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MIOCENE UPLIFT OF MID-CRUSTAL ROCKS IN THE RHODOPE METAMORPHIC CORE COMPLEX, CAUSED BY LATE ALPINE EXTENSION OF PREVIOUSLY THICKENED CRUST (THASSOS ISLAND, PANGAEON COMPLEX, NORTHERN GREECE)

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ABSTRACT

During the Miocene mid-crustal metamorphic rocks on the Island of Thassos were exhumed by slip on ductile extensional deformation faults. This deformation caused generation of a gently southwestward dipping transposed lithological layering. In particular, orthogneisses intercalated within metasediments show a strong mylonitic foliation. These orthogneisses are, at least partially, derived from Variscan magmatites, which show geochemical characteristics of S-type granites and granodiorites formed at a continental margin. At different structural levels of the metamorphic profile, these mylonitic orthogneisses occur in distinct shear zones. While the orthogneisses of the deeper structural levels show high temperature ductile flow followed by postkinematic annealing, in orthogneisses of the higher structural levels deformation continued through cooling into the brittle/ductile transition zone. These deformational features clearly indicate the correlation of the ductile deformation D3 to extension and exhumation of the mid-crustal rocks. Extensional deformation postdates crustal thickening during Alpine tectonic stacking. This is delineated by increasing pressures, infered from the phengite component of pre-Alpidic and two Alpidic white mica generations found in a metapegmatite.

Onset of extensional deformation not later than 26 - 23 Ma is constraint by Rb-Sr whole rock and white mica analyses. The Miocene metamorphic event is verified by a U-Pb monazite age of ± 20 Ma. Exhumation is recorded by Rb-Sr dates of white mica (23 - 21 Ma) and biotite (15 - 14 Ma).

An Eocene mineral age proves the assignment of rocks of S-Thassos to the upper plate. These rocks are deformed mainly by brittle mechanisms and are situated in the hanging wall of a cataclastic fault zone.

INTRODUCTION

The dominant structures of the North Aegean are mainly the result of late Alpine extensional deformation (Kolocotroni et al., 1991). Recently, the Strimon Valley detachment system has been interpreted as a major detachment normal fault, which emplaced the medium grade Rhodope Metamorphic Core Complex (Dinter & Royden, 1993; Sokoutis et al., 1993) and the mid-crustal rocks of the Pangaeon Complex. To the east of this fault, the upper

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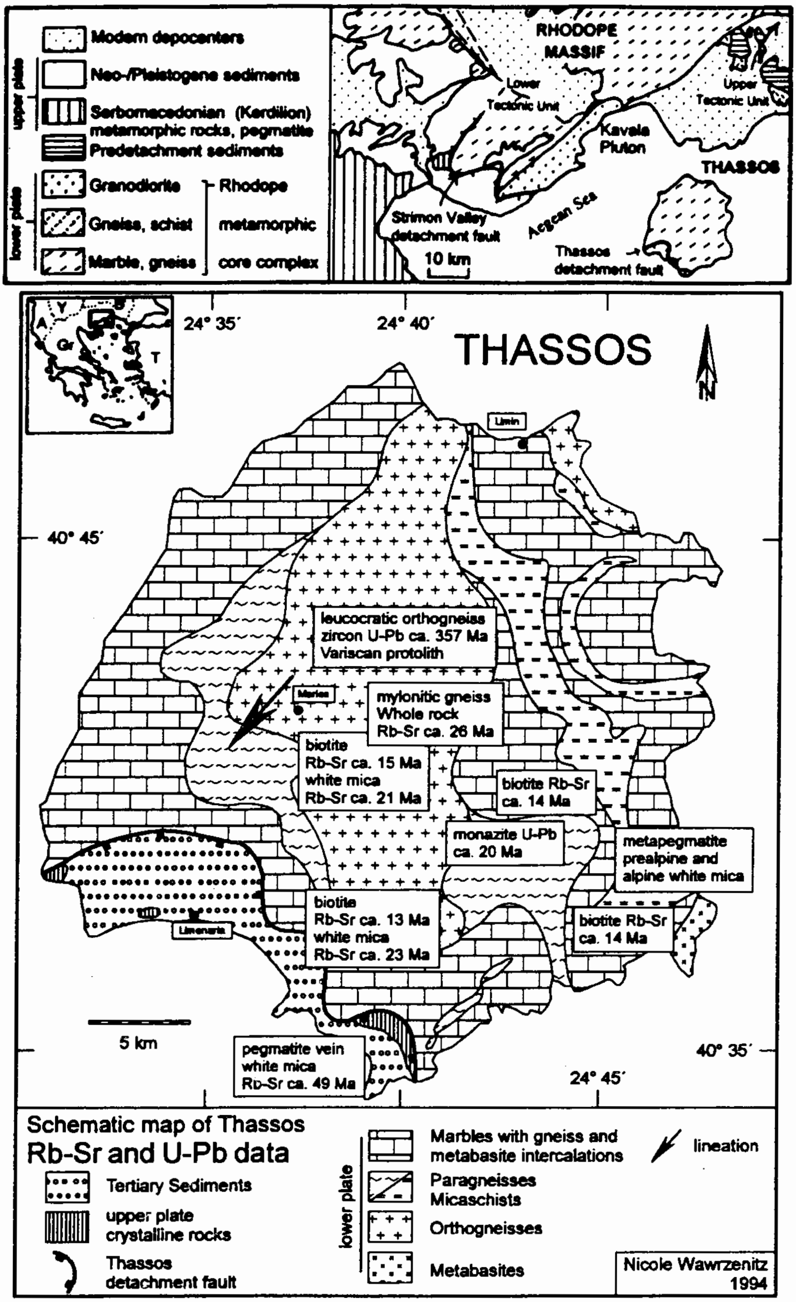


Fig. 1: Schematic map of the Rhodope Metamorphic Core Complex (modified after DINTER & ROYDEN, 1993). Detachments have teeth on upper plate. U-Pb and Rb-Sr data (N.Wawrzenitz) are presented in schematic map of Thassos Island, highly simplified after Workinggroup Prof. G. Nollau et al., in prep. Inset: Gr=Greece, A=Albania, B=Bulgaria, T=Turkey, Y= former Yougo-slavia.

plate is represented by the Kerdilion Unit of the Serbomacedonian Massif.

Scope of this study is to discuss the following aspects:

1. What age and geochemical characteristics show the protoliths of the mylonitic orthogneisses in the central part of Thassos Island?

2. Is it possible, to verify Alpine crustal thickening in the lower-plate, which is a necessary precondition for gravitational collapse (Van den Driessche & Brun, 1992) by barometric data?

3. What are grain size fabrics associated with the ductile normal de-tachment fault zones in different structural positions of the metamorphic profile?

4. What is the significance of Rb-Sr and U-Pb data, obtained on whole rock, white mica, biotite and monazite of the lower plate rocks?

5. Are there geochronological hints for the existence of upper-plate rocks on the Island of Thassos

GEOLOGICAL SETTING

Thassos Island belongs to the Rhodope Massif, situated in the Internal Metamorphic Belt of the Hellenides in Northern Greece (Papanikolaou & Panagopoulos, 1981). The Rhodope Massif consists of a Lower (Pangaeon Complex) and an Upper Tectonic Unit (Sidironero Unit) according to Papanikolaou (1984). To the west, the Lower Tectonic Unit is confined from the Serbomacedonian Massif (Kerdilion Unit) by the Strimon Valley Fault (Fig. 1). While previous workers have interpreted the Serbomacedonian Massif (Kerdilion Unit) to be overthrust onto the Lower Tectonic Unit along the Strimon Valley Fault during Miocene thrusting (Del Moro et al., 1989; Papanikolaou, 1984), recently the Strimon Fault has been shown to be a detachment normal fault (Dinter, 1993; Sokoutis et al., 1993).

Previously, Miocene Rb-Sr ages (22 - 12 Ma) of muscovite and biotite, found in metamorphic rocks of the Lower Tectonic Unit (Del Moro et al., 1989), were interpreted as to record overthrusting of the Serbomacedonian Massif onto the Lower Tectonic Unit during a compressional event. On the other hand, new U-Pb data from the Kavala Granodiorite robustly constrain a minimum age for extension (see above) with ca. 21 Ma (Dinter, 1993).

In contrast, early Eocene (50 - 45 Ma) hornblende mineral ages were obtained by K-Ar dating of amphibolites from the Upper Tectonic Unit. The amphibolites are considered to have formed at the expense of eclogites (Liati & Kreuzer, 1990).

Eocene to Oligocene mineral ages, documented on metamorphic rocks of the Kerdilion Unit, are interpreted as „cooling ages" following a last tectonometamorphic event (Harre et al., 1968; Marakis, 1969).

VARISCAN PROTOLITH OF A MYLONITIC ORTHOGNEISS

Geochemical analyses on whole rock and U-Pb investigations on zircon provide information about age and origin of the orthogneiss protoliths in the central part of Thassos Island.

<u>GEOCHEMICAL CHARACTERISTICS</u>

The geochemical characteristics of the white mica-quartz-feldspar gneiss and associated orthogneisses in the central part of Thassos point to S-type granodiorites and granites as educts. Mineral assemblage and zircon morphology agree with this assumption. The Nb- and Y- contents are typical for an origin at an active continental margin (Fig. 2a, b).

<u>U-PB INVESTIGATIONS</u>

Discordant U-Pb data of the analyzed zircons, separated from an orthogenic

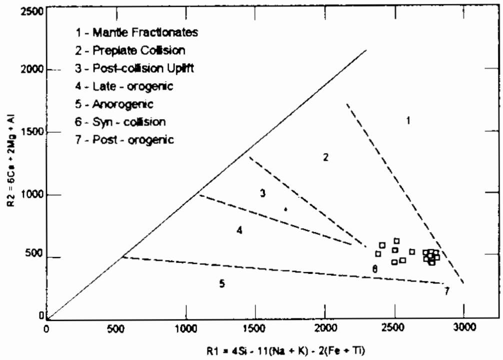


Fig. 2a: R1-R2 diagram after BATCHELOR & BOWDEN(1985)

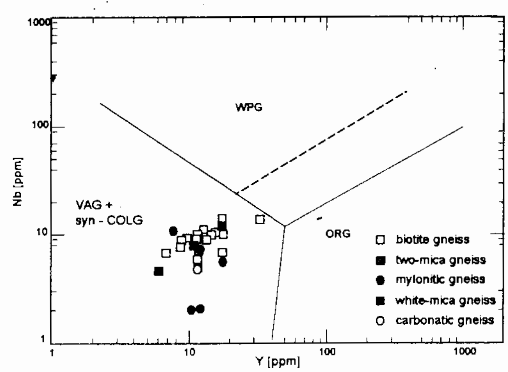


Fig. 2b: Nb-Y diagram after PEARCE et al. (1984).

white mica-quartz-feldspar gneiss, reveal a Variscan magmatic event. The U-Pb data points of long prismatic zircons are arranged in a linear array, which results in an upper intercept age of ca. 357 Ma (Fig. 4). Cathodoluminiscence imaging show a single staged growth of the long prismatic zircons (Figs. 3.1, 3.2). This supports the interpretation of the upper intercept age as an approximate crystallization age of the longprismatic zircons subsequent to formation of the protolith. However, U-Pb data of short prismatic zircon fractions suggest a possible Precambrian origin of the inherited cores (Fig. 4): cathodoluminiscence imaging of short prismatic zircons (Fig. 3.3) record round components in the crystal cores. Therefore, the short prismatic zircons represent non-cogenetic phases of inherited core and younger overgrowth. Due to the existence of more than one zircon generation in a single crystal, the short prismatic zircons are inappropriate for significant age determinations by means of conventional mass spectrometric analyses.

EVIDENCE FOR PRE-EXTENSIONAL ALPINE THRUSTING

In a metapegmatite, barometric estimations at the base of the phengite component (Massonne & Schreyer, 1987; Massonne, 1991) of different white mica generations (Fig. 6.1) infer increasing pressures (Fig. 5):

The protolith of the metapegmatite intruded into a low crustal level, as is indicated by the phengite-component of primary pegmatitic white mica (Si = 3.12-3.16 atoms p.f.u., resp. 2-3 kbar). Some of the white mica grains are zoned, showing an increased phengite-component from core to rim.

The Rb-Sr system of large pegmatitic white mica points out a minimum age of 244 Ma and was, thus, scarcely influenced during the Alpidic overprint. Probably, this reflects a rejuvenated Hercynian age.

During the Alpine event, the pegmatite was deformed and metamorphosed. Two different metamorphic generations of white mica can be distinguished. A prekinematic generation of white mica is oriented oblique to the mylonitic foliation. The grains are deformed (Fig. 5.1). The significantly higher phengite-component of these grains (Si = 3.28-3.32 p.f.u.) delineates increased pressures of about 8 kbar. This relates to crustal thickening during alpine tectonic stacking (D1-D2), which predates extensional deformation D3.

A later synkinematic generation of white mica was formed on the foliation planes. They crystallized during the mylonitization. The lower phengite

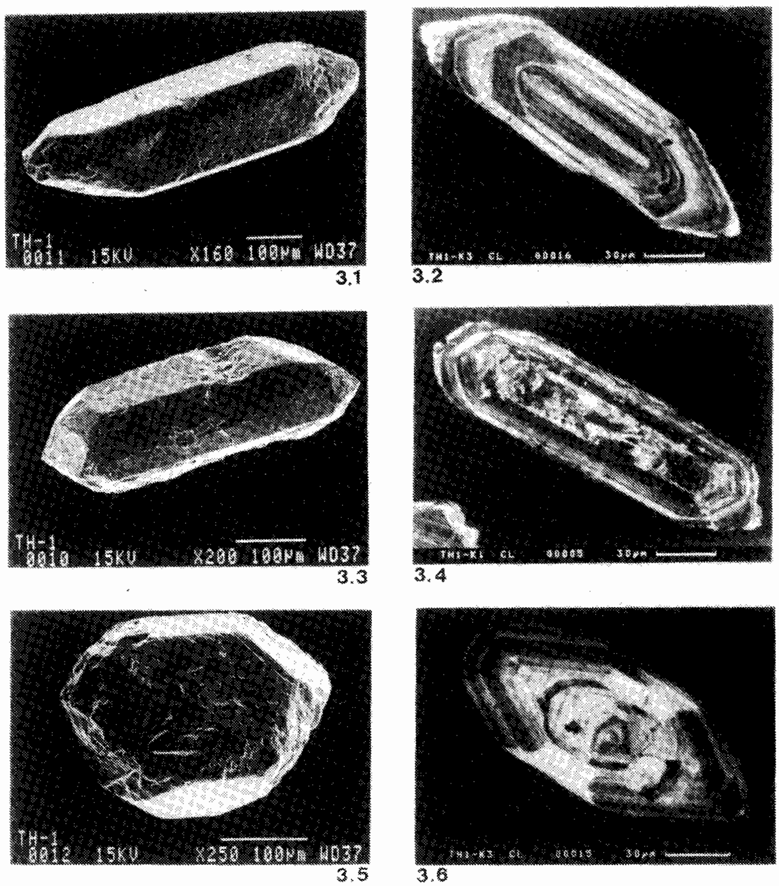


Fig. 3: SEM-images (left column) and cathodoluminiscence-images (right column) of zircon grains. 3.1.-3.2.) longprismatic zircon grains show single stage growth, 3.3-3.4) turbid longprismatic zircon grains show recrystallization, 3.5-3.6) short prismatic zircon grains show a round component in the core and a younger overgrowth.

component of these micas (Si = 3.24-3.28 p.f.u.) indicates decompression to about 6 kbar during the extensional deformation.

This relates to extensional deformation, that resulted from gravity collapse (Van den Driessche & Brun, 1992) of the thickened Alpine crustal wedge.

A finegrained fraction containing a mixture of the two metamorphic white mica generations was analyzed, yielding a Rb-Sr date of 26 Ma. This may be considered as a mixing age.

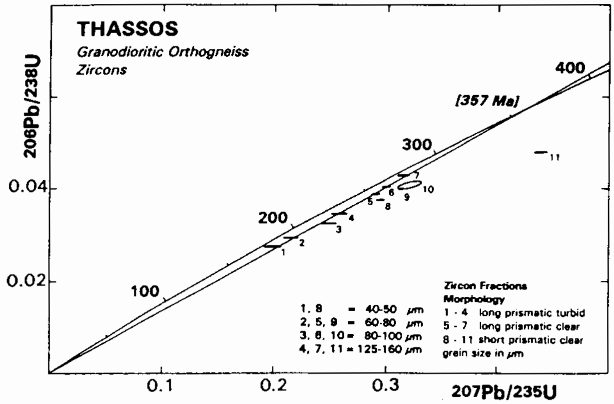


Fig. 4: Concordia diagram for U-Pb zircon data of a white mica-quartz-feldspar gneiss.

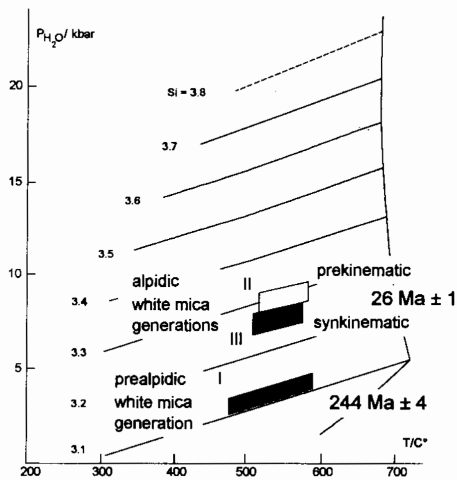


Fig. 5: P_{H_2O}-T-diagram with isopleths of Si p.f.u. for phengite coexisting with K-feldspar, quartz and biotite after MASSONNE, 1991. Temperature is robustly estimated due (I) the formation temperature of pegmatite 450°-650°C (RÖSSLER, 1981) and (II) oligoklas microfabrics; which show postkinematic annealing and equilibration-grainboundary configuration (≥ 500°C according to GANDAIS & WILLAIME, 1984).

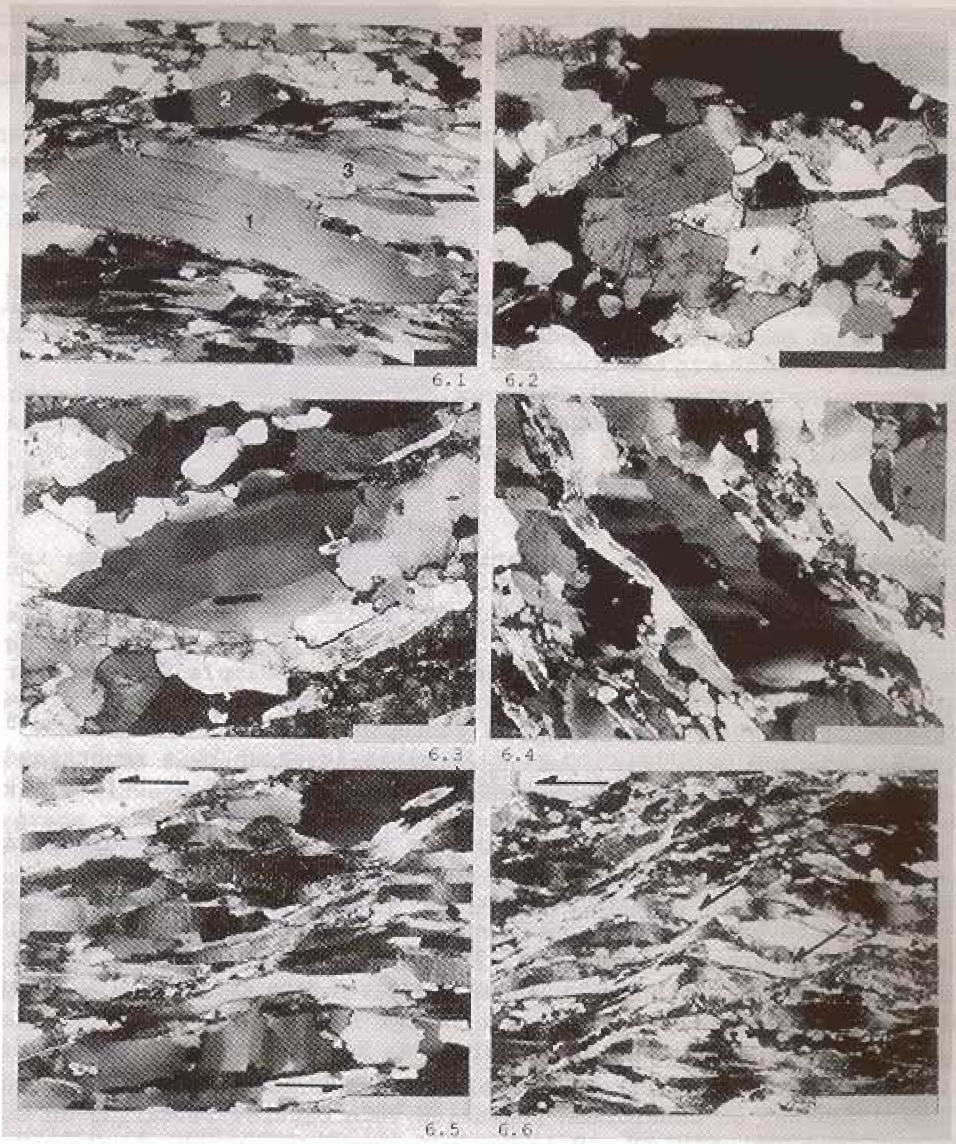
DUCTILE EXTENSIONAL DEFORMATION PATTERN

Distinct shear zones, formed during extensional tectonics, record top-to-SW directed sense of shear.

In the Upper Tectonic Unit on the mainland, a top-to-SW sense of shear as well is documented by KILIAS & MOUNTRAKIS (1989). However, mineral ages (LIATI & KREUZER, 1990) indicate, that this unit was uplifted towards a shallow structural level during the Eocene. The Oligocene Xanthi pluton shows a contactmetamorphic aureole. Thus, in the Upper Tectonic Unit, deformation correlated with top-to-SW shearing is significantly older than in the Lower Tectonic Unit on Thassos Island.

There, shear zones occur in different structural levels of the metamorphic profile and have been studied in mylonitic quartz-feldspar gneisses:

In deeper structural levels high temperature ductile flow was followed by postkinematic annealing. This is evidenced by quartz-microfabrics showing well developed subgrain-boundaries, that are orientated subnormal and subparallel to the trace of the crystallographic [c]-axis and by equilibrium grain boundary configurations in quartz and feldspar aggregates (Figs. 6.2, 6.3).



scale: bars = 0.5 mm

Fig. 6: Photomicrographs, crossed polars. 6.1.) pre-Alpidic white mica porphyroclast [1], Alpidic prekinematic white mica grain [2] is deformed, both surrounded by Alpidic synkinematic white mica grains [3] in metapegmatite, 6.2.-6.3.: dolomites from deeper structural level: 6.2) equilibrium grain boundary configurations in quartz and feldspar aggregates, 6.3.) quartz-subgrain-boundaries are orientated subnormal and subparallel to the trace of the crystallographic [c]- axis, 6.4.-6.6.: mylonites from higher structural level: 6.4.) quartz is deformed by ductile flow and dynamic recrystallization, quartz grains are strongly elongated, subgrain boundaries are oriented subparallel to the trace of the crystallographic [c]-axis, 6.5) low temperature deformation produced localised shear bands, in which mineral phases underwent grain size reduction, 6.6) ecc-fabric and mica fishes consistent with a top-to-SW sense of shear.

In higher structural levels deformation continued through cooling into the brittle/ductile transition zone. As a result, quartz grains are strongly elongated, show undulatory extinction and serrated grain boundaries. Subgrain-boundaries are orientated subparallel to the trace of the crystallographic [c]-axis (Fig. 6.4).

In addition, low temperature deformation produced localised shear bands, in which the mineral phases underwent grain size reduction. In the shear zones at the top of the profile, feldspar reacted by brittle mechanisms, while quartz was deformed by ductile flow and dynamic recrystallization (Fig. 6.5).

Throughout the profile, kinematic indicators, such as asymetrically rotated porphyroclasts, mica fishes and long axes of subgrains oblique to the mylonitic foliation, are consistent with a top-to-SW sense of shear (Fig. 6.6).

To sum up, microstructural features of shear zones, occuring within a distance of ca. 1200 m, may indicate a difference in synkinematic temperature exceeding ca. 200°C (O'Hara, 1990; Voll, 1976).

GEOCHRONOLOGICAL CONSTRAINTS

LOWER - PLATE MYLONITES

The onset of extensional deformation not later than 26 - 23 Ma is constrained by Rb-Sr whole rock and Rb-Sr white mica analyses.

A strongly mylonitized quartz-feldspar gneiss was cut perpendicular to the foliation into 15 slabs. These slabs were analysed by means of the Rb-Sr method on whole rocks (Fig. 7). The investigated sample is characterized by pressure solution phenomena, like grain size reduction and replacement of K-feldspar by white mica. Partial isotopic homogenization of the $^{87}Sr/^{86}Sr$-ratio between neighbouring profile-slabs is shown by a smoothened line in the profile diagram, calculated for the time of 26 Ma before present (Fig. 7).

U-Pb analyses of two monazite fractions of a biotite-plagioclase-gneiss revealed a nearly concordant mineral age of 20 Ma.

Rb-Sr dates of white mica yield ca. 23 - 21 Ma and of biotite yield Ca. 15 - 13 Ma. Conventionally, these dates are interpreted as cooling below the closure temperature (JÄGER, 1979) of ca. 500°C resp. ca. 300°C. The meaning and interpretation of the geochronological data are carefully discussed in the conclusions.

UPPER-PLATE PEGMATITE VEIN

At the top of the mylonitized lower-plate rocks, detached through cataclastic low angle faults, an undeformed pegmatite vein occurs, revealing an Eocene Rb-Sr date of white mica. This date shows a similarity to the Eocene „cooling ages" of the Serbomacedonian Massif (± 50 Ma) and is thus a first geochronological constraint for the existence of rocks belonging to the upper plate on Thassos Island. However, this has to be verified by further analyses.

DISCUSSION AND CONCLUSIONS

1. In several cases, leucocratic mylonites occuring in normal detachment systems may originate from synkinematically intruded magmatites (Brun & Van den Driessche, 1993). However, in the central part of Thassos Island the results of U-Pb data exclude at least partially a syn-extensional formation for the protoliths of the mylonitic orthogneisses. In contrast, Variscan granodiorites and granites are the possible protoliths of the mylo-nitic

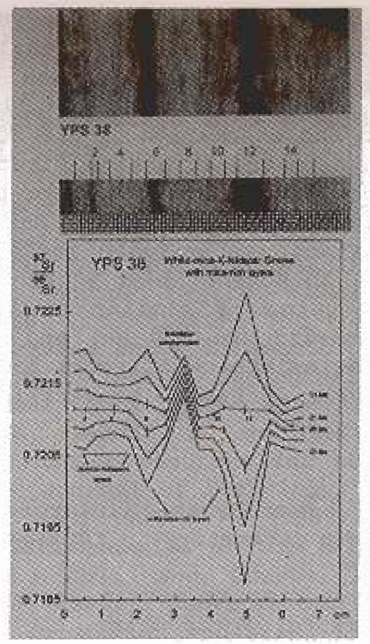


Fig. 7: Profile diagram showing the internal distribution of whole rock $^{87}Sr/^{86}Sr$-ratios, calculated for 13, 21, 26, 33 Ma

orthogneisses.

2. In the Lower Tectonic Unit Alpine crustal thickening is verified by Rb-Sr analyses and pressure estimations at the base of the phengite component of pre-Alpidic and Alpidic (pre- and synkinematic) white mica generations of a metapegmatite.

3. It's essential to consider the significance of associated processes on the Sr-homogenization. During the prograde P-T evolution, fluid migration related to dehydration reactions could have facilitated Sr-homogenization. On the retrograde P-T path, crystalplastic processes and fluid migration related to pressure solution would make isotopic homogenization possible. Rb-Sr whole rock ages record either an intervall of time on the prograde or on the retrograde P-T path (or even the climax). The important role of water activity during retrogressional mylonitization is recorded by features, like replacement of K-feldspar by white mica and sericitization of plagio-clase, which can be assigned to the retrograde P-T path. This retrograde reactions require hydration, and, thus, indicate an access of water during mylonitization.

The fluid phase is suggested to facilitate Sr-homogenization. If so, Sr-homogenization was mainly supported by the presence of a fluid phase during retrogression.

As outlined before, retrogression is correlated with the exhumation of the lower-plate rocks. From all this follows, that the whole rock age presumably represents the time of mylonitization on the retrograde path. Thus, a minimum age for the onset of extension is constraint with 26 - 23 Ma, by whole rock and white mica analyses.

4.The Rb-Sr mica ages obtained on several gneisses and mica schists clearly relate to continous uplift and cooling. However, they give only a rough approach to the time of cooling below the closure temperature of ca. 500°C for white mica and ca. 300°C for biotite (Jäger, 1979). The white mica date of 23 - 21 Ma and biotite date of 15 - 14 Ma can't be interpreted as „cooling ages", although they are often interpreted like this. This is because they result of samples, containing a mixture of two or three microstructurally distinguishable generations.

Only in some cases, mica generations can be seperated, according to grain size: The white mica generations of the metapegmatite show drastically different composition and Rb-Sr mineral ages. However, in most cases, different mica generations can't be separated for analyses, the obtained data are mixing ages.

The Miocene metamorphic event in the Lower Tectonic Unit is verified by U-Pb age determinations of monazite. This U-Pb mineral age clearly negates the still discussed possible rejuvenation of radiometric data without a contemporaneous ductile deformation in the Rhodope (ZAGORCEV, 1994).

5. At the time of ductile deformation and exhumation of the lower-plate rocks, the upper-plate has already been situated at a high structural level. Due to this constellation, metamorphic rocks from the upper-plate (the Kerdilion Unit), provide Eocene to Oligocene mineral ages (Harre et al. 1968, Marakis et al. 1968). For comparison, metamorphic rocks from the lower-plate reveal miocene mineral ages. An Eocene Rb-Sr white mica date, obtained on the upper-plate pegmatite vein, is similar to the Eocene „cooling ages" of the Serbomacedonian Massif (ca. 50 Ma) and is thus a first geochronological constraint for the existence of rocks belonging to the upper plate on Thassos Island. However, it has to be verified by further analyses.

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