EXTENSIONAL NEOTECTONIC STRUCTURES ADJACENT AND SUB-PARALLEL TO THE HELLENIC TRENCH

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ABSTRACT

The neotectonic structures described in this paper were caused by extension within the upper plate of the Hellenic arc and in a direction almost parallel to the arc. This fault system is located in westernmost mainland of Greece, slightly north of the latitude of the Corinth rift. The system consists of at least two elongate extensional basins (Amvrakikos Gulf and Trichonida Lake basins). These pull-apart basins, ~30-50 km in length and trending approximately WNW are connected to each other by a linear zone of active faulting that trends NNW and is ~50 km in length. Focal mechanisms from the region around the fault system are consistent with ~NS extension and left-slip on steep faults with approximately NW trends.

We interpret this deformational system to be kinematically similar to that of pull-apart basins linked by sinistral strike-slip. The elongate extensional basins are en echelon with and trend approximately parallel to the actively extending Corinth rift. In our interpretation, these basins are probably connected to the Corinth rift by faults with a left-slip sense of displacement, but these have yet to be studied. The western end of the northern basin (Amvrakikos Gulf) appears to end against the northeastern end of the Kefalonia Transform, which extends southwestward to merge with the northern end of the rapidly moving Hellenic Trench. Thus is seems likely that the fault system described here forms a part of the active deformational connection between the Corinth rift and the northern end of the Hellenic Trench.

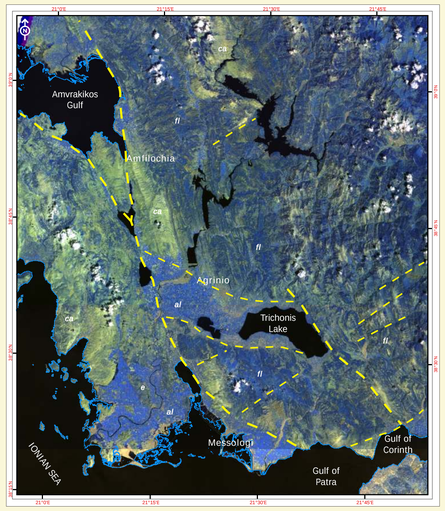


Figure 1. The interpreted *LANDSAT 7 - ETM+ (7,5,4/R,G,B)* image of western Sterea in Greece. The image was orthorectified on a 25m resolution grid using a DEM computed from the topographic 20m contour maps and spectrally analyzed. In this interpretation the surfacial water bodies are shown dark (lakes and sea) and several colors onshore can be related to the different rock outcrops. Most of the eastern area is covered by isoclinal folded alpine flysch series (fl) whose color is generally represented as dark blue and grey, depending on its lithological variations. The light green and yellow areas represent the exposure of alpine carbonate rocks (ca) whilst there are evaporites represented as dark green. The alluvial deposits take the light blue color at the areas between the lakes and at the deltas of the major rivers, near the town of Messologi. In this figure the yellow dashed lines are representing the major lineaments which are interpreted as the borders of the major fault blocks.

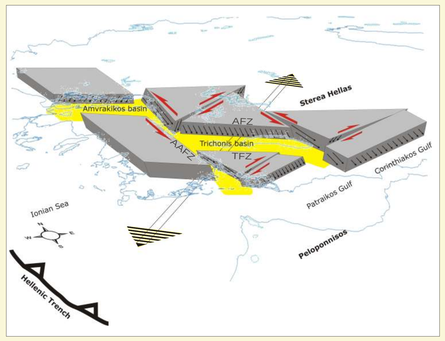


Figure 2. Three dimensional simplified block diagram in which the relative movement of the major fault blocks, is shown. The coastline and the location of the lakes are included in this figure for understanding the position of the neotectonic blocks. The yellow areas represent active post-alpine basins. The strip which connects the Amvrakikos and Trichonis basins is located along the Ampilochia - Aetoliko fault zone, where a number of lakes and a lagoon have been formed during the Pleistocene period due to recent strike slip movement. The red arrows show the horizontal component of slip and the black arrows show the kinematic indicators found on the fault surfaces during fieldwork. This diagram is similar to an ideal pull-apart basin model with the main structures being sub-parallel to the strike of the Hellenic Trench. In combination to the ENE-WSW striking, right lateral strike slip fault zones that have been identified across this area it is obvious that these structures are compatible with extension perpendicular to the Hellenic Trench even if the horizontal component of the movement is sub-parallel to the trench.

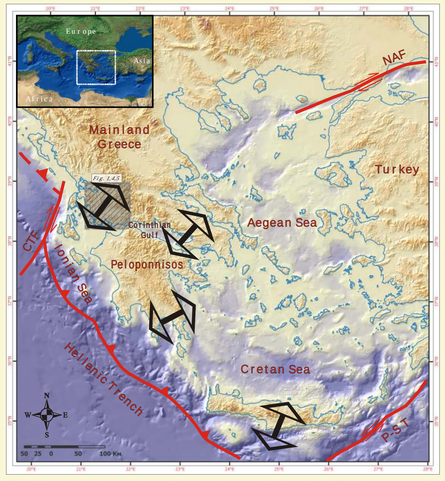
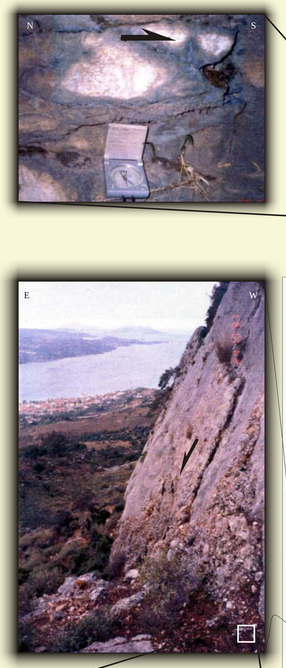


Figure 3. The location of the area of interest (box) that is adjacent to the Hellenic Trench. NE-SW extension formed the sub-parallel strike slip structures which are described in this study. The location of the large structures of Cephallonia Transform Fault (CFT) and North Anatolian Fault (NAF) are depicted in addition to the Hellenic Trench and the transpressional areas of Pliny and Strabo troughs (P-S T) to the SE.
The black arrows show the general direction of Plio-Pleistocene extension along the Hellenic Trench have been proposed by previous studies and are in agreement with the conclusions of this study.



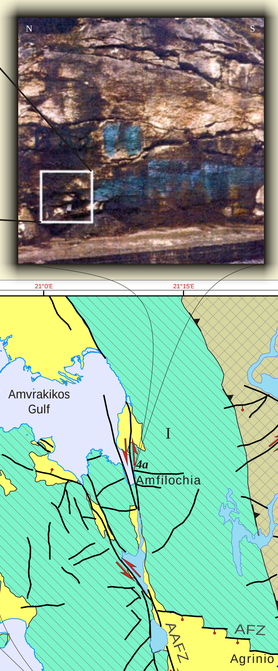


Figure 4a. The almost vertical fault surface at the northernmost segment of the AAFZ. The magnified photograph shows striations and slickenslides which are kinematic indicators compatible with the left lateral strike slip movement of the missing block.
The lateral sense of movement can be derived from the formation of several lakes along the middle segments of the fault zone. The relative direction of the block motion is not clear in many sites because of the presence of the evaporites which outcrop in the area.

Figure 4b. Fault scarp of a steep normal fault near Astakos village with tectonic breccia on the footwall and kinematic indicators showing that the eastern hanging wall is causing the relative subsidence of the area and creating the valley. This fault is active as previous lines of soil surface on the footwall indicate at least two recent movements. The present surface (red arrow) has subsided about 20 cm below the palaeo-surface (yellow arrow). This throw might have been caused by two seismic events as there is also another trace of the paleo-surface between the other two (black arrow).

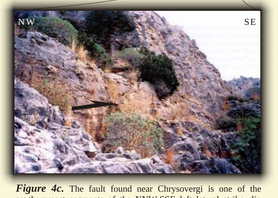


Figure 4c. The fault found near Chrysovergi is one of the southernmost segments of the NNW-SSE left lateral strike slip AAFZ. The sense of movement is documented with kinematic indicators found on the fault surface.

Figure 4. Geological map of the area showing the main geotectonic alpine unit outcrops in western Sterea in Greece. The colored areas represent the alpine tectonostratigraphic units of the external terrane of the Hellenides (Papanikolaou, 1997). The pelagic Pindos unit (**P**) has overthrust the neritic Gavrovo unit (**G**). The latter is tectonically overlying the Ionian unit (**I**) which is the most external unit of the Hellenides and although they seem to share the same Oligocene flysch.
Pindos unit is a sequence of sedimentary rocks of late Triassic to Palaeocene age which includes pelagic limestones, radiolarites, with a thin siliciclastic interval of early Cretaceous age (‘*Premier Flysch*’).
Gavrovo unit consists of shallow marine platform carbonates which range in age from late Triassic to middle Eocene. The transition to the late Eocene - Oligocene flysch is characterized by an unconformity or bauxite deposits.
Ionian unit is a series of limestones with intercalations of clay schists (middle Jurassic) and red thin bedded cherts (late Cretaceous) lying over the Triassic evaporites.
The Ionian and Gavrovo units show a common tectonic evolution after late Eocene time as they have the same flysch cover.
The yellowish areas represent the location of younger basins which are covered by post alpine sediments. Most of these sediments are of Pleistocene age but there are also Miocene rock outcrops especially at the westernmost area. The age of these sediments shows an active area adjacent to the Hellenic trench.
The most significant structure seems to be the Amphilochia - Aetoliko Fault Zone (AAFZ), of NNW-SSE direction, that is sub-parallel to the direction of the Hellenic Trench. Its kinematic character is left lateral strike slip movement documented through fieldwork in combination to morphotectonic observations and focal mechanism interpretation (Vassilakis, 1998). The strike slip sense of movement is clear along the AAFZ on almost every segment of this structure.
There are also smaller faults of normal or dextral strike slip but their significance is great as they indicate the same stress field, that is extensional and almost perpendicular to the Hellenic trench.
The most characteristic active faults are shown in the photographs, and the sense of movement of the missing wall is also shown.

Figure 4d. Impressive corrugations on the Alevrada fault surface showing the direction of the slip. The arrow is indicating the movement of the missing hanging wall as there were also various kinematic indicators on the fault surface compatible with the right lateral sense of movement.

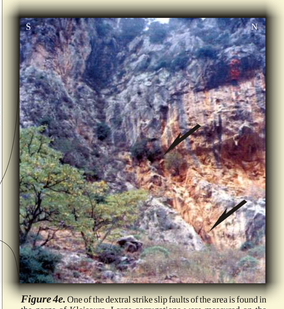


Figure 4e. One of the dextral strike slip faults of the area is found in the gorge of Kleisoura. Large corrugations were measured on the carbonate fault surface which show the lateral slip and the kinematic indicators are compatible with right slip sense of movement.

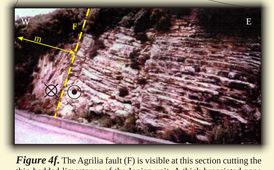


Figure 4f. The Agrilia fault (F) is visible at this section cutting the thin bedded limestones of the Ionian unit. A thick brecciated zone (m) is found between the two fault blocks. Striations show right lateral slip. The same sense of movement is determined by the 200 meter horizontal offset between the alpine units of Gavrovo and Ionia as shown at the geological map.

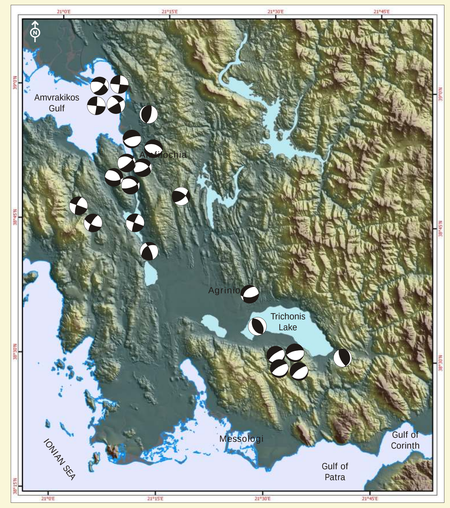


Figure 5. The location of the focal mechanisms after Hatzfeld et al (1995) on a shaded relief map. As it appears in this figure most of the events are located at the borders of the Trichonis and Amvrakikos basins and along a lineament which connects these two basins. There is a group of earthquakes with a significant lateral component, as shown at the momentary tensor solutions, concentrating along the direction of NNW-SSE, where the left lateral strike slip fault zone of Amfilochia-Aetoliko is located. At the eastern shore of Amvrakikos Gulf the mechanisms are showing strike slip faulting, with left lateral slip if the east striking plane is chosen. This might be connected to the bending of the above mentioned strike slip zone towards west. At the southern shore of Amvrakikos Gulf another group of events are related to an extensional regime, with normal faulting striking NNW-SSE. The focal mechanisms around Trichonis Lake are consistent with normal fault movement with the fault planes dipping north (at the southern part) or dipping south (at the northern shore of the lake). The two events that show reverse faulting have NW-SE striking axes, with an angle to the strike of the normal faults which are possibly related to local stress fields. All these seismological data are consistent with a pull apart basin model from both sides of the left lateral strike slip zone of NNW-SSE direction.

DISCUSSION

The existence of neotectonic structures caused by extensional deformation along a direction perpendicular to an active trench, such as the Hellenic one, is not a very common phenomenon (Fig.3). These structures are neotectonic grabens which are located at the westernmost mainland of Greece, in the province of Aetolia.

In general, there is a left lateral strike slip fault zone (Amfilochia-Aetoliko, AAFZ), striking NNW-SSE and two pull-apart basins, one at the western end of the AAFZ (forming the Amvrakikos Gulf graben) and the other at the eastern end (forming the Trichonis Lake graben). These pull-apart basins trend E-W which is perpendicular to the western part of the active Hellenic trench, and indicate NNW-SSE extension regime. The horizontal distance between these grabens is almost 40 km along the strike slip AAFZ, which is located 80-100 km east of the Hellenic trench where the subduction of the Appulian tectonic plate under the Aegean tectonic plate is taking place. This tectonic activity is probably related to the normal faulting in the Gulf of Corinth in the same direction.

The two grabens are relatively easy to locate using a shaded relief of the wider area, which was created after a 25 meter DEM interpretation. A LANDSAT-7 ETM+ satellite image was used for producing pseudo chromatic images, in order to distinguish the lithological boundaries (Fig.1). Several remote sensing techniques were applied and appear to be very useful, especially for improving the spatial resolution of the satellite images.

Although there is no clear association of the active faulting with any historical earthquakes, the above-mentioned structures are related to recent tectonic movements, as the river network has been affected and several morphotectonic formations have been formed. A number of lakes have, relatively recently, been formed along the strike slip fault zone, possibly because of the sinking of the faulted material between the two main fault blocks.

Evidence of the NNW-SSE left lateral strike slip movement was extremely difficult to find because of the lithology of the basement rocks, as flysch and evaporites are the most frequent lithologies at the surrounding area, along with Mesozoic limestones. Striations or corrugations of different scales were measured and the stress field was calculated (Fig.4). Most of the kinematic indicators were found on carbonate fault surfaces and are in agreement with the fault plane solutions derived by seismological data. The focal mechanisms of major seismic events showed the existence of a strong lateral component, in a NNW-SSE direction. An extensional stress field, related to E-W normal faulting, was calculated along the margins of the two grabens (Fig.5).

The eastern fault block can be separated in three smaller blocks of which the two outside blocks are raised relative to the central one, which forms the Trichonis graben. At the latter the lakes Trichonis and Lisimachia lie over impermeable Quaternary sediments, which have covered the alpine basement rocks. The margins of this graben have been created by normal fault zones dipping south (Agrinio AFZ) and north (Trichonis TFZ) (Fig.2). The raised blocks are highly eroded by streams, creating small gorges of N-S direction, parallel to the AAFZ. These act as secondary faults, displacing the western fault segments of the AFZ and TFZ and give an echelon sense of movement towards northwest.

Tectonic conditions at the northernmost part of the western block are similar. Here the second graben forms the southern margin of the Amvrakikos Gulf graben. A number of -more or less- E-W normal faults have been activated, raising the marginal areas along both sides of the gulf and contributing to the strong erosion caused by the river network. The Plio-Pleistocene sediments which are unconformably covering the alpine basement are affected by these faults, which also form the coastline.

The co-existence of these structures with the right lateral strike slip sense of movement that is observed at faults of generally ENE-WSW direction, is compatible with an extensional stress field along NE-SW orientation. This is almost perpendicular to the trend of the Hellenic Trench and is located nearly adjacent to it.

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Session: Neotectonics/Paleoseismology
Paper: 229.4 - Booth: P28