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SYNRIFT SEDIMENTATION DURING EXTENSIONAL FAULTING FROM MIDDLE LIAS TO MALM PERIOD AND INVERSION TECTONICS OF IONIAN BASIN IN EPIRUS (NW-GREECE).

V.KARAKITSIOS

ABSTRACT

Ionian Basin opening and its internal differentiation is attested by lateral facies and thickness variation of the Middle Liassic to Malm formations. The begining of the synrift sequence is represented by the Siniais Limestones and their lateral equivalent of Louros limestones in which identification and description of Brachiopodes and Ammonites indicate a Carixian to Domerian age. The geometrical characteristics of the distentional basin are deduced from direction of stratigraphic pinching out of the Middle Liassic to Malm formations and of synsedimentary tectonic features (slumps, synsedimentary faults) observed in their base in the hemi-grabens. The postrift period is marked by an Early Berriasian break-up unconformity representing the base of Vigla limestones, which their sedimentation was synchronous in the whole Ionian basin. The postrift sequence largely obscures the synrift structures and in same cases overlies directly the prerift sequence.

During Alpine orogeny, collision related compressive stresses on the margin induced the reactivation of pre-existing fractures and were responsible for the inversion tectonics that affected the Mesozoic basin. The geometric characteristics of the inverted basin depend on the lithology (evaporites), the geometry of the extensional structures, and the orientation of extensional faults.

The Ionian zone constitutes a good example of inversion tectonics of a basin.

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I. INTRODUCTION

The concept of inversion tectonics can be aplied at various scales to mountain belts such as the Hellenides. At the scale of hundreds of kilometres the whole Alpine belt can be considered to be the inverted margin of the Tethyan ocean in response to the collision of Apulia against Europe (GRACIANSKY & al. 1989). On a smaller scale of few tens of kilometres, the various sub-basins of the South-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.

One of the most representative examples of this inversion is the Ionian zone of external Hellenides (KARAKITSIOS 1990).

The Ionian zone of NW-Greece (Epirus) constitutes part of the most external zones of the Hellenides (Paxos zone, Ionian zone, Gavrovo zone; Fig. 1).

In the Early Lias NW-Greece was covered by a huge carbonate platform which, in the Middle Lias (Carixian) was intensively block-faulted (KARAKITSIOS, 1990). This process led to the opening of Ionian basin. Even thought the production of platform-carbonates persisted through the whole Jurassic in the adjacent Paxos (Preapulian) and Gavrovo zones, the Ionian basin became an area of stronger subsidence and faulting. This paleogeographic configuration continued with minor off-and onlap movements along the basin margins until the Late Eocene times, when orogenic movements and flysch sedimentation set in. In the Gavrovo and in the Ionian zones, the main orogenic movements took place at the end of the Burdigalian, in the Paxos and Apulian zones during the Plio-Pleistocene (IGRS-IFP, 1966; BIZON, 1967).

The present study will show that:

- compressive stresses during Alpine orogeny induced the reactivation of pre-existing fractures and were responsible for the inversion tectonics that affected the Mesozoic basin;
- the geometric characteristics of the inverted basin depend on the lithology (evaporites), the geometry of the extensional structures, and the orientation of extensional faults (in this paper, definition of extentional and contractional faults is given in Fig. 2).

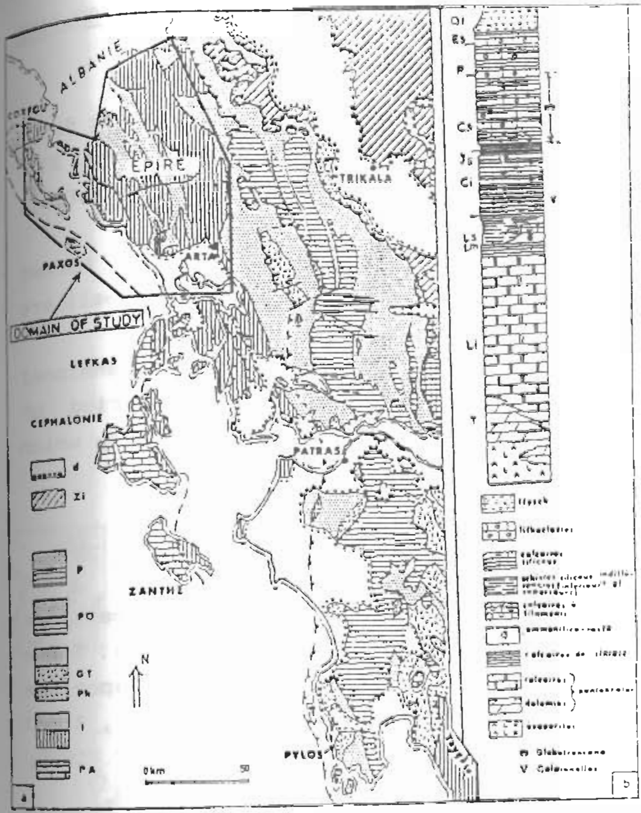


Fig. 1a. Structural map of Western continental Greece (by FLEURY 1980):
PA: Preapulian (Paxos) zone; I: Ionian zone; GT: Gavrovo - Tripolitza zone; PO: Pindos - Olonos zone; P: Parnasse zone; Zi: inner zones; d: unconformable post - tectonic formations.

Fig. 1b. Representative stratigraphical column of Ionian zone:
T: Triassic; L (Li,Lm,Ls): Lias (Early, Middle, Upper); Js: Upper Jurassic; Ci: Lower Cretaceous, Cs: Upper Cretaceous; P: Paleocene; Es: Upper Eocene; Ol: Lower Oigocene.

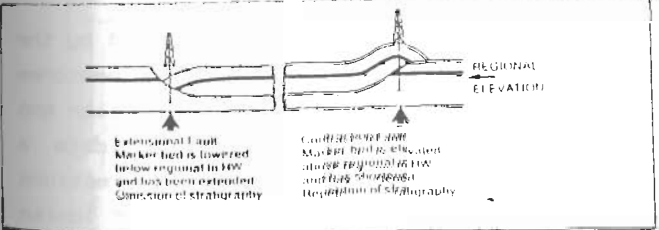


Fig. 2. Definition of A, extensional and B, contractional faults
(by WILLIAMS & al. 1989)

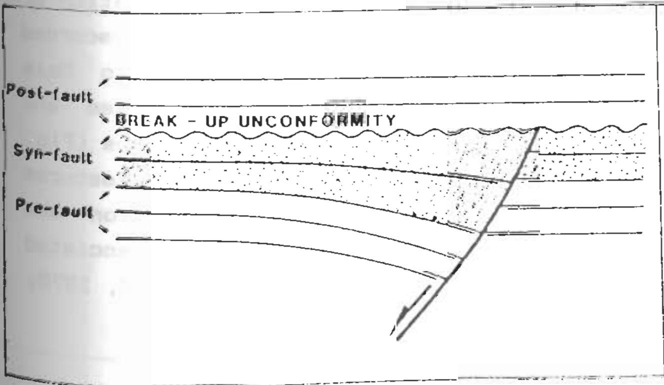


Fig. 3. Scematic diagram of stratigraphy accumulated before, during and after extensional fault movement. The break-up unconformity is shown as a wavy line at the top of the synrift sequence.
(by WILLIAMS & al. 1989)

II. GEOMETRY OF SYNRIFT SEQUENCES DEPOSITED DURING EXTENSIONAL FAULTING FROM UPPER LIAS TO MALM PERIOD.

Stratigraphy built up on extensional basins, in its simplest form, may exhibit three distinct sequences (WILLIAMS & al., 1989), (Fig. 3):
1- a prerift sequence is deposited prior to any extensional fault movement;
2- a synrift sequence is deposited during extensional faulting. Marked stratigraphic thickness changes from fault footwall to hanging wall are indicative of growth faulting;
3- a postrift sequence is deposited after the cessation of extensional faulting. The postrift sequence may be deposited after a period of non-deposition and/or erosion marked by a break-up unconformity which may remove part of the synrift sequence.

In the Ionian zone (KARAKITSIOS, 1990):

- the prerift sequence is represented by the Pantokrator limestones (Lower Lias: AUBOUIN, 1959; IGRS-IFP, 1966; KARAKITSIOS, 1990). These shallow water limestones overlie Early to Middle Triassic evaporites (POMONI- PAPAIOANNOU & TSAILA-MONOPOLIS, 1983; DRAGASTAN & al., 1985) through Foustapidima limestones of Ladinian-Rhetian age (RENZ, 1955; DRAGASTAN & al., 1985; KARAKITSIOS & TSAILA-MONOPOLIS, 1990);

- the beginning of synrift sequence which is being represented by the Siniais limestones and their lateral equivalent of Louros limestones (KARAKITSIOS & TSAILA-MONOPOLIS, 1988) in which identification and description of the Foraminifera, Brachiopods and Ammonites indicate a Carixian to Domerian age (KARAKITSIOS, 1990). These formations correspond to the general deepening of Ionian area (formation of Ionian basin), which was followed by the internal synrift differentiation of Ionian basin marked from smaller paleogeographic units as is recorded in the prismatic synsedimentary wedges of Upper Lias to Malm formations. In fact, (KARAKITSIOS, 1988-1991) lateral facies and thickness variation of the Middle Lias to Malm formations (Fig. 4,5a,5b,6,7,8) and directions of synsedimentary tectonic features (slumps, synsedimentary faults) indicate that deposition was structurally controlled by the distentional tectonic phase associated with the latest opening of the Tethyan Ocean (BERNOULLI & RENZ, 1970;

Fig. 4 - A: Location of the studied areas (a,b,c,...,n);
B: Simplified geological maps of the areas where the sections (A,B,...,Z) are located: 1) post-Alpine non-differentiated formations, 2) post-Vigla Alpine formations, 3) Vigla limestones, 4) Middle Lias to Malm formations, 5) Pantokrator limestones, 6) evaporites, 7) fault, 8) dip, 9) geological sections.

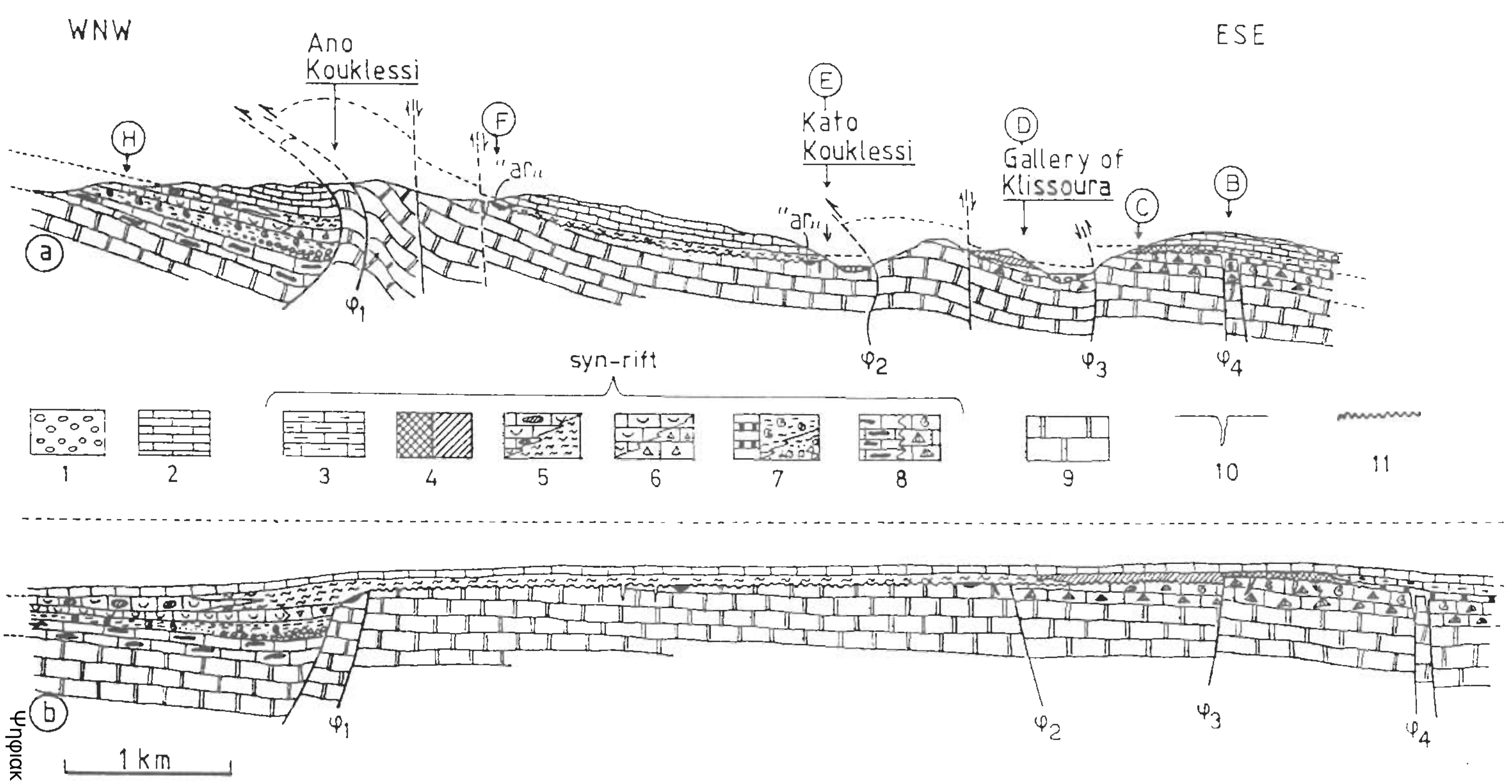


Fig. 5a. Klissoura-Kouklessi cross-section; a: actual, b: restored (Lower Berriasian) (by KARAKITSIOS 1990).

1:Quaternary; 2: Vigla limestones; 3,4,5,6,7,8: synrift formations (4,5: Upper Posidonia beds s.l.; 6: Limestones with Filaments; 7: Ammonitico Rosso; 8: Louros and Siniais limestones); 9: Pantokrator limestones; 10: sedimentary dyke; 11: unconformity.

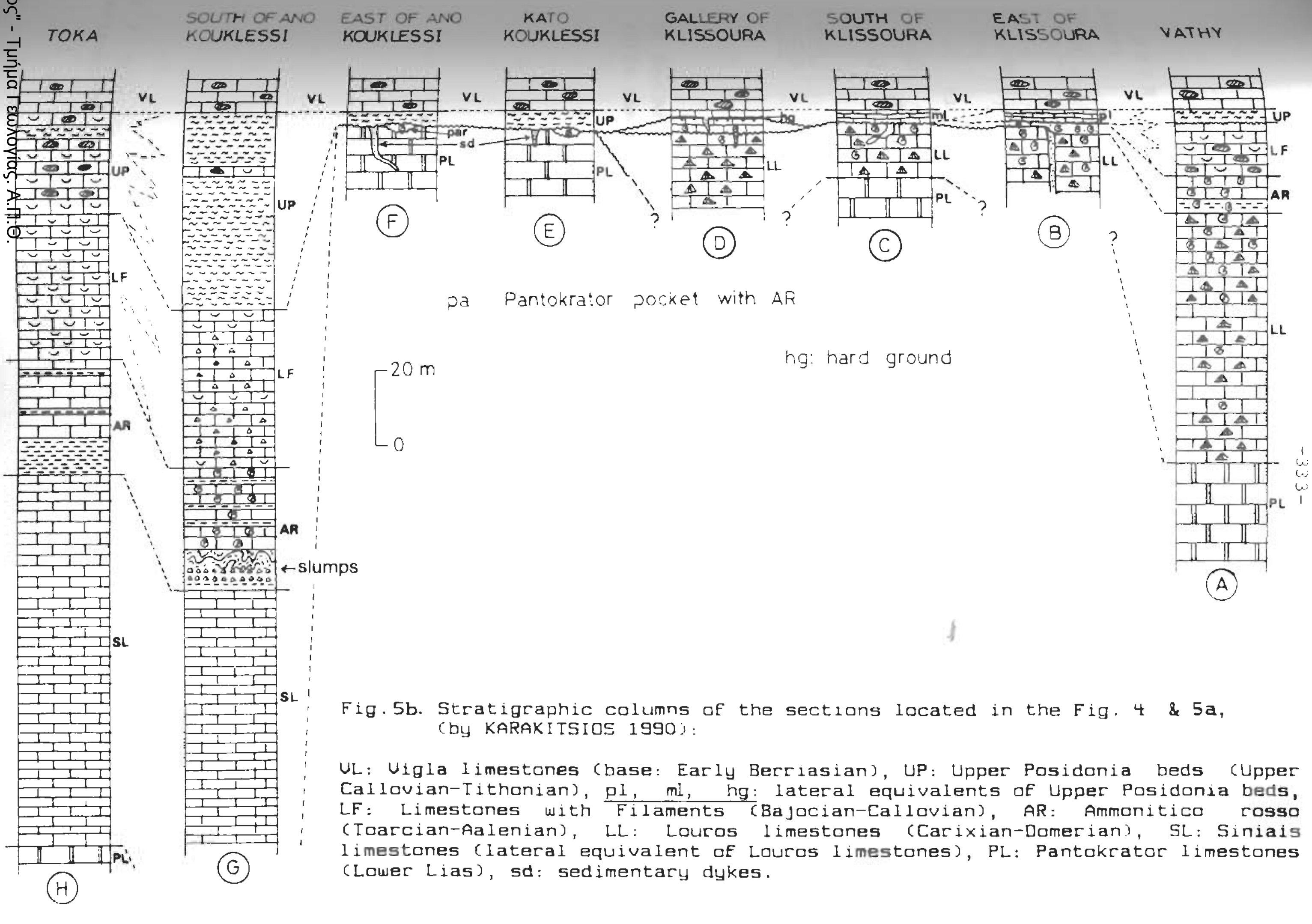


Fig. 5b. Stratigraphic columns of the sections located in the Fig. 4 & 5a, (by KARAKITSIOS 1990):

VL: Vigla limestones (base: Early Berriasian), UP: Upper Posidonia beds (Upper Callovian-Tithonian), pl, ml, hg: lateral equivalents of Upper Posidonia beds, LF: Limestones with Filaments (Bajocian-Callovian), AR: Ammonitico rosso (Toarcian-Aalenian), LL: Louros limestones (Carixian-Domerian), SL: Siniais limestones (lateral equivalent of Louros limestones), PL: Pantokrator limestones (Lower Lias), sd: sedimentary dykes.

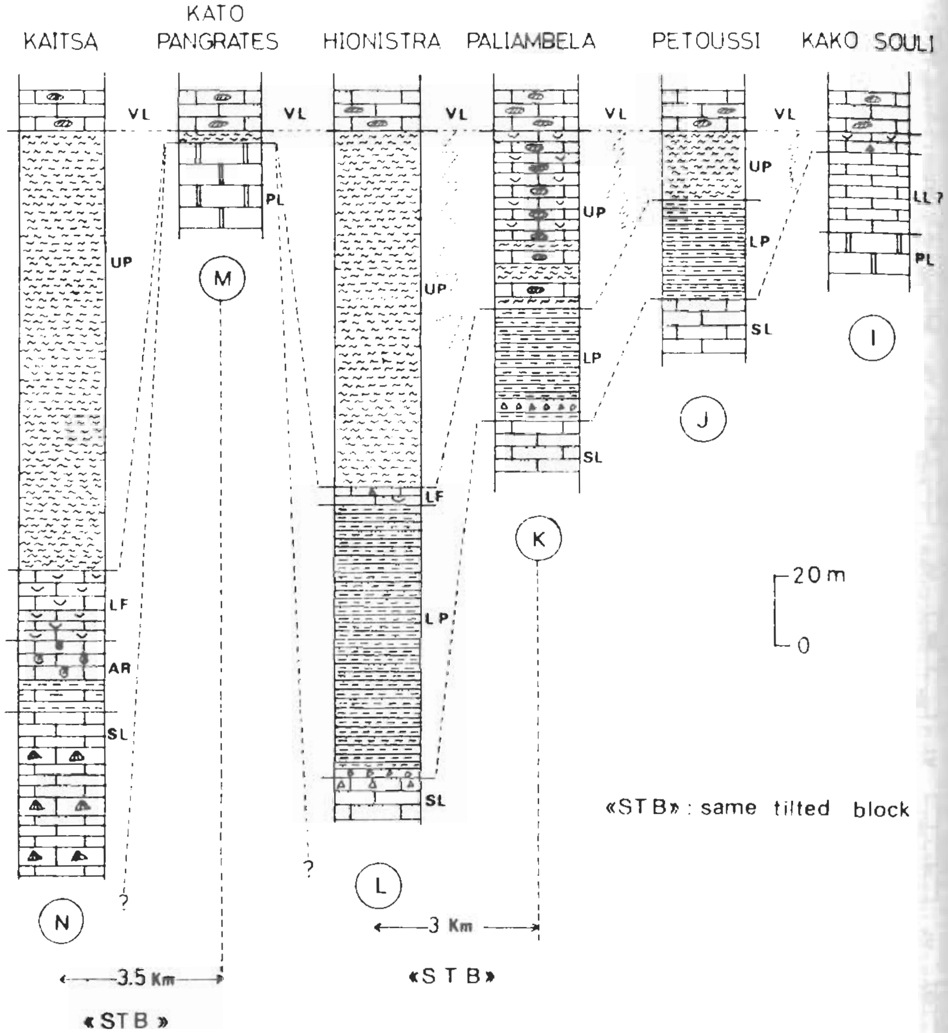
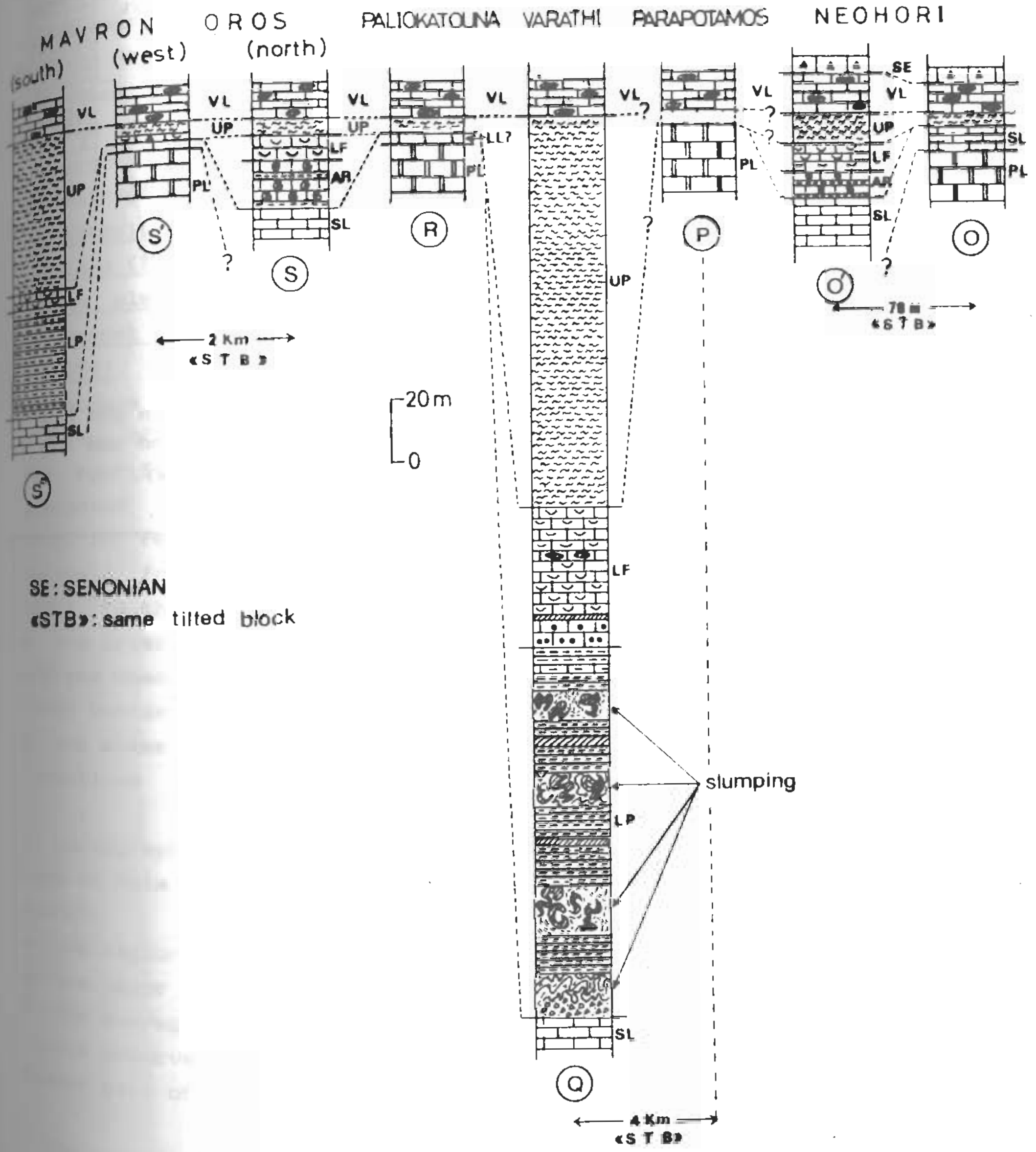


Fig. 6. Stratigraphic columns of the sections located in the Fig. 4 (cont tion) (by KARAKITSIOS 1990). For legend see Fig. 5b caption.



ig. 7. Stratigraphic columns of the sections located in the Fig. 4 (continuation) (by KARAKITSIOS 1990). For legend see Fig. 5b caption.

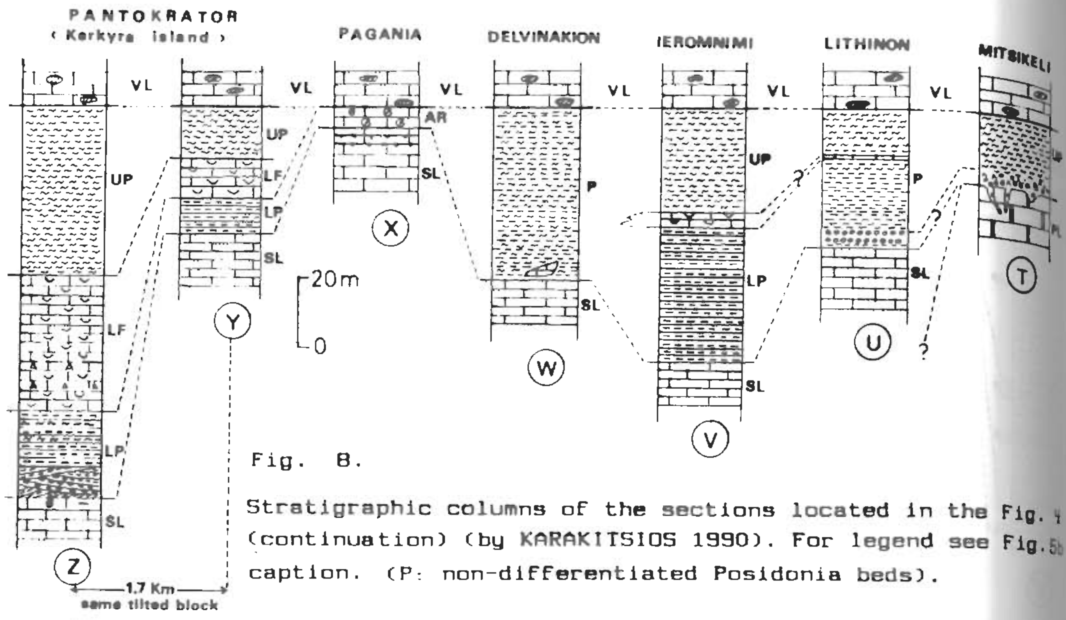


Fig. 8.

Stratigraphic columns of the sections located in the Fig. 4 (continuation) (by KARAKITSIOS 1990). For legend see Fig.5b caption. (P: non-differentiated Posidonia beds).

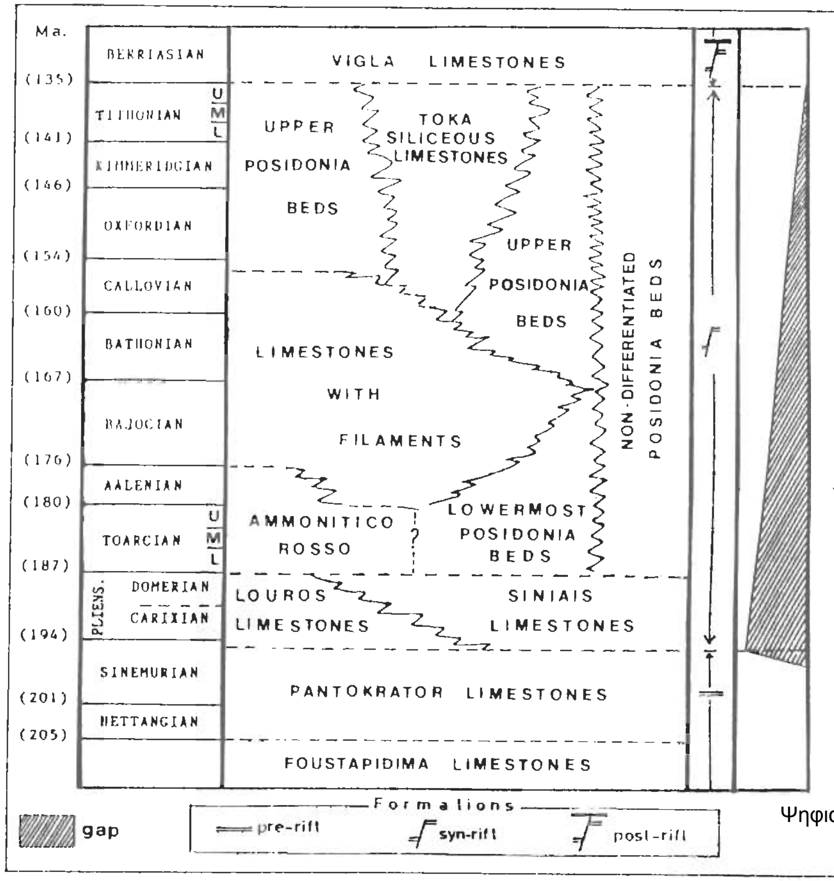


Fig. 9. Synthetic diagram showing stratigraphic relationships of the Upper Trias - Early Cretaceous formations of the Ionian sequence (by KARAKITSIOS 1990).

KARAKITSIOS, 1990). The Early Lias shallow marine platform was affected by intense block-faulting of listric geometry which was recorded (KARAKITSIOS 1990, 1991) by differential subsidence within each small paleogeographic unit. Prismatic synsedimentary wedges of the Middle Lias to Malm formations in the small paleogeographic units vary in thickness along an EW direction and underline the facies distribution (hiatus are located on top of tilted blocks and Ammonitico rosso or "Lowermost Posidonia beds" formation are located in the deeper part of the half-grabens). Influence of the Ionian zone evaporitic substratum halokinesis in the synrift mechanism, is not only theoretically possible (KARAKITSIOS, 1988) but it is also attested by the presense of gypsum elements observed in the conglomerate of the base of the "Lowermost Posidonia beds" in the Lithino section (KARAKITSIOS 1990, p. 150-154). The stratigraphic relationships of the Upper Trias to Early Cretaceous formations of Ionian sequence are given in the synthetic diagram of Fig. 9. The geometric characteristics of the beginning of the synrift intrabasinal differentiation into tilted blocks is presented in the paleogeographic and stuctural map of Upper Liassic (Fig. 10) recostructed from the lithostratigraphic analysis of the Jurassic formations all over the Ionian zone in Epirus (KARAKITSIOS, 1990). In this map, one can observe:

a- the areas of comlete, thick Upper Lias to Malm formations (zone "I") and the Ammonitico rosso and "Lowermost Posidonia beds" distribution in their bottom;

b- the areas where unconformity and hiatus are presented in these formations -submarine highs (seamounts) or rarely emerged areas- (zone "II");

c- cartographical direction of statigraphic pinching out of the Upper Lias to Malm formations (organized in sedimentary wedges on each tilted block);

d- the regional dip of various tilted blocks;

e- the major synsedimentary listric faults of Upper Liassic times;

f- the average direction of slumps axis and minor normal synsedimentary faults observed in the base of the Upper Lias to Malm formations in the deeper part of the tilted blocks;

- the postrift period is marked by an Early Berriasian (KARAKITSIOS, 1990; KARAKITSIOS & KOLETTI, 1992) break-up unconformity representing the base of Vigla limestones, which their sedimentation was synchronous

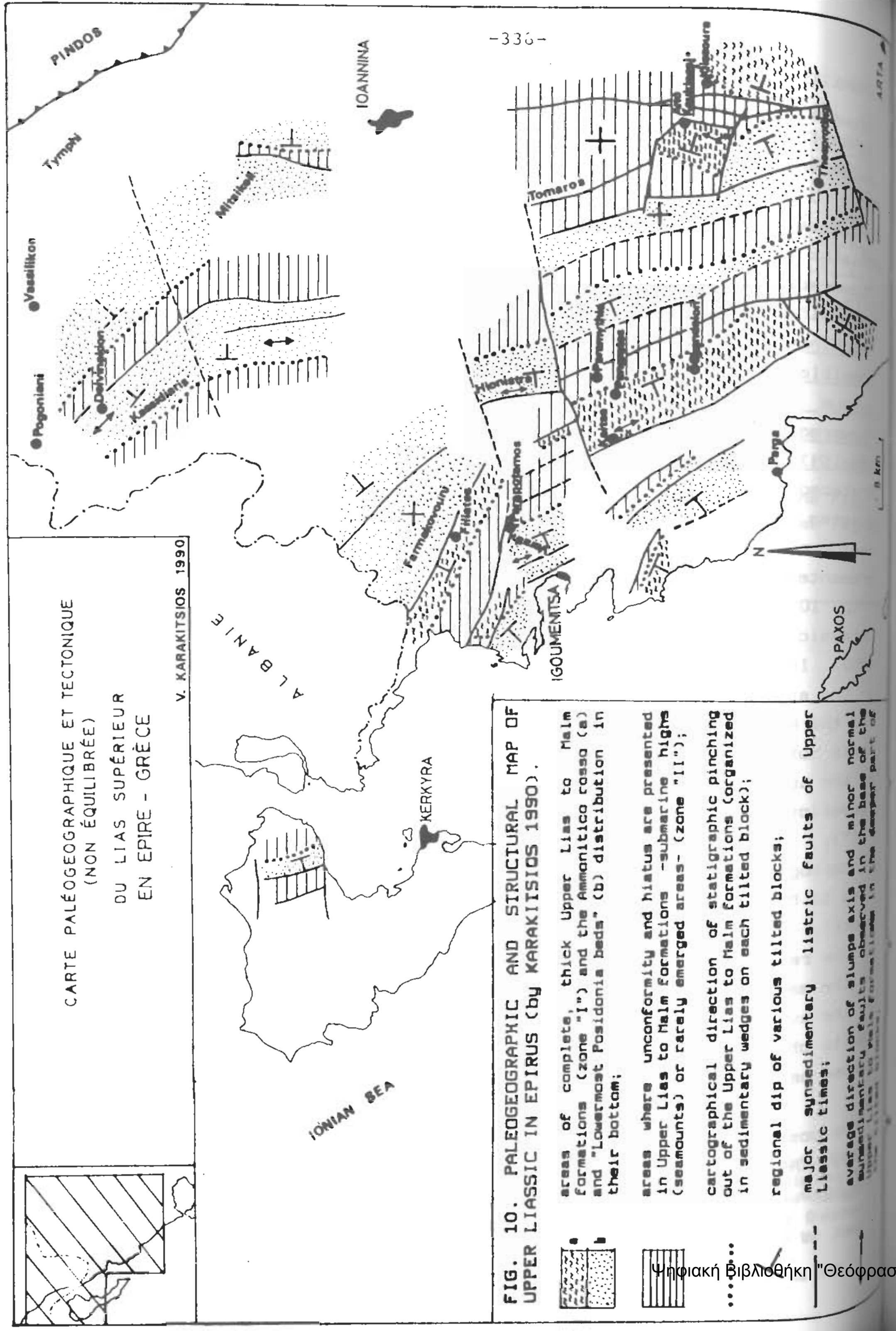


FIG. 10. PALEOGEOGRAPHIC AND STRUCTURAL MAP OF UPPER LIASSIC IN EPIRUS (by KARAKITSIOS 1990).

areas of complete, thick Upper Lias to Malm formations (zone "I") and the Ammonitico rosso (a) and "Lowermost Posidonia beds" (b) distribution in their bottom;

areas where unconformity and hiatus are presented in Upper Lias to Malm formations -submarine highs (seamounts) or rarely emerged areas- (zone "II");

cartographical direction of statigraphic pinching out of the Upper Lias to Malm formations (organized in sedimentary wedges on each tilted block);

regional dip of various tilted blocks;

major synsedimentary listric faults of Upper Liassic times;

average direction of slumps axis and minor normal synsedimentary faults observed in the base of the Upper Lias to Malm formations in the deeper part of [illegible]

in the whole Ionian basin. The postrift sequence (Vigla limestones and the overlain Alpine formations) largely obscures the synrift structures and in some cases overlies directly the prerift sequence (Fig. 5a,5b, 7,8). The deposits of Vigla limestones do not correspond to a sea-level rise due to eustatic reasons, but to a general sinking of the entire basin (KARAKITSIOS 1990; KARAKITSIOS & KOLETTI, 1992). The permanence of differential subsidence during the deposition of the Vigla limestones (as the strong variation in thickness of this formation shows: IGRS-IFP, 1966) is probably due (KARAKITSIOS, 1988-1991) to the continuation of halocinetic movements of the Ionian zone evaporitic substratum.

III. ALPINE TECTONICS OF IONIAN ZONE

Structural analysis of Ionian zone shows that orogenesis took place essentially during the end of Burdigalian (major phase of deformation: IGRS-IFP, 1966). The Ionian zone was considered as the assemblage of anticlines and synclines pushed against each other, by a system of moderate westward overthrusts which were accompanied by a transcurrent fault system (i.e. sinistral transcurrent fault of Petousi, dextral transcurrent fault of Ziros) that made the thrusts mechanisme easier (IGRS-IFP, 1966). However, even though eastward thrusts were pointed out by BRUNN (1956) and AUBOUIN (1959), in the internal (eastern) part of Ionian zone, yet no particular significance was given from any researcher. Observation of Ionian zone tectonics shows, in fact, that structures (folds, thrusts) in its eastern part, dump eastwards (Fig. 11). Cross-sections of Mitsikeli (Fig. 12) make very clear this divergence. In the central and western parts of the Ionian zone, structures are dumping westwards (Fig. 13, 14). But in all cases the localization of reversal faults and thrusts took place in the location of Jurassic paleofaults. Cross-sections mark the coincidence of structural units placed tectonically before 15 M.Y. with the paleogeographic units appeared 170 M.Y. earlier during the internal differantiation of Ionian zone. In order to observe this coincidence, one has to compare the paleogeographic and structural map of Toarcian times (Fig. 10) with the map of the present tectonic (Alpine) lines in Epirus (Fig. 11). The observed divergence (KARAKITSIOS, 1990) of the major compressional direction (= NNE-SSW; CUSCHING, 1985; KARAKITSIOS, 1990) from the normal to the direction of thrust surfaces, advocates

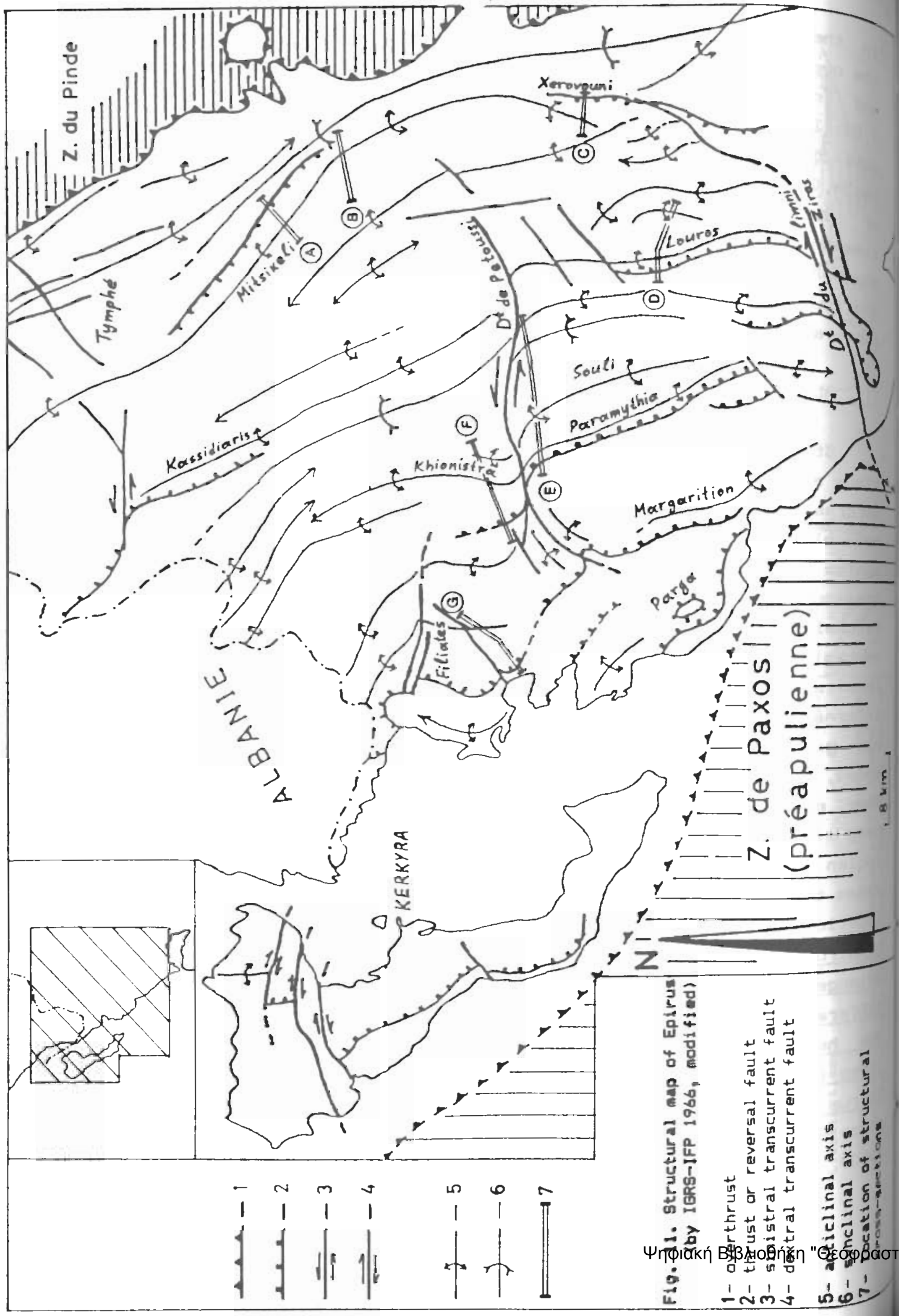


Fig. 11. Structural map of Epirus (by IGRS-IFP 1966, modified)

1- overthrust
2- thrust or reversal fault
3- sinistral transcurrent fault
4- dextral transcurrent fault

5- anticlinal axis
6- synclinal axis
7- location of structural cross-sections

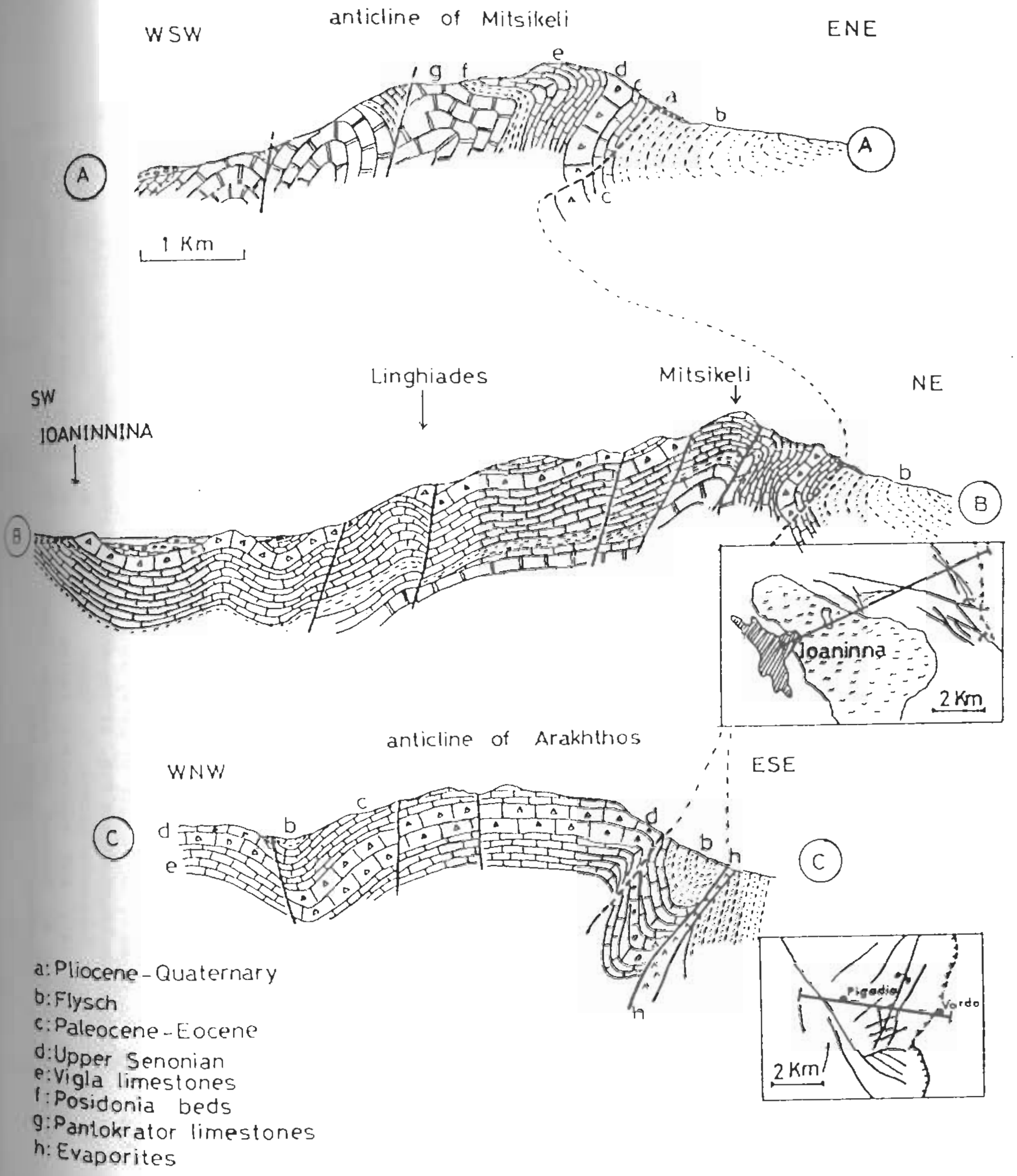


Fig. 12. Sections of Mitsikeli and its southern prologation. For sections location see Fig. 11 (by KARAKITSIOS 1990, based on field data and geological maps of IGRS-IFP 1966).

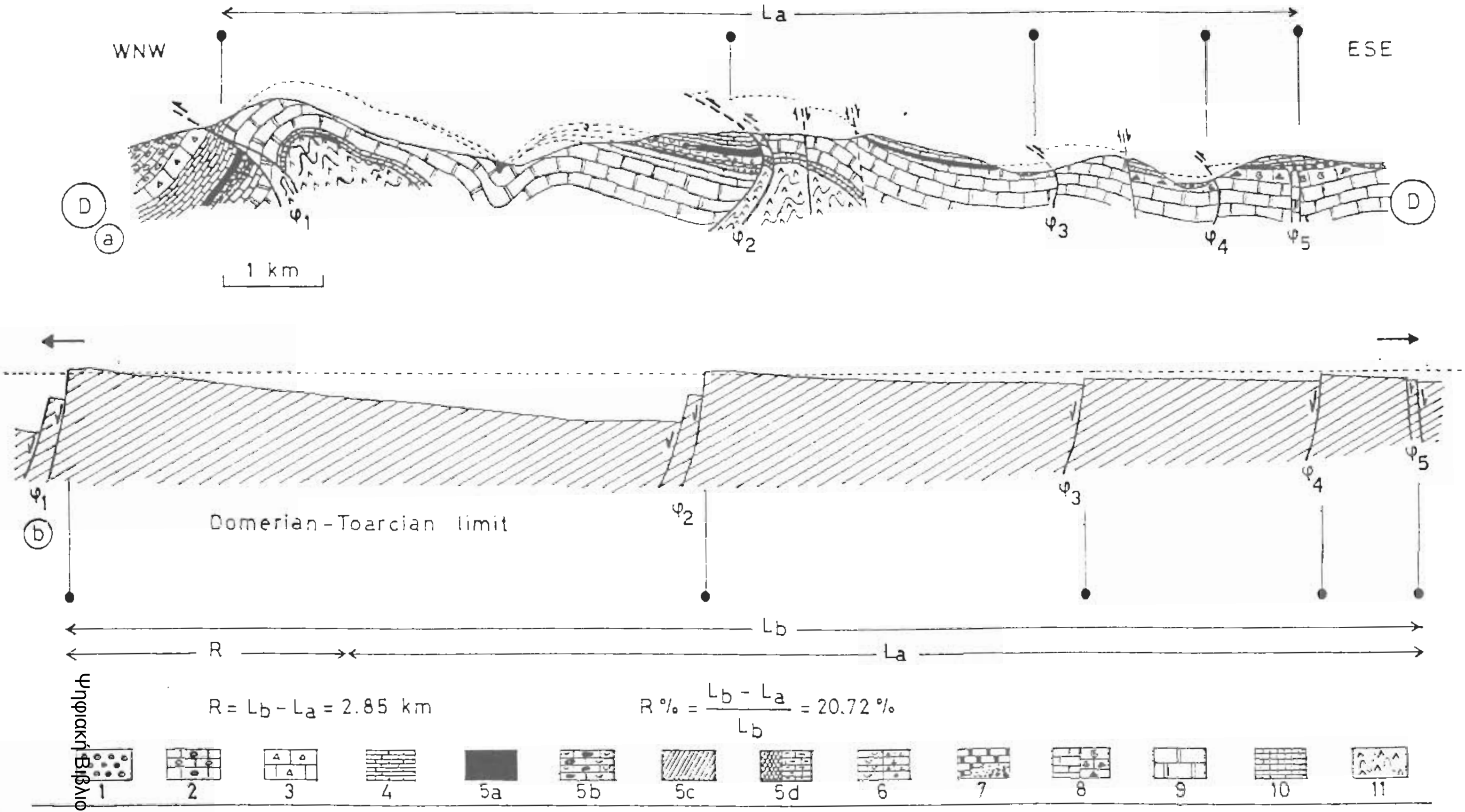


Fig. 13. Balanced cross-section of Derviziana-Klissoura (a) and restored section (b). For section location see Fig. 11 (by KARAKITSIOS 1990).
1: Quaternary; 2: Paleocene-Eocene; 3: Upper Senonian; 4: Vigla limestones; 5: Upper Posidonia beds (a), and equivalent facies (b,c,d); 6: limestones with filaments; 7: Ammonitico rosso; 8: Siniais and Louros limestones; 9: Pantokrator limestones; 10: Foustapidima limestones; 11: evaporites.

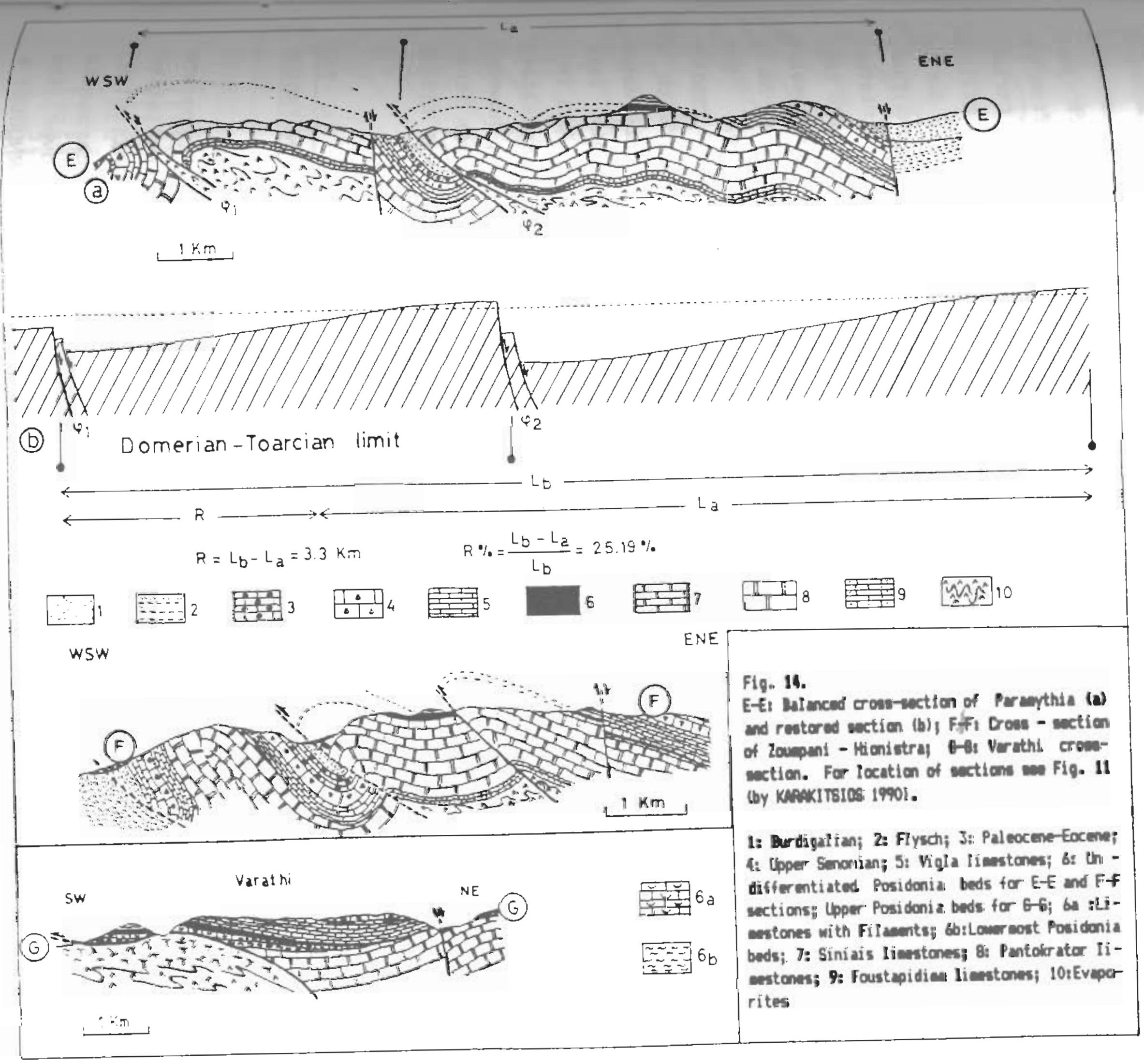
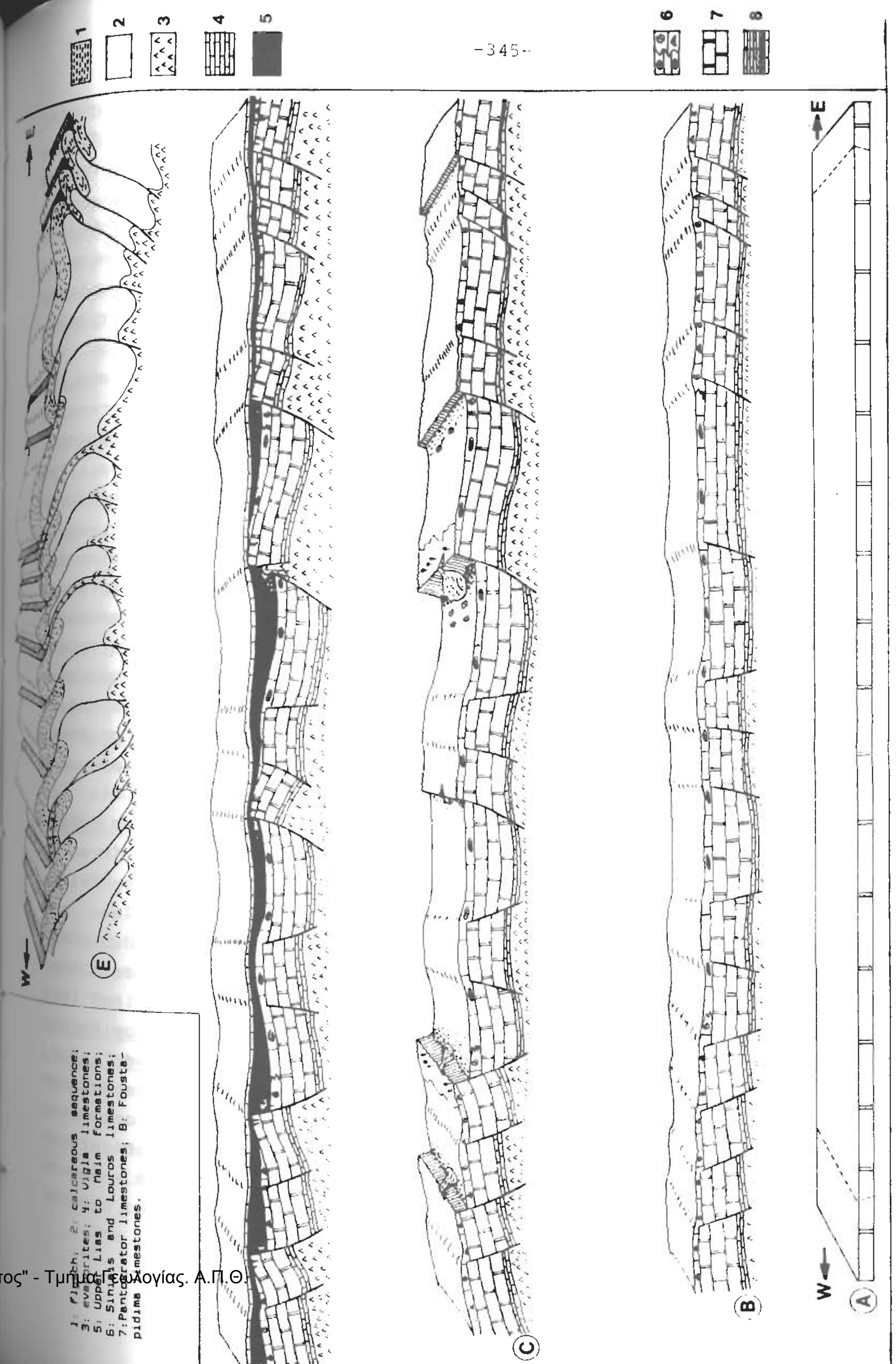


Fig. 14.
E-E: Balanced cross-section of Paramythia (a) and restored section (b); F-F: Cross-section of Zoumpani - Hionistra; G-G: Varathi cross-section. For location of sections see Fig. 11 (by KARAKITSIOS 1990).

1: Burdigalian; 2: Flysch; 3: Paleocene-Eocene; 4: Upper Senonian; 5: Vigla limestones; 6: Undifferentiated Posidonia beds for E-E and F-F sections; Upper Posidonia beds for G-G; 6a: Limestones with Filaments; 6b: Lowermost Posidonia beds; 7: Siniais limestones; 8: Pantokrator limestones; 9: Foustapidima limestones; 10: Evaporites that thrusts as break surfaces, should not owe their origin in this phase of deformation. These surfaces are more probably considered to be pre-existing, for instance ancient listric faults due to the distensional phase of Jurassic times which were reactivated in the new compressional status, principally as thrusts with horizontal component (Fig. 11). Wowever, the double divergence of Ionian structure -westward in the western and central parts and eastward in the eastern part respectively- is certainly due to the structures inherited from the distentional Jurassic phase which was translated from a certain symmetry of Ionian basin as far as this is concerned from the tilting of external (Apulian side) and internal blocks (Gavrovo side) during the same period of time (Fig. 10). As far as the transcurrent fault system of Epirus is concerned, the observation of the sinistral transcurrent fault of Petousi (KARAKITSIOS, 1990; Fig. 11) showed that this system is later than the folds and the direction of compression related to its activation is considered to be different (i.e. NE-SW to E-W) from that associated with the thrusts (NNE-SSW). The interpretation of seismic cross-sections involves (KARAKITSIOS, 1990) a westward growth of horizontal displacement of the Ionian zone, with a more expressed diapirism in the same direction. This is in accordance with the balanced cross-sections provided from the field data (see evaluated amount of shortening from East to West, Fig. 13,14). Consequently, a moderate decollement in the sub-surface evaporites, especially in the external domain of Ionian zone, is certain; however it is out of question to assimilate this decollement with that suggested by GUZZETTA (1981) in Epirus and BP (1971), JENKINS (1972) and SOREL & CUSCHING (1982) in Akarnania.

IV. PALEOGEOGRAPHIC AND STRUCTURAL EVOLUTION OF IONIAN BASIN IN THE ALPINE CONTEXT: AN ILLUSTRATION OF THE OPENING AND THE INVERSION TECTONICS OF IONIAN BASIN (FIG. 15)

During the Upper Triassic the Foustapidima limestones mark the end of favorable conditions for sulfates precipitation and the installation of a more frankly marin sedimentation in the Ionian area (KARAKITSIOS, 1990). During the the Lower Liassic (Fig. 15 A) a huge carbonate platform bordering the Southern Tethyan Ocean is established over the whole western Greece. This platform was characterized (BERNOULLI & RENZ, 1970; KARAKITSIOS, 1990) by a strong subsidence which was



1: Flysch, 2: calcareous sequence; 3: evaporites; 4: Vigla limestones; 5: Upper Lias to Malm formations; 6: Siniais and Louros limestones; 7: Pantokrator limestones; 8: Foustapidima limestones.

Fig. 15. Synthetic scheme of the opening and the inversion tectonics of Ionian basin (by KARAKITSIOS 1990).
A: Lower Lias; B: Domerian; C: Lower Toarcian; D: Lower Berriasian; E: Upper Burdigalian.

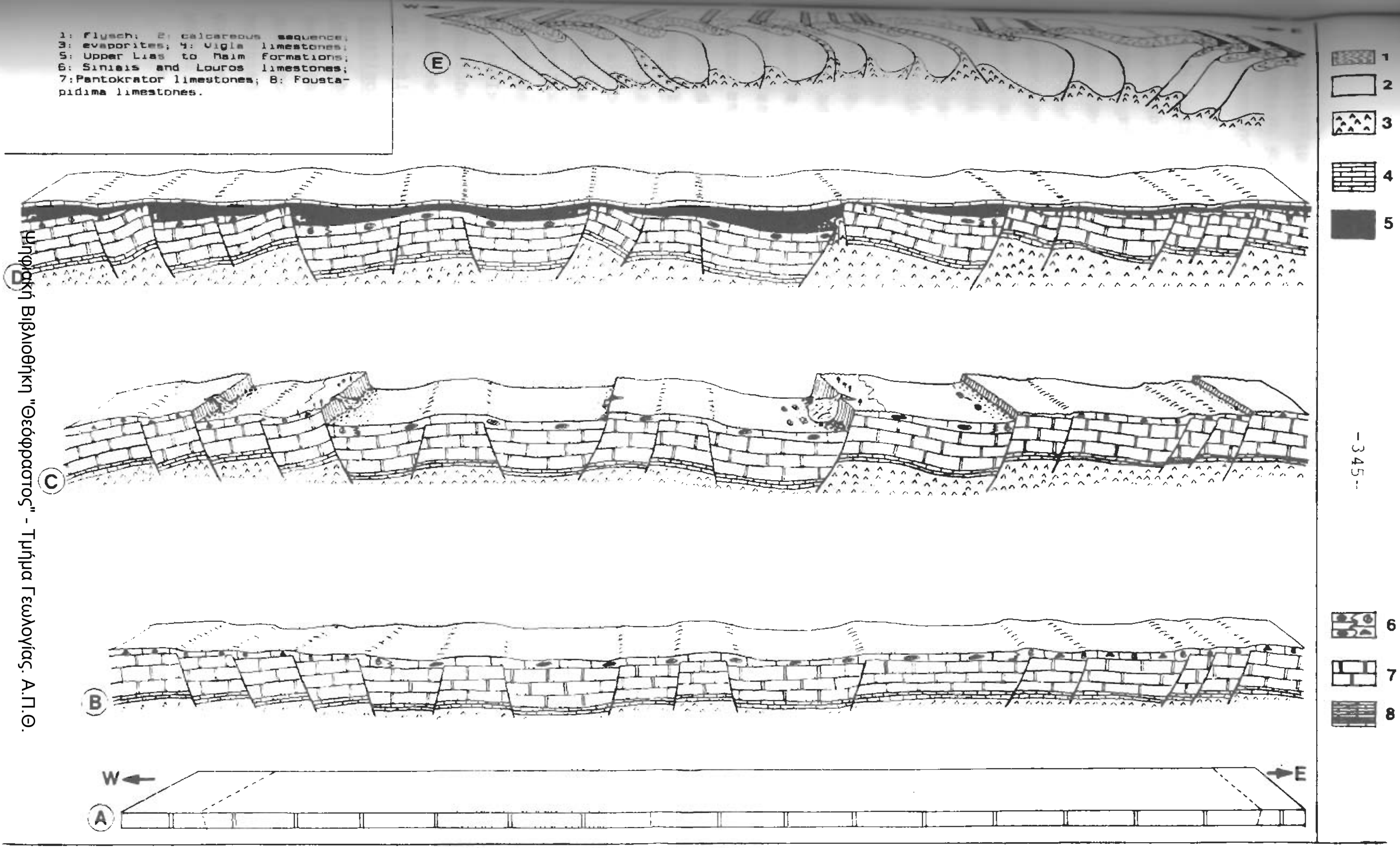


Fig. 15. Synthetic scheme of the opening and the inversion tectonics of Ionian basin (by KARAKITSIOS 1990).
A: Lower Lias; B: Domerian, C. Lower Toarcian; D: Lower Berriasian; E: Upper Burdigalian.

balanced by intensive carbonate sedimentation in a very shallow-water sedimentary environment (emersion limit) that accumulates a carbonate sequence (Pantokrator limestones) of more than a thousand metres thickness (IGRS-IFP, 1966; BP, 1971).

During Carixian times (KARAKITSIOS 1990), the initial shallow carbonate platform began to break up. The first general deepening of the Ionian area is testified from the Siniais and the Louros limestones deposits. The distension that involves this deepening was probably expressed by border faults which separated the Ionian basin from the adjacent Paxos (in the West) and Gavrovo (in the East) zones where the production of platform-carbonates persisted through the whole Jurassic. Louros limestones and their lateral equivalent of Siniais limestones, correspond, then, to the first synrift sediments of Ionian series. The Siniais facies occupied the axial part of Ionian basin whilst Louros facies its bordering areas (Fig. 15 B).

From Domerian to Toarcian limit, the continuation of distension was accompanied by intense block-faulting which led to the internal differentiation of Ionian basin (Fig. 15 C). Listric faults associated with this phase caused the separation of the initial basin into a number of small (in general between 2 to 10 kilometres across) paleogeographic units (on each tilted block) which was subjected to differential subsidence. Thus, in the deeper part of the half-grabens, Ammonitico rosso or "Lowermost Posidonia beds" formation were deposited. These deposits were also accompanied by products of submarine or aerial erosion derived from the top of the same tilted block and especially from the top of the adjacent tilted block (breccia with big elements or big blocks detached from the fault scarps, fallen in the depressed part of the tilted block; i.e. South Kouklesi and Delvinaki sections respectively). On the top of the tilted blocks, hiatus, hard-grounds and sendimentary dykes are located. These tops constitute either submarine high or (rarely) an emerged relief (the case of emerged relief is attested by the presence of Coniferous branches observed in the base of "Lowermost Posidonia beds"; i.e. Hionistra section, KARAKITSIOS 1990, p. 122 and 125). Gypsum injections into the fault surfaces are possible if fault throws are strong (i.e. Lithino section). These conditions persisted with minor modifications until Upper Jurassic whereas the sedimentation was being more and more calm with the progressive filling up of the depressed parts by the Upper Liassic to Malm formations.

During the Early Berriasian (Fig. 15 D) a general sinking of the entire basin is attested by the onset of the deposition of pelagic Vigla limestones in the whole Ionian zone. Apart from halocinetic movements which probably provoked the variation in thickness of Vigla limestones, the same conditions persisted until the Late Eocene times, when flysch sedimentation set in. Sedimentation remains always pelagic accompanied by clastic deposits derived from the adjacent Gavrovo and Apulian platforms

At the end of the Burdigalian (Fig. 15 E) the major compressional phase that affected the Ionian zone reactivates by reversing, to a great extent, the sense of motion of the pre-existing Jurassic extensional fault system. Listric faults were transformed in reversal faults, thrusts, or transcurrent faults. This phenomenon was facilitated by diapiric movements through the tectonic surfaces of the evaporitic base of the Ionian zone. A moderate decollement in the sub-surface evaporites, especially in the external domain of Ionian zone, is very probable; however, field data and available seismic cross-sections exclude a major decollement as that suggested by BUZZETTA (1981) in Epirus and BP (1971), JENKINS (1972) and SOREL & CUSCHING (1982) in Akarnania. The symmetry of the Ionian basin associated with the distentional phase of Jurassic times is manifested in the double divergence of its compressional structure (westward in the West and eastward in the East).

V.CONCLUSIONS

The Ionian zone constitutes a good example of inversion tectonics of a basin. Its paleogeographic and structural evolution is sufficiently comparable to Umbria-Marche zone of North Appenines (BARCHI & al., 1989; ALVAREZ, 1989; CECCA & al., 1990).

The organic matter accumulated in the Lowermost Posidonia beds of Ionian zone (JENKYNS, 1988; BAUDIN & LACHKAR, 1990) during the Late Lias, ''is directly related to the geometry of the opening of Ionian Basin that caused a particular type of some restricted sub-basins which geometry favored their stagnation and consequently the localy euxinic conditions of the sea floor waters. In these areas, the Jurassic black shales (Posidonia beds) were deposited especially during the Upper Liassic times (Lowermost Posidonia beds).

The influence of evaporitic substratum halokinesis in the synrift mechanism, which has been observed in the Ionian Basin, since the Upper Liassic times, has as result areas where the evaporitic substratum thickness was minimum (areas with Ammonitico Rosso or Lowermost Posidonia beds) and areas where its thickness was maximum (areas with hiatus of Middle Lias to Malm formations). As a consequence there may be an oil interest in the pre-evaporitic Ionian substratum research which is unknown in the exposure as well as in the bore hole.

Finally, the opening and the inversion tectonics of Ionian Basin influence, at the same time, the source rocks and the probable traps of Ionian zone.

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