics, whereas massifs are metamorphic or plutonic rocks, which have a higher resistance to tectonic forces. The distribution of the isotopic zones and massifs in Greece is depicted in *Figure 2* (Higgins & Higgins, 1996).

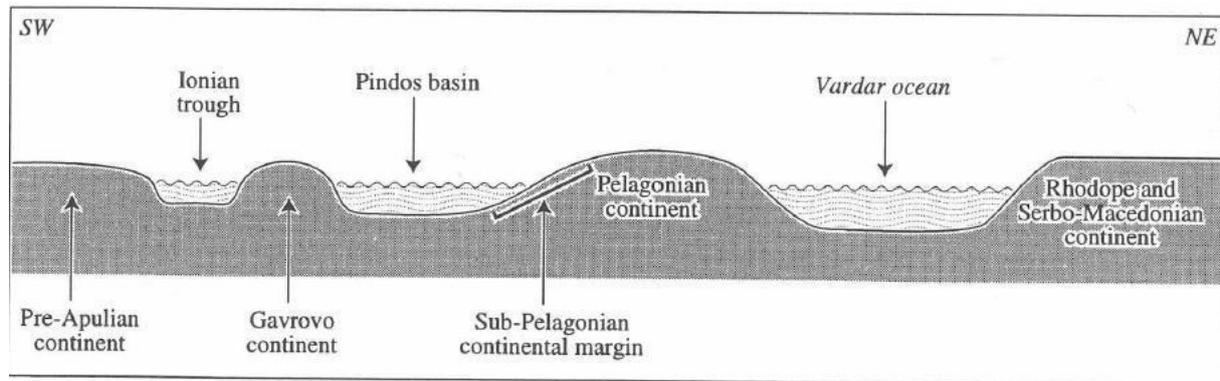


*Figure 2: Isotopic zones and massifs in the Aegean (Higgins & Higgins, 1996)*

The general history of the Aegean can be described with a closing ocean basin originally filled with islands and underwater ridges, where each part was thrust onto the neighbouring components to the north and east (Higgins & Higgins, 1996).

In the Early Jurassic the Rhodope and the Serbo-Macedonian massifs and the Sakarya zone built the north shore of the Tethys Ocean, which consequently was the southern margin of the Eurasian continent. A subduction zone dipped northwards under the continent to the south and all other zones were located further south next to the African continent, separated by a small ocean, which was part of the Tethys. A shallow, warm and tropical sea existed and the Pelagonian, Parnassos and Gavrovo zone were continental platforms within this environment. The Sub-Pelagonian zone was the continental margin to the Pindos basin, which was water-filled, as well as the Ionian trough to the

south-west (see Figure 3). This situation was comparatively unchanged until the end of the Jurassic, 130 million years ago, when a thrusting took place moving the Sub-Pelagonian continental margin and the Pindos Ocean eastwards onto the Pelagonian continental platform (Higgins & Higgins, 1996).



*Figure 3: Schematic section across the Aegean region before the compression (Higgins & Higgins, 1996)*

South of the Pre-Apulian zone, a new plate boundary was created in the Mid-Cretaceous, which marked a main change. Resulting from this boundary a new ocean basin, called Proto-Mediterranean began to develop. As there was hardly any change in the positions of Eurasia and Africa the Tethys Ocean basin began to close to the north. Some parts of the basin were subducted beneath Eurasia and others were stacked at the massif, such as in the Vardar zone (Higgins & Higgins, 1996).

In the following the isotopic zones of the Aegean were transported to the north, as a result of the expansion of the ocean to the south. Subduction and thrusting of the ocean basins westwards over the neighboring zones occurred and the continental fragments were likewise piled up. 35 million years ago, in the Tertiary, the Ionian and the Pre-Apulian zone remained the only zones still connected to the African mainland, whereas the Menderes massif had been welded onto Eurasia as well. 15 million years later the Ionian zone was almost completely absorbed and the Apulia and Hellenide mountain ranges were connected by thin continental crust (Higgins & Higgins, 1996).

During the Miocene oceanic crust was further subducted northwards beneath the Aegean along its east/west line and this resulted in the arching of the crust above the subduction zone and the development of the non-volcanic Hellenic arc, which consists of Crete, Karpathos, Rhodes and the western edge of the Peloponnes today. North of the non-volcanic Hellenic arc the subducted material melted building up the south Aegean volcanic arc with the overlying mantle, where volcanism is still active today, for example in Santorini and Nisyros. In the region north of Crete crustal extension occurred in connection with the subduction, which finally resulted in the inflation

of the once straight subduction zone into today's curve (Higgins & Higgins, 1996). At the latest stages of the Alpine orogenesis an alteration of compressional and extensional tectonic processes can be observed in the south Aegean region (Fassoulas, 1997). The extension was associated with the general movements of the plates, which resulted in the Neogene extension and the development of the grabens and horsts, which represent most of the mountains, valleys and islands of the current landscape (Higgins & Higgins, 1996). The post-orogenic extension began about 30 million years ago in the Aegean region and ended 5 million years from today. It is associated with the formation of metamorphic core complexes everywhere in the Aegean sea cycladics. The extensional stresses were due to the back-arc extension, which was a result of the roll back of the African plate subducting beneath the Aegean plate at the Hellenic trench (see also Figure 4). As the North Anatolian fault propagates to the west, it leads to differential velocities of the Anatolian-Aegean plate. The effect of this movement is the uplift of the Aegean-Anatolian plate, because it overrides the African plate between the Peloponnese in a zone of low-angle subduction (Charalampakis et al., 2014).

#### **4. Present day plate tectonic constellation in the Aegean**

Many details of the present constellation of the plates are still disputed. The African plate moves north-east with respect to Europe, sinking along the subduction zone underneath the Aegean plate at the Hellenic Trench, as shown in *Figure 4* (Higgins & Higgins, 1996). In the back arc area of the Hellenic subduction zone outcrops of one of the largest high pressure/low temperature zones can be seen (Fassoulas, 1997). East of this the motions of the plates are nearly parallel to the boundary and the subduction zone continues further east. The Anatolian plate to the north moves westward with respect to Europe and the movement is taken up by strike-slip faults at the North Anatolian Fault Zone, which ends at the northern Aegean Sea at the North Aegean Trough (*see Figure 4*). Within the Greek peninsula there are generally no simple plate boundaries to link up with the major structures and the motions are due to a number of smaller faults of all types (Higgins & Higgins, 1996). There is one model based on GPS measurements, which points out that the present day deformation of the Aegean is a result of the relative motion of four microplates named: Aegean, Central Greece, South Marmara and Anatoilia (*Figure 5*, Nyst & Thatcher, 2004).

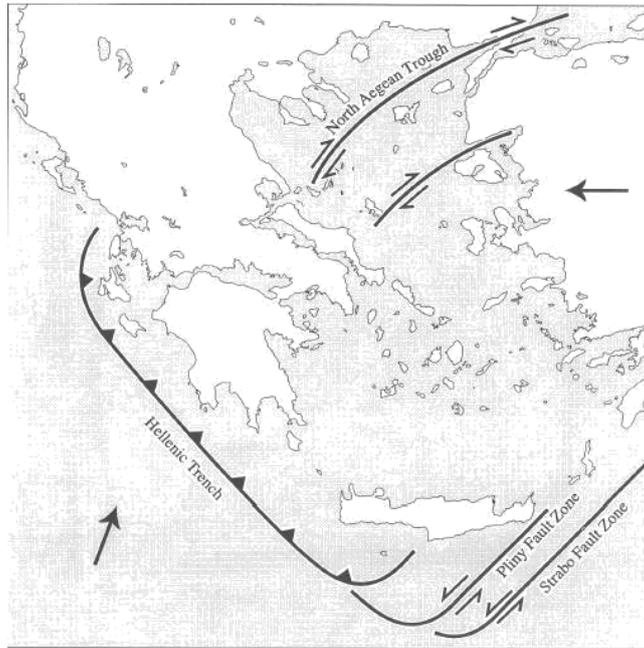


Figure 4: Present day plate tectonics in the Aegean (Higgins & Higgins, 1996)

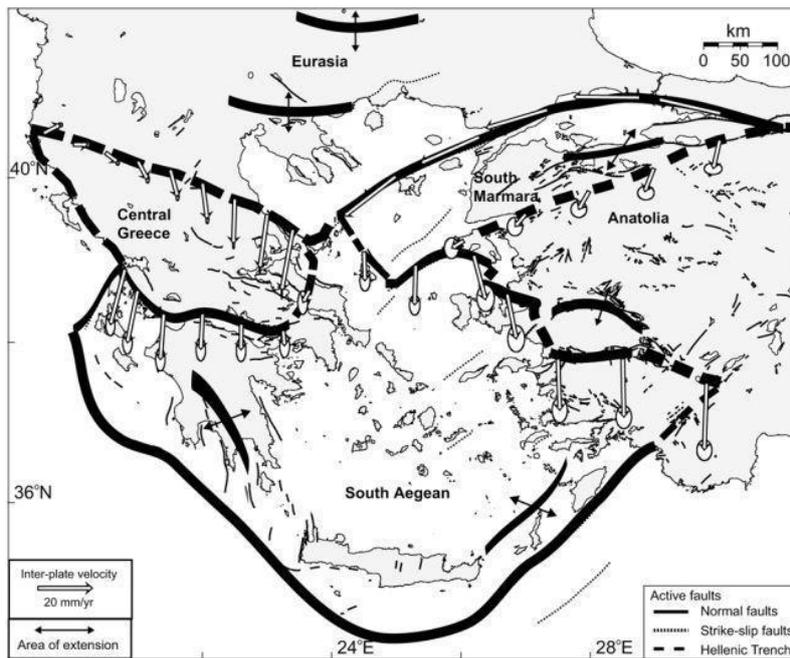


Figure 5: Four plates model of the Aegean (Nyst & Thatcher, 2004)

## 5. Conclusion

The main force causing the development of the Mediterranean is the rifting starting in the Mid-Cretaceous, which led to the movement of the African plate, followed by the collision of Africa and Eurasia accompanied by the closure of the Tethys Ocean. The newly formed ocean basin, Proto-Mediterranean developed from the Mid-Cretaceous on. Further subduction along the Hellenic trench in the Aegean then formed the non-volcanic Hellenic arc in the Miocene (Higgins & Higgins, 1996). 30 million years ago the post-orogenic back arc extension led to an uplift of the Aegean-Anatolian plate, resulting from the roll back of the subducted African plate. In the back arc area outcrops of one of the largest high pressure/low temperature zones can be viewed (Charalampakis et al., 2014; Fassoulas, 1997).

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