25th IAS MEETING OF SEDIMENTOLOGY, 2007, PATRAS – GREECE, Field Trips Guide Book, p. 123-142

FIELD TRIP P3

Studying the carbonates from Triassic to Eocene in the Ionian zone

V. Karakitsios

Department Historical Geology & Paleontology; University of Athens, Panepistimioupolis, 15784 Athens, Greece

The Ionian zone

From Triassic to Late Cretaceous the western Greece constituted part of the southern Tethyan margin. At the scale of hundreds of kilometres, the whole Alpine belt can be considered as the inverted margin of the Neotethyan Ocean in response to the collision of Apulia against Europe (de Graciansky *et al.*, 1989). On a smaller scale of a few tens of kilometres, the various sub basins of the Hellenic Tethyan margin have been inverted to produce the main Hellenic thrust sheets or folded zones. This occurred successively from inner (eastern) zones to external (western) zones (Karakitsios, 1995; (Fig. 1).

The Ionian zone exhibits three distinct stratigraphic sequences (Karakitsios, 1995; Fig. 2), representing a pre-rift, a syn-rift, and a post-rift stage of evolution of the Ionian realm, from a neritic platform environment to a pelagic basin.

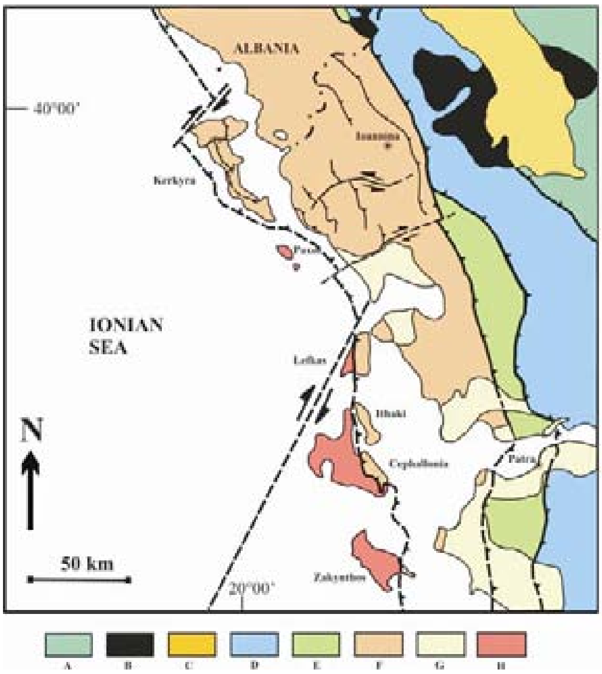

Fig. 1 Simplified geologic map of Western Greece. A. inner zones, B. Ophiolites, C. Mesohellenic molasse, D. Pindos zone, E. Tripolis zone, F. Ionian zone, G. Neogene – Quaternany (postalpine sediments), H. Preapulian zone.

The pre-rift sequence

The older known formations of this realm are the subsurface evaporitic series of Lower – Middle Triassic age, known only from borehole data. Their thickness is estimated to be more than 2000m, mainly consisting of alternating sulphate and carbonate sediments which were probably deposited in a “sabkha cotier” environment. On the contrary evaporites are rare in outcrops, consisting of small gypsum bodies which are always accompanied by extensive carbonate breccias, known as Triassic Breccias formation. Generally, gypsum and associated breccias crop out in areas aligned with or near to major trusts or faults, while in many cases they are injected through fault or thrust surfaces and they may cover much more recent formations (e.g Burdigalian). The Triassic Breccias are evaporite dissolution collapse breccias, as the former presence of evaporites is indicated by pseudomorphs after evaporites (Karakitsios & Pomoni – Papaioannou, 1998). The origin of these solution-collapse breccias is epigenetic, as a result of brecciation, after the syn-orogenetic diapiric intrusion of the evaporites, and mainly due to the atmospheric exposure of the subsurface evaporitic sediments. This is in accordance with: a) the halokinesis which took place from Early Jurassic, and b) the diapirism and inversion tectonics of the Ionian basin during orogenesis (Karakitsios, 1992; Karakitisos, 1995, Karakitsios & Pomoni – Papaioannou, 1998, Karakitsios et al., 2002).

The evaporites are overlying by the Foustapidima limestones of Ladinian – Rhetian age (Karakitsios & Tsaila-Monopolis 1988), followed by the shallow water Pantokrator limestones of early Lias age (Aubouin, 1959; IGRS-IFP, 1966; Karakitsios & Tsaila-Monopolis 1988, Karakitsios 1990, 1992). The Pantokrator limestones mainly consist of Algae (*Palaeodasycladus mediterraneus*, *Thaumatoporella parvovesiculifera*, *Porostromata*), onkolites, pellets and algal stromatolites with bird eyes indicating a very shallow sedimentary environment (intertidal environment). These limestones constituted part of the vast carbonate platform extended, during the early Lias, over the whole of western Greece. Strong subsidence was balanced by prolific carbonate sedimentation, resulting in the build-up of a shallow-water carbonate sequence more than a thousand metres thick (Pantokrator limestones).

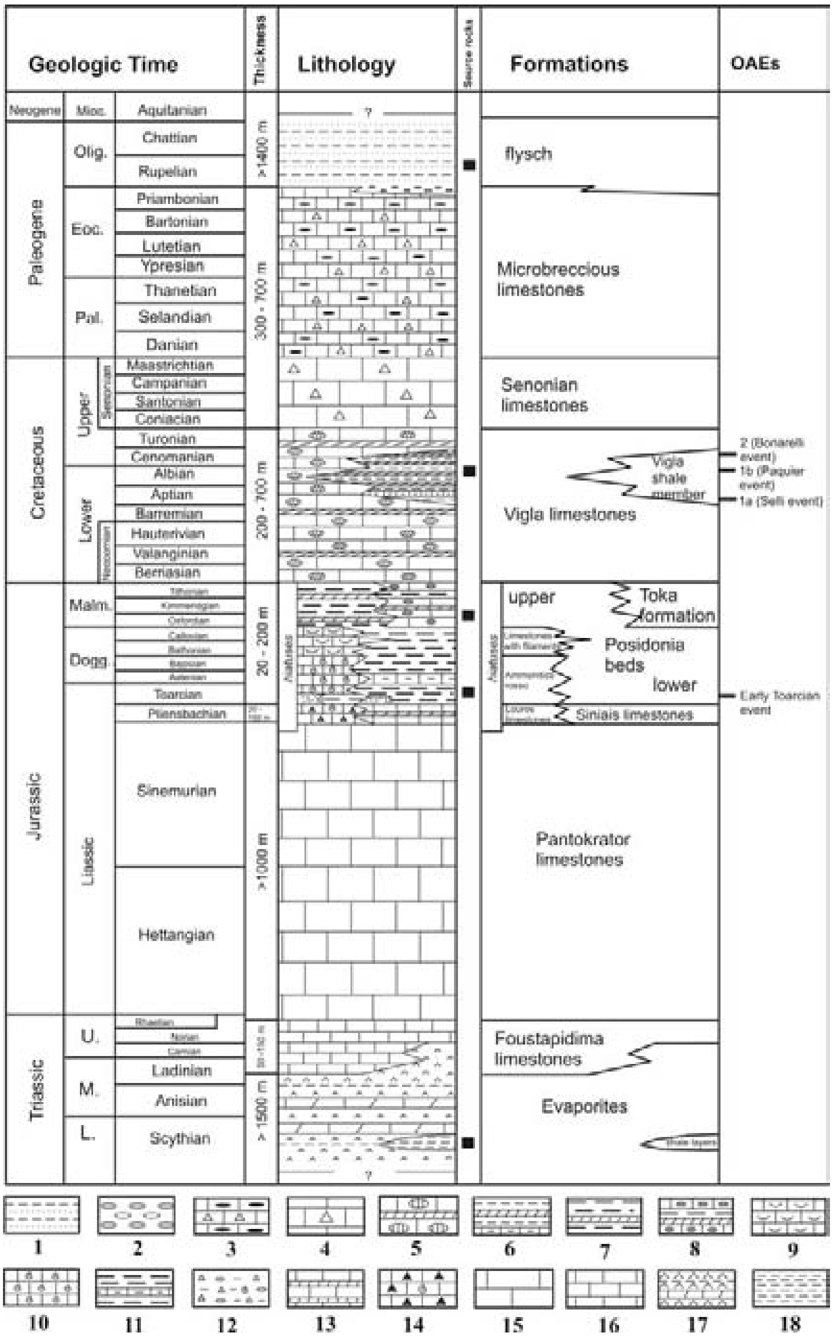

Fig. 2 Synthetic lithostratigraphic column of the Ionian zone (after Karakitsios 1995, modified).
1: pelites and sandstones, 2: conglomerate, 3: limestones with rare cherty intercalations, occasionally microbreccious, 4: pelagic limestones with clastic calcareous intercalations, 5: pelagic limestones with cherts, 6: cherty beds with shale and marl intercalations, 7: alternating cherty and shale bends, 8: pelagic limestones with cherty nodules and marls, 9: pelagic limestones with Lamellibranches, 10: pelagic, nodular, red limestones with Ammonites, 11: marly limestones and laminated marls, 12: conglomerates-breccias and marls with Ammonites, 13: pelagic limestones with rare cherty intercalations, 14: external platform limestones with Brachiopods, and small Ammonites in the upper part, 15: platform limestones, 16: thin-bedded black limestones, 17: evaporites, 18: shale horizons.

The syn-rift sequence

The beginning of the synrift sequence is represented by the Siniais Limestones and their lateral equivalent, the Louros limestones (Karakitsios & Tsaila – Monopolis, 1988). Foraminifera, brachiopods, and ammonites in Louros limestones indicate a Plienbachian age (Karakitisos, 1990, 1992). These formations correspond to the general deepening of the Ionian area (formation of Ionian basin), which was followed by the internal synrift differentiation of the Ionian basin marked by smaller poaleogeographic units. These palaeogeographic units were recorded in the prismatic synsedimentary wedges of the synrift formations, the Ammonitico rosso or Lower Posidonia beds, the Limestones with Filaments, and the Upper Posidonia beds.

Stratigraphic sections measured throughout the study area display abruptly changing thicknesses in the syntectonic sequences within a few kilometres. The opening of the Neotethyan Ocean was accompanied by the formation of a series of north-northwest- and east-southeast-trending conjugate faults. The early Liassic shallow marine platform was affected by listric block faulting, which was recorded in the differential subsidence within each small palaeogeographic unit (Bernoulli & Renz, 1970; Karakitsios, 1990). The directions of synsedimentary tectonic features (Fig. 3-4) indicate that deposition was controlled by structures formed during the extensional tectonic phase. The sedimentary style corresponds, in general, to a half-graben geometry. Prismatic synsedimentary wedges of the synrift formations in the small palaeogeographic units (in most cases the units did not exceed 5 km across) vary in thickness east-west. Thus, unconformities are located on top of tilted blocks and complete Toarcian to Tithonian successions with Ammonitico Rosso or lower Posidonia beds at their base are located in the deeper parts of the half grabens.

Fig. 3 Slumps at the base of the Lower Posidonia beds; Varathi.

Fig. 4 Slumps at the base of the Lower Posidonia beds; Varathi.

It is theoretically possible that the Ionian zone evaporitic substratum halokinesis influenced the synrift mechanism. In fact, during the Pliensbachian, the accumulated thickness of sediments over the evaporitic substratum exceeded 1700 m (Foustapidima Limestones: 200 m; Pantokrator Limestones: 1500 m; Siniais or Louros Limestones: more than 100 m). Under these conditions salt is usually less dense than its overburden. As a result there is an unstable condition of density inversion. The depth of buoyancy initiation, i.e. the rise of the salt through its denser overburden, depends on a number of factors. The presence of lateral heterogeneities such as thickness changes in the overlying sediment or irregularities on the surface of the salt layer are sufficient to trigger upward movement of the low-density salt at relatively shallow depths. Structural heterogeneities may also facilitate the initiation of diapirism at folds or points of structural weakness such as faults. In extensional faulted zones, diapirs tend to form through buoyancy where overburden load is most reduced in the footwall (Jackson & Galloway, 1984). Field data support this mechanism as the most likely driving force behind halokinesis in the Ionian basin. The presence of gypsum elements observed in the conglomerate at the base of the Lower Posidonia beds (Toarcian) in the Lithino section can easily be explained by evaporitic substratum halokinesis, which led to salt injection along listric faults separating tilted blocks close to the depression where conglomerates were deposited. The Lithino section located in the central Ionian zone is more than 70 km from the adjacent Paxos zone, where the Paxos-1 borehole penetrated anhydrite intercalations in the Liassic dolomites. It is also more than 50 km from the Gavrovo-Tripolitza zone, where sub-Cretaceous formations are unknown and their presence can only be hypothesized. The assumption that gypsum was transported from these zones by turbidity currents for such long distances and was deposited as centimetre-size grains is unreasonable (Karakitsios, 1990). Consequently, theoretical and field data suggest that the extensional phase provoked halokinesis in the Ionian zone evaporitic substratum (Karakitsios 1990; 1992; 1995). The halokinesis influenced the synrift mechanism by increasing the extensional fault throws. The combination of these factors resulted in the formation of areas where the evaporitic substratum thickness is maximal (areas with unconformity of the formations deposited during the Toarcian through Tithonian) and areas where the thickness is minimal (areas with Ammonitico Rosso or Lower Posidonia beds). This thickness distribution may considerably facilitate the choice of the favourable locations for boreholes in an attempt to reach, at shallow depths, the unknown subevaporitic Ionian substratum, which may have an oil interest.

The post-rift sequence

The postrift period was defined by an early Berriasian break-up that is marked by an unconformity at the base of the Vigla Limestones. Sedimentation during the postrift period was synchronous in the whole Ionian basin (Karakitsios, 1990; Karakitsios & Koletti, 1992). The postrift sequence (Vigla Limestones and overlying Alpine formations) largely obscures the synrift structures, and in some cases, directly overlies the Pantokrator Limestones prerift sequence. The deposits of Vigla Limestones do not correspond to a eustatic sea level rise, but to a general sinking of the entire basin (Karakitisos, 1992). The permanence of differential subsidence during the deposition of the Vigla Limestone, shown by the strong variation in thickness of this formation, is probably due to the continuation of halokinetic movements of the Ionian zone evaporitic substratum (IGRS-IFP, 1966; Karakitsios *et al.*, 1988; Karakitsios, 1990; 1992) (Figs 5-7).

Fig. 5 Vigla Limestones.

Fig. 6 Slumps observed in the Vigla Limestone Formation.

Fig. 7 Vigla Shales Member containing organic-carbon-rich horizons.

The post-rift formations, following the Vigla Limestones, consist of the Upper Senonian, which comprises two sedimentary facies: a) limestones with thin clasts and fragments of Globotruncanidae and rudists, b) microbreccious horizons with limestone and rudist fragments within a calcareous cementing material containing pelagic fauna. Thus the Upper Senonian corresponds to basin sedimentation, which reflects the clear distinction of the Ionian basin into a central topographically higher area, with reduced sedimentation taking place, and two surrounding lower taluses, with increased sedimentation. The adjacent to this area, two neritic platforms (the Gavrovo to the east and the Apulia to the west), provide clastic material to the Ionian basin.

The Paleocene and Eocene sediments appear in continuity after the Cretaceous, without significant facies changes. During the Paleocene, the erosion of the Cretaceous beds of the Gavrovo and Apulian platforms continues to provide the Ionian basin with microbreccious or breccious elements. However during the Eocene, the supply of clastic material diminishes significantly, especially in the central Ionian basin. The main facies, during this period, are platy sublithographic limestones with Globigerinidae and siliceous nodules, analogous to those of the Vigla Limestones, lacking however continuous cherty beds. The greatest thickness of the Eocene formations can be found in the marginal parts of the Ionian zone, where also the microbreccious beds are more frequent.

The flysch sedimentation commences at the Eocene – Oligocene boundary interval, in stratigraphic continuity with the underlying Upper Eocene limestones, through marly limestone transitional beds.

Tectonism

The main orogenic movements took place at the end of the Burdigalian (IGRS-IFP, 1966). The Ionian basin evolution constitutes an example of inversion tectonics of a basin sequence with evaporitic base (Karakitsios, 1995). The double divergence of the basin (westwards in the central and western part and eastwards in the eastern part) is attributed to structures inherited from the Jurassic extensional phase, which were reactivated during the compressional phase as westwards and eastwards displacements respectively. In general, extensional faults were entirely transformed into either reverse or transcurrent faults and/or thrusts, which is consistent with the classical inversion tectonic scheme. Although, in some cases during the compressional phase, extensional faults did not reactivate as thrusts in the way described above, but the most elevated footwalls were thrusted over the pre-existing hanging walls due to evaporitic base halokinesis (Karakitsios, 1995) (Fig. 8). This phenomenon was facilitated by diapiric movements of the evaporitic base's salt layer. Field and available seismic data point out that, at least, a moderate detachment took place along the sub-surface evaporites (Karakitsios, 1995).

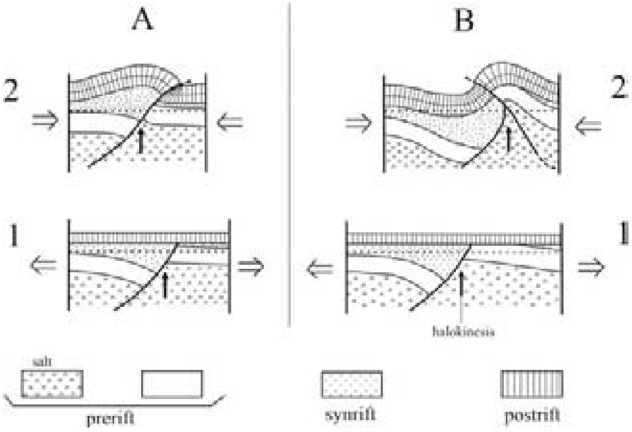

Fig. 8 Examples of inversion tectonics affecting a half-graben system with evaporitic basement (Ionian zone, northwest Greece). (A) Classical inversion tectonics. (B) Particular case of inversion tectonics observed at locations where the evaporitic substratum halokinesis was more expressed and consequently the footwalls of the extensional phase were above average. Therefore, during the compressional phase these most elevated footwalls have been thrust over the pre-existing hanging walls. (A1) and (B1) correspond to the beginning of the postrift period; (A2) and (B2) correspond to the end of postrift deposition and show the subsequent inversion geometries. (after Karakitsios, 1995, modified).

Petroleum Potential

Five organic-rich formations of source-rock potential have been observed in the Ionian basin: the Vigla shales (Aptian-Turonian), the Upper Posidonia beds (Callovian-Tithonian), the Lower Posidonia beds (Toarcian), the marly beds at the base of the Ammonitico Rosso (Early Toarcian), and shale fragments in the Triassic breccias. These five horizons have good hydrocarbon potential and their organic matter is of type I to II. In the central Ionian basin (oil window = 3700-5800m), the Triassic shales have already entered the gas window; the Lower and Upper Posidonia beds and the marls at the base of the Ammonitico Rosso are mature in terms of oil generation; the Vigla shales correspond to an early maturation stage (Karakitsios & Rigakis, 1996).

The preservation of the organic matter in the Lower and Upper Posidonia beds (Fig. 9-10), and the marls at the base of the Ammonitico Rosso, is mainly due to the geometry of the synrift period, whereas in the Vigla shales it is also related to the Cretaceous Anoxic Events. The organic rich shale fragments within the Triassic breccias were initially organic rich stratigraphic layers deposited in restricted sub-basins inside the evaporitic basin. The processes accounting for the formation of the evaporite dissolution collapse breccias are responsible for the present organic rich shale fragments incorporated within the Triassic breccias (Rigakis, 1999, Karakitsios & Rigakis, 1996).

Fig. 9 Laminated blue marls (organic-rich black shales) at the base of Lower Posidonia beds; Hionistra.

Fig. 10 Coniferous leaf (Brachyphyllum nepos saporta) observed in the marls of Fig.9.

Direct porosity measurements and electrical logging have shown that apart from the Triassic breccias and Pantokrator limestones, characterized by good porosity, the rest of the strata comprising the Ionian series have low porosity and negligible permeability values. Thus, it seems that fracture porosity-permeability plays the dominant role in determining hydrocarbon migration.

Studies concerned with the hydrocarbon trapping mechanism (based entirely on surface data) have revealed that potential traps are mainly connected with small anticlines, incorporated in larger synclines, at the contact zone between the calcareous and the clastic series of the Ionian zone. Additionally, the base of the evaporitic sequence could include potential traps if the pre-evaporitic basement is involved in the deformation of the overlying sedimentary cover.

Oceanic Anoxic Events

The Ionian Zone of western Greece exposes Jurassic and Cretaceous pelagic, thrust-imbricated sediments representing continental-margin sequences of the southern Tethys Ocean. Within these sequences, siliceous and organic carbon-rich sediments have been variously reported as commonly associated facies (Jenkyns 1988; Karakitsios 1995; Rigakis & Karakitsios 1998). Recent studies have demonstrated that some of these organic-rich strata document OAEs of a supra-regional geographical distribution to global events. Jenkyns (1988) mentions the early Toarcian OAE. Danelian *et al.* (2004) identified the early Aptian "Selli" event or OAE1a (Paliambella Section). Intergrated biostratigraphic, stable isotopic and molecular organic geochemical data allowed Tsikos *et al.* (2004) and Karakitsios *et al*. (2004) to identify the early Albian "Paquier" event or OAE1b (Gotzikas Section), and recently Karakitsios *et al.* (2006) to examine the Cenomanian – Turonian "Bonarelli" event or OAE2 (Gotzikas Section) (Figs. 11-13).

Fig. 11 A black shale horizon in the Gotzikas section (NW Epirus).

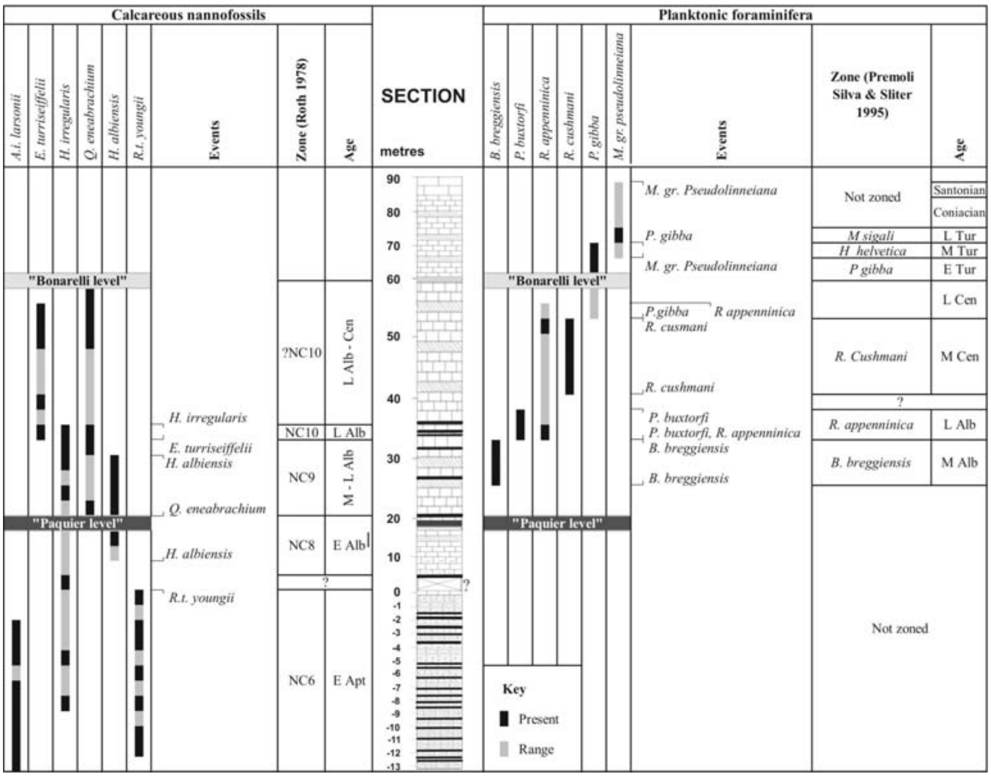

Fig. 12 Summary of the biostratigraphic information for the Gotzikas section. Biostratigraphy is based on observed distribution of calcareous nannofossils and planktonic foraminifera (Karakitsios et al. 2004).

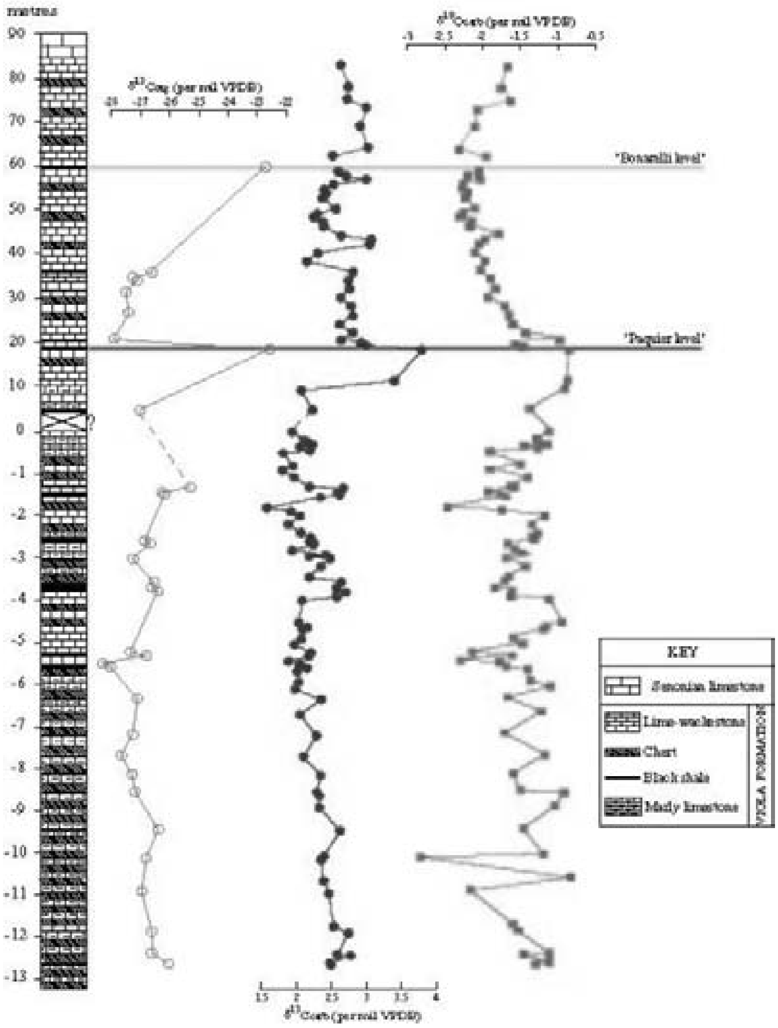

Fig. 13 Lithostratigraphic log and δ stable (C,O) isotope profiles across the examined Vigla section in the Gotzikas locality, Ionian zone, NW Greece. Note the different scales for the section above and below the section gap (Karakitsios et al. 2004).

FIELD TRIP GUIDE (Fig. 14)

1. *Ziros Section*

In this section we can observe the Triassic Breccias formation. They are typically unbedded rocks consisting of re-cemented angular fragments of limestones and dolomites – fetid, grey-brown to black and vuggy. The gypsum crops out under microcrystalline or flake form, white to grey in color, with rotated black or red traces, in confused masses into the breccias.

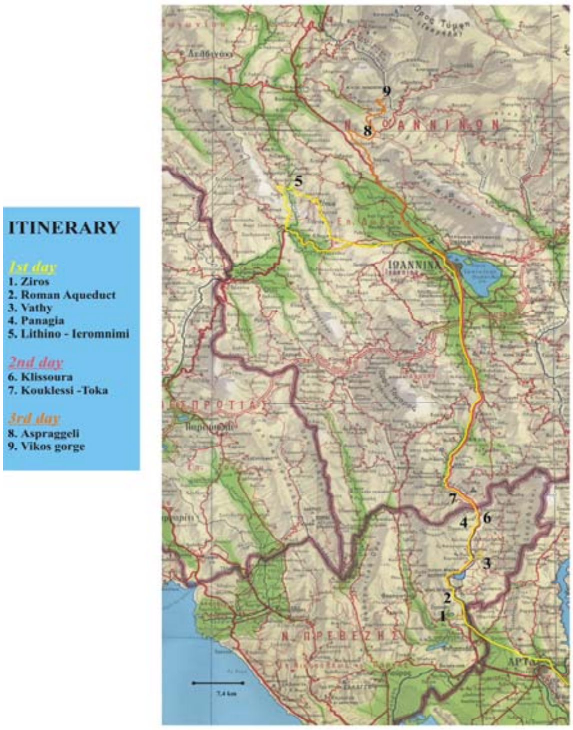

Fig. 14 Field trip itinerary.

Two main lithological types are distinguished: the massive gypsum and the stratified gypsum, with rare dolomite. The Triassic Breccias are essentially evaporite solution-collapse breccias. In fact, the microscopic observation shows the presence of former evaporites indicated by pseudo-morphs after evaporites. This transformation resulted from the aerial exposure of the injected subsurface evaporites, due to progressive dissolution of evaporites, by infiltration of meteoric fluids and by soil-forming processes (Karakitsios & Pomoni – Papaioannou, 1998). The only remnant of these evaporites is the rare gypsum bodies (subsurface anhydrite) found within the breccias.

2. *Roman aqueduct*

This Roman era aqueduct was constructed in the Pantokrator limestones, and continuous, through the different formations of the Ionian zone, to Nikopolis (near Preveza).

3. *Vathy Section*

In the eastern Louros Valley, east of the village Vathy, outcrop 40 m of the Pantokrator limestones (Fig. 15). These are massive, grey to white, crystalline to microcrystalline limestones and gravelly limestones with sparite cement. These bindstone to grainstone, neritic limestones contain calcareous algae, benthic foraminifera, ostracods, crustacean coprolites, gastropods and lamellibranches (Megalodon). The fauna and flora suggest an early to middle Lias age (e.g. *Palaeodasycladus mediterraneus*, *Thaumatoporella parvovesiculifera*), and an inner platform (intertidal) depositional environment close to emergence (Karakitsios & Tsaila-Monopolis, 1988, Karakitsios, 1992).

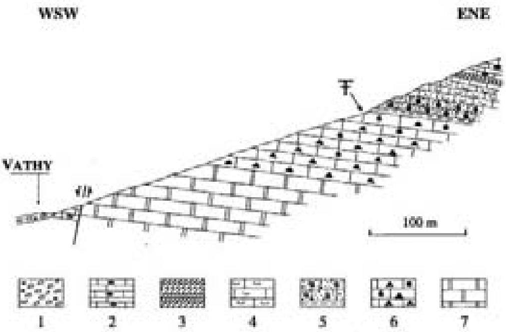

Fig. 15 Vathy section: 1: Quaternary surface formations, 2: Vigla limestones, 3: Upper Posidonia Beds, 4: Filament limestones, 5: Ammonitico rosso, 6: Louros limestones, 7: Pantokrator limestones.

The Pantokrator limestones are followed by some 60 m of Louros limestones, peloid-rich grainstones to packstone, characterized by intense secondary micritization. These contain oncoids, intraclasts and varied fauna (foraminifera, ostracods, spicules and sponge debris, exhinoderm fragments, gastropods, pelecypods, brachiopods and ammonites). The brachiopods and ammonites are found mainly in the upper part of the formation, with the ammonites dominating in the last few metres. The microfauna and flora is comprised of: *Involutina liassica*, *Trocholina umbo*, *Globochaete alpine*, *Ophthalmidium* cf. *carinatum*, *Ophthalmidium martanum*, *Frondicularia* sp., *Nodosaria* sp., *Ammobavulites* sp., *Lenticulina* sp., *Spirillina* sp., *Sigmoilina* sp., *Reophax* sp., *Robuloides?* sp., *Trocholina* sp., *Ophthalmidium* spp., Lagenidae, Ammodiscidae, Lituolidae indet., Textulariidae (?), and Valvulinidae. The Louros limestones are indicative of a deeper depositional environment characteristic of the outer platform area (Karakitsios & Tsaila-Monopolis, 1988). In the final metres of the Louros formation, immediately below the Ammonitico rosso, a rich ammonite fauna has been described (Karakitsios, 1992; Dommergues et al., 2002) comprising the taxa: Phylloceratetaceae sp., *Lytoceras* sp., Dactylioceratidae sp., Harpoceratinae sp., and *Neolioceratoides schopeni*. This fauna indicates a late Domerian age for these strata (Hawskerense Subzone) (Figs. 16-17).

The Vathy Section continues with 12 meters of Toarcian ammonitico rosso (Karakitsios & Tsaila-Monopolis, 1988; Karakitsios et al., 1988; Karakitsios, 1992). The basal 2 meters contain brecciated grey-blue marls with thin interbeds of green nodular limestones and red marl intercalations. The lower and middle part is rich in Ammonites (*Polyplectus pluricostatus*, *Lytoceras franesci*, *Haploceras subexaratum*, *Rhymatoceras* gr. *erbaense*, *Phylloceras* sp. of Toarcian age (Karakitsios, 1992).

The Ammonitico rosso formation is followed by 15 meters of limestones with filaments. These are nodular beige - grey or beige limestones with silex in the lower part and beige sublithographic limestones alternating with pseudoconglomeratic limestones. The radiolaria identified in the last meters of the formations are of Callovian age (Karakitsios *et al.*, 1988). Above the limestones with filaments appear 3 m of Upper Posidonia beds rich in Radiolaria, composed of jaspis and argilosiliceous joints. The reduced thickness of the Upper Posidonia beds and the age of the following formations indicate towards condensed sedimentation.

Finally the section contains Vigla limestones, white – crème sublithographic limestones with thin siliceous beds, with *Calpionella alpine* and *Calpionella elliptica*, at its base, dating the beginning of the post-rift sequence in the Berriasian (Karakitsios, 1992).

Fig. 16 Here we can observe the upper part of the Louros Limestones (LL) and the contact with the Ammonitico Rosso (AR).

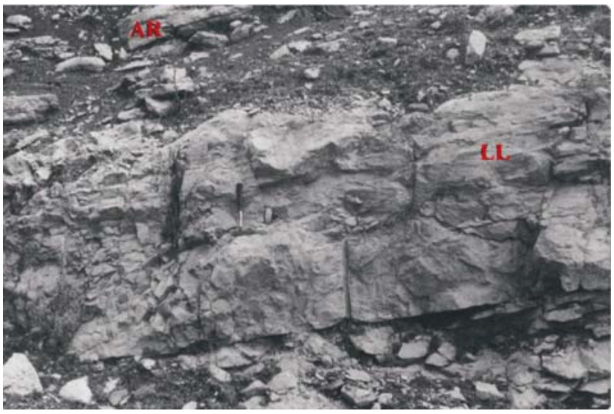

Fig. 17 Detail of the uppermost part of the Louros limestone formation.

4. *Panagia Section*

About 300 m above the Panagia village, a pelagic sequence of thinly bedded Vigla limestones (Berriasian - Turonian) of about 250m thickness is observed, which towards the stratigraphic top, contains the Vigla shale member. Here, the base of the Vigla limestones sequence overlies with unconformity the Pliensbachian Louros limestones. This unconformity is well observed in the gallery of the motorway from Arta to Ioannina (Fig. 18). A significant stratigraphic gap exists between the two formations, encompassing most of the Jurassic (Toarcian to Tithonian). At the base of the Vigla limestones Calpionelids and Aptychus are observed. In terms of paleoenvironment, the Panagia Cretaceous sequence is interpreted as pelagic accumulation on a Jurassic seamount which could temporary emerged during Toarcian to Tithonian.

The 5m of Vigla limestones underling the Vigla shale member are thinly bedded (10 to 30 cm thick) (Fig. 18). Chert layers and nodules are relatively abundant and it is striking that many limestone beds display, in their middle part, a 2-8 cm thick, irregular bedded chert layers. Some shale layers of 2 cm thickness are also present. The Vigla shale Member is represented by 35-40m sediments, consisting in the first 3-4 meters by a cyclic alternations of radiolarian chert beds of 4-10 cm thickness and thin shale interlayers of 0,5 to 4 cm thick. They are followed by about 20m of alternating thinly bedded limestones and chert beds, containing marcassite nodules (Fig. 19). The Member ends by about 9m of an alternation (reddish to greenish-yellowish in color) of radiolarian cherts and thin shaly interlayers. This member contains in other localities of Epirus the Cretaceous OAEs (Selli, Paquier and Bonarelli events) (Tsikos et al., 2004; Karakitsios et al., 2007). The anoxia is manifested here by the presence of marcassite nodules (Fig. 19).

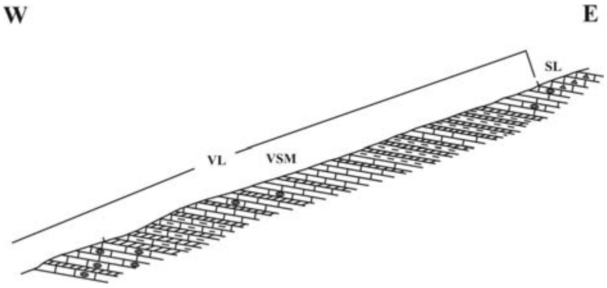

Fig. 18 Panagia Section. SL: Senonian Limestones, VL: Vigla Limestones, VSM: Vigla Shale Member.

Fig. 19 Marcassite nodules observed in the Vigla Shale Member.

5.1. *Lithino Section*

On the local road from the village Zitsa to the village Lithino (about 24 km WNW of Ioannina) and close to Lithino, outcrop the Upper Liassic – Malmian formations (Fig. 20). The base of this section consists of the upper 20 meters of the Siniais limestones formation. They are characterized by the typical facies of the formation (platy limestone, sublithographic, alternating with siliceous beds). Nevertheless the appearance of certain beds resembles that of Louros limestones.

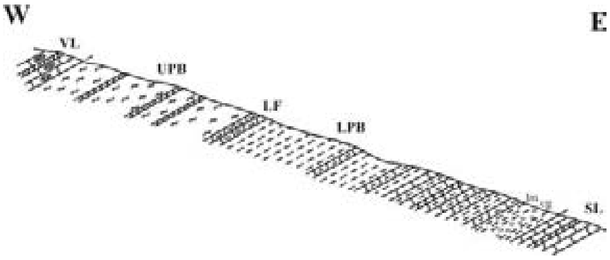

Fig. 20 Lithino Section. VL: Vigla Limestones, UPB: Upper Posidonia Beds, LF: Limestones with Filaments, LPB: Lower Posidonia Beds, SL: Siniais Limestones, cg: conglomerate, lm: laminated dark-colored marls of Toarcian age.

In stratigraphic continuity appear 40 meters of non-differentiated Posidonia beds. They contain in their base, immediately above the uppermost bed of the Siniais limestones:

- 60 cm yellow – green laminated marls, rich in organic material,
- 40 – 45 cm conglomerate, with elements (approximately 0,4 – 0,8 cm mean size). The microscopic observation shows that it is a polygenic conglomerate (Fig. 21), with a marly limestone matrix, containing three types of elements: a) Siniais limestone facies, b) Louros limestone facies, c) elements composed exclusively of gypsum.
- 40 cm yellow – green laminated organic-carbon-rich marls,
- 10 m yellow – dark blue marly limestones, in many cases bituminous, and siliceous marls,
- 5 m platy limestones with rare cherts,
- Dark cherts and siliceous marls, which continue until the top of the formation.

The conclusions that can be drawn from this section are summarized below. The presence of the conglomerate bed at the base of the Posidonia beds demonstrates the presence of erosional zones in the vicinity of their sedimentation domain. These zones may correspond either to emerged topographic reliefs, which underwent aerial erosion, or to submarine topographic highs, where the intensity of the currents is the most important erosional factor. The conglomerate elements show that these zones consist, in the uppermost part, of Siniais and Louros limestones. We can therefore conclude that, the Ionian zone, having entered the syn-rift extensional deepening phase, expressed by the deposition of the Siniais and Louros limestones, was differentiated further by the onsite of topographic highs and lows. The topographic highs were thereafter eroded, and supplied the low-grounds with clastic material of Siniais and Louros limestone origin (Fig. 21).

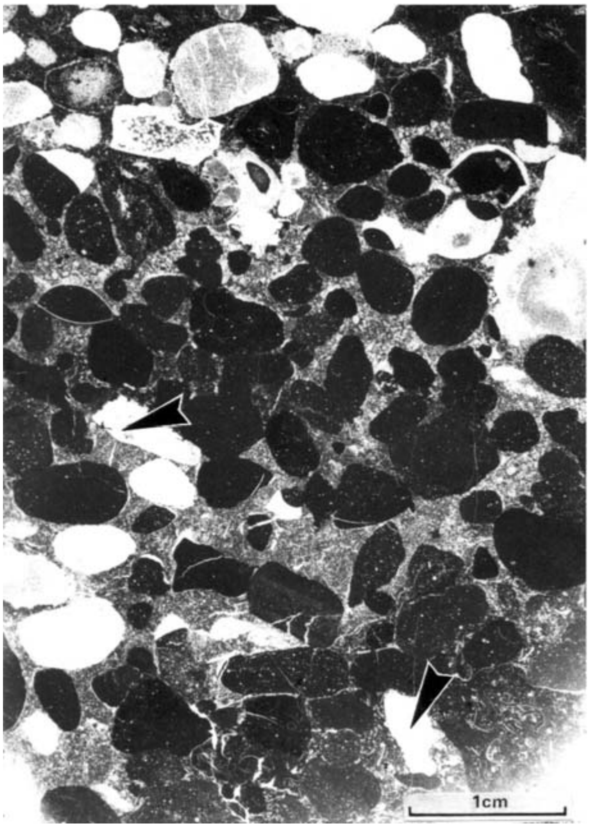

Fig. 21 Thin section from a conglomerate horizon observed in the base of the Lower Posidonia beds. This polygenic conglomerate is composed of marly calcareous matrix and three types of elements: the first facies is similar to the Siniais Limestones, the second facies corresponds to the Louros Limestones, and the third facies is composed uniquely of gypsum.

The presence of conglomerate gypsum elements show that, the eroded areas are connected with presence of gypsum. Additionally the preservation (non-dilution) of the gypsum elements, which were transferred and deposited in the depression (as seen in the present section), implies rapid sedimentation conditions, which favored the burial and protection of these elements. This hypothesis is indeed confirmed by the fine texture of the overlying sediments. Furthermore, the presence of gypsum elements can easily be explained by evaporitic substratum halokinesis, which led to salt injection along listric faults separating tilted blocks close to the depression where the conglomerates were deposited. The Lithino section located in the central Ionian zone is more than 70 km away from the adjacent Paxos zone, where the Paxos-1 borehole has penetrated anhydrite intercalations in the Liassic dolomites. It is also more than 50 km away from the Gavrovo - Tripolitza zone, where the sub-Cretaceous formations are unknown. The assumption that the gypsum was transported from these zones by turbidity currents for such long distances and was deposited as centimeter – size grains is unreasonable (Karakitsios, 1990; 1995). Consequently, theoretical and field data suggest that the extensional phase provoked halokinesis in the Ionian zone evaporitic substratum (Karakitsios, 1990; 1992; 1995); the halokinesis influenced the synrift mechanism by increasing the extensional fault throws.

5.2. *Ieromnini Section*

This section is located about 3 km WNW of the Lithino Section. From base to top, we can observe the following. The upper part of the Siniais limestones, affected by synsedimentary faults with direction NNW-SSE, which form small horsts and grabens, where took place the deposition of the Upper Liassic – Malmian formations. Following appear 30 meters of Lower Posidonian beds, comprising siliceous grey – green marls rich in Posidonia. The limestones with filaments appear with a thickness of 2 meters, as platy limestones with silex. The syn-rift sedimentation ends with the deposition of the Upper Posidonia beds, with a thickness of 40 meters, which are more siliceous than the Lower Posidonia beds. The present section is completed with the Vigla limestones (Figs. 22, 23). The Upper Liassic – Malmian succession presents a westward reduction in thickness.

6.1. *Klissoura South-East Section*

This section (Fig. 25), located about 1300 m ESE of the village of Klissoura, outcrops some 10 meters of Louros limestones. The microfauna is similar to that of Vathy section. The Louros limestones SE of Klissoura are crossed by paleofaults with throws of several meters marked by spectacular sedimentary dykes filled with yellow-brown breccia with micritic limestone matrix containing small filaments and spicules of sponges as well as calcareous material (Karakitisos, 1992).

Fig. 22 Lower Posidonia beds, Limestones with filaments, and Upper Posidonia beds, in stratigraphic succession.

Fig. 23 Bosistra buchi (Posidonia) in the Lower Posidonia beds.

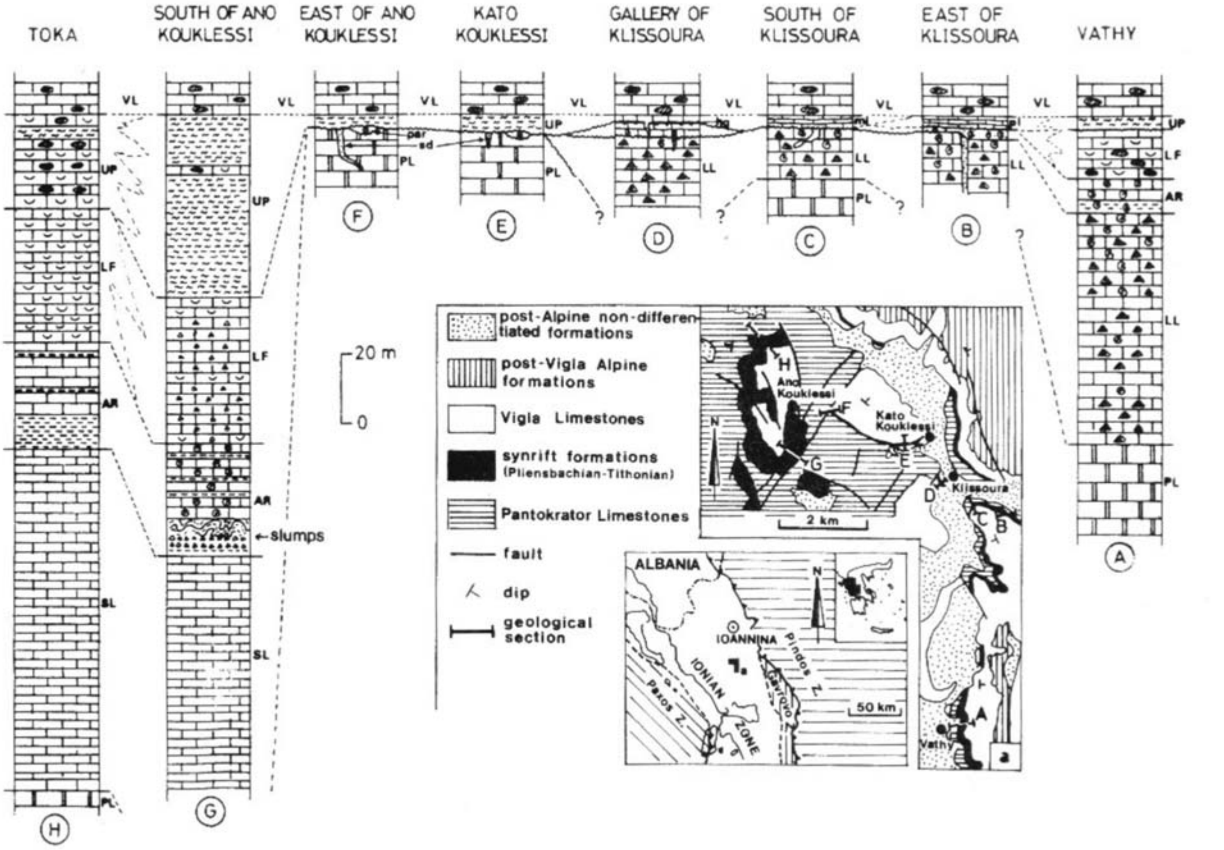

Fig. 24 Stratigraphic columns of the central Ionian zone of the Epirus region. VL: Vigla Limestones (base: early Berriasian), UP: Upper Posidonia beds (late Callovian – Tithonian), pl and ml: lateral equivalents of Upper Posidonia beds, hg: hardgroung, LF: Limestones with Filaments (Bajocian – Callovian), AR: Ammonitico Rosso (Toarcian – Aalenian), par: Ammonitico Rosso (AR) filling the pockets of Pantokrator Limestones (PL), LL: Louros Limestones (Pliensbachian), SL: Siniais Limestones (lateral equivalent of Louros Limestones), PL: Pantokrator Limestones (early Liassic), sd: sedimentary dikes.

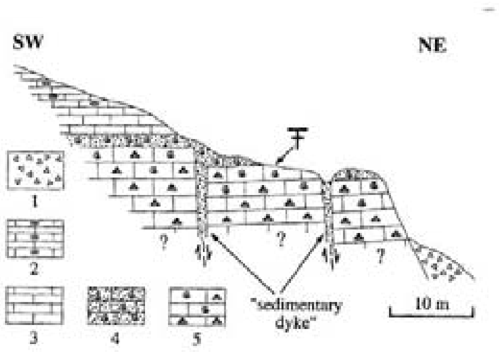

Fig. 25 Klissoura South-East Section (the outcrop is some 1300 m SE of the village): 1: scree, 2: Vigla limestones, 3: Upper Posidonia Beds, 4: Transitional limestones to Ammonitico rosso, 5: Louros limestones.

The top of the Louros limestones, immediately below the ammonitico rosso, is rich in brachiopods of the species: *Zeilleria mutabilis*, *Spiriferina gryphoides*, *Phymatothyris rheumatica*, *Propygope (nucleate) aspasia*, *Pisirhynchia retroplicata*, *Phymatothyris* cf. *cerasulum* (Dommergues et al., 2002; Karakitsios, 1992).

In addition we can observe the following ammonite taxa: a) in the final meter below the top of the formation: Phylloceratаceae sp., *Phylloceras* sp., *Lytoceras* sp., *Calliphylloceras* gr. *bicoclae*, *Protogrammoceras (Paltarpites?)* sp., *Lioceratoides* sp., *Arieticeras* gr. *bertrandi*, *Arieticeras* gr. *algovianum*, *Arieticeras* sp., *Leptaleoceras ugdulenai*, *Leptaleoceras* sp., b) two to four meters below the top of the formation: *Protogrammoceras dilectum*. These ammonites, as a whole, allow the final meters of the Louros limestones to be dated to the middle Carixian – end of Domerian. However, most of the above fauna are of mid-late Domerian age.

6.2. *Klissoura East Section*

On the northern side of the Klissoura Gorge (about 500 m east of Klissoura village) outcrop some 12 m of the Louros limestones (Fig. 26). Their upper part is affected by two palefaults. The top two meters of the formation yielded the taxa: Phylloceratаceae sp., *Calliphylloceras* gr. *bicicolae*, *Arieticeras* gr. *bertrandi*, *Arieticeras* sp., which are assigned to mid Domerian age.

Above the Louros limestones, there are 4 meters of Ammonitico rosso. These nodular limestones are affected by paleofaults, which also affect the Louros limestones. Within the Ammonitico rosso, there has been identified one ammonite, cf. *Hildaites borealis* of Lower Toarcian age.

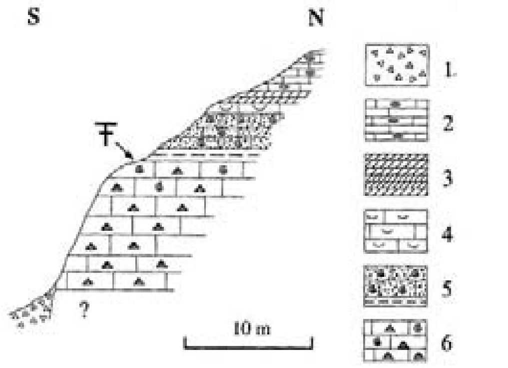

Fig. 26 Klissoura East Section: 1: Scree, 2: Vigla limestones, 3: Upper Posidonia Beds, 4: Filament limestones, 5: Ammonitico rosso, 6: Louros limestones.

Following are 10 meters of platy limestones with silex, which also contain filaments, Sponge spicules, Ammonites and Aptychus. According to Karakitsios (1992), these limestones probably correspond to a vertical transitional face to the overlying Vigla limestones. Within this formation, an ammonite of lower Kimmeridgian age has been identified (Karakitsios, 1992). In this section we can also observe the gradual reduction in the thickness of the syn-rift formations, namely the Ammonitico rosso.

6.3. *Klissoura South Section*

This section is situated about 500 m south of the village of Klissoura (Fig. 24B). The base is comprised of Pantokrator limestones with algae, which passes to 20 m of the Louros limestones with brachiopods (*Zeilleria mutabilis*, *Spiriferina gryphoidea*, *Phymatothyris rheumatica*, *Propygope (nucleata) aspasia*, *Pisirhynchia retroplicata*, *Phymatothyris* cf. *cerasulum*) and ammonites (*Programmoceras* gr. *dilectum* of Carixian age (Karakitsios, 1992).

The Louros limestones are followed by 4 to 5 meters of micritic white limestones, rich in pelagic Lamellibraches, and associated with small Ammonites, which are in turn followed in angular unconformity by the Vigla limestones formation with *Calpionella alpine* (Fig. 27).

Fig. 27 The early Berriasian breakup unconformity between the Vigla Limestones (on top) and the Louros Limestones (which contain Pliensbachian ammonites in their upper part). The contact is marked by 3 – 4 m of pelagic sediments

6.4. ***Section at the entry point of the Klissoura gallery***

This section is located nearly 800 m NW of the Klissoura South Section (Fig. 24D). More than 15 meters of the Louros limestones can be observed, containing the brachiopods: *Phymatothyris rheymatica*, *Pisirhynchia retroplicata, Nucleata (Propygope) aspasia, Phymatothyris* cf. *cerasulum*, *Plectothyris (?) fimbrioides*, along with pelagic Lammelibranches. The Louros formation is followed in unconformity (Fig. 28) by 4 meters of marly massif limestones, with pelagic Lamellibranches and small Ammonites.

Fig. 28 Disconformity between equivalent facies of the Upper Posidonia beds (UJ: Upper Jurassic formation) and the Louros Limestones

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One Ammonite, of Oxfordian age, was found positioned perpendicular to the stratification, indicating a low energy depositional environment. Following the Ammonitico rosso formation, is the Vigla limestones, rich in *Calpionella alpina* and *Stomiosphaera moluccana*.

7.1. ***Kato Kouklessi Section (Hani)***

This section is located some 300 meters west of the Kato Kouklessi village (Fig. 24E). From base to top, we observe first the Pantokrator limestones, followed by one meter of a yellow – green conglomerate comprising a matrix of micritic limestone rich in filaments, calcified radiolaria, sponge spicules, ammonites, and clasts of micritic limestone material with foraminifera and ammonites of the same facies as the Louros limestones. This matrix reveals an ammonite fauna similar to either *Crassiceras* or *Mercaticeras*. These forms correspond to the middle Toarcian.

Above this breccious formation, appear 3 meters of marly limestones alternating with siliceous banks. The uppermost siliceous bank, which corresponds to a hard ground, is rich in Lamellaptychus of Tithonian - Berriasian.

In stratigraphic continuity appear above the Vigla limestones with Calpionellindae (*Calpionella alpine*, *Calpionella elliptica*, *Tintinnopsella* sp.) and Coccolithes (Coccolithaceae, *Watznaueria barnesae*, Radiolaria) of the Lower Berriasian.

7.2. *Ano Kouklessi East Section*

This section is located some 300 meters east of the village of Ano Kouklessi (Fig. 24F). The upper part of the Pantokrator limestones is marked by the presence of erosional cavities and sedimentary dykes (Figs. 29-31). These cavities and dykes are filled with breccias of the Ammonitico rosso with Toarcian Ammonites. Following are two meters of marly limestones in alterations with siliceous beds. The section's upper part is composed of the Vigla limestones.

In this section the gradual reduction in thickness of the Upper Liassic – Malmian formations towards the WNW can again be observed.

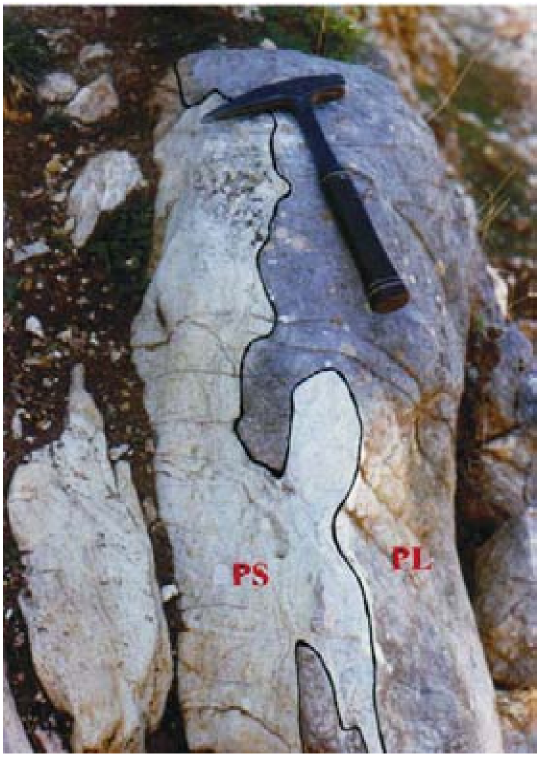

Fig. 29 Stratigraphic contact between the Upper Posidonia Beds (PS) (with a thickness reduced up to 3 m) and the Pantokrator Limestones (PL).

Fig. 30 Ammonitico Rosso (Toarcian) filling the erosional cavities of Pantokrator Limestones (early Liassic).

Fig. 31 Sedimentary dyke on top of the Pantokrator Limestones composed of calcareous breccias of micritic cement with rare filaments, radiolarian, and spicules of Spongiae. The elements are composed of bioclast lime wackestones with small ammonites, spicules of Spongiae, radiolarian and rare filaments.

7.3. *Ano Kouklessi South Section*

The lower meters of this section (Fig. 22G) are composed of the Pantokrator limestones with algues (mainly *Palaeodasycladus mediterraneus*). These are followed by 150 m of the Siniais limestones (Fig. 32), sublithographic with nodules, silex and occasional centimeter-thick argillaceous intercalations (in the upper part of the formation). Within the Siniais formation, the following fossils have been identified: *Globochaete alpine*, *Stomiosphaera asdadensis*, Lagenidae, Ostracodes, fragments of Echinoderms, *Vidalina martana?*. In the final two meters below the Ammonitico Rosso, there has been identified a microfauna of Upper Sinemurian – base of Toarcian age (Karakitsios, 1990).

Fig. 32 Siniais Limestones formation.

Fig. 33 Breccia zones with big elements derived from Siniais Limestones, at the base of Ammonitico Rosso.

The synrift phase (Figs. 33-34) commences with the deposition of about 35 meters of Ammonitico rosso, which can be separated in two parts. The lower part comprises some 12 meters of grey – blue marls with breccias intercalations. The upper part consists of 23 meters of nodular limestones.

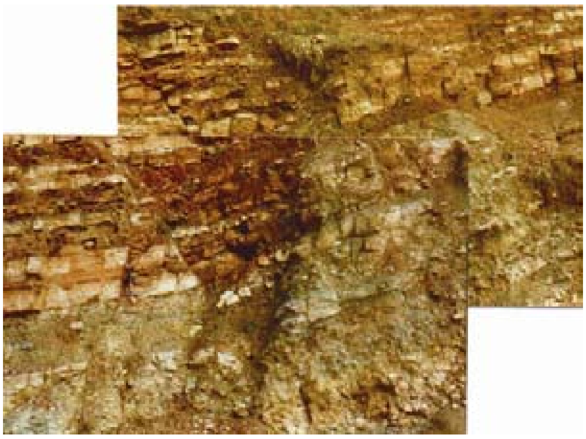

Fig. 34 Synsedimentary normal faults observed in the lower part of Ammonitico Rosso.

About 45 meters of limestones with filaments, consisting of nodular limestones beige – grey, with pseudoconglomerate and mince intercalations of red marls at its base. The upper part of this formation is more siliceous. Aubouin (1959) has described in this formation the ammonite *Skirroceras (Cadomites) bayleanus* of Middle Bajocian age. However this same specimen was re-identified by C. MANGOLD as *Stephanoceras (Skirroveras)* sp. indet. of Lower Bajocian age. The final synrift formation observed in this section is the Upper Posidonian Beds (50 meters in this section), which appear here in its typical facies. The Vigla limestones continue above the synrift facies. In their base appear Radiolaria and *Calpionella alpina*.

7.4. *Toka Section*

In this section (Fig. 24H), we can observe a gradual reduction in the thickness of the Siniais limestones formation, towards WNW. The Toka section, some 1.5 km NNW of Ano Kouklessi, includes about 100 m of the Siniais limestones, with argillaceous intercalations in the upper part. Above the Siniais limestones, appear the Ammonitico rosso with the Ammonites *Phymatoceras robustum, Phymatoceras* sp., *Hammatoceras* sp. of Middle - Upper Toarcian age (Figs. 35-37). This formation is followed by the limestones with filaments, present here with a thickness of about 40 meters.

Fig. 35 Lower part of marly Ammonitico Rosso: laminated blue marls (lower part) and red marls (upper part) affected by a synsedimentary fault.

The upper part of the section comprises 5 – 6 meters of the typical Upper Posidonia Beds, followed by nearly 20 meters of thinbedded limestones alternating with siliceous horizons. In the uppermost part, an intercalation of about three meters of the typical Upper Posidonia Beds can also be observed.

The Toka Section demonstrates a transition between the two types of facies of the Upper Posidonia Beds, as they appear in the "Kouklessi syncline"; the first type can be studied in the Section south of Kouklessi and corresponds to the Upper Posidonia Beds s.s., while the second type appears in the centre of the Toka gorge and corresponds to its lateral equivalent. This Toka formation, which replaces the Upper Posidonia Beds in the Toka Section, is affected greatly by intense slumps. It resembles greatly the Vigla limestones, which appear above, but differs from them both in the color and the microfacies of the limestones. The stratigraphic boundary between the two formations is the first appearance of the *Calpionella alpina*, at the base of the Vigla limestones.

Fig. 36 Gradual westward reduction in thickness of the formations deposited during the Toarcian through Tithonian.

Fig. 37 Detail of laminated marls at the lower part of Ammonitico Rosso.

8. *Aspraggeli Section*

On the road from Ioannina to East Zagoria, after the Aspraggeli village crossroad, outcrop the Maastrichtian, the Paleocene and Eocene sediments of the Ionian zone. The Paleocene formations appear as 40 meter of microbreccious limestones, with marly limestone cement containing Globigerinidae and *Globorotalia* sp. The Ypresian – Lower Lutetian interval has a 180 meters thickness in this section, comprising microbreccious massif limestones, on the lower part, and thin-bedded platy limestones with Globigerinidae, *Globorotalia* sp. and *Alveolina* sp., on the upper part. The Upper Lutetian comprises some 170 meters of thin-bedded platy limestones with Globigerinidae, containing some thick microbreccious limestone beds with large Foraminifera (*Discocyclina* sp., *Asterodiscus* sp., *Fabiania* sp., *Discocyclina* cf. *marthae*, *Nummulites* sp.). The uppermost part of the Eocene consists of 80 meters of thin-bedded platy limestones with rare cherty beds and nodules, containing abundant large Foraminifera, mainly towards the top. The Eocene formations are followed by laminated green-yellow marls, which correspond to the transitional beds to the Ionian flysch. Slumps appear in some horizons in this section.

9. ***Vikos Gorge***

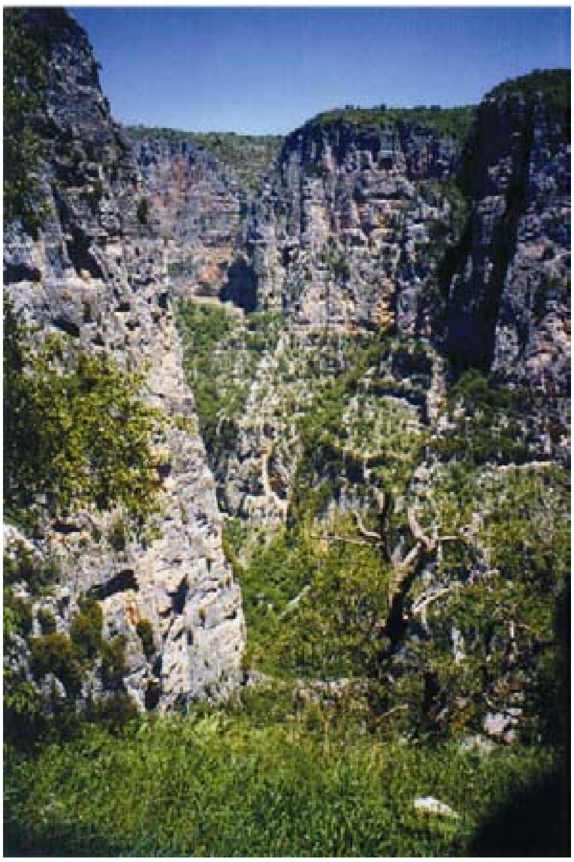

Fig. 38 Paleocene – Eocene Limestones in the Vikos gorge.

Fig. 39 Eocene facies in the Vikos region.

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