Δελτίο Ελληνικής Γεωλογικής Εταιρίας τομ. XXX/2, 507-512, 1994
Πρακτικά 7ου Επιστημονικού Συνεδρίου, Θεσσαλονίκη, Μάιος 1994

Bulletin of the Geological Society of Greece vol. XXX/2, 507-512, 1994
Proceedings of the 7th Congress, Thessaloniki, May 1994

MIOCENE EXTENSIONAL TECTONICS IN THE MENDERES-MASSIF, SOUTHWESTERN TURKEY

R. Hetzel* and O. Dora**

ABSTRACT

Structural and radiometric studies in the central part of the Menderes-Massif reveal the generation of a low-angle, gently NNE-dipping extensional shear zone with a top-to-the-N to NE shear sense (i.e. movement of the hanging wall towards north to northeast). Regional ductile deformation was accompanied by the intrusion of two syntectonic granodiorites that yield Miocene $^{40}Ar/^{39}Ar$ ages of 12,2±0,4 and 13,1±0,2Ma on biotite. Decreasing temperature during uplift and tectonic denudation of the massif caused the development of a cataclasite zone associated with a gentle N-dipping detachment fault and the deposition of Neogene sediments. Progressive uplift with minor rotation of the detachment fault to its present gentle dip (15o) caused southward tilting of the Neogene sediments in the hanging wall. Ongoing extension created a steep normal fault, which truncates the detachment fault and constitutes the southern margin of the present Gediz Graben.

INTRODUCTION

The Menderes-Massif in southwestern Turkey is an elongate (200x300km) culmination of metamorphic rocks, which is composed of several submassifs separated by E-W-trending graben (Fig. 1, 2) (Dora et al. 1990). Schematically the Menderes-Massif can be subdivided into a core consisting of augengneisses, high-grade schists and an overlying mantle or cover series with low to medium-grade schists, phyllites, quartzites and marbles (Dürr 1975). After considerable controversy about the age of the main tectonic and metamorphic events in the Menderes-Massif (Schuiling 1962, Ketin 1966, Brinkmann 1976) it is now generally accepted that the main metamorphism and deformation is of Alpine age (Dürr 1975, Ashworth & Evirgen 1984, Sengör et al. 1984, Satir & Friedrichsen 1986). Rb/Sr mica-ages obtained by Satir & Friedrichsen (1986) range from 63-48Ma

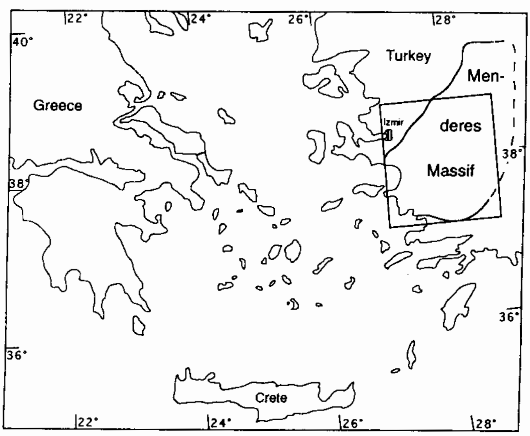

Fig. 1: Location of the Menderes-Massif in g Aegean realm (from Dürr 1975).

* Johannes Gutenberg Universität, Institut für Geowissenschaften, Saarstr. 21, 55099 Mainz, Germany.
** D.E.Ü. Department of Geological Engineering, 35100 Bornova/Izmir, Turkey.

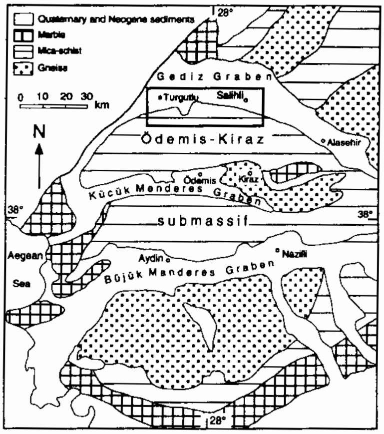

Fig. 2: Simplified geological map of the Menderes - Massif (from Dora et al. 1990).

(muscovite) to 50-27Ma (biotite) and reflect the main Alpine metamorphism and subsequent cooling of the Menderes-Massif. Due to the paucity of radiometric and palaeontological data the stratigraphy of the Menderes-Massif is still poorly known and its geologic history is largely based on lithologic correlations with better dated neighbouring regions (Sengör et al. 1984).

This paper presents preliminary results of a study dealing with the Alpine tectonic evolution of the central part of the Menderes-Massif. Detailed structural investigations in combination with $^{40}Ar/^{39}Ar$ dating provide evidence for important Miocene extensional tectonics.

GEOLOGY OF THE STUDY AREA

The subject of the present contribution is an area located in the demis-Kiraz submassif along the southern margin of the Gediz Graben between Turgutlu and Salihli (Fig. 2, 3). The different rock-types in this area belong to the cover series of the Menderes-Massif (Dora et al. 1990) and include mica-schists, phyllites, quartzites and marbles. The whole sequence has a tectonic foliation parallel to the compositional layering. In general the foliation dips gently to the N with stretching lineations plunging N to NE (Fig. 3).

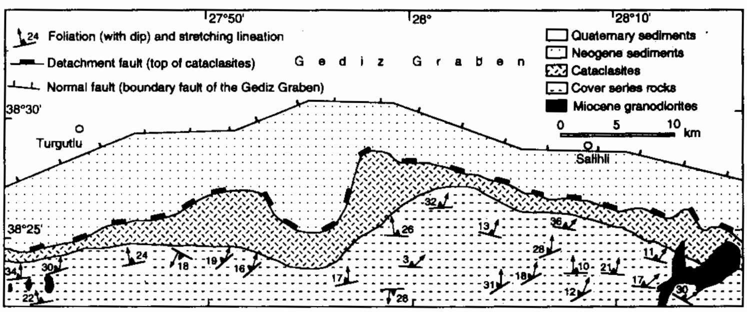

Fig. 3: Geological map of the study area. Location is shown in Fig. 2.

Asymmetric, northvergent folds with wavelength of 10 to 100m locally disturb the uniform foliation pattern. Two granodiorite intrusions SW of Turgutlu and SE of Salihli are present in the cover series rocks. At the top of the cover series rocks a 20 to 50m thick zone of cataclasites extends along the whole length of the study area (Fig. 3).

The cataclasites possess a planar surface which is a very characteristic geomorphological feature. The cataclasite surface extends along the whole length of the study area and is dipping N the NE at an angle of 13o to 18o. On top of the cataclasites occur weakly consolidated Neogene sediments made up of coarse-grained conglomerates and minor sandstones that are dipping 10o to 15o to the south (Paton 1992). They constitute a 3 to 4km broad, E-W trending belt immediately south of the active boundary fault of the Gediz Graben (Paton 1992).

DUCTILE DEFORMATION

Well-developed N to NE trending stretching lineations in the cover series rocks together with the uniform foliation pattern indicate the presence of a large-scale gently NNE - dipping shear zone that extends for at least 50km in

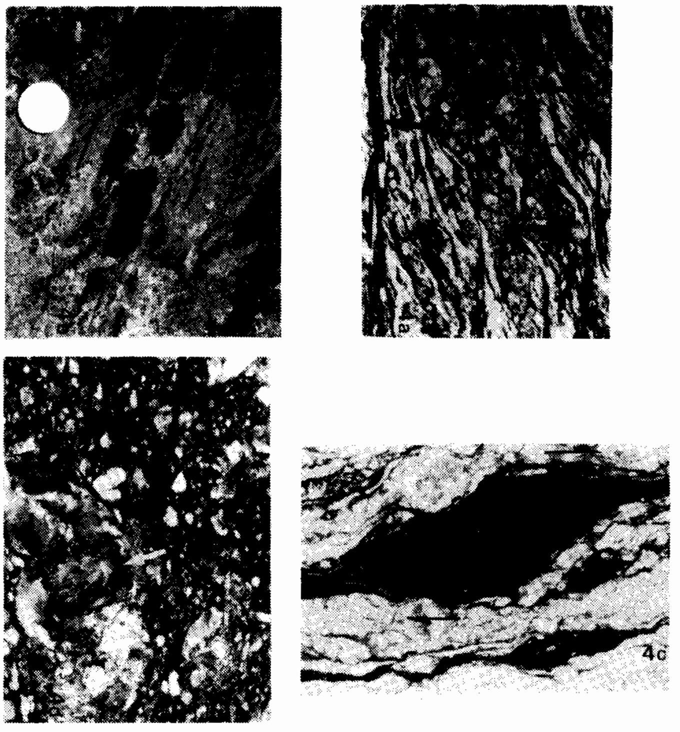

Fig. 4(a-d): (a) Extensional shear bands in the cover series mica-schists. The shear bands are horizontal in the photomicrograph and indicate a dextral shear-sense. Two vertical arrows show shear bands filled with fine-grained chlorite. Width of photomicrograph is 2.5mm. (b) Asymmetric boudinage of competent layer in cover series rocks indicating a dextral shear sense. Coin is 2cm in diameter and view is towards the west. (c) Biotite-"fish" in the Salihli granodiorite indicating a dextral sense of shear. Width of photomicrograph is 5mm. (d) Cataclasite derived from the Salihli granodiorite. White arrow indicates large clast with seriticised igneous plagioclase in the center surrounded by quartz showing older ductile deformation features. Width of photomicrograph is 2.5mm.

an E-W direction (Fig. 3). Abundant kinematic indicators reveal a consistent top-to-the-N to NE shear sense in the cover series rocks (i.e. the hanging wall is moving towards the N-NE. In phyllites and schists these are asymmetric extensional shear bands (Fig. 4a), assymetric boudings (Fig. 4b) and abundant muscovite-"fish" (Hanmer & Passchier 1991). In mylonitic quartzites oblique grain shape fabrics (steady state foliation) (Means 1981) occur.

The two granodiorites possess foliations and stretching lineations parallel to and continuous with those of the country rock. S-C-fabrics (Berthé et al. 1979) as well as biotite-"fish" (Fig. 4c) (Lister & Snoke 1984) indicate that the intrusions were deformed in the same top - to - the N to NE shear regime as the cover series rocks. In addition the Turgutlu granodiorite has a contact-metamorphic aureole, where the relationship between foliation and andalusite porphyroblasts indicates considerable post-emplacement deformation. These observations demonstrates that the granodiorites are syntectonic with respect to the extensional ductile deformation. The granodiorites have been dated by 40Ar/39Ar on biotite and yield plateau ages of 12,2±0,4Ma (Salihli granodiorite) and 13,1±0,2Ma (Turgutlu granodiorite)(detailed results will be published elsewhere).

BRITTLE DEFORMATION

The cataclasites at the top of the cover series rocks are derived from the different cover series rocks, however it is often difficult to decide which rock-type was the precursor. In the upper part and especially on top of the cataclasites occur numerous fault planes that are oriented parallel to the cataclasite surface. Striations on the fault planes trend N to NE and brittle kinematic indicators like Riedel shear planes and lunate structures (Petit 1987) indicate a top-to-the-N to NE movement of the hanging wall.

The cataclasites are coherent rocks with a fine-grained matrix consisting of quartz, chlorite and minor amounts of muscovite in which larger lithic and mineral fragments (mainly quartz and feldspar) occur. Near the top of the cataclasites brown amorphous iron oxides and/or hydroxides and calcite occur as dispersed particles and more concentrated in irregular distributed anastomosing cracks. More regular microscopic veins filled with quartz or calcite ± iron oxides/hydroxides originated as shear or extension fractures. Quartz clasts and lithic fragments in the fine-grained cataclastic matrix commonly show undulose extinction and bulging of grain boundaries indicating dynamic recrystallization prior to cataclastic deformation (Fig. 4d).

DISCUSSION

Metamorphic conditions during the regional ductile deformation of the cover series rocks can be inferred from the deformation mechanisms in feldspar and quartz. The dynamic recrystallization of quartz and the brittle deformation of feldspar (mainly syn- and antithetic shear fractures) in the granodiorites as well as in the cover series rocks point to greenschist facies conditions during ductile deformation (Voll 1976, Altenberger et al. 1987, Pryer 1993). This conclusion is supported by the growth of fine-grained chlorite in asymmetric extensional shear bands and the transformation of rare garnet to biotite and chlorite in mica-schists.

Diffusion studies on biotite from a granodiorite similar to the intrusive rocks in the study area suggest a closure temperature for biotite in the range of 345o-280oC, depending on the rate of cooling (Harrison et al. 1985). Due to the tectonic denudation (in contrast to erosional denudation) of the Ödemis-Kiraz submassif it is assumed that the rate of uplift and cooling was relatively fast. In this case the closure temperature in biotite is assumed to be rather high and here a closure temperature in the range of 320o-340oC is assumed. The granodiorites have been deformed under grenschist-facies temperatures. Biotite ages are therefore interpretated as cooling ages, however temperatures during ductile deformation were only slightly higher than the closure temperature for biotite. Due to the rapid tectonic exhumation of the submassif the ages are probably near to the intrusion age.

As the granodiorites are syntectonic the age determinations give a minimum age of ≈13Ma for the onset of extensional deformation in this part of the Menderes-Massif. It is emphasized here that these ages are minimum ages and that the onset of extension in the Menderes - Massif is probably older. This is supported by a [illegible] Menderes-Massif, where extension started in latest Oligocene/early Miocene times (Seyitoglu et al. 1992).

The cataclasites are interpreted to have been formed, when crystal-plastic behaviour of quartz and therefore ductile deformation in the cover series rocks became impossible at temperatures of around 275oC (Voll 1976). Strain was then concentrated in a more restricted zone of cataclastic flow associated with the development of a low-angle normal fault. The striated fault surfaces at the top of the cataclasites and the regional development of this planar feature are the expression of this detachment fault. The kinematic indicators (Riedel shear planes and lunate fractures) at the top of the cataclasites indicate a top-to-the-N to NE displacement of the hanging wall along the detachment fault (Petit 1987).

Different deformation phases (extensional as well as minor compressional events) of late Miocene to Quaternary age have been derived from the analyses of fault mechanisms in southwestern Turkey (Angelier et al. 1981). The inferred NNE extension direction of the main extensional event is in agreement with our results from the detachment fault, however no evidence for any compressional events on the rotation of the extension direction were found in our study area. In contrast the parallelism between stretching lineations in the cover series rocks and striations on the low-angle normal fault demonstrates that the extension derection remained more or less the same during the tectonic exhumation of the submassif.

The progressive syntectonic uplift of the Ödemis-Kiraz submassif is well illustrated by the Salihli granodiorite. After the ductile deformation of the granodiorite (see Fg. 4c) succesive uplift of the submassif led to the incorporation of the granodiorite into the cataclasite zone (see Fig. 4d). Abundant lithic fragments and quartz clasts in the cataclasites show evidence of earlier ductile deformation and indicate that the ductile fabrics were completely reworked during later cataclastic deformation.

All the previous workers have related the Neogene sediments to the formation of the Gediz Graben (e.g. Angelier et al. 1981, Paton 1992). In contrast we suggest that the Neogene sediments presently exposed along the southern margin of the Gediz Graben were deposited in the hanging wall of the low-angle normal fault during continental extension. During progressive uplift and extension the sediments were tilted and emplaced against the cataclasite surface. Consequently the sediments are not related to the formation of the Gediz Graben but are older. The Gediz Graben is only the latest extensional feature and its steep main-bounding normal fault immediately north of the Neogene sediments truncates and off-sets the older detachment fault.

REFERENCES

ALTENBERGER, U., HAMM, N., KRUHL, J.H. (1987). Movements and metamorphism north of the Insubric Line between Val Loana and Val d'Ossola (Italy). Jb. Geol. 130: 365-374.

ANGELIER, J., DUMONT, J.F., KARAMANDERESI, H., POISSON, A., SIMSEK, S., UYSAL, S. (1981). Analyses of fault mechanisms and expansion of southwestern Anatolia since the late Miocene.. Tectonophysics, 75: 1-9.

ASHWORTH, J.R., EVIRGEN, M.M. (1984). Garnet and associated minerals in the southern margin of the Menderes Massif, southwest Turkey. Geol. Mag. 121(4): 323-337.

BERTH, D., CHOUKROUNE, P., JEGOUZO, P. (1979). Orthogneiss, mylonite and non coaxial deformation of granites: the example of the South Armorican Shear Zone. J. Struct. Geol., 1: 31-42.

BRINKMANN, R. (1976). Geology of Turkey. Amsterdam, Elsevier, 158 pp.

DORA, O. Ö., KUN, N., CANDAN, O. (1990). Metamorphic history and geotectonic evolution of the Menderes Massif. International Earth Sciences Congress on Aegean Regions; Proceedings: 102-115 (ed. Savascin, M.Y. & Eronat, A.H.).

DÜRR, S. (1975). Über das Alter und geotektonische Stellung des Menderes-Kristallins/SW-Anatolien und seine Äquivalente in der mittleren Ägäis. Habilitationsschrift, Marburg/Lahn, 107 pp.

HANMER, S., PASSCHIER, C.W. (1991). Shear-sense indicators: a review. Geol.Survey Canada, Paper 90-17.

HARRISON, T.M., DUNCAN, I., MCDOUGALL, I. (1985). Diffusion of 40Ar in biotite: Temperature, pressure and compositional effects. Geochimica, Cosmochimica Acta, 49: 2461-2468.

KETIN, I. (1966). Tectonic units of Anatolia (Asia Minor). Bull. Min. Res. Expl. Inst. Turkey, 66: 23-34.

LISTER, G.S. and SNOKE, A.W. (1984). S-C-Mylonites. J. Struct. Geol. 6, 617-638.

MEANS, W.D. (1981). The concept of a steady-state foliation. Tectonophysics, 78: 179-199.

PATON, S. (1992). Active normal faulting, drainage patterns and sedimentation in southwestern Turkey. J. Geol. Soc. Lond., 149: 1031-1044.

PETIT, J.P. (1987). Criteria for the sense of movement on fault surfaces in brittle rocks. J. Struct. Geol. 9, 597-608.

PRYER, L.L. (1993). Microstructures in feldspars from a major crustal thust zone: the Grenville Front, Ontario, Canada. J. Struct. Geol., 15: 21-36.

SATIR, M., FRIEDRICHSEN, H. (1986). The origin and evolution of the Menderes Massif, W-Turkey: A rubidium/strontium and oxygen isotope study. Geologische Rundschau, 75/3: 703-714.

SCHUILING, R.D. (1962). On petrology, age, and structure of the Menderes migmatite complex (SW-Turkey). Bull. Min. Res. Expl. Inst. Turkey, 58: 71-84.

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 No 7: 693-707.

SEYITOGLU, G., SCOTT, B.C., and RUNDLE, C.C. (1992). Timing of Cenozoic extensional tectonics in west Turkey. J. Geol. Soc. Lond., 149: 533-538.

VOLL, G. (1976). Recrystallization of quartz, biotite and feldspars from Erstfeld to the Leventina Nappe, Swiss Alps, and its geological significance. Schweiz. mineral. petrogr. Mitt., 56: 641-647.