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NEW INVESTIGATIONS ON THE TYROS FORMATION NEAR ANO VERGA (KALAMATA/PELOPONNESE)

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ABSTRACT

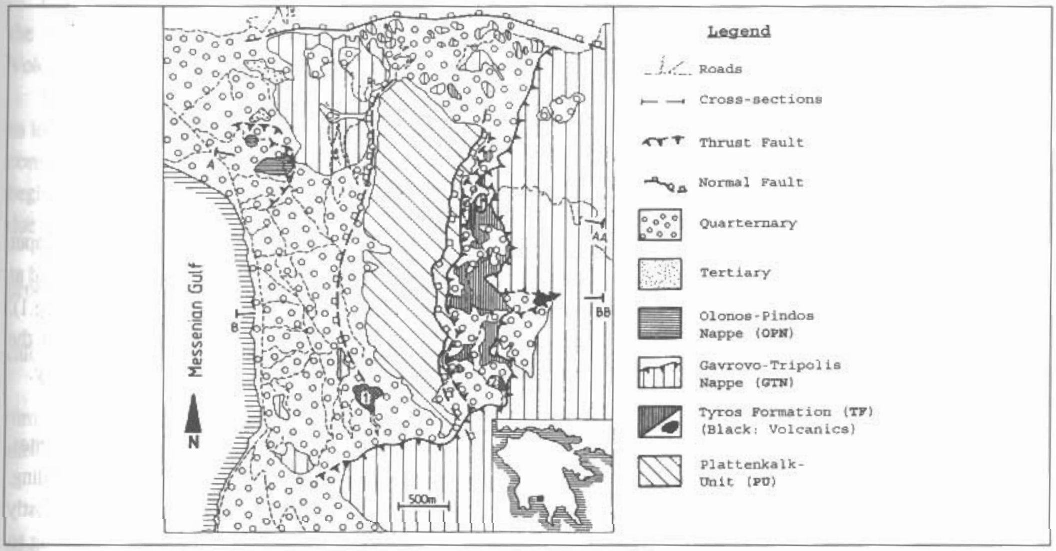
Limestones, breccias and sandstones of the Tyros Formation N of Ano Verga (former Ano Selitsa), SE of Kalamata/Peloponnese (Greece) contain a fauna confirming a Permian age and are affected by low-grade metamorphism. Geochemical and thin section analysis of strongly alterated volcanic rocks of the Tyros Formation suggest an original chemism varying between basaltic andesite, andesite, trachy-andesite and basaltic trachy-andesite.

As a result of a detailed new geological mapping (scale 1:10.000) E of Kalamata, a formerly unknown remnant of the Olonos-Pindos Unit was discovered and new details of the tectonic structures E of Kalamata can be given.

KEY WORDS: Permian - Fusulinids - Tyros Formation - Plattenkalk Unit - Olonos-Pindos Unit - Gavrovo-Tripolis Unit - Andesites

1. INTRODUCTION

An outcrop of the Tyros Formation near Ano Verga (fig.1), 6km SE of Kalamata/Peloponnese and its tectonic setting were investigated in a detailed study.



1: Kato Verga 2: Ano Verga (former Ano Selitsa)
Fig. 1: Simplified geological map of the study area

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Gavrovo-Tripolis Unit. The tectonically topmost unit consists of the Olonos-Pindos Unit, which is preserved only as a small, up to now unknown remnant in the northwestern part. The Tyros Formation consists of volcanics, limestones, marls, shales, breccias and sandstones. Its upper and lower boundaries are characterised by thrust faults.

Central Hellenic nappes	Olonos-Pindos Unit	tectonically uppermost unit
Western Hellenic nappes	Gavrovo-Tripolis Unit	
	Tyros Formation	
	Plattenkalk Unit	tectonically lowermost unit

Fig. 2: Tectonic units in the area E of Kalamata, Messenia

The area E of Kalamata is characterised by three neo-tectonic structures, the Kalamata-Avramio-Graben, the Dimiova-Perivolakia-Graben and the Kalathio-Horst (Mariolakos et al. 1989, Zelilidis & Doutsos 1992).

2. TYROS FORMATION

In southern Greece several outcrops of the Tyros Formation are known, mainly from the central and southern Peloponnese (Brauer 1983, 1984, Doert et al. 1985, Gerolymatos 1994, Lekkas & Papanikolaou 1978, Manutsoglu et al. 1993, Panagos et al. 1979, Thiebault & Kozur 1979, Paraskevopoulos 1964) and from Kythira island (Danamos 1991). First descriptions and investigations from the type locality Tyros at the eastern coast of Lakonia (Peloponnese) were given by Ktenas 1924,1926. Possible outcrops in Crete are still being discussed (Krahl et al. 1983, Doert & Kowalczyk 1985, Dornsiepen & Manutsoglu 1994, 1996).

2.1. TYROS FORMATION EAST OF KALAMATA

In the area E of Kalamata a subdivision into six members is usefull:

- Red and Green Volcanics — top
- Calcareous Member
- Transition Member
- Calcareous-Clastic Member
- Shales and Quartzites
- Black Shales and Limestones — bottom

The strata below the Transition Member are obviously much more dominated by terrigenous input than those above. Massive volcanic rocks are found only at the top of the sequence. Gypsum was found at the southern slope of the gorge which is representing the northern boundary of the study area (fig.1). Because of faulting (see below) and dense vegetation, the outcrops could not be correlated within the strata sequence. Differing from the published geological map gypsum occurs in scattered outcrops only.

2.1.1. CALCAREOUS-CLASTIC MEMBER

Alternations of limestones, calcareous sandstones, fossiliferous breccias and minor quartzites, intercalating with shale, silty shale and siltstones can be found. The beds often show graded bedding. Breccias, with component sizes of a few mm up to several cm, show a rich fossile content, mostly foraminifera belonging to the suborders *Lagenina*, *Fusulinina* and *Textulariina* (nomenclature according to Loeblich & Tappan 1988). Thin section analysis resulted in the determination of the following genera:

Robuloides Reichel, 1946	(M.Permian-M.Triassic)
Climacammina Brady, 1873	(Early Carboniferous-Permian)
Pachyphloia Lange, 1925	(Late Permian)

Abundant tests of fusulinid foraminifera (suborder *Fusulinina*) are currently investigated, showing

sp. and *Triticites* sp.. Permian age.

Additionally fragments of brachiopods (*Productus*? sp.), echinoderms, bryozoans (*Integrata*? sp.), porifera and algal crusts occur. Partly strong recrystallisation and pressure solution are common features. Quartz is a major component in breccias, feldspar can be observed. There were no indications for a higher degree of metamorphism, the growth of new minerals is restricted to white mica chlorite (alteration product) and eventually feldspar, suggesting low-grade metamorphism at maximum. The maximum thickness is about 150m, but intense intern folding and minor thrusting were observed and must be considered.

2.1.2. CARCAREOUS MEMBER

This member consists of carbonates, predominantly darkgrey, finegrained to micritic limestones and marls. Furthermore sandstones and shales occur. Graded bedding and cross-bedding can be seen in limestones. In thin-sections of carbonates sporadic dolomitisation with growth of idiomorph crystals of dolomite within the micritic matrix can be found. Moreover, detrital quartz, white mica and sporadic feldspar occurs. Some beds are rich in fragments of calcareous algae belonging to *Mizzia* sp. and probably *Gymnocodium* sp., indicating a Permian age, together with gastropods, bivalves and foraminifers (fam. *Miliolidae*). Feeding structures were found in samples of dark marls and shales; pyrite is omnipresent. The limestones can be classified as sparse to packed intrabiomicrite (floatstones), indicating sedimentation on an open marine shelf or a platform (SMF 2 resp. SMF 7 referring to Wilson 1975). Thickness of this member ranges up to 250m (folding, thrusting).

2.1.3. RED AND GREEN VOLCANIC ROCKS

Volcanic rocks are a characteristic member of the Tyros Formation and are reported and investigated from different parts of the Peloponnese and Crete. (Ktenas 1924,1926, Brauer 1983,1984, Paraskevopoulos 1964, Pe-Piper 1982, 1983, 1984, Pe-Piper et al. 1982, 1984, Dornsiepen & Manutsoglu 1994, 1996).

East of Kalamata volcanics occur as isolated bodies of rocks at the top of the Tyros Formation. Only the Green Volcanics without bedding have been observed in outcrops. Besides, Green Amigdaloidal Volcanics, red porphyries and volcanic breccias occur, but were found only as fragments of bedrock.

Thin sections of all samples show mainly porphyric fabrics, and substantial alteration of minerals, due to low-grade metamorphism or hydrothermal influence. Both matrix and phenocrysts (up to 3mm in size) consist of feldspars, mostly polysynthetical twins or zonal crystals without orientation. They show beginning as well as almost complete alteration into calcite. Pyroxene could not be found in the samples, due to complete alteration.

Red Volcanics (P50, appendix) show idiomorphic crystals of quartz and opaque minerals, most probably Fe-oxides (red rock-colour) resulting from alteration of pyroxenes, esp. augite.

The alteration of the pyroxenes in the Green Volcanics (P51, P53, appendix) led to abundant genesis of chlorite (green rock-colour), occuring as dispersed fine flakes.

The Amigdaloidal Volcanics (P52, appendix) are characterised by dark bluegreen amigdales of a few mm in size, which consist of epidote (center) and chlorite (peripheral). Chemism and mineralogy are similar to the Green Volcanics.

Brauer 1983 reports comparable alterations from near Molaoi-Talanta, SE-Lakonia (Peloponnese).

Own X-Ray analysis of samples (see appendix) from near Ano Verga were carried out. The computer-sustained interpretation (NewPet for DOS) of the first data shows a chemism varying between basaltic andesites, andesites, trachy-andesites and basaltic trachy-andesites, with uncertainties due to alteration and related mobility of some elements.

Additionally, several trace-element discrimination diagrams (figs.3a-d) shall help to interpret the (paleo-) tectonic environment. The trace element data show no unequivocal trend, varying between island-arc tholeiites (IAT) and calc-alkaline basalts (CAB), indicating some relation to subduction influence, esp. on one obviously altered sample (P53, appendix), plotting in the lower right angle and thus sustaining thin section analysis (see above).

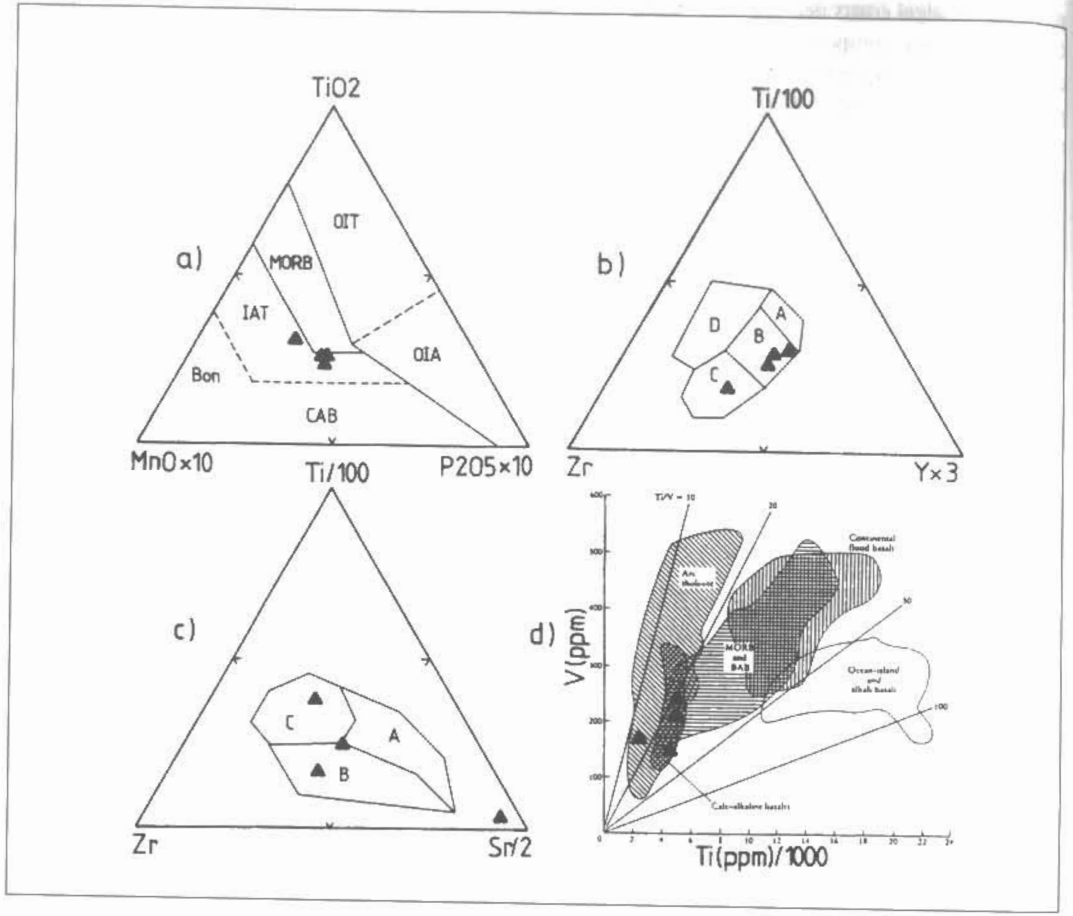

Fig. 3: Several trace element discrimination diagrams(in Rollinson 1996): a) after Mullen 1983; b) after Pearce & Cann 1973 (**A**:IAT; **B**:MORB,IAT,CAB; **C**:CAB; **D**:WPB); c) after Pearce & Cann 1973 (**A**:IAT; **B**:CAB; **C**:MORB); d) compiled from Shervais 1982

Pe-Piper 1982 reported volcanics from SE-Lakonia to be IAT and also resulted in subduction-related volcanism. In contrast, field data indicate a relationship of the Triassic andesitic volcanics with the breaking-up of Gonwana and an onset of rifting in Early Mesozoic time (Robertson et al. 1991, Jacobshagen 1994). Probably this contradiction could partly be explained by asuming an earlier subduction process, which has already ceased by the time of Early Mesozoic rifting, but showing some influence on rift volcanism by contamination (Robertson et al. 1991, pp.291-293).

Another interesting explanation is proposed by Dornsiepen & Manutsoglu 1996. They demonstrate that, concerning trace element data, the Tyros volcanics show similarities to low-Ti continental flood basalts (CFB), which are known to occur in areas characterised by large-scale extension structures. If further investigations show up no other tectonic environment or magmatic differentiation processes being responsible for a comparable geochemical composition, this could be a good and less complicated solution to explain contrasting geochemical data and conclusions derived from strata sequence analysis.

Piper 1983, 1984, Pe-Piper et al. 1982, 1984). E of Kalamata the contact with the surrounding Permian strata could not be investigated because of poor outcrop quality, so there is uncertainty in dating. But conspicious red and green shales, found in the basal parts of the Permian(?) Transition-Member, seem to be related to volcanics of Tyros Formation, as is reported also from different outcrops on the Peloponnese (Ktenas 1924, 1926, Doert & Kowalczyk 1985). So the investigations by Ktenas 1924, 1926 and data from this study make an already Permian volcanism possible.

3. TECTONIC ANALYSIS

The upper and basal boundaries of the Tyros Formation are characterised by thrusting. The basal tectonic contact shows a conspicious breccia, as already stated by Doert & Kowalczyk 1985 and referred to as tectonites. The Tyros Formation is reduced in thickness constantly towards the North, almost completely missing north of the study area and obviously preserved as lense- or wedge-like remnants at the base of the Gavrovo-Tripolis Unit. The observed folding and minor thrusting within the Tyros Formation certainly have distorted the original thickness. This must be considered when looking at values given in fig.4. Most members, although reduced in thickness, can be traced over almost the whole outcrop area. Analysis concerning the orientation of the fold axes show a well developed maximum for NNE-SSW-directions, dipping to NNE, but less clear maxima for ESE-WNW-directions. Most likely this is because the best outcrops are to be found along W-E-profiles, thus preferably exposing fold-axes with N-S-orientation. The Calcareous-Clastic Member and Calcareous Member where analysed separately and are showing the same directions of fold axes.

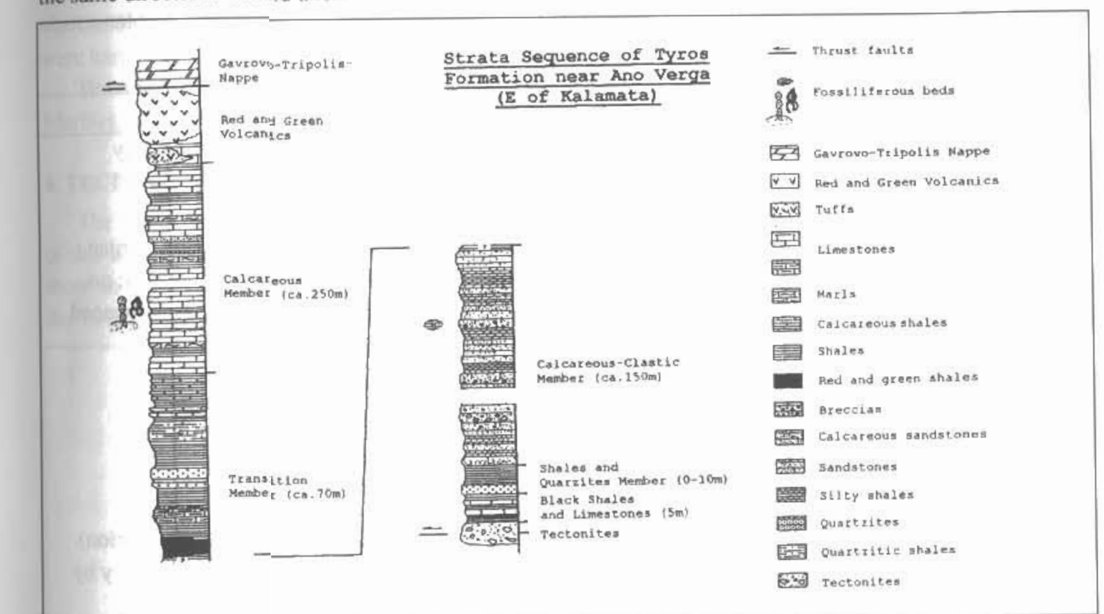

Fig. 4: Compiled strata sequence of the Tyros Formation E of Kalamata

4. CONCLUSIONS AND A NEW DEFINITION OF THE TYROS FORMATION

Fossil-data suggest a Permian age for the Tyros Formation and partly for the Red and Green Volcanics at this location. The metamorphism of carbonates is restricted to the growth of mica and sporadic feldspar in carbonates. The metamorphism of the volcanics is characterised by alteration of pyroxenes to chlorite and calcite or to calcite, quartz and Fe-oxid, indicating epizonal metamorphism. Thrust-related folding and [illegible] observed within the sequence.

No continuous section of the Tyros Formation is known, which could clear up the stratigraphic relationships with the tectonically over- and underlying units (Gavrovo-Tripolis Unit, Phyllite-Quartzite Unit, Plattenkalk Unit), and this often causes problems or confusions in correlating the strata sequences.

Frequently, lithological similarities between the Tyros Formation and the Phyllit-Quarzite Series are observed (Dornsiepen & Gerolymatos 1994, Dornsiepen 1988; Gerolymatos 1994). Furthermore, different grades of metamorphism of the Tyros Formation, up to low-grade (about 400°C, 4kbar in Jacobshagen 1994, slightly higher values in Gerolymatos 1994) and the Phyllit-Quarzite Series (eg. Seidel et al. 1982, Gerolymatos 1994) were reported. On the other hand some carbonate-sequences of the Tyros Formation seem similar to carbonates belonging to the Gavrovo-Tripolis Unit, as mentioned e.g. by Brauer 1983, 1984, causing a discussion about a former sedimentary contact. As mentioned above, in Crete Karnian/Late Triassic strata sequences reffered to as Rabdoucha beds (Sannemann & Seidel 1975, Kopp & Ott 1977) are correlated with the Tyros Formation by some authors.

No strata of Mid-Triassic and especially Ladinian age, could be proved up to now, which is also recognized e.g. by Brauer 1983 (p.92), Dornsiepen & Manutsoglu 1996 (p.103) and Gerolymatos 1994 (pp.19,24). A hiatus in the Mid-Triassic exists apparently, not only for the Tyros Formation, but also for the Talea-Ori Group (König & Kuss 1980, Thorbecke 1987) and Phyllite Group (Krahl et al. 1983) in Crete.

A Triassic age for volcanics belonging to the Tyros Formation is frequently stated (see above), according to Brauer 1983 possibly comprising the Anisian to Norian. The lack of record for the Mid-Triassic and the volcanism obviously are related to major tectonic events (Dornsiepen & Manutsoglu 1996, Robertson et al. 1991).

Authors	Locality	Age
Brauer 1983, 1984	SE Lakonia: Plytra, Molai	Permotriassic (Permian only assumed by comparing with literature)
Doert & Kowalczyk 1985	SE of Kalamata	Late Murghabien-Late Permian
Doert et al. 1985	Krokee, Xyli	Permian, Scythian, Karnian; no continuous sections, lense-shaped tectonic units
Fytrolakis 1971	SE of Kalamata (Ano Verga)	Paleozoic
Gerolymatos 1994	Summary for the Peloponnese;	Permian-Rhaetian; Hiatus? in the Ladinian
Ktenas 1924,1926	Tyros, Krokee, Chamospilia, Phiniki, Apidia, Molai	Permian?-Werfenien?
Lekkas & Papanikolaou 1978	Tyros, Molai, Vresthena, Feneos	Late Paleozoic (only by citation)
Panagos et al. 1979	Krokee	Carboniferous-?Permian (only by citation)
Paraskevopoulos 1964	Krokee, Molai-Sykea	Mid Carboniferous-Permian;
Thiebault & Kozur 1979	E of Monastery Sotyros	Late Paleozoic (only by citation) - Late Triassic

Table 1: Various outcrops and ages of the Tyros Formation

Referring to the original definition by Ktenas 1924, a new definition for the Tyros Formation is proposed here: The Tyros Formation is a non- to low-metamorphic strata sequence consisting of shales, marls, sand- and limestones with intercalations of andesitic volcanics. The Tyros Formation comprises Permian to Early Triassic (Skythian to Late Anisian) age. The upper stratigraphic boundary shall be respectively. [illegible] Formation, and shall keep their former names or can be considered as the basal rocks of the Gavrovo-Tripolis carbonate unit.

5. PLATTENKALK UNIT

In the study area the outcrop of the Plattenkalk Unit comprises Triassic? to Early Oligocene age. With exception of the Grey Marbles, all other ages result from comparison with data derived from literature (Jacobshagen 1986, Psonis 1981). In spite of the tectonic situation the total thickness of about 360m could be estimated as a result of detailed geological mapping. The strata sequence mainly comprises grey, finegrained marbles, interbedded with chert-nodules or ribbon-cherts of various, in most cases black colour.

The strata sequence in the study area consists of:

- Vathia-Beds (Early Oligocene?; max. 26m) top
- Coloured Marbles (Eocene?; max. 25m)
- Grey Marbles (Cretaceous-?; 40m)
- Grey Marbles with ribbon-chert and chert-nodules (at least 200m)
- Brown Marbles with reddish chert-nodules(30m)
- Reddish Cherts (only locally, 15m)
- Grey Marbles with black ribbon-chert (Mid Liassic?; 25m)
- Bulky Dolomite (Triassic?) bottom

The Reddish Cherts are probably a variation of Brown Marbles with reddish chert-nodules. These strata were hard to trace because of dense macchia.

The only fossil-data could be gained from a coarse-grained, detritical intercalation at the base of the Grey Marbles, indicating Cretaceous age by including fragments of rudistids, probably related to *Radiolites* sp.

6. TECTONIC CONSIDERATIONS

The rocks of the Plattenkalk Unit are forming a W-facing, steep morphological slope. The top region of this slope consists of E-dipping Grey Marbles, Coloured Marbles and Vathia-Beds. The Grey Marbles show an increase of outcrop thickness from the South (6-12m) to the North (about 40m), most probably due to faulting, for an E-dipping fault-plane forms the lower boundary of the Grey Marble.

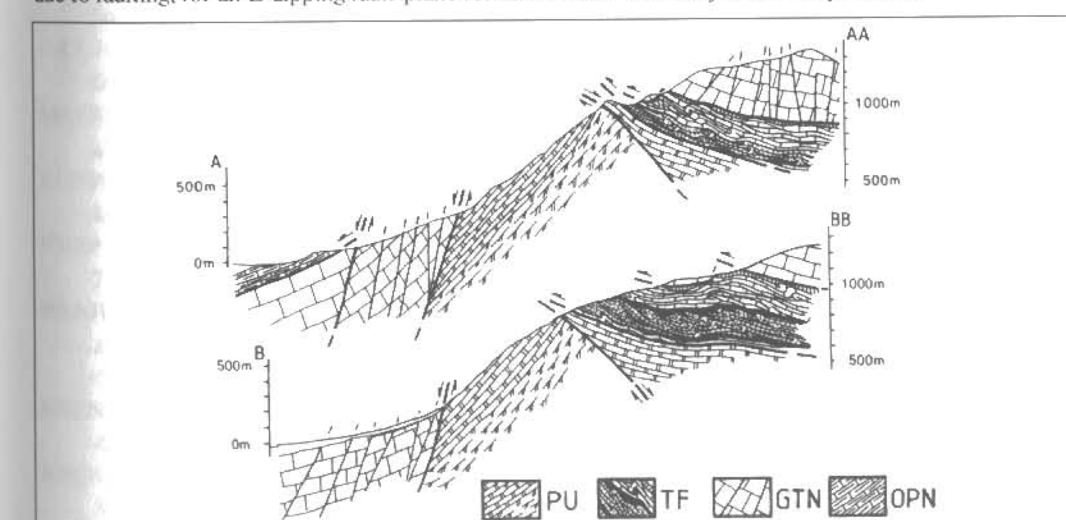

Fig. 5: Cross-sections of the study area (locations, abbreviations see fig 1)

Bulky Dolomite, can be seen (see fig.5).The simpliest explanation would be a pre-existant syncline structure, which later was affected by (neo-tectonic) block-faulting, leading to horst-graben-structures as described by Mariolakos et al. 1989 and Zelilidis & Doutsos 1992. Such a pre-existant syncline with an N-S-trending axis, is indicated by a change of dip of the Grey Marbles from E to W, which can be seen at a locality 1,5 km north of Ano Verga. Except for the Plattenkalk Unit, the strata of the W-dipping limb of the syncline are missing due to erosion. The close spatial neighbourhood of the Olonos-Pindos Unit to the Plattenkalk Unit (see figs.1,5) can be explained best by a normal fault.

The gorge at the northern boundary of the study area is caused by a N-dipping normal fault, a fault plane can be seen cutting the Plattenkalk Unit, the Tyros Formation and the Gavrovo-Tripolis Unit. Here, fragments of the Gavrovo-Tripolis nappe are obviously creeping northward down into the gorge along this normal fault, creating a morphology that could be mistaken as step faults.

APPENDIX: DATA FROM XRF-ANALYSIS

Samples		detect. minim.	P50	P51	P52	P53
SiO_2	%	0,01	57,2	56,80	54,80	68,10
TiO_2	%	0,001	0,760	0,800	0,850	0,460
Al_2O_3	%	0,02	16,60	16,70	17,60	10,40
Fe_2O_3	%	0,01	10,12	7,42	9,50	5,72
MnO	ppm	0	1087	1332	1323	647
MgO	%	0,01	2,39	3,32	4,61	1,81
CaO	%	0,01	2,64	4,09	2,25	7,33
Na_2O	%	0,02	3,43	5,88	3,98	2,32
K_2O	%	0,01	2,41	0,73	2,88	0,18
P_2O_5	%	0,005	0,060	0,120	0,110	0,060
F	%	0,4	0	0	0	0
As	ppm	20	0	5	0	0
Ba	ppm	20	244	100	193	44
Ce	ppm	40	0	38	0	1
Cl	ppm	400	506	7	5	4
Co	ppm	8	19	22	26	13
Cr	ppm	6	25	86	46	36
Cs	ppm	30	22	0	0	0
Cu	ppm	8	16	66	91	62
Ga	ppm	4	17	18	11	8
La	ppm	30	0	38	45	10
Nb	ppm	4	0	0	0	0
Nd	ppm	30	0	8	6	0
Ni	ppm	6	19	36	33	29
Pb	ppm	10	15	10	12	27
Rb	ppm	4	42	5	48	0
s	%	0,002	0	0	0	0
Sn	ppm	30	21	9	5	0
Sr	ppm	4	61	212	165	1271
Ta	ppm	8	0	4	0	2
Th	ppm	4	0	13	10	6
U	ppm	6	0	0	0	0
V	ppm	6	155	210	236	178
W	ppm	30	14	12	0	0
Y	ppm	4	20	25	24	12
Zn	ppm	6	91	97	62	32
Zr	ppm	4	41	127	70	32

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