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EXAMPLES OF ALPIDE DEFORMATION FROM EPIRUS: LOCAL ANOMALIES OR NEED TO RE-EVALUATE THE AMOUNT OF SHORTENING IN THE WESTERN HELLENIDES?

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ABSTRACT

Epirus, in NW Greece, comprises a sequence of Tertiary thrusts and represents the destroyed eastern passive margin of the Apulian platform. A large number of thrusts with a western vergence as well as east-vergent back-thrusts occur in the area. E-W trending strike-slip fault zones play an important role in the Alpide evolution.

Two areas of Alpide deformation, both located along the Souli strike-slip Fault System, are presented. Detailed mapping and tectonic analysis of the structures have been carried out in both examples. Some geological cross-section has been prepared. Taking into account the ramp-flat model, was possible to interpret them down to a hypothetical basal detachment and to attempt the palinspastic reconstruction of the involved tectonic units. The structural analysis carried out in the area also permits to describe the kinematics of the main tectonic units. In the light of the presented geological and structural data the quantifiable amount of sortening is much larger than know in the literature. So, for the Ionian Zone of Epirus is proposed a shortening greater than 50%.

INTRODUCTION

External Hellenides are a typical example of a fold-and-thrust belt built up during the Alpide orogeny. In continental Greece it testifies the destruction of the eastern passive margin of the Apulian platform (*e.g.* Aubouin *et al.* 1970, Bernoulli & Laubscher 1972, Mountrakis 1983, Robertson & Dixon 1984). Four main palaeogeographic zones (Paxos, Ionian, Gavrovo and Pindos) have been distinguished since many years (Philipsson 1898, Renz 1940, Brunn 1956, Aubouin 1959), which for the occasion worked as geotectonic units and have been piled up with a common westward vergence.

The study area lies in Epirus (fig. 1) within the Ionian Zone that represented a large marine basin

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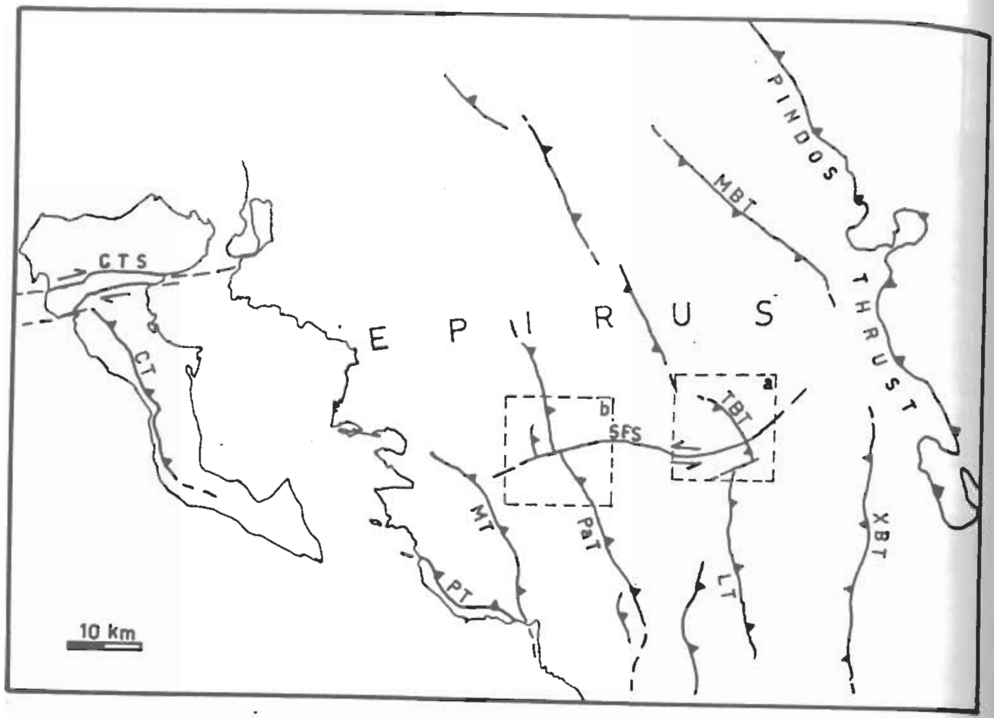

Fig. 1: Sketch map of Epirus with the major tectonic structures. Boxes indicate the two study areas: a) Dodoni area, b) Paramithia area. MBT: Mitsikeli Back-Thrust; XBT: Xerovouni Back-Thrust; TBT: Tomaros Back-Thrust; LT: Louros Thrust; SFS: Souli Fault System; PaT: Paramithia Thrust; MT: Margariti Thrust; PT: Parga Thrust; CTS: Corfu Transcurrent System; CT: Corfu Thrust.

formed during Liassic times in between the Gavrovo and the Apulian platforms. The Cainozoic tectonics of the area is characterized be the westward emplacement of the Pindos nappe onto the Gavrovo Zone. In Northern Epirus, the Pindos Zone is nowadays in direct contact with the Ionian Zone due to a complete overthrusting of the underlying Gavrovo Zone as the Metsovo tectonic window indicates (Zouros & Mountrakis, 1990).

Within the Ionian Zone several major thrusts have been described as well as other important tectonic features like great E-W trending strike-slip fault systems.

Most of the thrusts (fig. 1) show a "normal" westward vergence (Louros, Paramithia, Margariti and Parga Thrusts) and similarly most of the folds are asymmetric with east-dipping axial planes. Nevertheless in the area some important tectonic structure with an opposite vergence also exists (Mitsikeli, Xerovouni and Tomaros Back-Thrusts). Since all the Alpide edifice of the Hellenides was created by.west-vergent thrusting, we refer here to the east-vergent thrusts as back-thrusts.

Moreover the large E-W fault zones, like the Corfu Trascurrent System (Caputo, 1986) or the Souli strike-slip Fault System, also known in the literature as Petoussi Fault (IGRS-IFP 1966), play an important role in the Alpide tectonic evolution of the area. Indeed, on the two sides of these faults the amount of displacement and the style of the NNW-SSE trending shortening structures often change.

This work is in the frame of a broader project for the study of the structural evolution of the External Hellenides partially carried out in Pindos (Zouros & Mountrakis 1990, Zouros *et al.* 1991) and still in progress in the Ionian Zone. In the present paper we show the results obtained from two key-areas both across the Souli strike-slip Fault System. The first is around the Tomaros Mountain, near the ancient oracle at Dodoni, and the second is the Chionistra Mountain and surroundings in the central part of the Paramithia Range near the omonymous village.

Based on a new detailed mapping at the scale 1:20.000, giving a particular care to the tectonic structures, we discuss about the tectonic style. According to the obtained results and applying a ramp-flat geometry we also argue on the amount of shortening occurred during the Alpide orogenesis.

STRATIGRAPHIC SEQUENCE

The stratigraphic column of the Ionian Zone (fig. 2) is represented by a mainly calcareous sequence first with a neritic facies and then with a pelagic sedimentation. But the oldest known deposits are the Triassic evaporites that actually crop out as a mass of gipsum, breccias and scattered limestones. The real thickness is unknown and very difficult to estimate, also because of the diapiric phenomena occured in the area.

Massive neritic limestones and sometimes dolomites form the Pantokrator Formation (*Pantokratorkalk* of Renz 1955) which follows. Its age is Early-Middle Lias and its total thickness is of several hundred meters.

On the top, during and after the break-up of the carbonatic platform, till then continuous from Apulia to Gavrovo, a composite sequence was deposited (Late Lias-Malm). First, well stratified limestones with chert in nodules and layers (Sinies Formation, Renz 1955), then few meters of the

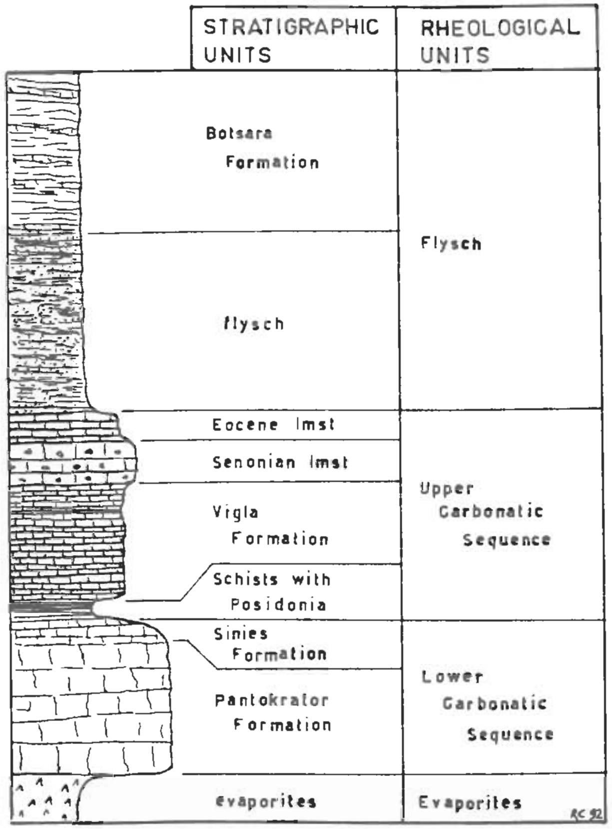

Fig. 2: Schematic column representing the lithostratigraphic (left) and the rheological (right) sequences of the Ionian Zone.

typical *Ammonitico Rosso*, the rare *Calcaires a filamentes* (IGRS-IFP 1966) and finally the siliceous and marly 'Schists with Posidonia' (Aubouin 1959, IGRS-IFP 1966). The all sequence as well as each single formation is extremely laterally variable either in the sedimentary facies, but especially in their thickness. Each single unit could be missing at all or all together could be from several tens of meter up to few hundred.

From the Tithonian up to the Senonian the pure pelagic Vigla Formation (Renz, 1955; IGRS-IFP, 1966) is deposited. It consists of thin-bedded limestones with frequent cherty layers. Also in this case the thickness is variable but always remarkable (500-1000 m).

A turbiditic calcareous medium- to thick-bedded sequence (100-300 m) of Late Senonian age rests on the Vigla Formation. During Paleocene and Eocene, due to the restoration of more pelagic conditions, the alternance of coarse-grained turbidites with micritic pelagic layers follows (200 m) and it ends up the Alpide carbonate sequence.

Indeed, from Late Eocene begins the flysch sedimentation that also continues during Oligocene-Aquitanian and, in restricted areas, like the Botzara Basin, up to the Burdigalian. Sedimentary facies, rates of deposition and thickness of the flysch is quite variable, especially from east to west and their study is beyond the goals of the present research. Concerning the thickness of the flysch deposits in particular, it is probably much less than what described in the literature (up to 2500 m, IGRS-IFP 1966). According to our field experience and for comparison with the Pindos flysch (Lorsong 1977, Zouros & Mountrakis, 1990) the diffuse, but till now undetected, presence of thrusting and shortening within these terrigenous formations created a tectonic syn- and post-sedimentary thickening. It is noteworthy to report that in the flysch several meaningful angular unconformity exists. A major one occurs in Early Burdigalian which separates a typical flysch sequence from the Botsara Formation which has a more classic molassic facies (Burdigalian, IGRS-IFP 1966, Desprairies 1978).

RHEOLOGICAL SEQUENCE

Despite of the lateral variations mentioned above, the described Mesozoic-Cainozoic sedimentary sequence, that characterizes the whole Ionian Zone is rather uniform at a small scale. According to the tectonic evolution of the area and considering the lithostratigraphic column from a mechanical point of view we performed a different and simplyfied 'rheological' sequence (fig. 2): Evaporites, Lower Carbonatic Sequence (Pantokrator and Sinies Formations), Upper Carbonatic Sequence (from the Schists with Posidonia up to the Eocene limestones) and Flysch. In this case as lateron when referring to the units of the rheological sequence, to distinguish them from the lithostratigraphic ones, we use capital letters (*i.e.* Flysch *versus* flysch or Evaporites *versus* evaporites).

The Evaporites, as a consequence of their lithology but specially because of the strong difference in mechanical behaviour with the overlying Pantokrator Formation, played an extremely important role during the compressional tectonics not only promoting the formation of huge detachment surfaces but also working as a kind of 'lubricant' during the thrust emplacement (IGRS-IFP 1966, Nikolaou 1986).

The Lower Carbonatic Sequence always acts as a strong rigid block particularly due to its lithological uniformity and to its massive bedding. It folds with difficulty and when it does it creates large-ray structures. Among the four rheological units, it behaves and deforms as the most fragile one.

On the contrary, the Upper Carbonatic Sequence is generally characterized by thin-bedded sediments with frequent lithological variations and alternances. Thus the deformation occurs in a much more ductile way. Spectacular folding is often present. Within the sequence exist several incompetent levels, like the upper siliceous horizon of the Vigla Formation (IGRS-IFP 1966), which during shortening behaved as detachment surfaces. But among all, the basal siliceous and marly unit of the Schists with Posidonia is certainly the most important detachment surface and often allowed large displacements of the Upper Carbonatic Sequence relative to the Lower Carbonatic Sequence.

Finally, the Flysch with its typical alternance of sandstones, siltstones and marls, with an immature process of cementation, the ductility of the fine-grained layers and their abundance, show a style of deformation quite different from the Upper Carbonatic Sequence due to its much more plastic rheological behaviour. In this case also, because of the strong rheological difference with the underlying unit and the presence within the sequence of many incompetent levels, the potential surfaces of detachment are numerous.

GEOLOGICAL AND TECTONIC SETTING OF THE DODONI AREA

The area is located SW of Ioannina and it includes the Tomaros Mount (fig. 3). The mountain is mainly built up by the Lower Carbonatic Sequence, in its higher parts, and by the Upper Carbonatic Sequence in the rest. All around crops out the Flysch, except on the south where the Upper Carbonatic Sequence still prevails. The Souli Fault crosses Tomaros Mount and all the area in an E-W to ENE-WSW direction so dividing it into two well defined sectors. The Souli Fault, is a strike-slip left lateral fault system characterized by a complex deformation, due to its Alpide activity as well as to its recent one (Boccaletti *et al.* 1992).

In the northern sector the mountain (fig. 4a), that has a lengthened NW-SE shape, consists of a huge asymmetric antiform with a west-dipping axial plane and a north-dipping hinge. The NE flank of the massif is affected by a basal NNW-SSE trending back-thrust (Dodoni Back-Thrust), which brings the Carbonatic Sequence onto the Flysch, and by a parallel system of synthetic and antithetic reverse faults. Along this highly fractured zone scattered but significant evidences of Evaporites have been observed. The whole brittle structure disappears northwards and continues as a simple an-

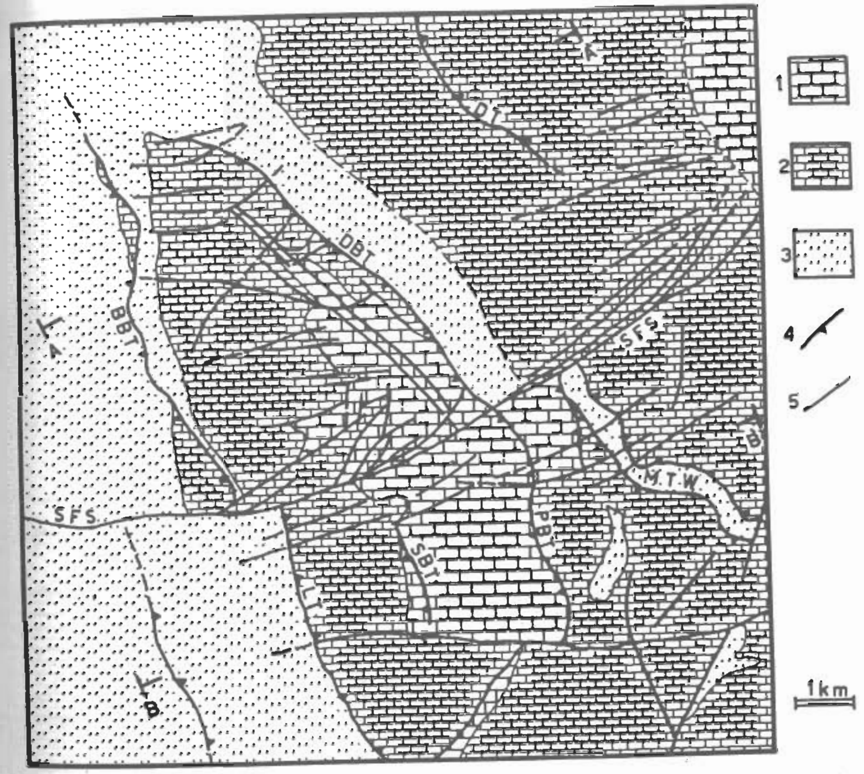

Fig. 3: Simplyfied tectonic sketch of the Dodoni area. 1: Lower Carbonatic Sequence (Lias), 2: Upper Carbonatic Sequence (Dogger-Eocene), 3: Flysch (Oligocene-Burdigalian), 4: thrusts, 5: other faults. The traces of the geological cross-sections, represented in fig. 4, are shown. DT: Dendraki Thrust; DBT: Dodoni Back-Thrust; BBT: Baussi Back-Thrust; MTW: Manoliassa Tectonic Window; PBT: Paleochori Back-Thrust; SBT: Selama Back-Thrust; LT: Lippa Thrust; SFS: Souli Fault System.

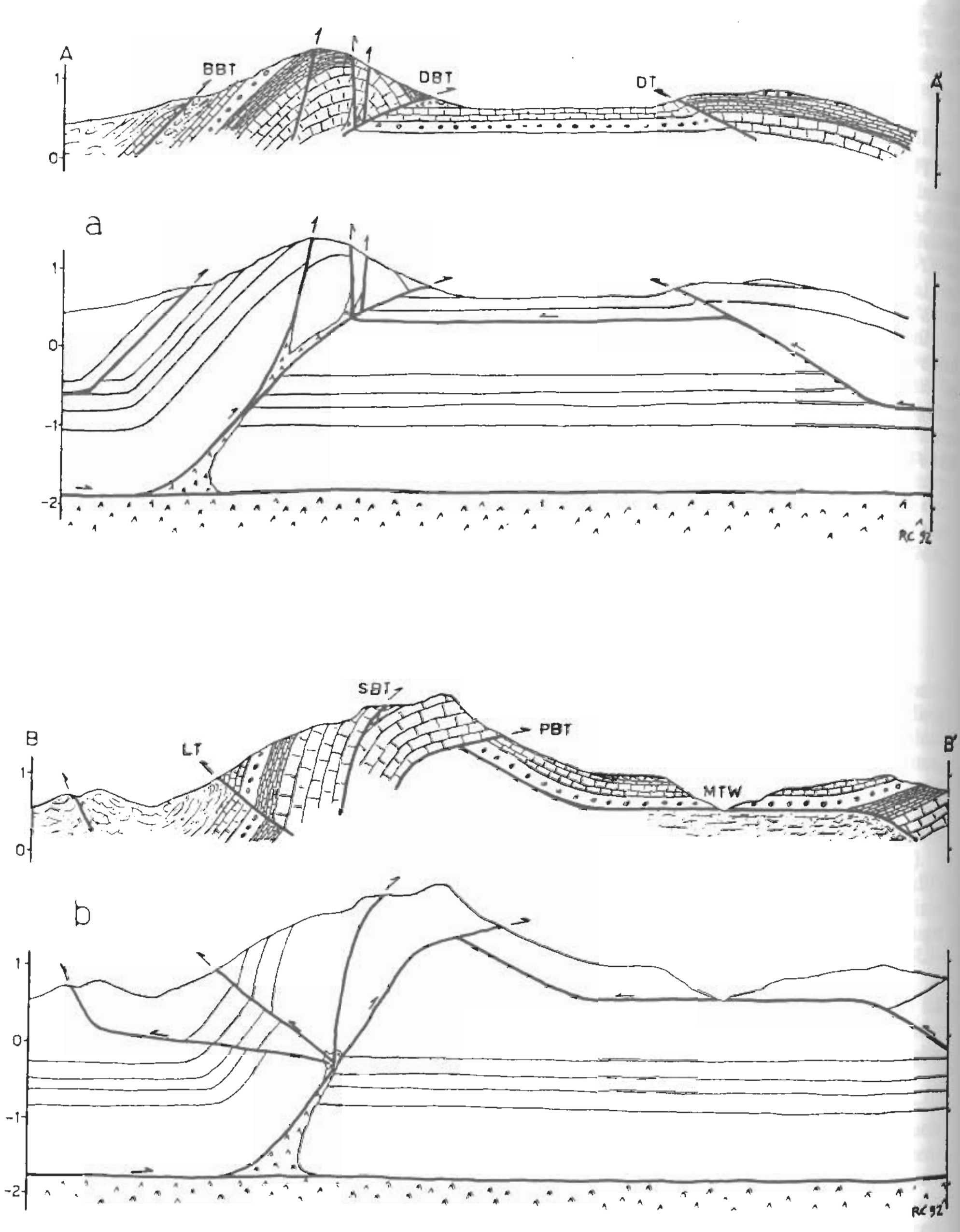

Fig. 4: a) northern and b) southern geological cross-sections of the Dodoni area (upper ones) and their interpretation down to a hypothetical basal detachment. Symbols as in fig. 3. Vertical scale in kilometres. See text for further explanations.

ticline. Indeed, the Flysch underlies the Lower Carbonatic Sequence, to the south, and the Upper Carbonatic Sequence to the north. Moreover the same structure is affected by several faults at high angle with it. Some of them are mainly normal, some other, more or less parallel to the Souli Fault, are strike-slip (sinistral).

On the contrary, on the western side of the antiform the Upper Carbonatic Sequence is in continuity with the Flysch and there creates a structural slope. Further west a second minor back-thrust (Baussi Back-Thrust) exists. Both the hanging-wall and the footwall blocks are cut obliquously. At the base in the former block the Eocene limestones (top of the Upper Carbonatic Sequence) locally crop out, while in the latter block the fracture plane is within the Flysch, to the north, and cuts down reaching the Flysch-Upper Carbonatic Sequence contact, to the south. In the hanging-wall the upper levels of the Flysch (Botsara Formation) are also involved.

NE of Dodoni a minor NW-SE compressive feature within the Upper Carbonatic Sequence exists, in its northern sector it appears as a thrust (Dendraki Thrust) while it transforms southwards into an asymmetric anticline.

A different geological and tectonic setting characterizes the area south the Souli Fault (fig. 4b). The Tomaros seems to be a huge west-dipping monocline dominated by the Pantokrator massif limestones in its higher peaks.

The most striking feature is located E of the Tomaros Mount along the Potamia Valley where the Flysch appears in a tectonic window (Manoliassa Tectonic Window) below the Carbonatic Sequence. All around are the higher levels of the Upper Carbonatic Sequence perfectly flat lying, except WNW where the Lower Carbonatic Sequence directly overthrusts the Flysch of the tectonic

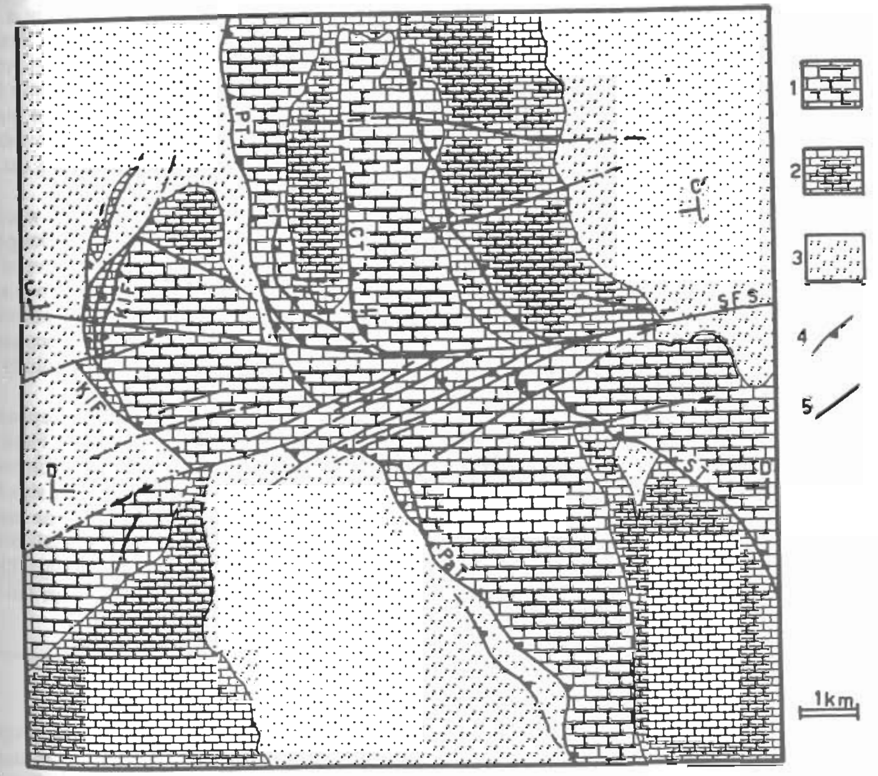

Fig. 5: Simplyfied tectonic sketch of the Paramithia area. The traces of the geological cross-sections, represented in fig. 6, are shown. CT: Chionistra Thrust; PT: Petrovitsa Thrust; KIF: Kallithea Imbricate Fan; ST: Souli Thrust; PaT: Paramithia Thrust; SFS: Souli Fault System. Symbols as in fig. 3.

window. Indeed, on the eastern foothills of Tomaros Mount close to the Souli Fault System a back-thrust (Aghia Paraskevi Back-Thrust) brings the Lower Carbonatic Sequence onto the Flysch and the Upper Carbonatic Sequence joining with the horizontal detachment of the above mentioned tectonic window.

At a higher altitude the Palaeochori Back-Thrust generates the emplacement of the Pantokrator Formation onto the Upper Carbonatic Sequence. On the western flank of the massif a minor synthetic back-thrust (Selama Back-Thrust) also occurs involving both Carbonatic Sequences. All these low-angle structures end off against the Souli Fault, on the north, and the Kopani Fault, on the south. While the former fault has a clear prevailing left-lateral strike-slip motion, the latter fault shows a more complex and multiphase kinematics with normal components of movement (down-thrown southern block) as well as strike-slip.

The western side of the mountain shows a structural slope with the Lower and the Upper Carbonatic Sequences in continuity, similar to that observed in the northern sector. A prominent difference is the thrusting of the whole series onto the Burdigalian Botzara Formation (Lippa Thrust) in striking contrast with the opposite back-thrusting which occurs northern.

GEOLOGICAL AND TECTONIC SETTING OF THE PARAMITHIA AREA

The study area includes the central sector of the Paramithia Mountain Range and extends from the Petoussi village, to the E, up to the Koritiani village, to the W (fig.5). The E-W trending Souli Fault System, crosses the area separating it into two major sectors as in the Tomaros Mount area.

In the northern sector the eastern side of the Paramithia Range is characterized by a large eastward and gently dipping monocline showing in stratigraphic continuity all the units from the Pantokrator Formation, to the west, up to the Flysch, to the east (fig. 6a). In contrast, the western part of the Mountain Range is characterized by a large-ray fold system locally cut by minor faults either parallel to the folding and transversal to it (*i.e.* parallel to the Souli Fault). On the western flank a major thrust causes the westward emplacement of the Lower Carbonatic Sequence onto the Flysch (Petrovitsa Thrust). Near the top of the frontal wall a minor thrust exists involving the Pantokrator and the Sinies Formations.

In the southern sector the major structure is the NNW-SSE trending Paramithia Thrust where the Lower Carbonatic Sequence overlies the Flysch (fig. 6b). In between, several wedges belonging to the Upper Carbonatic Sequence are interposed showing that thrusting occurred along several subparallel planes. On the eastern side of the Paramithia Range, the Upper Carbonatic Sequence and in a limited extent also the Flysch crop out showing a strong folding. The whole folded ensemble is overthrusted from the east, obliquously with respect to the fold axes, by the Lower Carbonatic Sequence (Souli Thrust) which creates an eastward dipping monocline in stratigraphic continuity with the higher Meso-Cainozoic units.

The Paramithia Thrust to the north is clearly cut by the Souli Fault and even if it apparently seems to continue in the northern Petrovitsa Thrust, the tectonic importance of the Souli Fault System and its unambiguous large late- and post-Alpide left-lateral displacement definitively disprovide such an interpretation. Accordingly, the northern continuation of the Paramithia Thrust should be looked for along the Kallithea Imbricate Fan. This structure consists of a major thrust plane separating the overlying Lower Carbonatic Sequence and the Flysch. In between are several small wedges made of the Upper Carbonatic Sequence and Flysch as locally occur along the Paramithia Thrust. Northwards the structure is completely masked by the scree cones mainly coming from the huge Petrovitsa Thrust front and it is not possible to make any reliable interpretation.

DISCUSSION

Based on the geological maps here presented (figs. 3 and 5) and according to the proposed geological sections (figs. 4 and 6) it is clear that the area has been affected by a strong thrust tectonics. To explain and describe thrust tectonics Rich (1934) have introduced for the first time geometrical principles. Since then, several contributions enriched the literature on thrust belt analysis using restorable cross-sections and interconnections or relationships among faults (*e.g.*

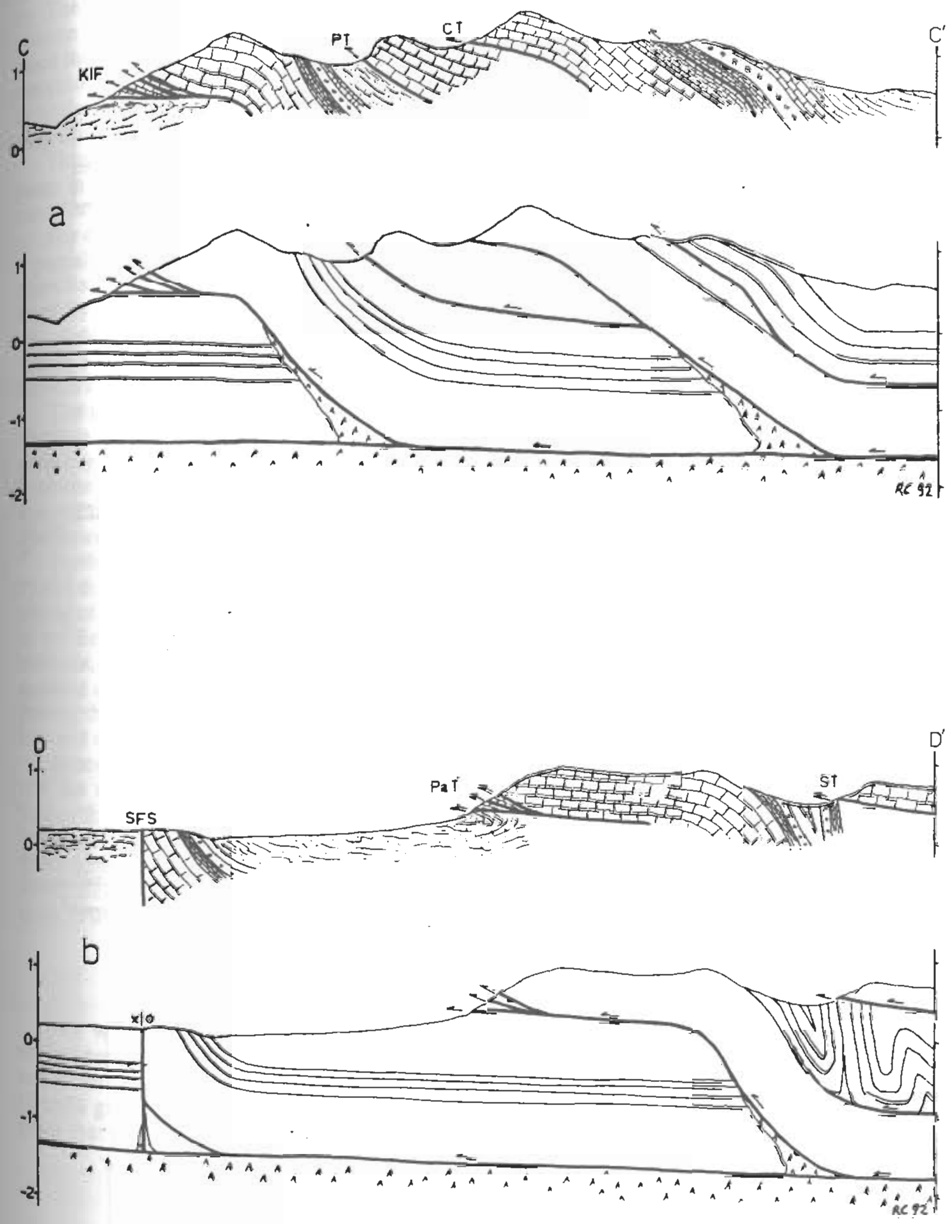

Fig. 6: a) northern and b) southern geological cross-sections of the Paramithia area (upper ones) and their interpretation down to a hypothetical basal detachment. Symbols as in fig. 5. Vertical scale in kilometres. See text for further explanations.

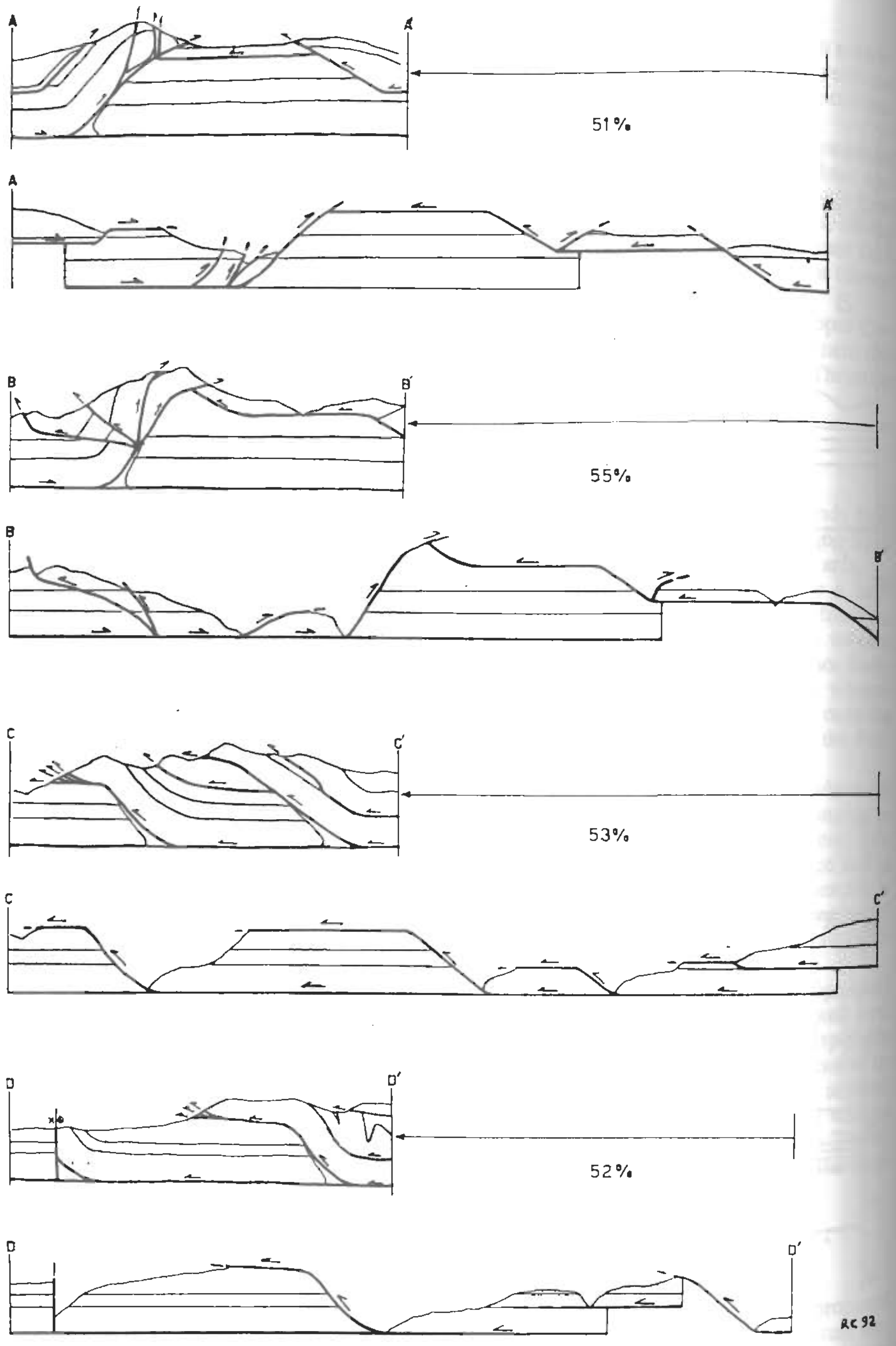

Fig. 7: Geological cross-sections from Dodoni (a and b) and Paramithia (c and d) areas and their palinspastic restoration obtained applying conservative criteria. The amount of shortening estimated for each section is indicated. See text for further explanations.

Douglas 1950, Norris 1959, Dahlstrom 1970, Elliott 1976, Boyer & Elliott 1982, Butler 1983). When seismic prfiles were available and became of common use, the whole 'ramp-flat model' was tested and generally confirmed (*e.g.* Bally *et al.* 1966).

The ramp-flat model seems to fit quite well to the geology of the region. First of all we have to assume the presence of a flat lying basal detachment where huge amount of transport has occurred since the Alpide tectonics and where the Evaporites behaved as the lubricant. The second basic assumption concerns the thickness of the involved stratigraphic sequence that we may consider roughly uniform for the scale we work at. According to these hypothesis and constructing the sections deep down to the basal detachment we applied the ramp-flat geometry.

Thus the deformation which occurred in the study area could be tentatively represented as appears in figs. 4 and 6. Indeed the use of this model enable us to explain most of the surficial structural features, as major thrusts and faults as well as the principal monoclines.

For example, in the central part of the northern section of the Dodoni area (fig. 4a) we proposed a partial doubling of the sequence for comparison with the structural situation we dectect in the Manoliassa Tectonic Window of the southern section (fig. 4b). Althoug the importance of the Souli Fault System has been emphasized we think that the main Dodoni Back-Thrust, in the northern sector, could be related to the Paleochori Back-Thrust. In so forth the Lippa Thrust may be considered just as a minor structure due to the doubling of the Lower Carbonatic Sequence occurred along the Selama Back-Thrust (fig. 4b).

The geometry of the deep structures of the Paramithia area seems to be less complicated. In the northern section (fig. 6a) a series of east-dipping thrusts occur and particularly the highest sector is probably related to the doubling of the Lower Carbonatic Sequence. A remarkable feature in the southern section (fig. 6b) is the detachment between the Lower and the Upper Carbonatic Sequences that occurs in the eastern part, the disharmonic folding of the latter sequence and the subsequent overthrusting by the Souli Thrust.

Furthermore, we attempt a palinspastic restoration of the proposed geological cross-sections (fig. 7) and due to the conservative restitution we operated we may also infer a minimum amount of shortening of more than 50% for both areas. Moreover, several minor compressional structures observed in the field but, because of their relatively small dimensions, not shown in the maps neither in the sections, certainly produce further shortening. Its real entity could not be exactly estimated unless a detailed and systematic work, that is beyond the goals of the present research, is carried out. Nevertheless the contribution of these minor but widely diffuse structures to the total shortening is important and certainly constrains the amount of shortening much higher than 50%.

Speculating some more and extrapolating similar amounts of shortening and style of deformation for all the Ionian Zone we may tentatively estimate its original width. If we consider that in Epirus this zone is about 80 km large it results a probable original value not less than 200 Km.

More work is certainly necessary but what arises from the present study is the clear evidence that a general re-evaluation of the amount of shortening of the Ionian Zone as well as of all the External Hellenides must be carried out in the future. Its implications in terms of palinspastic restorations, crustal shortening, block rotations, tectonic style, etc.are crucial.

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