REGIONAL-SCALE TERTIARY EXTENSION-RELATED KINEMATIC FRAMEWORK IN NORTHERN AEGEAN REGION: EVIDENCE FROM THE EASTERN RHODOPES-THRACE (BULGARIA-GREECE) AND THE BIGA PENINSULA (NW TURKEY)

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Introduction

Since the first recognition of metamorphic core complexes of cordilleran-type in the Cyclades (Lister et al., 1984), the Aegean region is now considered as a natural laboratory for studying processes of crustal extension and exhumation of metamorphic terrains (Jolivet, Patriat, 1999; Jolivet, Faccenna, 2000). Many studies in the Aegean region and its surroundings (e.g. South Rhodope, Cyclades, Menderes Massif) have demonstrated the protracted Oligocene-Miocene back-arc extension (Dinter, Royden, 1993; Sokoutis et al., 1993, Gautier, Brun, 1994; Hetzel et al., 1995). Ductile shear fabrics associated with stretching lineations in this region were used to establish kinematic directions of extension relative to active deformation (Jolivet et al., 1994; Walcott, White, 1998). In this contribution, we present regional kinematic study of exhumed basement rocks in the northernmost part of the Aegean region, yet with a still poorly constrained extension-related kinematic framework. The considered key areas are the Eastern Rhodopes and Thrace of south Bulgaria and northern Greece and the Biga Peninsula of northwest Turkey. The kinematic analysis highlights continuous record of NNE–SSW to NE–SW kinematic direction from Paleocene to Miocene syn- to post-orogenic extension.

Geological setting

The regional-scale tectonic pattern of the Eastern Rhodopes and Thrace areas is dominated by late Alpine metamorphic domes, namely the Kesebir-Kardamos and the Byala reka-Kechros domes (Fig. 1, Bonev, 2005; Bonev et al., 2005a, b). From the base to the top, both large-scale structures expose a pre-Alpine and Alpine basement consisting of (i) a lower high-grade tectonic unit, (ii) an upper high-grade tectonic unit, and (iii) an overlying low-grade Jurassic-Early Cretaceous subduction-accretion unit. Basement units are bounded by contractional, syn-metamorphic thrust contacts, and low-angle extensional detachments respectively related to pre-latest Late Cretaceous crustal thickening and Tertiary extension (Krohe, Mposkos, 2002; Bonev et al., 2005a, b). Other important features of both areas are (iv) Late Cretaceous-Paleocene/Eocene-Oligocene granitoids that intrude basement rocks, and (v) syn- to post-tectonic sedimentary deposits (Maastrichtian to Pliocene), including Late Eocene-Oligocene volcanic and volcanic-sedimentary successions, that represent cover sequences.

The Biga Peninsula of northwest Turkey (Fig. 1, Okay et al., 1991 for review) exposes in ascending order: (i) high-to medium-grade basement rocks in several occurrences, including the Kazdağ Massif and Çamlica micaschists (Okay, Satir, 2000a, b) and the Kemer micaschists (Bonev, Beccaletto, 2005), (ii) the various units of the Karakaya Complex, (iii) the accretion-related mid-Cretaceous Çetmi mélange (Okay et al., 1991; Beccaletto et al., 2005), (iv) the Ezine Zone, where the Permo-Triassic sedimentary Ezine Group is tectonically overlain by the Barremian Denizgören ophiolite, and (v) widespread occurrence of plutonic, volcanic and associated volcano-sedimentary rocks, related to the transition from a collisional to an extensional tectonic regime during the Cenozoic. Distinct units are intercalated by shallow-dipping mylonitic shear zones, extensional detachments and late faults (belonging to North Anatolian Fault System - NAFS) (Okay, Satir, 2000a; Beccaletto, Bonev, 2005; Beccaletto, Steiner, 2005).

Kinematics

Shear structures associated with the stretching lineations in mylonitic metamorphic tectonites were systematically measured, in order to establish the kinematic direction and sense of tectonic transport in the exhumed ductile crust (Fig.1). Kinematic analysis demonstrates regionally consistent (1) NE–SW

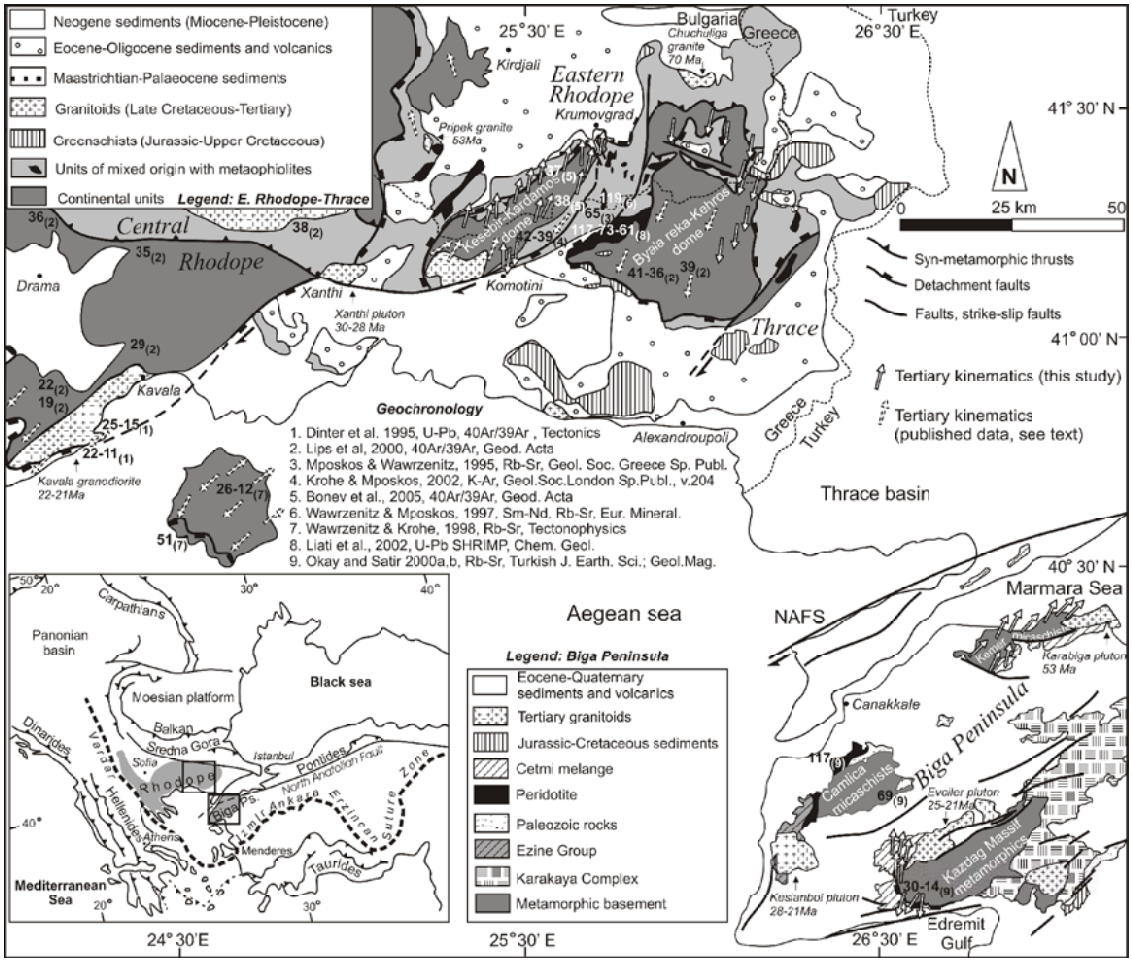

Fig. 1. Synthetic kinematic map of extension direction and shear senses in the studied areas of northern Aegean region. Arrows show the mean of measurements on several sites of stretching lineations and shear senses. Dashed arrows: data for comparison from Dinter and Royden, 1993, Burg et al., 1996, Wawrzenitz and Krohe, 1998, Krohe and Mposkos, 2002.

(~20-40°) extension direction in the core of the Kesebir-Kardamos dome with top-to-the NE ductile then brittle shear sense in the north, and (2) NNE–SSW direction (~20°) with top-to-the SSW shear sense in the core of the Byala reka-Kechros dome under the same deformation conditions. Similarly, in the corresponding parts of these domes in northern Greece, the kinematic direction is consistently oriented NNE–SSW to NE–SW and associated with analogous ductile to semi-brittle shear senses in both large-scale structures. Shear sense variations (i.e. top-to-the SW shear in the Kesebir-Kardamos dome to the south) most likely account for extension-induced ductile flow accommodation in the footwall during its upward bending or possibly activity on conjugate detachments.

In the northern Biga Peninsula, NE-directed (~40°) ductile to semi-brittle extension characterizes the metamorphic strip of the Kemer micaschists. Further south, the Alakeçi mylonitic zone (AMZ, Okay, Satir, 2000b), bounding the northern flank of the Kazdağ Massif presents evidence of down dip top-to-the NNE extension (~20°), assisting exhumation of this part of the massif. To the south, the Şelale detachment (Beccaletto, Steiner, 2005) accommodates top-to-the SSW extensional exhumation of its southern flank. Overall, the basement rocks in the Biga Peninsula present a NNE–SSW to NE–SW extension direction.

Based on syn-kinematic metamorphic conditions within the shear structures, the metamorphic crystallizations demonstrate that shearing took place in decreasing metamorphic conditions from amphibolite to greenschist-facies. The ductile fabrics have been progressively overprinted by semi-brittle structures and finally brittle faults implying progressive exhumation of basement rocks from ductile to brittle field, consistent with the extension.

Discussion: from syn- to post-orogenic extension in northern Aegean region

The geometry of the kinematic framework in the basement rocks considered in this study shows regionally consistent orientation of the stretching lineations and extension direction with an overall NE–SW trend. Local variations in the kinematic direction are due to drag against late faults and/or block-rotation linked to neotectonic (active) deformation. Shear senses variations attest for local conditions of the stress field associated with the style and mode of extension. Bivergent mode of extension is locally established (Beccaletto, Bonev, 2005). This kinematic framework combined with the age constraints indicates spatial and temporal consistency of the regional trend of extension direction from the latest Paleocene to Miocene.

Stratigraphic ages (syn- and post-tectonic sedimentary basin fill) and regional geochronology (metamorphic/cooling ages in the basement rocks, crystallization ages of magmatic rocks) provide constraints for the timing of extensional deformation in the region. Following and/or coeval with the late phase of Cretaceous crustal thickening, the NE–SW oriented extension in the northernmost Aegean commenced earlier to the north (Paleocene-Eocene, e.g. the Kesebir-Kardamos dome, the Kemer mica schists, possibly onset of activity of the AMZ on the northern flank of the Kazdağ Massif). This syn-orogenic extension relates to subduction-collision history coeval with the closure of the Vardar Ocean. Then, it was followed by a late Oligocene-Miocene Aegean post-orogenic back-arc extension, which evolved further south (e.g. southern flank of the Kazdağ massif, the Thasos metamorphic core complex, e.g. Wawrzenitz, Krohe, 1998, the Strymon Valley detachment, e.g. Dinter, Royden, 1993) and relates to roll-back of the remnant oceanic slab in the Mediterranean region (Wortel, Spakman, 2000). Southward migration of extension in the north Aegean region with an overall maintained kinematic direction and the associated time equivalent magmatism accounts for sequential retreat of the subduction boundary along the Eurasian plate margin from the Oligo-Miocene to Present.

Conclusions

1. Stretching lineations orientation and kinematic analysis of exhumed ductile crust in northernmost Aegean region constrains a regionally consistent NE–SW kinematic direction of extension from the Paleocene to Miocene.
2. NE-directed syn-orogenic extension (Paleocene-Eocene) recorded mainly in the north was followed by post-orogenic extension that evolved in the south (late Oligocene-Miocene), which appears SSW-directed. Possibly, syn-orogenic extension interfingers with or was gradually replaced by post-orogenic extension in some areas.
3. Regional-scale correlations of the studied extended terrains in the northern Aegean suggest that they were kinematically coupled during the Tertiary extension-related tectonics, showing also many other temporarily common features inherent to this deformation phase, such as magmatism and basin sedimentation.

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РЕГИОНАЛНА КИНЕМАТИЧНА РАМКА СВЪРЗАНА С ТЕРЦИЕРНА ЕКСТЕНЗИЯ В СЕВЕРНОЕГЕЙСКИЯ РЕГИОН: ДАННИ ОТ ИЗТОЧНИ РОДОПИ-ТРАКИЯ (БЪЛГАРИЯ-ГЪРЦИЯ) И ПОЛУОСТРОВ БИГА (СЗ ТУРЦИЯ)

Николай Бонев, Лоран Бекалето

Изследването представя регионален поглед върху кинематиката на метаморфни единици от Източни Родопи и Тракия (България-Гърция) и полуостров Бига в Северозападна Турция в хода на терциерна екстензия, обусловила тяхната ексхумация, придружена от зони на пластично и крехко-пластично срязване и полегати разломи на отделяне. ССИ-ЮЮЗ до СИ-ЮЗ направление, маркирано от линейност на разтягане определя кинематичната рамка на корова екстензия в тази част на Северноегейската област. Асоциращите кинематични индикатори демонстрират СИ и ЮЗ насочен тектонски транспорт, отчитащ деформацията за дадена регионална структура. Локално кинематичната картина има бивергентен характер. Кинематичният анализ насочва към запис на син- и посторогенна екстензия в интервала палеоцен-миоцен, подчинена на геодинамични условия, обусловени от затваряне на Вардарския океан при субдукция-колизия и отдръпване на субдукционната граница по ръба на Евроазиатската плоча.