Δελτίο της Ελληνικής Γεωλογικής Εταιρίας τομ. XXXII/1, 145-152, 1998
Πρακτικά 8ου Διεθνούς Συνεδρίου, Πάτρα Μάιος 1998

Bulletin of the Geological Society of Greece vol. XXXII/1, 145-152, 1998
Proceedings of the 8th International Congress, Patras, May 1998

STRUCTURE AND CRUSTAL THICKENING OF THE MENDERES MASSIF, SOUTHWEST TURKEY, AND CONSEQUENCES FOR LARGE-SCALE CORRELATIONS BETWEEN GREECE AND TURKEY

K. GESSNER[1], U. RING[1], W. LACKMANN[1], C.W. PASSCHIER[1] & T. GÜNGÖR[2]

ABSTRACT

The gross structure of the Menderes Massif consists of a south-dipping nappe pile comprising a Pan-African basement sandwiched between a lower and an upper sedimentary unit. Sedimentation in the latter units lasted at least until the Cretaceous. Structural and metamorphic work reveals an early major deformational event that was associated with top-north thrusting. This early event occurred during prograde amphibolite-facies metamorphism and caused stacking within the basement unit. Subsequentely, the basement was thrusted upon the lower sedimentary unit indicating that this event is of Alpine age. Alpine thrusting in the Menderes Massif depicts a conspicuous progression in space and time from south to north. Our work indicates that the architecture and the northward progradation of the tectonic development of the Menderes Massif is different to the structure and the tectonic evolution of the adjacent Attic-Cycladic Massif. To account for this dissimilarity, we propose that an about north-trending dislocation zone separated both massifs at least intermittently during the Alpine orogeny.

KEY WORDS: Structure, Contraction, Crustal Thickening, Metamorphism, Alpine Orogeny, Menderes Massif, Attic-Cycladic Massif, Greece, Turkey.

1. INTRODUCTION

The Menderes Massif is commonly viewed as the eastern continuation of the Attic-Cycladic Massif (Jacobshagen 1986). It has been proposed that the Menderes Massif consists of a Precambrian/Cambrian "core" overlain by a "cover" comprising Paleozoic and Mesozoic sediments (Dürr et al. 1978, Dora et al. 1995) although Sengör et al. (1984) noted some shortcomings of this simple scheme. In the central Menderes Massif, there is ample evidence that the "core" is sitting structurally on top of the "cover" and not vice versa (Izdar 1971). At the southern margin of the massif, however, the "cover" occurs structurally on top of the "core". Tectonic transport responsible for the internal structure and metamorphism of the Menderes Massif is generally assumed to be south directed and of Paleogene age (Sengör et al. 1984).

In this contribution, we aim to resolve the general architecture and the nature of early Alpine crustal thickening of the Menderes Massif. Our work suggests that the traditional view of the structure and the kinematic evolution of the Menderes Massif is poorly constrained and might indeed be seriously flawed. Furthermore, the early tectonometamorphic history of the central and southern Menderes Massif shows marked differences to that of the adjacent Aegean islands. This will have implications for large-scale tectonic correlations between Greece and Turkey.

2. ARCHITECTURE

A generalised map (Fig. 1) and cross section (Fig. 2) in conjunction with structural mapping reveals the overall architecture of the central and southern Menderes Massif. In contrast to earlier studies, we propose

1 Institut für Geowiss... Mainz, Germany.
2 Jeologi Mühendisligi Bölümü, Dokuz Eylül Üniversitesi, 35100 Bornova, Tyrkey.

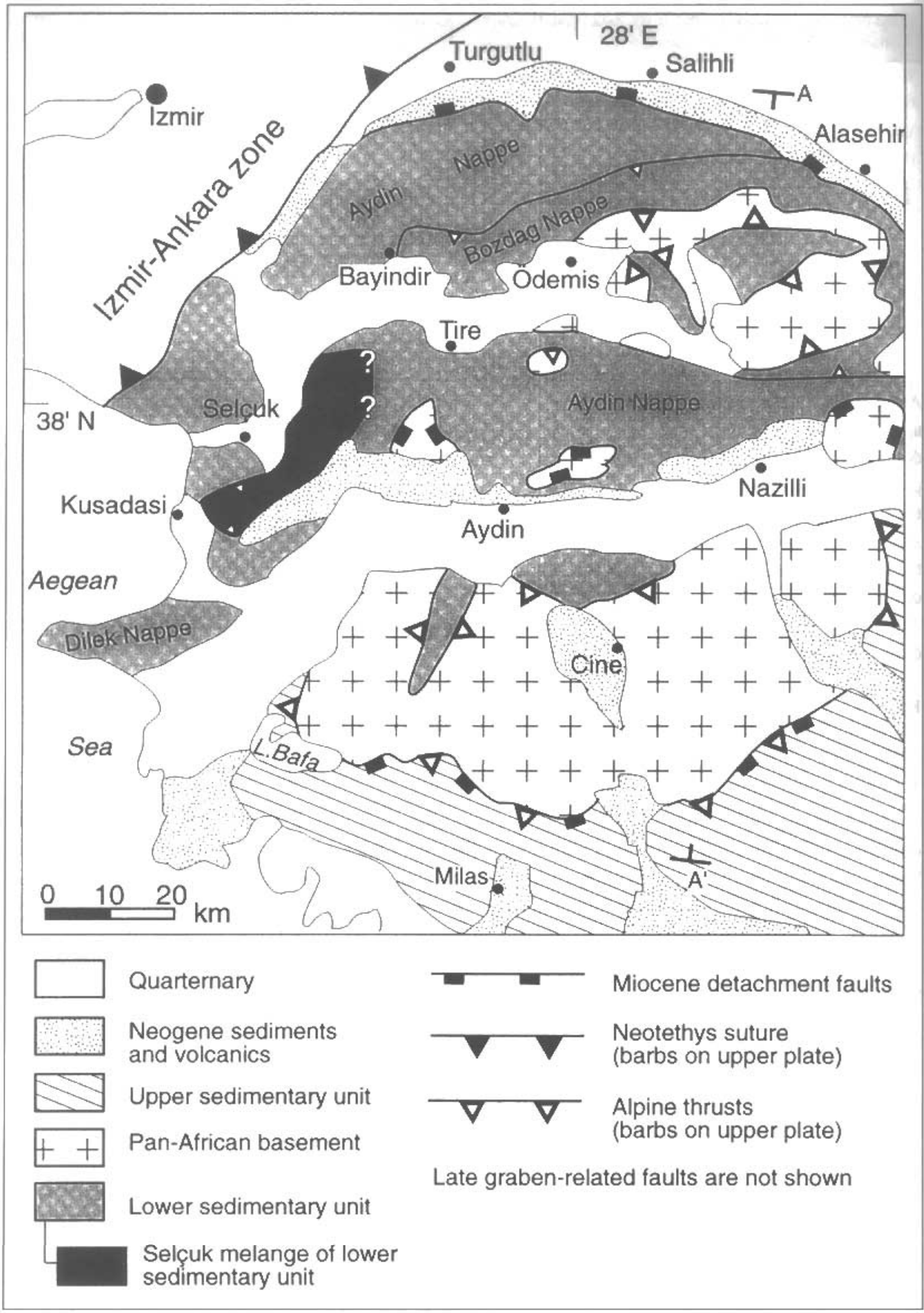

Fig. 1: Simplified tectonic map of the central and souther Menderes Massif showing the three major tectonostratigraphic units discussed in text (modified from Bora et al. 1998 and Candan et al. 1997).

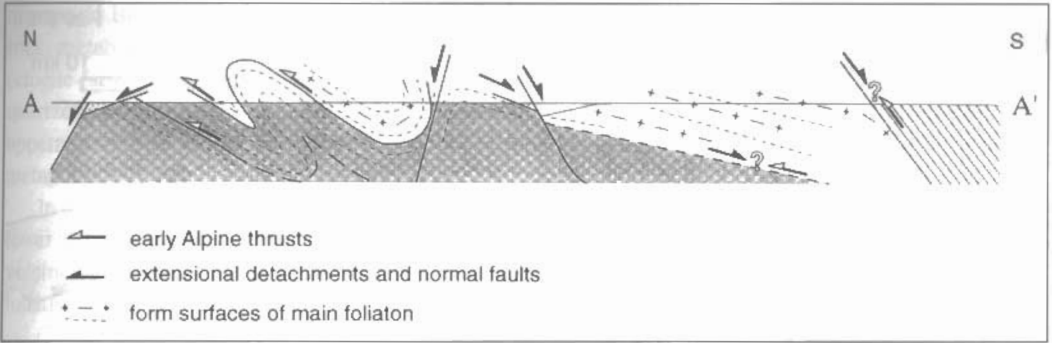

Fig. 2: General cross section through the central and southern Menderes Massif showing south-dipping pile of tectonic units and post-nappe large-scale north-vergent folding. Subsequentely these contractional structures and cut by extensional detachments and normal faults. For position of cross section and patterns refer to Fig. 1.

that the Menderes Massif consists of three major tectonic units, i.e. a lower sedimentary unit, a Pan-African basement and an upper sedimentary unit. These units can be further subdivided into a number of individual nappes. We describe and interpret the tectonic units in ascending order and emphasize that this outline is in part speculative.

(1) A lower sedimentary unit in the central and northern massif. This unit shows some striking differences across the Menderes Massif. In the Selcuk area, the lower sedimentary unit consists of at least two members: A lower member, the Dilek nappe, composed of a shelf sequence comprising metapelite, quarzite, metabasite lenses and metabauxite-bearing marble which is overlain by the Selcuk melange, an assemblage of ophiolitic rocks embedded in a serpentinitic and shaly matrix (Erdogan & Güngör 1992, Candan et al. 1997). As discussed in Ring et al. (1998), both members can be correlated with nappes of the so-called Cycladic blueschist unit in the Aegean (see also Candan et al. 1997 for correlation of the Dilek nappe with the Vourliotes nappe on Samos Island). More significantly, both members show a high-pressure metamorphic overprint in the Selcuk area (Candan et al. 1997, Ring et al. 1998). This high-pressure overprint did not affect the lithologic equivalents of the Dilek nappe further east in the Bayindir and Aydin regions. Tentatively, we refer to the non-high-pressure part of the lower sedimentary unit as the Aydin and Bozdag nappes (Fig. 3) but we conceive that the internal structure of both nappes is probably composite and might include a number of individual nappes and thrust sheets.

The Aydin nappe comprises metapelite, quarzite and metabauxite-bearing marble. The Bozdag nappe rests above the Aydin nappe and is made up of partly quarzitic metapelite with intercalated metabasite lenses. Most Turkish geologists (see summary in Dora et al. 1995) regard what we call Bozdag nappe as "core schist", thereby ascribing it a Precambrian/Cambrian age. We maintain that the age of the metapelite and metabasite is unkown. The lines of reasoning why we include the Bozdag nappe to the lower sedimentary unit and not to the Pan-African basement unit are: (i) In the Alasehir region, the Bozdag nappe is intruded by Triassic granitoids (T. Reischmann, pers. comm. 1997) which are possibly related to the south-directed subduction and closure of a remnant basin of Paleotethys (Sengör et al. 1984, Dannat 1997). A similar association of Triassic granitoids and metapelite of the shelf sequence from the Cycladic blueschist unit of Samos Island has been reported by Ring et al. (1998). (ii) Dora et al. (1995) reported that these Triassic granitoids north of Alasehir have "intrusive contacts with the schist and marble", thereby indicating that metapelite of the Bozdag nappe is associated with marble. It is generally accepted, however, that marble is a typical constituent of the metasedimentary units of the Menderes Massif and does not occur in the Precambrian/Cambrian basement (Dürr et al. 1978, Dora et al. 1995). (iii) Metabasite of the Bozdag nappe shows no evidence for an early phase of granulite- and eclogite-facies metamorphism which has been reported by Oberhünsli et al. (1997) for metabasite of the basement unit.

The tectonic relationships between the Dilek nappe and the Selcuk melange with the non-high-pressure

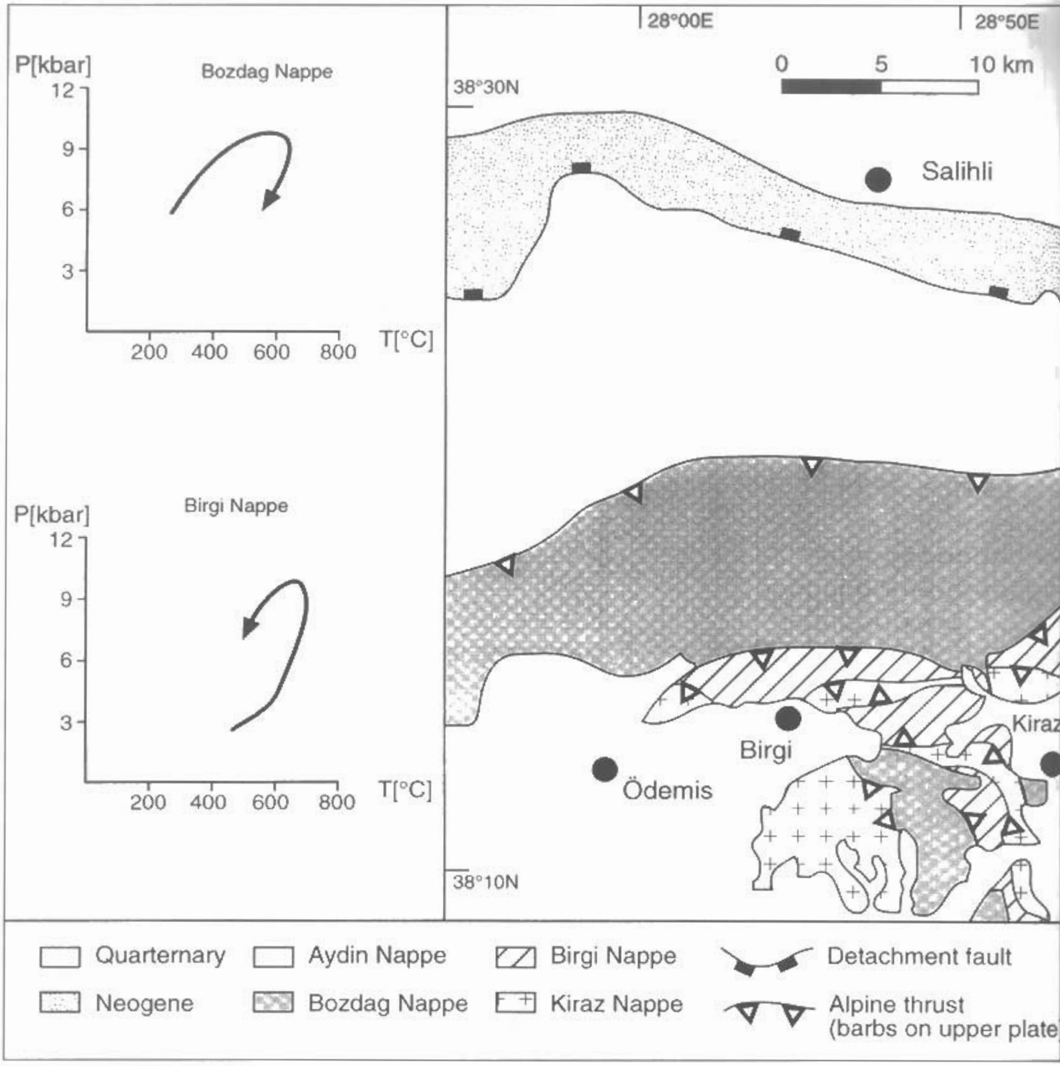

Fig. 3: Detailed map of the Ödemis region showing different nappes of the lower sedimentary unit and the basement unit. Insert shows schematic P-T-t paths for the Bozdag and Birgi nappe respectively, illustrating different P-T-t evolution of both nappes (modified from Lackmann 1997).

nappes of the lower sedimentary unit is an unresolved issue. Nonetheless, it appears to us that the Dilek nappe and the Selcuk melange are tectonometamorphically similar to the Cycladic blueschist unit, whereas the structural and metamorphic development of the Aydin and Bozdag nappes is different.

According to Altherr & Seidel (1977), the shelf sequence represents a fossil Atlantic-type continental margin whereas the Selcuk ophiolitic melange might have originated in a suture zone. In the Cyclades, the shelf sequence has a basement of Variscan ortho- and paragneiss (Reischmann 1997) which has not been found in the Menderes Massif.

(2) The Pan-African basement unit consisting of metagranite, augengneiss, metabasite and a succession of metapelite and quartzofeldspathic rock. Intrusion of most of the magmatic rocks took place at the Precambrian/Cambrian boundary (Reischmann et al. 1991, Loos & Reischmann 1995, Dannat 1997). In the ödemis area, the basement unit consists of at least two nappes (Fig. 3) which are characterized by different P-T-t histories. Above the Bozdag nappe of the lower sedimentary unit occurs the partly

migmatitic Birgi nappe. The latter is composed of the succession of metapelite and quartzofeldspathic rock, metabasite and the Birgi metagranite. The metabasite shows evidence for an early granulite- and eclogite-facies metamorphism (Oberhänsli et al. 1997). Much of the interlayered metapelite-quartzofeldspathic rock succession of the Birgi nappe resembles a Pan-African flysch sequence. The uppermost nappe of the basement unit is the Kiraz nappe which largely consists of augengneiss and metagranite. The metagranite in part intruded the augengneiss.

In the central and northern Menderes Massif, Miocene granitoids intruded the basement unit and the lower sedimentary unit (Reischmann et al. 1991, Hetzel et al. 1995). These intrusions become more voluminous towards the north where they are associated with migmatites which crosscut an Alpine foliation that is associated there with top-northeast extensional structures (Verge 1995).

(3) An upper sedimentary unit consisting of metapelite and quarzite at the base and overlying metabasite and metabauxite-bearing marble that are as young as Cretaceous (Dürr et al. 1978). Metapelites of the basement unit and of the upper sedimentary unit have been intruded by the Precambrian/Cambrian granitoids (Reischmann et al. 1991, Loos & Reischmann 1995, Hetzel & Reischmann 1996).

3. TECTONOMETAMORPHIC HISTORY

Detailed structural mapping and quantitative P-T work have been conducted at the boundary between the lower sedimentary unit and the basement unit in the central part of the Menderes Massif (Fig. 3). Metamorphism in the Aydin nappe is of greenschist-facies grade; however, quantitative P-T data are lacking. Maximum P-T conditions in the Bozdag nappe are 9-11 kbar and 600-650°C and the P-T-t path for the rocks of the Bozdag nappe is clockwise (Lackmann 1997). Maximum pressure in the overlying Birgi nappe of the basement unit is similar to that of the Bozdag nappe; however, temperatures in the Birgi nappe are somewhat higher (650-700°C) and its P-T-t path is anticlockwise (Lackmann 1997) (Fig. 3).

All nappes of the basement unit and the Bozdag nappe show early deformation structures that developed during amphibolite-facies metamorphism and predate the greenschist-facies extensional structures described by Hetzel et al. (1995). Early structures include a penetrative, moderately to steeply south-dipping foliation and an associated strong north-trending stretching lineation made up by stretched quartz-feldspar aggregates and aligned kyanite and biotite. Kinematic indicators associated with this stretching lineation are abundant asymmetric feldspar porphyroclasts and rotated garnets that yielded a regionally consistent top-north sense of shear (Fig. 4).

Detailed microstructural and microprobe work indicates that these early structures formed along the prograde part of the above outlined P-T-t paths (Lackmann 1997). Microstructures that include rotated garnet are associated with thrusting of the basement nappes onto each other and of the latter upon the lower sedimentary unit. This suggests that thrusting and the subsequent peak of amphibolite-facies metamorphism is of Alpine age. Nevertheless, we acknowledge that at least parts of the basement unit experienced high-grade metamorphism during the Pan-African orogeny (Oelsner et al. 1997).

Because the early structures developed during prograde metamorphism, we infer that thrusting and associated crustal thickening caused peak metamorphism of the various nappes. The decrease in metamorphic temperatures structurally downward might be due to thrusting of relatively hot internal units onto relatively cold units in the foreland of the advancing thrusts. An as yet unresolved question is whether or not metamorphic pressure also decreases structurally downward. Quantitative P-T work in the Aydin and Kiraz nappes is in progress and will resolve this issue.

4. DISCUSSION

We believe that our work allows us to discuss some far-reaching implications for the tectonic evolution of the eastern Mediterranean:

(1) The internal structure of the Menderes Massif is apparently not that of an "old core" overlain by a

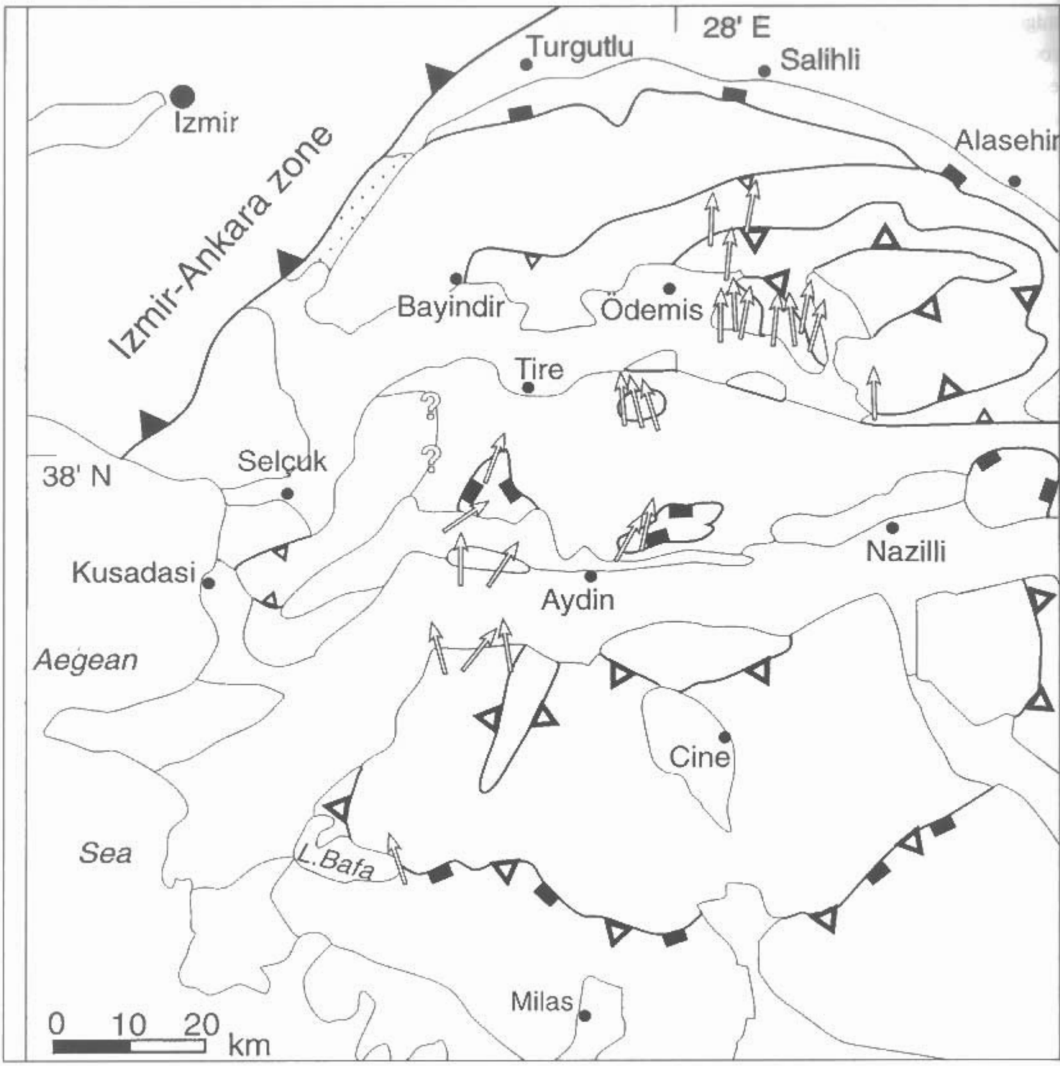

Fig. 4: Shear-sense indicators of early Alpine crustal contraction in map view. Each arrow represents the mean of up to 15 measurements and shear-sense analyses. The center of the arrow represents the general locality of the measurements.

younger envelope of sediments. We propose that at least two different major metasedimentary units exist in the Menderes Massif, the lower of which can be correlated lithologically with the Cycladic blueschist unit. The Variscan basement of the Aydin and Bozdag nappes is obviously not exposed in the Menderes Massif, however. Additionally, the tectonometamorphic evolution of the Aydin and Bozdag nappes is different from that of the Dilek nappe, the Selcuk melange and the Cycladic blueschist unit.

On top of the lower unit follows a Pan-African basement which has no equivalent in the Aegean. Structurally above this Pan-African basement is another sedimentary unit. Because this upper sedimentary unit has been intruded by the Pan-African granitoids that largely make up the basement unit, we suppose that this sedimentary unit might have been the original cover of the Pan-African basement. We assume that this basement had a pre-Alpine paleogeographic position much farther south than the Variscan basement of the Aegean. This would explain why the Pan-African basement and the upper sedimentary unit were not intruded by the Triassic granitoids.

(2) Tectonic transport during early Alpine crustal thickening in the Menderes Massif was top-north

directed and did probably not involve a high-pressure overprint. Top-north thrusts juxtaposed the Pan-African basement with the shelf sequence of the Aydin and Bozdag nappes. Top-north thrusting explains the generally south-dipping structure of the Menderes Massif and contradicts earlier views of south-directed nappe stacking in the Menderes Massif.

The age of the north-directed contractional event is poorly constrained. According to Sengör et al. (1984) it occurred in the Eocene and Early Oligocene. Therefore, the north-directed thrusts in the Menderes Massif presumably postdate Late Cretaceous top-southeast emplacement of the Lycian nappes upon the Menderes Massif (Collins & Robertson 1997).

Eocene and Early Oligocene structures associated with early crustal thickening in the adjacent Aegean, and possibly in the Dilek nappe and Selcuk melange, are top-southeast directed and are associated with widespread high-pressure metamorphism (Ridley 1984, Ring et al. 1998). This suggests that there must have been a fundamental dislocation zone that separated the Menderes and the Attic-Cycladic Massifs during the Paleogene. Conceivably, this dislocation zone was related to collision of the continental fragment of the Menderes Massif with Eurasia. Ring et al. (1998) supplied further evidence that this dislocation zone also played a role during subsequent differential crustal extension between both areas.

REFERENCES

ALTHERR, R. & SEIDEL, E. 1977. Speculations on the geodynamic evolution of the Attic-Cycladic crystalline complex during alpidic times. In: *Geology of the Aegean Region (edited by Kallergis, G.), Proceedings, VI Colloquium, Athens.* Institute of Geology and Mineral Exploration, 347-351.

CANDAN, O., DORA, Ö.O., OBERHÄNSLI, R., OELSNER, F. & DÜRR, S. 1997. Blueschist relics in the Mesozoic cover series of the Menderes Massif and correlations with Samos Island, Cyclades. *Schweiz. Mineral. Petrogr. Mitt.*, **77**, 95-99.

COLLINS, A.S. & ROBERTSON, A.H.F. 1997. Lycian melange, southwestern Turkey: An emplaced Late Cretaceous accretionary complex. Geology, 25, 255-258.

DANNAT, C. 1997. Geochemie, Geochronologie und Nd- und Sr-Isotopie der granitoiden Kerngneise des Menderes Massivs, SW-Türkei. Unpubl. Ph.D. thesis, Universitüt Mainz, 120 pp.

DORA, O.Ö., CANDAN, O., DÜRR, S. & OBERHÄNSLI, R. 1995. New evidence on the geotectonic evolution of the Menderes Massif. *Proceedings of the Colloquium on the Agean region,* Izmir/Güllük 1995.

DÜRR, S., ALTHERR, R., KELLER, J., OKRUSCH, M. & SEIDEL, E. 1978. The median Aegean crystalline belt: Stratigraphy, structure, metamorphism, magmatism. In: Alps, Appeninnes, Hellenides (edited by Cloos, H., Roeder, D. & Schmidt, K.), Schweizerbart, Stuttgart, 537-564.

ERDOGAN, B. & GÜNGÖR, T. 1992, Menderes Masifi'nin kuzey kanadinin stratigrafisi ve tektonik evrimi: *TPJD Bületeni,* **2,** 1-20.

HETZEL, R. & REISCHMANN, T. 1996. Intrusion age of Pan-African augen gneisses in the southern Menderes Massif and the age of cooling after Alpine ductile extensional deformation. *Geol. Mag.,* **133,** 565-572.

HETZEL, R., RING, U., AKAL, C. & TROESCH, M. 1995. Miocene NNE-directed extensional unroofing in the Menderes Massif, southwestern Turkey. *J. geol. Soc. Lond.,* **152,** 639-654.

IZDAR, E. 1971. Introduction to geology and metamorphism of the Menderes Massif of western Turkey. In: Geology and history of Turkey (edited by Campell, A.S.), 495-500.

JACOBSHAGEN, V. 1986, Geologie von Griechenland. Gebrüder Bornträger, Berlin, 363 pp.

LACKMANN, W. 1997. P-T Entwicklung von Metapeliten des zentralen Menderes Massiv, Türkei. Unpubl. Diploma thesis, Universität Mainz, 75 pp.

LOOS, S. & REISCHMANN, T. 1995. Geochronological data on the southern Menderes Massif, SW Turkey, obtained by single zircon Pb evaporation. *Terra abstracts,* **8,** 353.

OBERHÄNSLI, R., CANDAN, O. DORA, O.Ö. & DÜRR, H.S. 1997. Eclogites within the Menderes crystalline complex, western Turkey, Anatolia. *Lithos* (in Press).

OELSNER, F., PARTZSCH, J.H. & OBERHÄNSLI, R. 1997. Repeated high pressure overprint in the Menderes Massif, SW-Turkey. *Terra abstracts*, **9**, 407.

REISCHMANN, T., KRÖNER, A., TODT, W., DÜRR, S. & SENGÖR, A.M.C. 1991. Episodes of crustal growth in the Menderes Massif, W Turkey, inferred from zircon dating. *Terra abstracts*, **3**, 34.

REISCHMANN, T. 1997. Single zircon Pb/Pb dating of tectonic units from the metamorphic complex of Naxos, Greece. *Terra abstracts*, **9**, 496.

RIDLEY, J. 1984. The significance of deformation associated with blueschist-facies metamorphism on the Aegean island of Syros. In: The geological evolution of the eastern Mediterranean (edited by Dixon, J.E. & Robertson, A.H.F.), *Spec. Publs. Geol. Soc. Lond.*, **17**, 545-550.

RING, U., LAWS, S. & BERNET, M. 1998. Structural analysis of a complex nappe sequence and late-orogenic basins from the Aegean Island of Samos, Greece. *J. Struc. Geol.*, submitted.

SENGÖR, A.M.C., SATIR, M. & Akkök, R. 1984. Timing of tectonic events in the Menderes Massif, western Turkey: Implications for tectonic evolution and evidence for Pan-African basement in Turkey. *Tectonics*, **3**, 693-707.

VERGE, N. 1995. Oligo-Miocene extensional exhumation of the Menderes Massif, western Anatolia. *Terra abstracts*, **8**, 117.