Πρακτικά	4ου Συνέδριου	Μάϊος 1988
Δελτ. Ελλ. Γεωλ. Εταιρ.	Τομ. XXIII/1 σελ. 63-74	Αθήνα 1989
Bull. Geol. Soc. Greece	Vol. pag.	Athens

DEFORMATION AND METAMORHISM IN THE CRYSTALLINE COMPLEX OF THE ISLAND OF THASSOS (NORTH GREECE) A SHORT OUTLINE

A. PETEREK, M. MAJER*

ABSTRACT

Very intense horizontal movements during the main-phase deformation D_2 have produced an outstanding example of large scale transposition on the island of Thassos. Since nearly all minor and major fold structures were destroyed by shearing the more than 2000 m thick metamorphic system has often been misinterpreted as a stratigraphic succession.

An earlier deformation D_1 is only preserved in relic form.

A distinctive deformation D_3 occurred in a shallow tectonic level and is characterized by dominantly brittle deformation.

Metamorphism M_1 reached at least medium grade conditions. A dynamical-retrograde metamorphism M_2 regressed the earlier mineral assemblages up to the conditions of the upper greenschist-facies. M_3 affected mainly shear zones and took place under conditions of the lower greenschist-facies.

INTRODUCTION

The area of the island of Thassos belongs to the Lower Tectonic Unit of the Southern Rila-Rhodope-Massif (according to PAPANIKOLAOU & PANAGOPOULOS 1981) (Fig. 1). Especially since KRONBERG and his collaborators have carried out research work within the area between the rivers Strymon and Nestos, the Southern Rila - Rhodope - Massif is considered as a more than 10 km thick palaeozoic metasediment-series, that has been deformed by broad anticlines and synclines and younger cross-folds and metamorphosed only one time during the Alpine orogenies.

During the last decade, however, new investigations and reinterpretations have revealed that the structural style of the South-Rhodope-Massif is of a much more complex nature than actually assumed (DIMADIS & ZACHOS 1983; KOKKINAKIS 1977; LUNDBERG 1978; PAPANIKOLAOU et al. 1981).

In contrast to the old conceptions the structure is dominated by isoclinal folding and there exists at least one earlier deformation phase connected with an older metamorphism.

GEOLOGICAL FIELD OBSERVATIONS

The investigated areas are located in the Northeastern part (Ypsarion area) and in the Southern part (Trikorfon area) of the island of Thassos (Fig. 2).

* Institute of Geology and Mineralogy, Schloßgarten 5, 8520 Erlangen, W-Germany

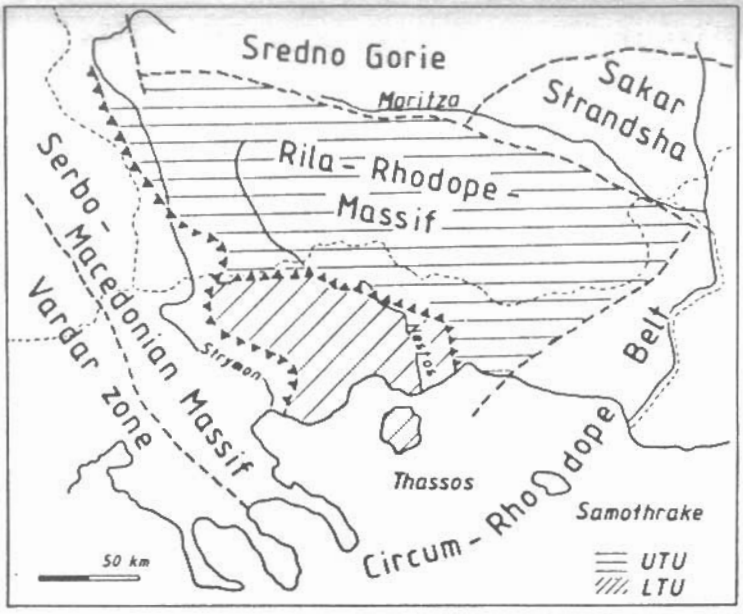


Fig.1.: The Rila - Rhodope - Massif and the neighbouring zones (according to PAPANIKOLAOU et al. (1981) and KRONBERG et al. (1970). UTU: Upper Tectonic Unit; LTU: Lower Tectonic Unit.

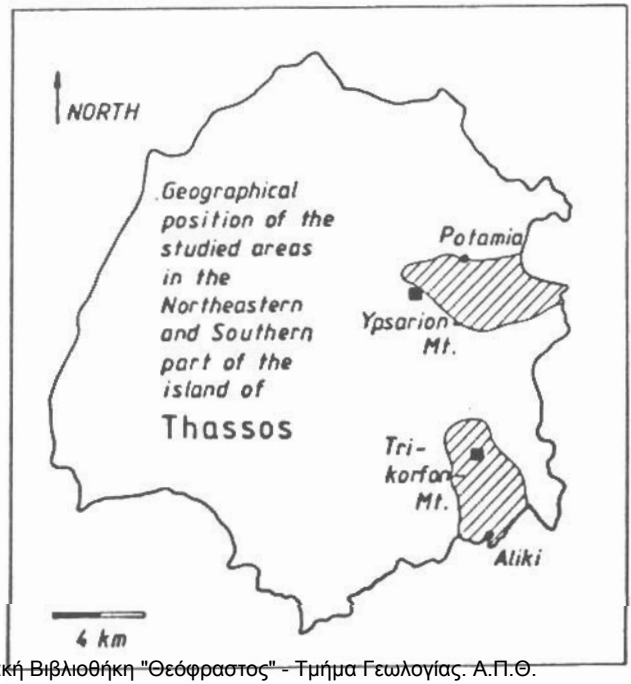


Fig.2.

Furthermore, we were able to gain numerous insights into the structure of the whole island.

The metamorphic system of Thassos is made up by various gneisses, schists, marbles and amphibolites. The structural style is apparently simple, there are only few obvious folds bounded on both sides by undisturbed foliation planes. The first impression is one of a layering that represents a simple stratigraphic sequence. But on closer inspection one has to recognize that frequent repetition of individual horizons occur and that the whole area is intensely folded.

Therefore it is impossible, particularly after taking the small-scale structures (tight and isoclinal shear and flexure-shear folds, shearing, flattening, transposition structures, thrusting) into consideration, to interpret the lithostratigraphical sequence of Thassos as a sedimentary succession with cyclic sedimentation and lateral facies variation.

According to our opinion the structural style of Thassos is an outstanding example of large scale transposition.

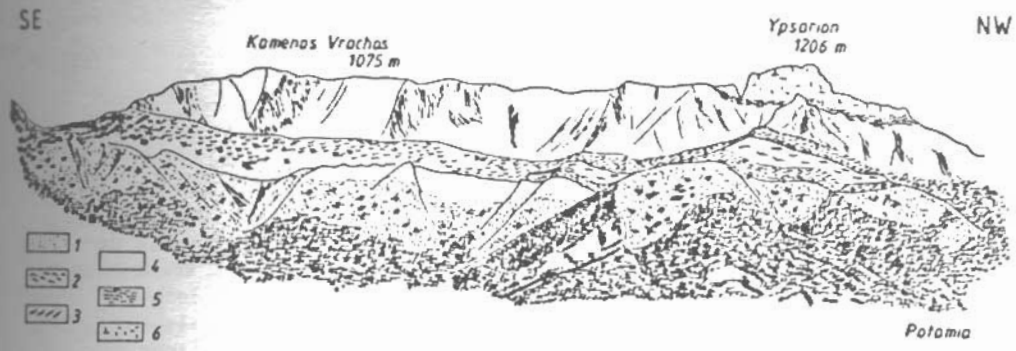


Fig.3.: Panorama of the Northeastern part of the Ypsarion mountains.
1 dolomite marble; 2 gneisses; 3,4 Marble of Profitis Elias;
5 mica-schists; 6 gneisses (of Maries).

DEFORMATION PHASES, STYLE OF FOLDING AND METAMORPHISM

In the crystalline complex of the island of Thassos four deformation phases can be recognized:

Deformation D_1

The main-phase deformation D_2 has more or less destroyed the earlier tectonic and metamorphic history of the rocks. Structures of the deformation D_1 are preserved in relic form, mainly expressed by its s_1-foliation, which is isoclinally folded and transposed by D_2.

The D_1-deformation is particularly indicated by quartz veins, formed within the metapelites parallel to s_1 and passively deformed during D_2. By this the number of deformation events may be counted even if s_1 etc. is completely

destroyed in strongly deformed parts of the rock series (according to VOLL 1960, 1968).

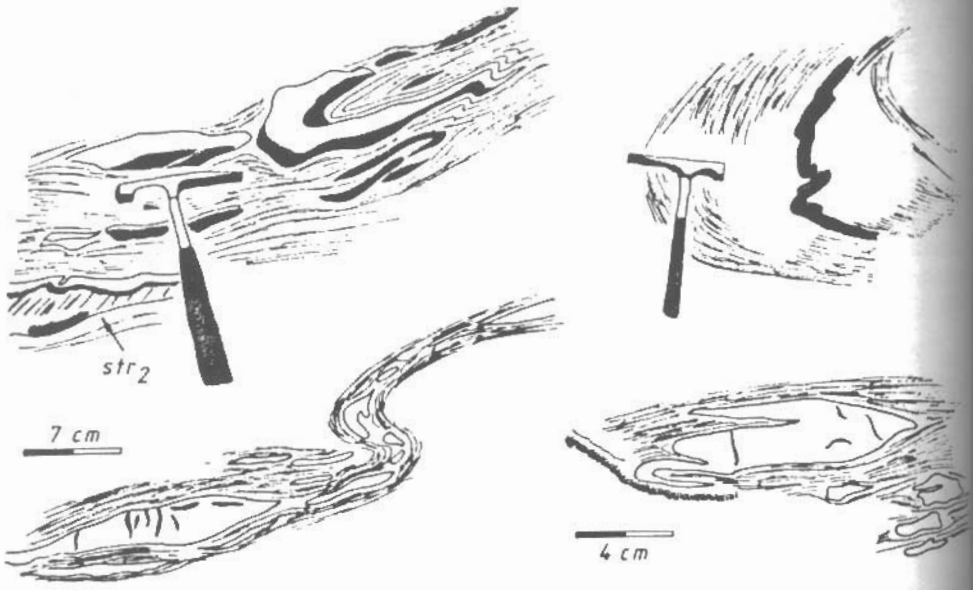


Fig. 4: Quartz veins within various metapelites, folded by D_2-deformation. These quartz veins were formed parallel s_1 and indicate now the earlier deformation phase D_1 in mesoscopic scale. In the most cases D_2-folds are destroyed by intense shearing and the quartz veins are preserved as boudins.

The deformation phase D_1 appears to have been associated with progressiv m e t a m o r p h i s m M_1, which reached at least medium grade (i. e. am phibolite-facies) conditions. This is documented by relics of an-rich pla gioclase 1 (mostly oligoclase - andesine), kyanite 1 and sillimanite in th gneisses and in the gneiss-schists. Plag 1 (mainly strongly saussuritiz and replaced by plag 2 (albite - oligoclase) and K-feldspar during M_2) ap pear often as cataclastically broken porphyroclasts (up to some mm in diam eter), surrounded by recrystallized grano- up to lepidoblastic quartz- an feldspar-texture.

M a i n - p h a s e d e f o r m a t i o n D_2

The main-phase deformation D_2 with NE/SW trend encompasses the most set o structures as mesoscopic folds and associated transposed foliation s_2 a well as pronounced penetrative lineation str_2. The deformation D_2, begin ning with isoclinal folding and following transposition of older foliations accompanied by shearing, strong flattening and boudin-formation, produced repetition of [illegible] with metamorphism all earlier D_1- and D_2-structures.

Boudinage during D_2 formed boudins with elliptical and spin[illegible] pro-file (a result of separation by necking rather than fracture under ductile conditions; RAMSAY 1967), and can be distinguished by this from angular and blocky boudins, formed by D_3-deformation. D_2-boudins are often rod-like in shape (three axial ellipsoides, mostly stretched in direction of the stretching lineation), so D_2-boudins can be observed in ac- as well as in bc-planes.

D_2-major structures: D_2-deformation produced a repetition of lithologies by intense isoclinal folding and shearing affected the whole area, thus creating a transposition in large scale (Fig.5, 6). Although all major isoclinal folds are destroyed by intense shearing, the existence of minor isoclinal folds, shearing and transposition structures as well as repetition of lithologies permit us to draw the conclusion that the major structures - now destroyed - are real, therefore.

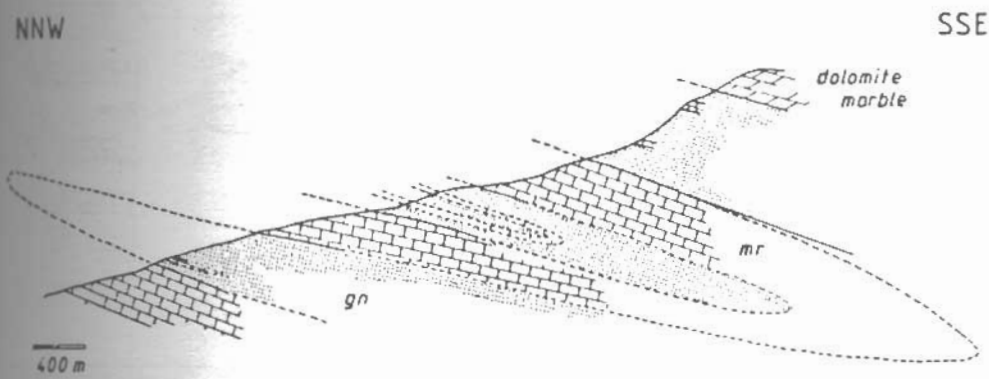


Fig.5.: Structural section through the lower part of the series of Potamia, normal to the main-phase folds and stretching lineations, for illustration of the repetition of individual gneiss (gn) and marble (mr) horizons by isoclinal folding; in the North of Klisidi Mt.

According to ZACHOS (1977, 1982) the metamorphic unit of the Eastern part of Thassos is built up by several individual formations, particularly characterized by different marbles, separated by various gneisses and amphibolites. Detailed mapping, however, revealed that the formation boundaries are affected by intense isoclinal folding and shearing, too. An illustration of a dynamic concept for the development of large-scale transposition forming individual formations and repetition of lithologies in the formations themselves, is given in Fig. 6.

In fact, major structures could be of a much more complex nature, because we have to presume superposition of D_1- and D_2-major structures.

The study of the tectonic maps reveals the existence of broad anticlines and synclines striking parallel to the main-phase folds and the stretching-lineations str_2. At present, however, we are not sure whether these structures are created during the course of D_2 deformation (even later during D_3) or whether they are the expression of disharmonic folding during the main-phase deformation. But maybe these structures are connected with

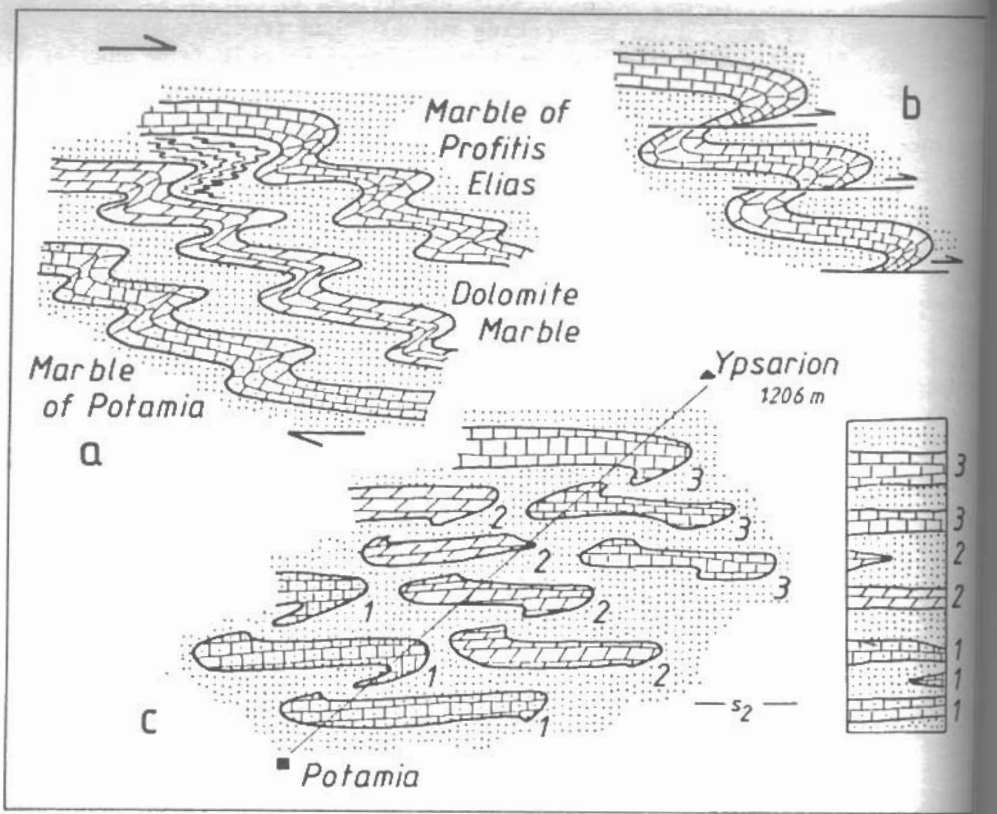


Fig.6.: A possible sequence of events in the development of the large-scale transposition by isoclinal folding and shearing in the Northern part of Thassos.
a) Horizontal movement (maybe in the limb of an isoclinal, regional fold) produces tight and isoclinal folding of the whole area. A fundamental feature of this model is that the new axial plane schistosity (the later shear plane) is nearly parallel to the old s_0- and s_1-foliations.
b) Further shearing leads to detachment of the thinned limbs.
c) Sliding along the new s_2-planes and old s_1-planes as well as further shearing resolves the old lithological framework. In this state boudinage and flattening are very common.
A section through this transposed lithological sequence now suggests an originally pseudostratigraphic succession. Note the apparently existence of individual formations (1-3).

In our illustration we did not take into consideration 1) the special effects of transposition within the gneiss - series, 2) originally different thickness of the various gneiss- and marble-series, 3) disharmonic folding, 4) D_1-major structures.

updoming by penecontemporaneous granites, that are, however, affected by D_2-deformation. It is significant that granites and orthogneisses are very often situated in the centre of such anticlines in the Southern Rhodope (KRONBERG 1969; KOKKINAKIS 1977).

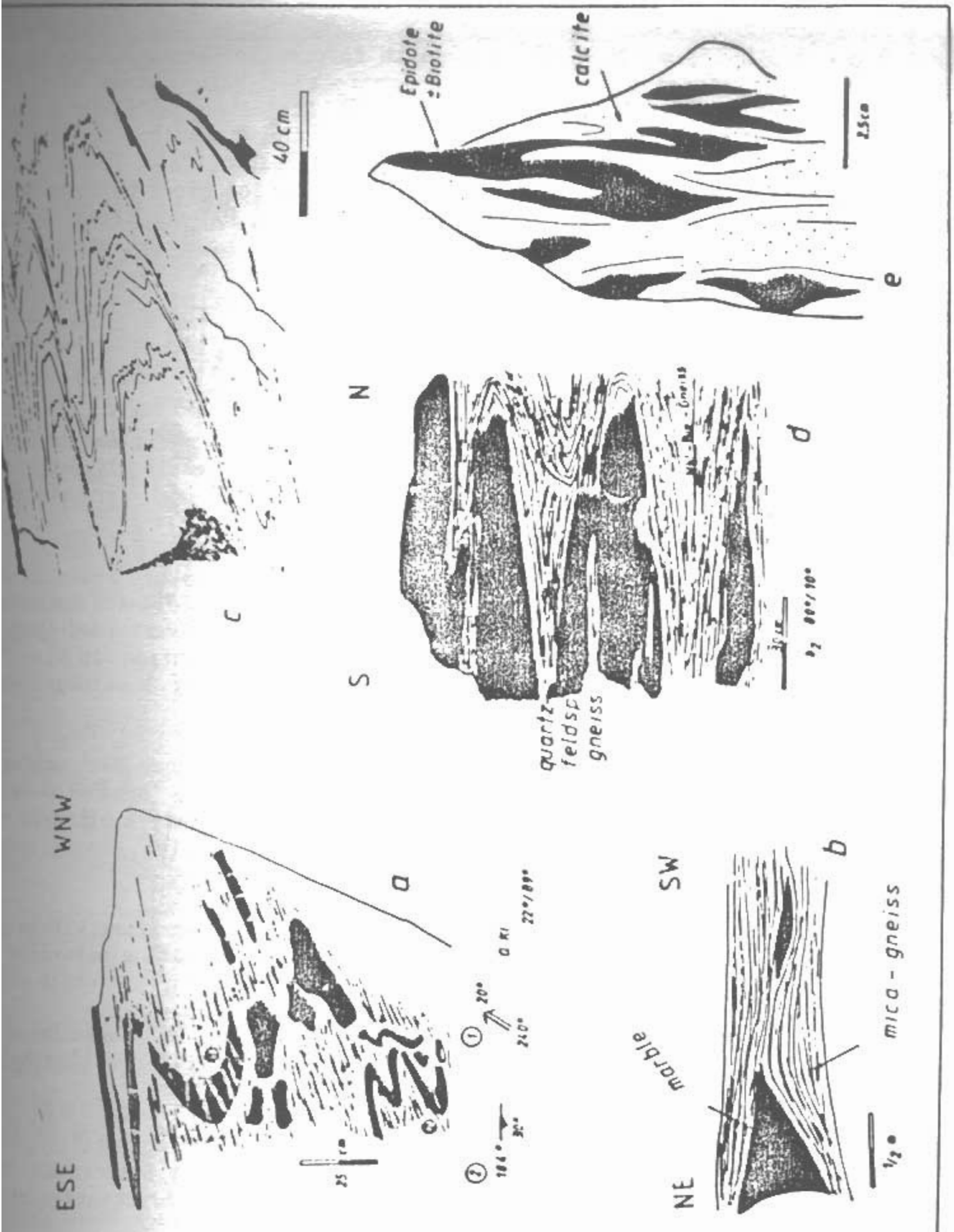


Fig.7.: Compilation of various D_2-minor structures.

a) Isoclinal shear fold within biotite-plagioclase schists with an intercalation of quartz-feldspar-gneiss.
b) Lenses of marble within mica-gneisses, separated by boudinage during D_2.
c) Isoclinal shear fold within a banded calcite marble.
d) Intenselly isoclinally folded quartz-feldspar- and hornblende-biotite-gneisses.
e) Transposition structures in a hand specimen of a carbonate-silicate rock.

Metamorphism M_2 (synchronous to deformation phase D_2) has to be considered as an almost complete dynamic-retrograde metamorphism with regional character (according to STÖCKHERT 1982). At the beginning the retrogression occurred under medium grade conditions (lower amphibolite-facies). This is indicated by the recrystallization of oligoclase and Ti-rich biotite in the gneisses as well as the crystallization of green hornblende in the amphibolites (Fig. 9). The continuous decrease in P/T-conditions during D_2 up to upper greenschist-facies conditions created mineral assemblages that do not belong only to one metamorphic grade at the end of M_2.

D_3 - deformation

Deformation phase D_3 represents a distinct deformational event and is built up by a suite of distinctive structures, which are not completely explained up till now. D_3 occurred under shallow conditions in the upper crustal level, indicated by dominantly brittle deformation.

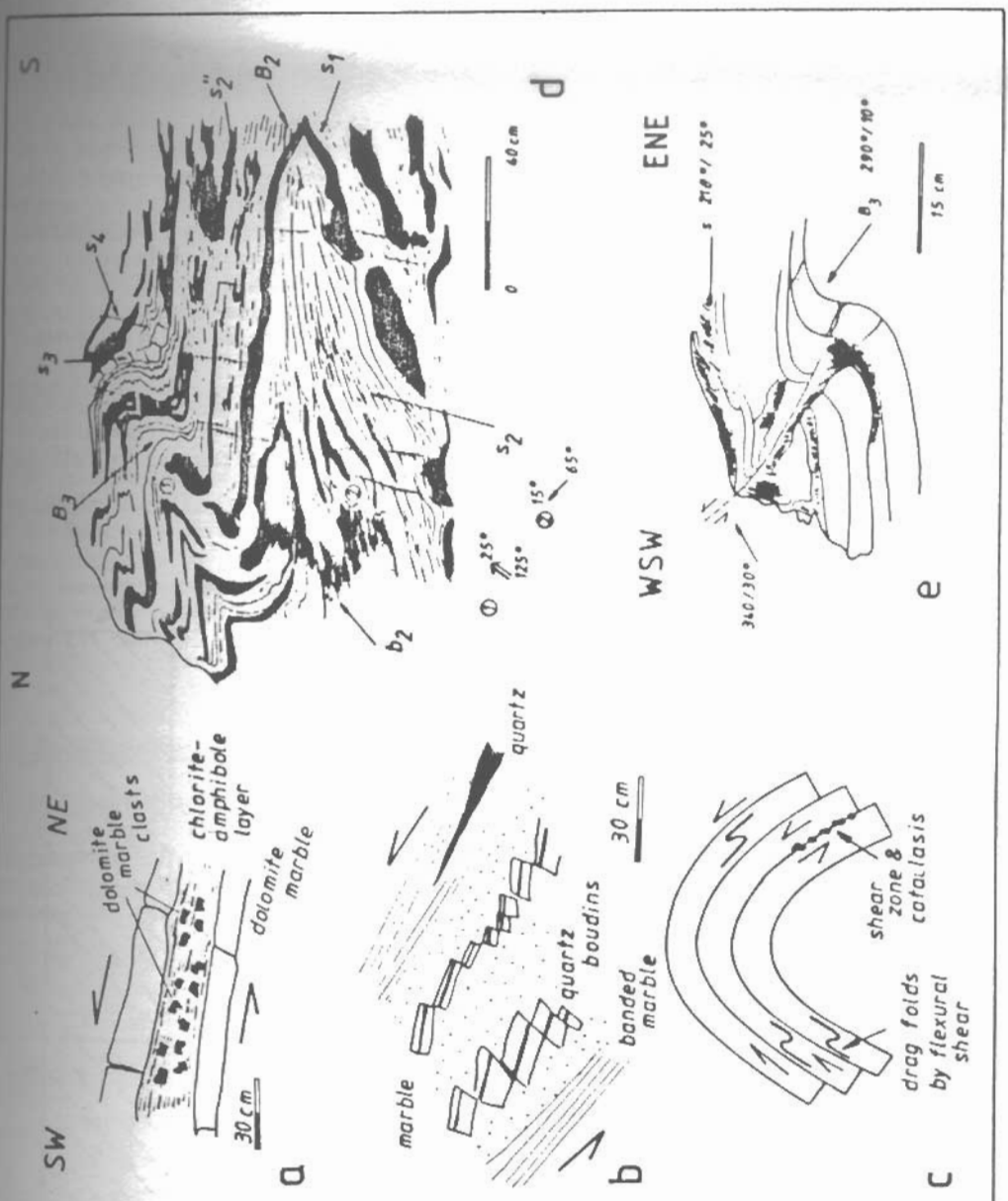
In general D_3-folds are open up to closed disharmonic flexure folds in dm-up to m-scale. They have a SE/NW axial direction and the foldaxes are medium or shallow in steepness. These minor folds are often overturned towards SW or NE and were affected by reverse faulting. D_3-deformation is also represented by kink folds, kink bands, angular and blocky boudinage, wavy folding as well as shearing subparallel to the s_2-planes.

Some of the folds, as described above, and boudins could have been produced by shear on surfaces subparallel to the s_2-planes. This is suggested by a) the shape of the folds, b) the fact, that D_3-folds are mainly limited to one horizon and bounded on both sides by undisturbed foliation planes, c) the nearness to shear zones.

The shearing during D_3-deformation occurred in discrete horizons within cm-up to m-wide zones, located subparallel to the s_2-planes. The behaviour of the rocks affected indicates a phase of brittle deformation (under lower greenschist-facies conditions). Cataclasis is very common.
According to our opinion the shearing subparallel to the s_2-planes based on genuine lateral movement as well as on flexural slip (flexural gliding) on surfaces in the limb of a major fold (Fig. 8,c).

Within the marbles calcite and within the gneisses quartz recrystallized during D_3, whereas dolomite in the dolomite marble was only brecciated. In a late state of this deformation we have only recognized brecciation of all minerals.
Protomylonitic gneisses, cataclastic gneisses, chlorite- and talc-schists (LASKARIDIS 1985), tremolite- and actinolite-schists appear within the movement zones.

The major D_3-structures: During deformation D_3 the metamorphic system of Thassos was bended in large scale (100 m up to some km) by broad anticlines and synclines in NW/SE direction. For example the Northeastern part of the island lies on a large structure comprising an antiform.
In the Southeastern part of the island, the area of Prinos-Orakaro the structural style is dominated by large closed folds (in 10 m up to 100 m-scale) with axial surfaces which are approximately vertical. These folds are isrupted by reverse faulting. In this area D_3-deformation produced a fault-fold-



a) Shear zone within the dolomite marble. Dolomite-marble clasts within a chlorite-amphibole(tremolite/actinolite) layer (according to LASKARIDIS 1985).
b) Angular boudins formed by D_3-deformation.
c) Schematic diagram for illustration of flexural slip (flexural gliding) accompanied by cataclasis on the s_2-planes as well as development of D_3-drag folds.
d) Overturned D_3-fold within biotite gneisses with intercalations of carbonate-silicate rocks; Scala Potamias. Note the isoclinal D_2-folds that are overprinted by the D_3-fold. Above this D_3-fold we recognized a D_3-shear zone. That is why we interpret this structure as a drag fold (see also c).
e) Wavy fold within a gneiss, showing reverse faulting.

Fig.8.: Compilation of various D_3-minor structures.

structure.

Metamorphism M_3 during D_3-deformation occurred under low grade conditions (i. e. lower greenschist-facies) and was accompanied by further retrogression of the earlier mineral assemblages. However, M_3 has mainly affected the shear zones located parallel or angular to the s_2-planes. New crystallization of tremolite, actinolite, chlorite, talc and epidote is very common.
The different behaviour of the minerals quartz, calcite and dolomite, as above described, permits a rough estimation of temperature during M_3 between 300 and 400° C (VOLL 1968).

Rocks outside the shear zones are little affected. M_3 is mainly expressed by transformation of garnet into biotite and chlorite or transformation of actinolite into chlorite. Saussuritization and sericitization of feldspar is common, too.

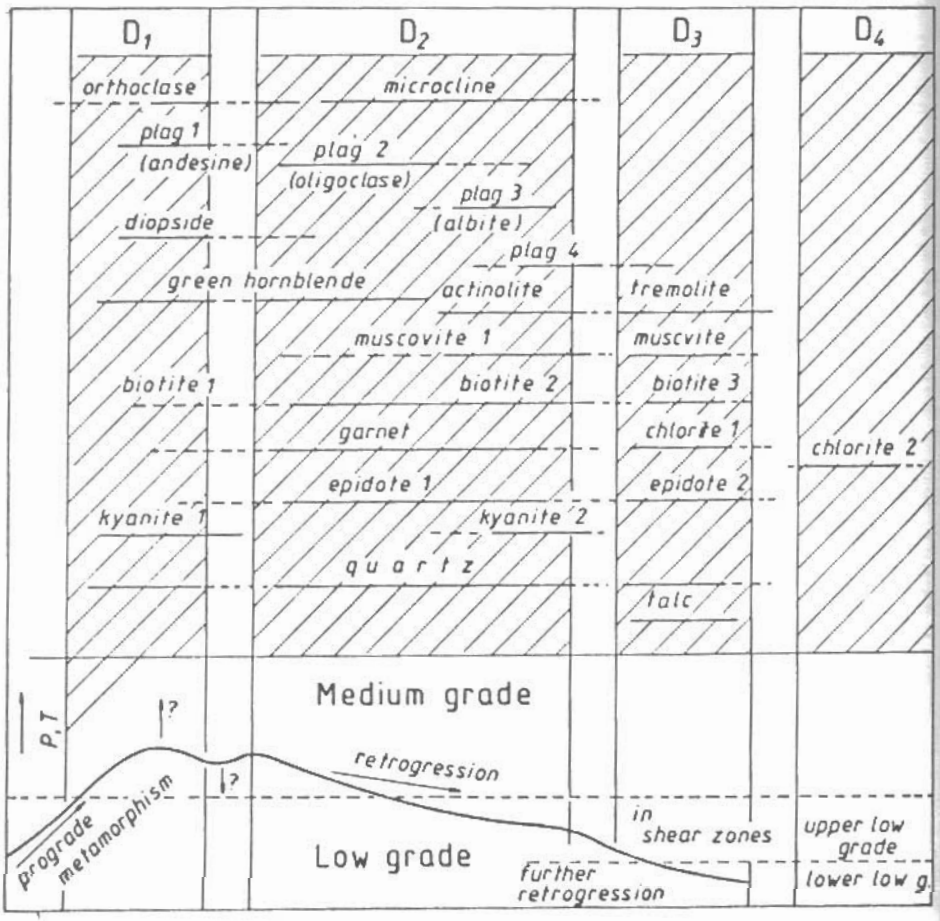


Fig. 9: Schematic diagram of the relation between deformation and crystallization of the minerals in the gneisses and amphibolites of the studied areas.

Deformation D_4: Young faulting

Since the end of the late-Alpine orogenies young faulting has intensely affected the crystalline complex of the island of Thassos. Certainly a part of fracturing striking NW/SE is connected with deformation phase D_3. Post-Alpine faulting fractured the rocks by two systems of normal faults: system 1 strikes NW/SE and NE/SW and system 2 strikes E/W and N/S. A dynamic model for the post-Alpine crustal deformation of the North Aegean region was proposed by DOUTSOS & FERENTINOS (1984).

CONCLUSIVE REMARKS

This paper should only be regarded as a first outline of the research work in progress at present on the island of Thassos (supervised by Prof. Dr. G. NOLLAU, Erlangen). Our investigations, however, have clearly revealed that in the Southern part of the Rhodope-Massif repeated deformation and metamorphism took place.
Since our geological investigations on Thassos are far from being finished yet, we would prefer to abstain from discussing our findings in a regional-geological context in this paper.

ACKNOWLEDGEMENTS

We are indepted to Prof. Dr. G. NOLLAU, Erlangen, for his supervision and support of our investigations. This paper is part of the geological research programme on the island of Thassos, and therefore we would like to thank all our colleagues of the Institute of Geology, Erlangen, for their helpful discussions and for giving us their unpublished informations.

REFERENCES

DIMADIS, E. & ZACHOS, S. 1983: The geotectonic position of the Skaloti-Echinos granite and its relationship to the metamorphic formations of Greek Western and Central Rhodope.- Geol. Balc., 13.5, 17-24

DOUTSOS, T. & FERENTINOS, G. 1984: Post-Alpine crustal deformation in North Aegean Region (Greece).- Geol. Balc., 14.6, 37-46.

HOBBS, B. E., MEANS, W. D. & WILLIAMS, P. F. 1976: An outline of Structural Geology.- Springer, 571 p.

KOKKINAKIS, A. 1977: Das Intrusivgebiet des Symvolon-Gebirges und von Kavala in Ostmakedonien, Griechenland.- Thesis Univ. München, 255 p.

KRONBERG, P. 1969: Gliederung, Petrographie und Tektogenese des Rhodopen-Kristallins im Tsal Dag, Simvolon und Ost-Pangäon (Griechisch-Makedonien).- [illegible]

KRONBERG, P., MEYER, W. & PILGER, A. 1970: Geologie der Rila-Rhodope-Masse zwischen Strimon und Nestos (Nordgriechenland).- Beih. Geol. Jb.,

88, 133-180

LASKARIDIS, K. 1985: Petrographisch-gefügekundliche Untersuchungen im Raum Limenas-Panagia-Potamia der Insel Thassos (N-Griechenland).- Dipl.-Arb. Univ. Erlangen, 153 p. (unpublished)

LUNDBERG, B. R. 1978: Geology of the Rhodope crystalline rocks.- IAEA. TR., 9, Vienna

MAIER, M. 1987: Petrographie, Metamorphose und Tektonik im Kristallin S' und W' des Trikorfons, SE-Thassos/N-Griechenland.- Dipl.-Arb. Univ. Erlangen (unpublished)

PAPANIKOLAOU, D. & PANAGOPOULOS, A. 1981: On the structural style of Southern Rhodope, Greece.- Geol. Balc., 11.3, 13-22

PETEREK, A. 1986: Geologische, strukturelle und petrographische Untersuchungen im Ostnordosten der Insel Thassos (Nordgriechenland).-Dipl. Arb. Univ. Erlangen, 206 S. (unpublished)

RAMSAY; J. G. 1967: Folding and fracturing of Rocks.- McGraw-Hill, 368 p.

STÖCKHERT, B. 1982: Deformation und retrograde Metamorphose im Altkristallin südlich des westlichen Tauernfensters (Südtirol).- Thesis Univ. Erlangen

VOLL, G. 1960: New work on petrofabrics.- Liverpool and Manchester Geol. Journal, 2/3, 503-567

VOLL, G. 1968: Klastische Mineralien aus den Sedimentserien der Schottischen Highlands und ihr Schicksal bei aufsteigender Regional- und Kontaktmetamorphose.- Habilitationsschrift, Fakultät für Bergbau und Hüttenwesen, T. U. Berlin, 360 p.

ZACHOS, S. 1977: Report to the geological mapping on the island of Thassos.- IGME Xanthi (in Greek)

ZACHOS, S. 1982: Geological map of the island of Thassos. 1 : 50 000.- IGME Athens