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MULTIPHASE CRUSTAL THICKENING IN THE CENTRAL PARTS OF THE BALKAN PENINSULA

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ABSTRACT

The anomalously thick (up to 50 - 55 km) crustal segment (Rhodope Massif) in the central parts of the Balkan Peninsula has an almost isometric oval shape. It formed in result of a multiphase process of crustal thickening interrupted by episodes of crustal thinning and destruction. The principal thickening episodes were related to multiphase Precambrian intense folding and shearing, and to Hercynian crustal melting and granitoid igneous activity. Alpine crustal thickening was due to Mid Cretaceous thrusting and shearing; homogeneous ductile deformation; crustal anatexis and intrusion of Late Cretaceous magmas. Paleogene collapse structures and related igneous activity played an important role in the redistribution of the crustal thicknesses. The overall extension since the Late Miocene contributed to continuing crustal thinning through normal faulting (including along low-angle normal faults) and erosion in the uplifted blocks.

INTRODUCTION

The central parts of the Balkan Peninsula are characterized (Fig. 1) by increased crustal thickness deduced mainly on the basis of gravity studies (DOBREV and SCHUKIN, 1967; VELČEV et al., 1970; MAKRIS, 1977; YOSIFOV and PČELAROV, 1977; data of Yugoslav geophysicists generalized by ANĐELKOVIĆ, 1982) taking also into account magnetometric data, data on the isostasy (DOBREV and STANOEV, 1985), the geothermal field, and the deep seismic sounding and the reflected seismic waves (VOL'VOVSKIY et al., 1985; DACHEV, 1988). The aim of the present paper is to outline the principal processes and mechanisms which may have contributed to crustal thickening in the past as well as the principal thickening events recorded by geologic evidence.

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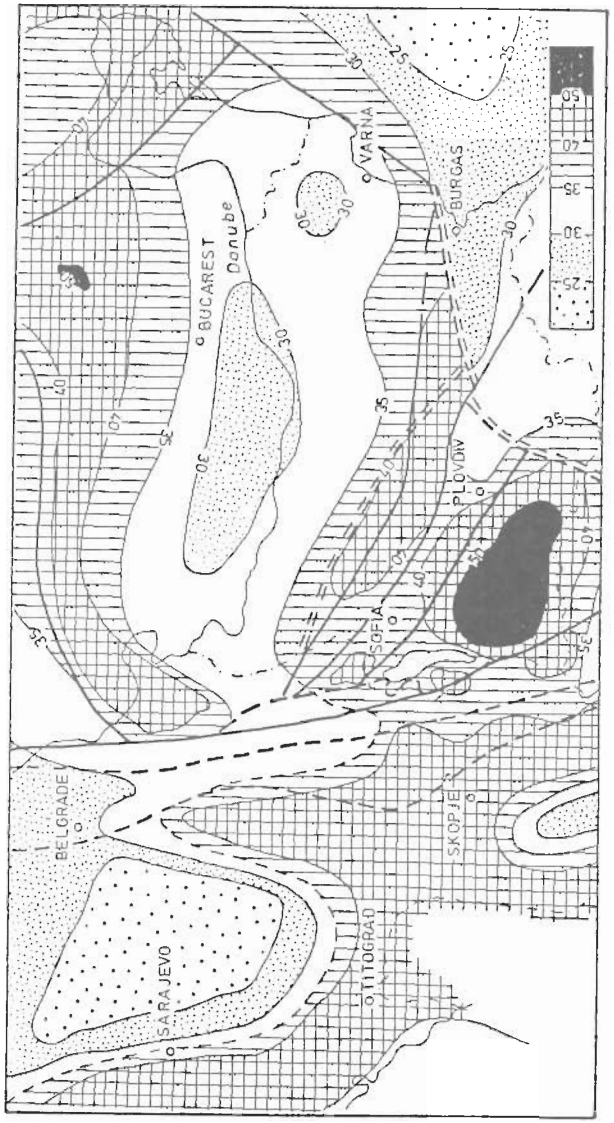

Fig.1. Sketch for the depth of the Mohorovičić discontinuity in the central and northern parts of the Balkan Peninsula. After data summarized by ANĐELKOVIĆ (1982) and DACHEV (1988). Areas of thin crust stippled, areas of thick crust black or cross-hatched. Important crustal faults with thick lines, faults displacing Moho (after VELČEV et al., 1982, and DACHEV, 1988) with double dashed lines.

Although some of the geological data are controversial and may be interpreted in a different manner, the proposed ideas account for most of the evidence, and are consistent with existing plate tectonic models for the development of the region (BOYANOV et al., 1989).

CRUSTAL THICKNESS DISTRIBUTION

The eastern part of the Balkan Peninsula is characterized (Fig. 1) by two large positive gravity anomalies which correspond to two crustal thickness minima. The more important one coincides with the Black Sea depression, and continues to the west of the latter into the Strandža and East Rhodope tectonic units. It is bound to the west by the Zlatograd-Yambol gravity threshold (VELČEV et al., 1970) probably displaced by faults of the Marica fault belt. This positive anomaly probably continues also to the southwest into the thin-crusted Aegean region. The other positive anomaly corresponds to the Moesian platform. This region (crustal thickness about 30 - 35 km) is bound to the north by the linear negative anomaly of the Carpathians, and to the south and southwest, by another linear negative anomaly which partially coincides with the Balkanides but is shifted slightly to the south, in the northern parts of the Srednogorie zone. There, a concentration of Paleozoic granitoids within the Sredna gora crystalline block is observed (DOBREV and SCHUKIN, 1967).

Unlike the linear negative gravity anomalies bound to the young Alpine fold belts with thickened crust, the largest negative anomaly on the peninsula has almost isometric outline (Fig. 1). The crustal thickness in that area reaches more than 50 km in the Rhodope massif. Two small gravity minima are situated in northwest prolongation of the massif, and the whole negative field is bound to the west by the linear positive anomaly ("gravity ridge" - DACHEV, 1988) which coincides with the Struma (Kraištid) and Vardar lineaments. The large almost isometric gravity anomaly of the Rhodope massif coincides with the position of the largest granitoid batholiths of Sredna gora and Rila - West Rhodope (JARANOFF, 1960) as well as with the isostatic anomalies and maxima of recent uplift (DOBREV and STANOEV, 1985). After corrections introduced according to the seismic data (DACHEV, 1988) the relief of Moho outlines the Rhodope massif west of the Zlatograd - Yambol gravity threshold as a considerably thickened crustal lenticular body.

Besides the lateral inhomogeneities of the crust, vertical inhomogeneities (DACHEV, 1988) are also detected. They may be explained with the state of crustal material at different pressures and temperatures, the lateral distribution of the principal layers being dependent on the previous tectonic history (ZAGORČEV, 1990). Deformations in the lower anhydrous crust (layer "A") may occur as homogeneous strain but cataclastic flow in the deeper parts and movements along deep shear zones have been possible in epochs of crustal thickening (DEWEY et al., 1986). The hydrous crust (layer "B") could be deformed by cataclastic flow and grain-size reduction with considerable friction-induced temperature increase. A thin low-velocity layer (Fig. 2) has been recently found only within a restricted area of the Rhodope massif (VOL'VOVSKIY et al., 1985). Its discontinuous character has been related, according to DACHEV (1988), to the supposed deep thrusting in the Rhodope massif.

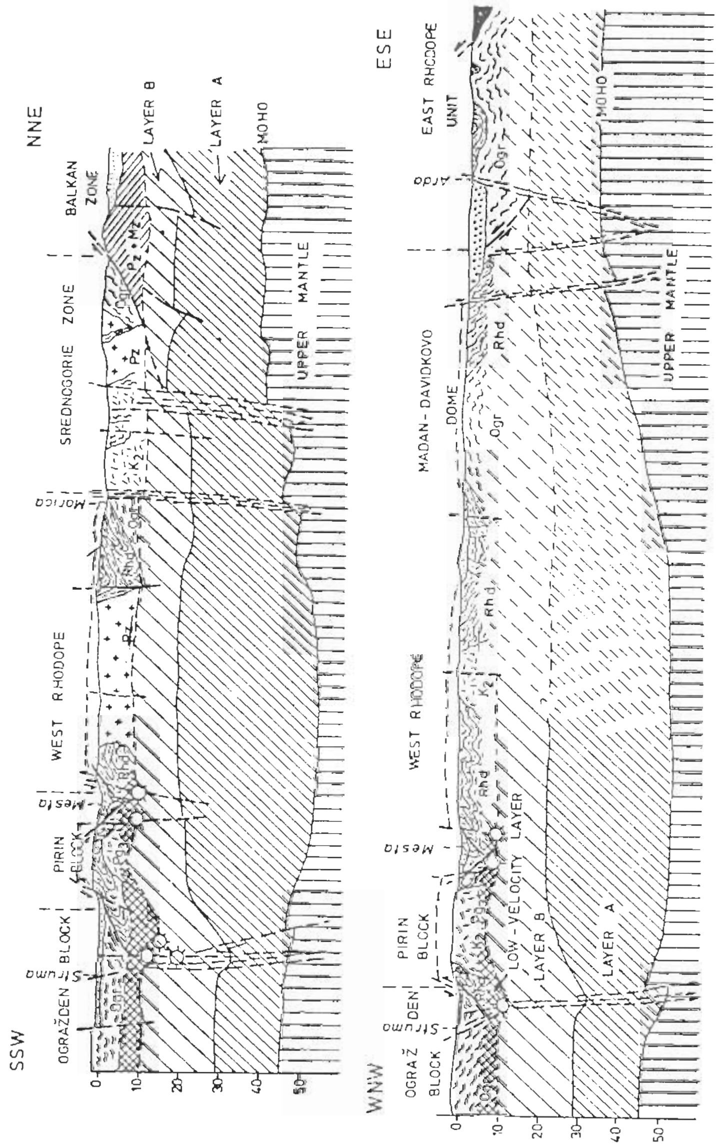

Fig. 2. Schematic deep sections through the central parts of the Balkan Peninsula. Partially after DACHEV (1988) modified by ZAGORČEV (1990). Eastern part of the WNW-ESE section highly conjectural.

Similar low-velocity layers in other regions are characterized (DEWEY et al., 1986) by maximum shear strength of the "wet" quartz, and by deformations through superplastic flow. Consequently, the low-velocity layer can take over considerable deformations in phases both of predominant compression or extension. The granitoid-metamorphic crust situated over the low-velocity layer can be deformed mainly in a brittle manner, by shear faulting and fracturing, and the normal faults and fault zones usually converge towards the upper boundary of the low-velocity layer with concentration of seismic foci in that area. The rheologic properties of the low-velocity layer do not exclude the possibility of independent behaviour of the regions above and beneath it, and even of existence of a compression regime in depth, and of extension regime within the granitoid-metamorphic crust (ZAGORČEV, 1990) with strain concentration and superplastic flow within the low-velocity layer. Thus, the existence of the latter cannot be considered as a definite proof for considerable horizontal movements (translations) but is significant for the adjustments at the boundaries between layers with different rheological behaviour.

THICKENING EVENTS AND MECHANISMS IN THE PAST

The early thickening of the crust within the future Thracian massif occurred in the Precambrian, during isoclinal folding of the Ograzdenian (Prarhodopian) and Rhodopian Supergroups (KOZHOUKHAROV and others in ZOUBEK, ed. 1988) coevally to amphibolite facies regional metamorphism. Tight to isoclinal synmetamorphic folding played an important part in different pre-Hercynian (and most probably, Precambrian) tectonic units and zones now preserved as relics within the Alpine tectonic zones (Fig. 3), as e.g. the Sredna gora crystalline block, the Pirin-Pangaion zone, etc. As early as the Vendian or the Early Paleozoic, a Thracian (Proto-Rhodope) massif (BONČEV, 1978) formed as a thickened crustal lens, and was partially covered at its periphery by Vendian - Cambrian(?) diabase-phyllitoid complexes directly related to similar formations within an ocean basin to the north. During the Hercynian collisions (HAYDUTOV, 1989) anatexis within this thickened crustal lens produced granitoid magmas of the Southbulgarian granitoids which intruded in three principal phases dated by ZAGORČEV and MOORBATH (1986b). The first phase occurred immediately after the formation of a basic (including ultrabasic cummulates) intrusive belt along the axis of the Sredna gora crystalline block which could have represented a deep expression of a Hercynian island arc. The granitoids of the first phase intruded almost simultaneously with some portions of the basic magma of the belt, with complicated assimilation and hybridization phenomena. They are of a I-type, with a comparatively low Sr$_i$ (about 0.706), a low A/CNK molar ratio, and high FeO and CaO contents. The second and third-phase granitoids were intruded in deep to moderate mesozonal conditions at decreasing depth. They consist of granites to leucogranites with a high A/CNK ratio (1.0 to 1.4), comparatively high (about 0.71) Sr$_i$, and low CaO and FeO contents most similar to late-collision to post-collision granitoids (HARRIS et al., 1986). Crustal anatectic origin confirms the formation within a thickened crust with increased heat flow. Intrusion at progressively shallower depths within the time

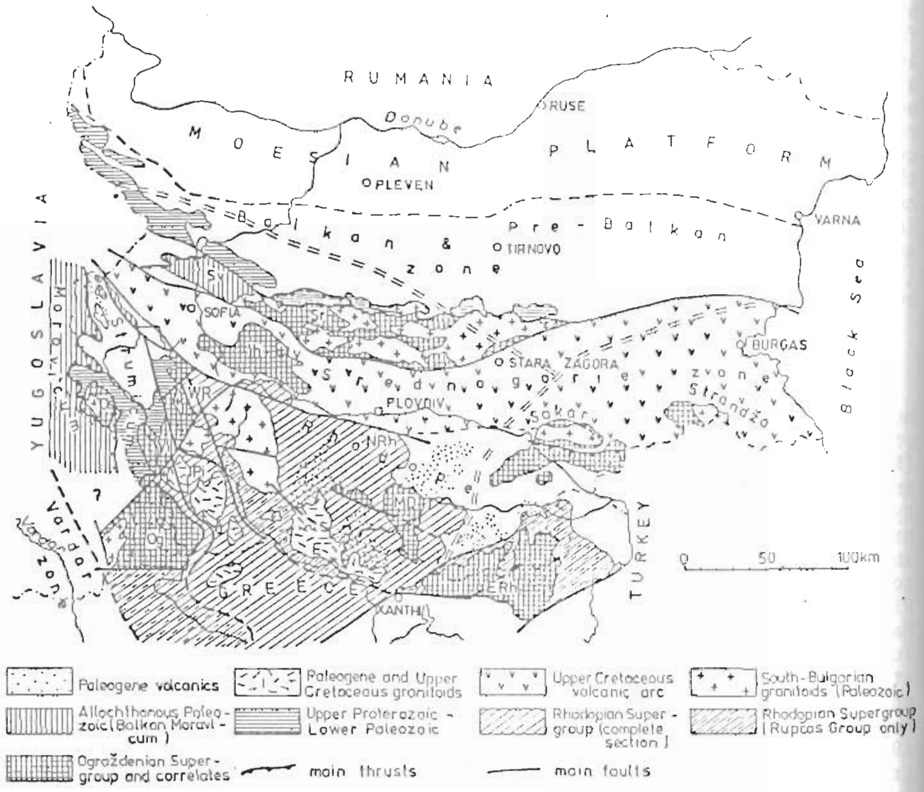

Fig. 3. Tectonic sketch map of Bulgaria. Important structures: Sv - Svoge anticlinorium; Sr - Sredna gora crystalline block; Os - Osogovo anticline; WR - West Rila block; Vl - Vlahina block of the Struma zone (Strumicum); Og - Ogražden block; Pi - Pirin-Pangaion zone; NRh - North Rhodope anticline; MD - Madan-Davidkovo dome; E - Elatia pluton; ERh - East Rhodope unit. Deep faults displacing Moho (after VELČEV et al., 1970, and DACHEV, 1988) with double dashed lines.

interval 340 Ma BP - 240 Ma BP is probably related to the continuous uplift of the Thracian massif. The consecutive erosional late Hercynian thinning of the Thracian massif possibly resulted in crustal thickness reduction with ca. 10 km thus obtaining a temporary isostatic equilibrium.

The beginning of the Alpine development of the southern margin of the Eurasian continental plate (BOYANOV et al., 1989) was marked by littoral sedimentation, and the moderately thinned crust of the Thracian massif probably maintained a slow uplift tendency. The same supposed (but not yet definitely proven) attitude of this future Rhodope massif probably persisted during the whole Triassic and Jurassic when shallow marine basins developed to the north with gradual deepening (culminating with the Late Jurassic - Early Cretaceous Niš-Troyan flysch trough), and the Tethyan (Vardar) ocean, to the south and southwest.

Mid Cretaceous tectonics was most important for the Alpine tectonic development. Due to the closure of the Tethys ocean through northeast-directed subduction under the former Thracian massif, parts of the continental slope (Morava zone) and of the Thracian massif itself (Ogražden block) were uplifted and thrusted over the Strumicum and parts of the Thracian massif. Deformations at different depths took place through different mechanisms. Thus, the uplifted and thrusted units were characterized by thin-skinned tectonics (folding of ductile multilayers, decollement or brittle fracture, shear and thrusting) in conditions of low temperature and pressure. In deeper levels within the autochthonous to parautochthonous Strumicum, the deformation took place in conditions of very low-grade metamorphism and was expressed mainly as folding and simple shear along competence contrast boundaries. Within the Rhodope massif itself, Mid Cretaceous tectonic events occurred in conditions of crustal thickening and increased heat flow coevally with metamorphic greenschist to amphibolite facies events. At least two phases of crustal thickening and deep-seated shear may be considered. The first phase consisted of shear folding with NE-SW trending fold hinges and composite lineation (intersection + stretching + mineral lineation), the tight to isoclinal folds being formed in greenschist to amphibolite facies conditions, and schistosity and lineation being superimposed also over Hercynian granitoids. This thickening was probably coeval to crustal thinning in the East Rhodope (Circum-Rhodope) zone, and was partially carried out through lateral crustal flow. Both phenomena began in conditions of higher ductility, shear and flow, with necking and flaking at deeper levels, and the high heat flow triggered crustal melting (anatexis of Rhodopian-type metamorphics, ZAGORČEV and MOORBATH, 1986a) with formation of granitic to monzonitic magmas. The process continued later in conditions of decreasing ductility with northwest-vergent thrusting (East-Rhodope complex thrust of Boyanov - BOYANOV et al., 1989).

The subsequent Late Cretaceous development was marked by a total change in the stress field and further differentiation of tectonic regimes. Disintegration processes within the northern edge of the former Thracian massif developed into a full separation of the Rhodope massif from the Sredna gora crystalline block through a WNW-ESE trending volcanic island arc and back-arc trough (Srednogorie zone) which formed over the thinning crust and was marked by extensive igneous activity. Crustal thickening continued to the south, within the Rhodope massif, with south-vergent shear (BURG et al., 1990) in amphibolite-facies conditions, the NE-SW stretching lineation almost coinciding with the older hinge-parallel lineation. The igneous activity across the system of former (or dying-out) subduction zone, plateau (newly-formed Morava-Rhodope zone) and volcanic island arc and trough (Srednogorie zone) developed (Fig. 4) from the Turonian to the Campanian included. The coeval intrusive magmatism in the Srednogorie zone was characterized by a low Sr_i (about 0.704), low (0.6 to 0.8) A/CNK ratio and high FeO and CaO contents, the initial magma being probably of upper mantle origin (ZAGORČEV and MOORBATH, 1987) and evolving with assimilation, storage and hybridization. Several intrusive phases are usually distinguished, the total duration being of the order of 10 Ma. In the same time, granitoid magmas of crustal origin formed and intruded within the thickened crustal lens of the Rhodope massif. They were characterized by high Sr_i (ca. 0.71) which became lower in the southern parts of the massif.

In the Maastrichtian, intracontinental collision in the north of the Morava-Rhodope zone resulted in its uplift and north-vergent thrusting over the Srednogorie zone. Internal movements within the Rhodope massif contributed either to additional thickening (local thrusts) in the compressive phases, or to crustal thinning through extension and rapid uplift by normal faulting along low-angle and steeper normal faults. The Rhodope massif reached its greatest crustal thickness (probably about 65 - 70 km), and starting isostatic uplift triggered a fast erosional thinning. Paleocene - Oligocene lacustrine sediments with thick breccias covered the eastern periphery of the massif sealing the Late Cretaceous thrusts (KOZHOUKHAROV et al., 1991).

Paleogene deformation was dominated by intracontinental collision in different regimes (BOYANOV et al., 1989). A sequence of extensional events with normal faulting and acid to intermediate volcanism (at deeper levels, with intrusion of granitoid crustal melts) occurred within the areas of thickened crust (Rhodope massif) whereas magmas with lower Sr_i (upper mantle or mixed origin) were formed at the southern and eastern peripheries of the massif in the areas with thinned crust.

After the Early Miocene compression phase, the crustal deformations proceeded in conditions of overall extension. The thickened crust of the Rhodope massif favoured continuous isostatic uplift combined with extensional collapse. Normal faulting along steep and low-angle faults, and erosion in the uplifted blocks resulted in gradual crustal thinning in the region.

CONCLUSIONS

Deformation mechanisms leading to crustal thickening in the region included isoclinal folding; homogeneous deformation; ductile flow and possible lithospheric flaking; movements along low-angle ductile shear zones and thrusts with stacking of thrust sheets; vertical or/and lateral supply of mantle or crustal material through magmas or/and fluids.

Crustal thickening processes began during the Late (?)

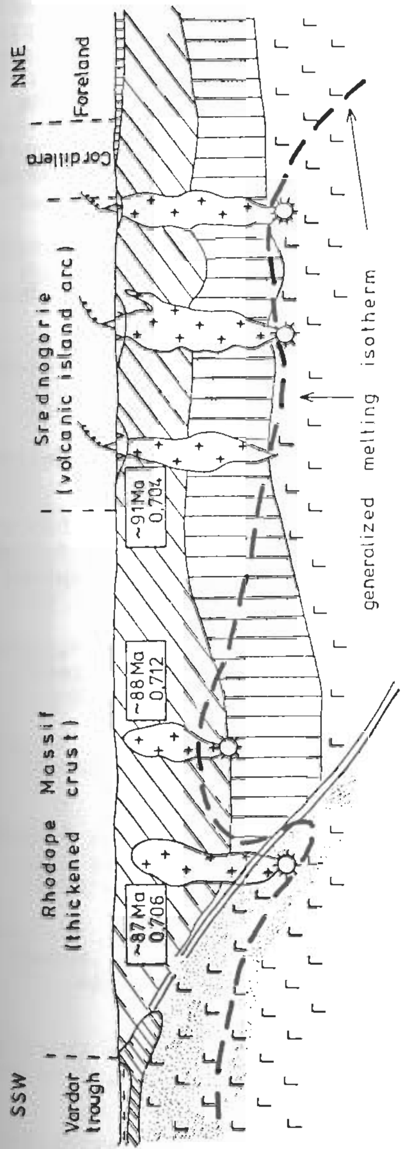

Fig. 4. Schematic section for the Late Cretaceous crustal thickening (Rhodope Massif) and thinning (Srednogorie zone) with corresponding Rb-Sr whole-rock isochron ages of the Late Cretaceous intrusions, and their initial Sr_i ratios. After BOCCALETTI et al. (1974) modified by ZAGORČEV and MOORBATH (1987).

Proterozoic folding and metamorphism. A thickened crustal lenticular body (Thracian massif) existed already in the Early Paleozoic, and was further modified during Hercynian collision events as witnessed by the Hercynian- Southbulgarian granitoids. Thickening and thinning episodes characterized different parts of this old massif during the Alpine tectonic events when it belonged to the southern margin of the Eurasian plate. The estimated maximum crustal thickness amounted to c. 70 km in the Late Cretaceous, 50 - 62 km in the Late Eocene, and 45 - 55 km in recent times. The superposition of geodynamic domains with differing orientation created a pattern of a "symmetrical orogen" around the thickened lens of the massif.

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