Some remarks on the Kinematic Evolution of Messinia Province (SW Peloponnesus, Greece) during the Pleistocene based on Neotectonic, Stratigraphic and Palaeoecological Observations

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Detaillierte stratigraphische und paläontologische Untersuchungen der postalpinen Sedimente (Mergel, mergelige Kalksteine, Sandsteine und Konglomerate) der Sektionen von Filiatrito Rema (westlich der Kyparissia-Berge) und Thouria-Ano Amfia (Messenia-Graben) brachten folgendes Ergebnis:

- Die Sedimente sind reich an planktonischen und benthonischen Foraminiferen und anderen Fossilien.
- Das Auftreten der Index-Foraminiferen Globorotalia truncatulinoides und Hyalinea balthica zeigt pleistozänes Alter an.
- Mindestens seit dem Ende des Pliozäns sollte die gesamte Messinia-Provinz im Absinken begriffen sein.
- Während des älteren Pliozäns fand die Sedimentation in Tiefen von 80 bis 100 m statt (Vorkommen von Pyrgo depressa, Bigerina nodosaria etc.), wogegen für das frühe Pleistozän Tiefen von 50 bis 80 m anzunehmen sind. Dies ist ein Hinweis auf die Abnahme der Subsedenz während des frühen Pleistozäns.
- Die mittlere Absenkungsrate liegt im Bereich von 0.2-0.3 mm/Jahr, wogegen die mittlere Hebungsrate zwischen 0.625 und 0.375 mm/Jahr variiert.
- Die neotektonische Morphostruktur der Kyparissia-Berge, zusammen mit dem westlichen Teil des Kato (unterer) Messinia-Sub-Graben, und der Taygetos Mt.-Horst verhalten sich, vom kinematischen Standpunkt her, als tektonische Dipole, die um eine NNW-SSE streichende Rotationsachse nach Osten rotieren.

Abstract: The province of Messinia (SW Peloponnesus) is one of the tectonically and seismically most active areas in Greece (Hellenic Arc) due to its neighbouring with the Hellenic Trench, considered as the collision boundary between the African and European Plates. The neotectonic structure of SW Peloponnesus is characterized by the presence of large grabens and horsts bounded by wide fault zones, trending N-S. At the margins or inside these 1st order neotectonic megastructures a great number of smaller order structures are present.

Detailed stratigraphic and palaeoecological studies of the postalpine sediments (marls, marly limestones, sandstones and conglomerates) of sections from Filiatrito Rema (west of the Kyparissia Mt.) and Thouria-Ano Amfia (Messenia graben) showed the following:

- They are rich in planktonic and benthic Foraminifera and other fossils.
- The presence of the index Foraminifera Globorotalia truncatulinoides and Hyalinea balthica is indicating a pleistocene age.
- Since at least the end of Pliocene the whole Messinia province should be under subsidence.
- During the Late Pliocene the sedimentation took place in depths up to 80-100 m (presence of Pyrgo depressa, Bigerina nodosaria etc.), whereas during the Early Pleistocene at depths about

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50-80 m. This is an indication of the decreasing of the subsidence during the Early Pleistocene.
- The mean subsidence rates are in the order of 0.2-0.3 mm/y whereas the mean uplifting rates range from 0.625 to 0.375 mm/y.
- The Kyparissia Mt. neotectonic morphostructure together with the western part of Kato (Lower) Messinia Sub-graben and the Taygetos Mt. horst behave, from kinematic point of view, as tectonic dipoles, rotating towards east, around a rotational axis trending NNW-SSE.

1. Introduction

The province of Messinia (SW Peloponnesus) is one of the tectonically and seismically most active areas in Greece. This is due to its neighbouring with the Hellenic Trench, which is considered as the collision boundary between the African and European plates (Fig. 1).

From geotectonic point of view, the western part of the study area has belonged to the Hellenic Island Arc from Late Pliocene to Early Pleistocene, although nowadays is a part of the Peloponnesus peninsula.

In this paper we try to interpret the kinematic evolution of Messinia province during the last stages of the neotectonic period taking into account: (i) the facies, (ii) the thickness and (iii) the present-day altitude of the post-alpine marine sediments. Cross sections in two localities were studied, three at Filiatrito Rema (west) and two at Thouria-Ano Amfia (east) (Fig. 1).

The area has been studied from the stratigraphic point of view by MARCOPoulos-DIACANTONI et al. (1989, 1990), whereas the neighbouring areas by HAGEMAN 1977, KELLETAT et al. 1978, KOWALCZYK & WINTER 1979, KOUTSOVELI 1987, KAMBRIS 1987, ZELILIDIS et al. 1988, FRYDAS 1990.

2. Geology
2.1. Alpine formations

In the major area of Messinia two alpine geotectonic units occur. The Tripolis Unit in the east and its equivalent Gavrovo-Pylos Unit in the west, which consists of neritic limestones - dolomits and flysch (Upper Eocene - Lower Miocene(?)), and the Pindos Unit, consisting of thinbedded multifoldet limestones, radiolarites and flysch. From geotectonic point of view, the Pindos Unit overthrusts the Tripolis Unit.

2.2. Post-alpine formations

The post-alpine formations overlie unconformably the above mentioned alpine units and consist of marine and continental deposits.

The post-alpine marine sediments consist of marls, sandstones and conglomerates, the total thickness of which differs from place to place. The thickness of these sediments has been estimated, based on geophysical and geological data, to be more than 500 m near the city of Kalamata.

The overlying continental deposits consist mainly of red-coloured siliceous sands, sandstones and conglomerates which should be of Middle and Late Pleistocene age. The Holocene is represented by unconsolidated and consolidated alluvial deposits, clastic material and talus cones.

3. Lithostratigraphy
3.1. Western Messinia - The Filiatrito Rema Section

The Filiatra area is located about 80 km western of Kalamata (Fig. 4). The post-alpine sequences of the area consist of marl, marly sandstone, marly lime-
stone, sandstone and conglomerate. These deposits feature a small inclination towards SW.

The lithological columns of 3 sections from different places along the Filiatrinopoulos are given at Fig. 2. A great number of micro- and macrofossils, collected from these sediments, has been determined.

The sediments of the Filiatrinopoulos Formation are rich in fossils. They contain planktonic and numerous benthic Foraminifera, numerous Bryozoans, infrequent Brachiopods, Bivalves, Gastropods, Scaphopods, tubes of Worms, Radiolaria, Ostracods, Echinoids, Porifera, Corals and Algae. Foraminifera and Mollusca dominate the fauna.

As also supported by sedimentological study, the whole faunal assemblage confirms a very shallow, high to low energy (conglomerate - sandstone - marl) inner shelf environment for this formation.

The rich micro- and macrofauna as well as the Algae collected from Filiatrinopoulos Rema confirm a Pleistocene age for the fossil bearing strata, particularly for the Low Head Member (Fig. 2: section horizons A, B, C: 1, 2, 4).

The Pleistocene age is based on the presence of the index Foraminifera Globorotalia truncatuloides and Hyalinea balthica at the sections A, B and C of Fig. 2. Gl. truncatuloides is collected from the sections: A, horizon 1; B, horizon 2; C, horizon 1, 2, 4. Hyalinea balthica comes from the section B, horizon 2.

It should be stressed here that the sequences of this area have been considered to belong to Late Pliocene. This consideration cannot be accepted now, because of the occurrence of the species Gl. truncatuloides and H. balthica which after BIZON & BIOZON (1984) appear for the first time at the Lower Pleistocene.

The majority of the taxa shows very wide stratigraphical ranges. A great part of the fauna is characteristic for Tertiary - Quaternary.

From the fossil assemblage, and especially from the characteristic Foraminifera, it is evident that, from the palaeogeographical point of view, the study area became gradually shallower from the lower members of the formation to the upper ones. This is based on the presence of Hyalinea balthica at the lower members of this formation and the frequent presence of the Algae Lithophyllum racemus in the deposits of the upper members of the sequence (section A, horizons 1, 2, 4).

As it is known H. balthica flourishes in depths between 80 and 250 m (BIZON & BIOZON, 1984) whereas L. racemus prefers very shallow water. Concerning the palaeoclimatic conditions during the deposition of the above mentioned sequences, the fossil assemblages (colonial Corals, Bryozoans, Sponges, Molluscs) and bioactivity traces are indicative of temperate palaeoclimatic conditions.

Based on the above mentioned, the palaeogeographical conditions at Filiatrinopoulos area during the Lower Pleistocene could be summarized as follows: (i) marine environment, (ii) relatively low sedimentation rates and (iii) shallow and temperate water.

3.2. Eastern Messinia, Thouria - Ano Amphipolis sections

The areas of Thouria and Ano Amphipolis are located at the eastern margin of the Kalamata - Kyparissia neotectonic megagraben, around 10 km north of Kalamata.
a. Thouria Section

It consists mainly of marls with intercalations of sands and sandstones. The sediments are rich in fossils, containing planktonic and numerous benthic Foraminifera, Bryozoans, Bivalves, Gastropods, Scaphopods, tubes of Worms, Ostracods, Echinoids, Porifera. The total thickness of the section measures 13 m (Fig. 3), and the beds dip about 15°-20° towards SW. The detailed analysis of the faunal assemblages of the section results in the following:

i. 2 m above the road, the Late Pliocene sediments outcrop (presence of Globorotalia inflata and characteristic macrofossils).

ii. 4 m above the road, the base of the Early Pleistocene (presence of Hyalinea balthica) is located.

The above mentioned indicate that:
- the sedimentation was continuous from Late Pliocene to Early Pleistocene.
- the environment was a shallow marine, low energy one. The latter indicates that the sedimentation should have taken place at a palaeo-bay area, open to the larger Kato (Lower) Messinia palaeo-gulf, but it was protected from the currents.

b. Ano Amphia section

It consists of sandstones and sandy marls with a total thickness of about 25 m (Fig. 3). The beds dip about 15°-20° towards SE. The sediments (mainly the upper members) are rich in fossils, with benthic Foraminifera being dominant. The designated fossils belong to macro- and microfauna: tubes of Worms, Radiolaria, Brachiopods, Bryozoans, in-frequent Gastropods, Bivalves, Echinoids, Holothurians, Ostracods, Scaphopods, Porifera, Foraminifera (planktonic and benthic) and Algae.

Though the rich invertebrated fossils, and among them the Flabellipicen flabelliformis, Terebratula ampulla, Cadulus cf. gadus etc., are indicative of the Pliocene age, the presence of the benthic Foraminifera Bulimina basispinosa and Marginulina cherensis is an evidence for a Pleistocene age of the sequence. The occurrence of a great number of benthic Foraminifera as well as that of the Algae Lithophyllum racemus in the upper member of the sequence indicate more shallow, temperate sea water and low energy sedimentation. A detailed account of occurrence and palaeoclimatic significance has been presented by MARCOPOULOU-DIACANTONI et al. (1989, 1990).

Fig. 3: Thouria - Ano Amphia lithological sections.

4. Neotectonic Structure of Messina Area

The neotectonic structure of SW Peloponnesus is characterized by the presence of large grabens and horsts bounded by wide fault zones. Such big structures are the Taygetos Mt. megahorst, Kalamata - Kyparissia megagraben, Gargaliani - Filiastra megahorst and Kyparissia Mts. which represent a complex morphotectonic structure (Fig. 4).

At the margins and/or inside these 1st order neotectonic megastructures a great number of 2nd and 3rd order smaller structures (smaller horsts and grabens) are present, which trend either parallel or roughly perpendicular to these 1st order neotectonic megastructures.
5. Neotectonic - Kinematic Interpretation

As already mentioned, the Filiatrina Rema section belongs to the Gargaliani - Filiatra megahorst whereas the Thouria - Ano Amphia section to the eastern margin of Kato (Lower) Messinia graben. When the thrust movements terminated (Middle Miocene) the Messinia province emerged and the morphogenetic processes started. Thus, the area eastern of Kyparissia Ms. should have remained as a land up to the Middle Pliocene, while the area directly western of Kyparissia Ms. remained as land until the Late Pliocene. This is concluded from the occurrence of Upper Pliocene marine deposits at the Thouria - Ano Amphia section while at the Filiatrina Rema section deposits of this age are absent. The area western of Kyparissia Ms. (Gargaliani - Filiatra megahorst) should possibly have been submerged during the Late Pliocene, but the Upper Pliocene sediments are in deeper points and therefore are not visible.

Therefore, since at least the end of Pliocene the whole Messinia province (Gargaliani - Filiatra megahorst, Kyparissia Ms., Kalamata - Kyparissia megagraben) should be under subsidence. This regime may have started earlier. That means that during the Late Pliocene the margins of Kato (Lower) Messinia graben were gradually subsiding below the sea level, whereas at the same time the Gargaliani - Filiatra megahorst continued to be above the sea level.

Marine sediments, mainly of coastal facies, were deposited on a well-formed palaeorelief in the Kato (Lower) Messinia graben. We believe that, in this graben, the sedimentation was continuous from Late Pliocene up to the end of Early Pleistocene, while in the Gargaliani - Filiatra megahorst it was continuous at least during the Early Pleistocene. For this area it is difficult to be proved if the transition from Pliocene to Pleistocene was continuous, as the upper limits of the Pliocene sequences do not outcrop here.

The palaeoecologic data (based on the fossil assemblages) of Kato (Lower) Messinia graben indicate that during the Late Pliocene the sedimentation took place in depth up to 80-100 m (presence of *Pyrgo depressa*, *Bigenerina nodosaria*, etc.).

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Fig. 4: 1st and 2nd order neotectonic macrostructures. The 2nd order neotectonic macrostructure of Kalamata - Kyparissia megagraben, 1: Kato (Lower) Messinia graben, 2: Meligala horst, 3: Ano Messinia graben, 4: Dorion basin, 5: Kyparissia - Kato Nero graben.

Inside the Kyparissia - Kalamata megagraben for example, the following 2nd order neotectonic macrostructures are distinguished (Fig. 4): (1) the Kato(Lower) Messinia graben, (2) the Meligala horst, (3) the Ano Messinia graben, (4) Dorion basin and (5) Kyparissia - Kalo Nero graben.

The smaller order neotectonic macrostructures, from the dynamic point of view, are connected to each other, as they are located between two 1st order neotectonic macrostructures, one positive (horst) and one negative (graben) which resulted from the same stress field. On the contrary, from the kinematic point of view, they differ. This differentiation has appeared either very early, that is from the very first stages of their creation, or later, during their evolution (MARIOLAKOS et al., 1989).

The study area mainly deals with an E-W trending section crossing the following 1st order neotectonic macrostructures from W to E (Fig. 5): (I) the Gargaliani - Filiatra megahorst, (II) the Kyparissia Ms., which we consider as a synclinic graben structure, (III) the Kyparissia - Kalamata megagraben.
At the first stages of the sedimentation during the Early Pleistocene, the sedimentation should have taken place at depths of about 50-80 m (presence of *G. truncatulinoides* and *H. baltica*), while the presence of the algae *Lithophyllum racemus* in the upper horizons of the sediments indicates that the sedimentation should have taken place at shallower depths, namely at 10 - 60 m in both areas. This is an indication that somewhere in the middle of the deposition time the subsidence at the depositional area was decreasing, becoming progressively more stable until the filling up of the basin with sediments.

The subsidence regime, therefore, did not change abruptly to an uplifting one, but this shift passed through a phase of relative constancy.

The uplifting regime was followed by the regression of the sea that resulted in the occurrence of the Lower Pleistocene marine deposits at the present-day altitude of 400 m, at the western slopes of Kyparissia Mts., whereas at the eastern slopes of the same mountains they occur at an altitude between 200 m and 280 m. In the area of Thouria-Ano Amphia (eastern margin of Kato (Lower) Messinia graben) they occur at an altitude of 360 m (Fig. 4).
The above mentioned data allow the estimation of
the order of the mean subsidence rate during the
sedimentation (Lower Pleistocene) and the mean
uplift rate during the phase of uplift. To calculate
the mean rates of subsidence and uplift, the fol-
lowing must be taken into account in addition to the
above mentioned:

(I) the visible thickness of the Lower Pleistocene
marine sediments which is 150 m in both sections.

(II) we have ascertained, in the area of Messinia,
that at least 100 m thickness of Lower Pleistocene
marine deposits have been eroded (Ano Amphia).
In order to estimate the mean subsidence rate, the-
therefore, we have to take into account that the whole
thickness of the Lower Pleistocene marine deposits
is more than 150 m at the western area (Gargarialian
- Filiatra megahorst) and 250 m at the eastern area
(Kato (Lower) Messinia).

(III) we accept that these deposits have been up-
lifted up to around 500 m of altitude at the western
slopes of Kyparissia Mts. and around 250 m at its
eastern slopes, whereas at the eastern margin of
Kato (Lower) Messinia graben (Ano Amphia) the
marine Pleistocene deposits have been uplifted up
to an altitude of around 450 m.

(IV) the disagreements about the timing of the
Pliocene - Pleistocene boundary are well known.
Some of the researchers accept that it is 2.4 Ma and
others 1.6 Ma or in some intermediate timings. For
our calculations we have accepted the Pliocene
- Pleistocene boundary to be at 1.6 Ma.

(V) the global climatic changes are well known
during the transition from Pliocene to Pleistocene.
Therefore, the decrease of the sea depth could be
attributed to eustatic movements, but (1) as the
fossil assemblage indicates that they could live in
sub-tropic climatic conditions, and (2) as we ob-
served a widespread transgression of the lower plei-
tocene sea, we believe that the changing of the sedi-
mentation conditions was due mainly to tectonic
activity.

Taking into account the above mentioned, we tried
to calculate the mean subsidence rates Vs for the
western and eastern areas of Kyparissia Mts., which
are the following:

(Filiatra area)

\[
Vs1 = \frac{150,000 \text{ mm}}{800,000 \text{ y}} = 0.19 \text{ mm/y}
\]

(Ano Amphia area)

\[
Vs2 = \frac{250,000 \text{ mm}}{800,000 \text{ y}} = 0.3125 \text{ mm/y}
\]

Therefore, the mean subsidence rates are in the
order of 0.2 mm/y and 0.3 mm/y for the Filiatra
and Ano Amphia areas respectively.

The mean uplift rates Vu for the areas western
and eastern of Kyparissia Mts. and the area of Ano
Amphia are:

(Filiatra area)

\[
Vu1 = \frac{500,000 \text{ mm}}{800,000 \text{ y}} = 0.625 \text{ mm/y}
\]

(Aristomenis area)

\[
Vu2 = \frac{380,000 \text{ mm}}{800,000 \text{ y}} = 0.475 \text{ mm/y}
\]

(Daras - Strefion area)

\[
Vu3 = \frac{300,000 \text{ mm}}{800,000 \text{ y}} = 0.375 \text{ mm/y}
\]

(Ano Amphia area)

\[
Vu4 = \frac{450,000 \text{ mm}}{800,000 \text{ y}} = 0.56 \text{ mm/y}
\]

Thus, the western edge of Kyparissia Mts. was
under uplifting regime since the end of Early Plei-
tocene (0.8 Ma) with a 0.6 mm/y mean rate, while
the eastern edge was uplifted with a mean rate of
about 0.425 mm/y. In other words, the western
edge of Kyparissia Mts. was uplifted with 0.2 mm/y
higher rate than the western one (Fig. 6).

The eastern margin of Kato (Lower) Messinia gra-
ben was uplifted with a mean rate of 0.55 mm/y.
That means 0.07 mm/y lower rate than the western
eastern edge of Kyparissia Mts.

Taking into account in addition that the Upper
Pliocene (?) marine deposits occur at altitudes of
not more than 300 m in the Sparti (Evrotas River)
megagraben (eastern of Taygetos Mt.), the fol-
lowing can be suggested:
I. That two main neotectonic units, Kyparissia Mts. and Taygetos Mt., behave from the kinematic point of view as tectonic dipoles rotating towards east around a rotational axis trending NNW-SSE.

II. Based on other evidences, as morphological (MARIOLAKOS, 1986), geological and tectonical (MARIOLAKOS et al., unpublished papers), the rotational axis of the Kyparissia Mts. neotectonic unit plunges towards SSE, whereas that one of Taygetos Mt. neotectonic unit plunges towards NNW. III. The rotation along the cross section depicted on Fig. 6 is more intensive at Kyparissia Mts. compared to the rotation of Taygetos Mt. (compare line (1) and line (2) of Fig. 6).

In this point, we would like to underline that the upper limit of the marine Pleistocene deposits outcrop at different levels at the eastern margin of the Kato (Lower) Messinia graben and especially that the altitude of the upper limits becomes gradually lower towards North. Therefore, the three-dimensional kinematic is more complicated than the above described as the neotectonic deformation is not only of brittle type but it is of brittle - ductile type (MARIOLAKOS & FOUNTOULIS, 1990).

6. References


