The northwestern segment of the North Rhodopean extensional system and related fabrics in the Rila-Rhodopean batholith

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In the northwestern Rhodope and northeastern Rila Mts., a major ductile to brittle extensional shear zone has recently been identified, called North Rhodopean Extensional System (NRES; Gerdjikov, Gautier, 2006). The north-dipping shear zone reflects extreme localization of extensional shearing in the uppermost hundred meters of the footwall unit, a thick pile of high grade, commonly migmatitic rocks that display pervasive top-N to top-NW extensional shearing (Vacha unit). The contact with lower grade metamorphic rocks of the hanging-wall unit is a low-angle normal fault zone parallel to the underlying mylonitic fabrics, marked by gouge, cataclasites and ultracataclasites of variable thickness. To this moment, the extensional shear zone has been identified from Krichim (SE) to the village of Sestrimo (NW), generally following the present mountain slope (Valkova, Spiridonov, 1979; Gerdjikov et al., 2006). Near Sestrimo, Dimov and Georgiev (2000) also described thin ultramylonitic shear zones with top-NNW kinematics, interpreted as reflecting ductile extension.

Earlier studies in this area focused mainly on brittle tectonics. Beside steep normal and strike-slip faults that characterize the mountain slope, the existence of a few large faults with low dips is known for more than 50 years. They have been regarded as south-verging thrusts (Bonchev et al., 1951), north-verging thrusts (Ivanov et al., 1989), or extensional detachment faults (Ivanov et al., 2000). Late Cenozoic south-verging thrusting along the northern margin of the Rila mountain is well established where slices of metamorphic rocks and granitoids overlie “Oligocene” sediments of the Raduil-Sestrimo basin, as first noted by Koen (1936). Intense cataclasis characterizes the lowermost 20-50 m of these slices, a feature supporting tectonic emplacement rather than gravity sliding of large olistoliths. The overridden sediments can be seen to cover unconformably a body of leucocratic granite emplaced at around 37.5 Ma (von Quadt, Peycheva, 2005), which confirms that thrusting occurred significantly after the Late Eocene. Borehole data from the Dolna Bania area suggest at least several kilometres of displacement (Antova, 1983). An important point in our interpretation is that thrusting along the northern margin of the Raduil-Sestrimo basin is distinct from and most probably younger than low angle normal faulting associated with the NRES.

The area of the village of Sestrimo represents both the northwesternmost reliable track of the NRES and the northeastern margin of the Rila-Rhodopian batholith (RRB). As such, it provides a unique opportunity to decipher the temporal relations between extensional shearing and the emplacement of various granitoids of the RRB. However, the answer depends partly on where exactly the northeastern boundary of the RRB lies in the field, and what the host rocks are. Two interpretations exist in the literature: (1) the RRB lies away from the NRES, as it is flanked to the northeast by a wide zone of high-grade rocks representing a “granitized” host (Ermolaev et al., 1977; Valkov et al., 1989) and (2) the “granitized” rocks are actually part of the RRB, whereas the true host rocks form just a thin strip located immediately beneath the “North Rhodopean thrust” — here reinterpreted as part of the NRES (Geological map of Bulgaria, scale 1:200 000; Ivanov et al., 1989; Dimov, Georgiev, 2000). Dimov and Georgiev (2000) described three ultramylonitic shear zones in this debated area but did not provide data about their host rocks.

The results of our field investigations appear consistent with the second interpretation. In the area of Kriva reka (southwest of the village of Sestrimo) a huge, rather monotonous body of medium-grained mesocratic granodiorite forms the outer rim of the RRB. A pronounced foliation is ubiquitous, with the strain intensity varying from protomylonites to mylonites. A restricted area (around N42.182, E23.878) displays advanced in situ melting in the form of di-

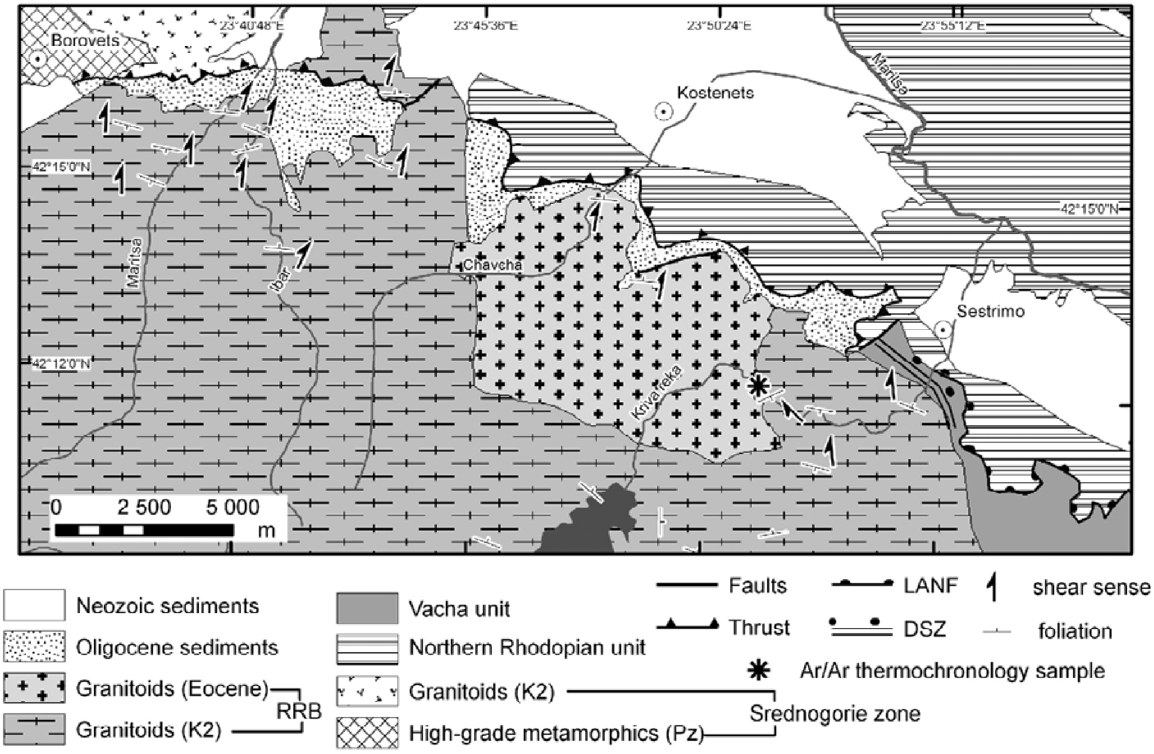

Fig. 1. Geological map of the northeastern slopes of Rila mountain (after Antova, 1983)
RRB — Rila-Rodopean batholith; NRES — North Rhodopean Eztensional System: LANF — low angle normal fault, DSZ — ductile shear zone. The dip of the foliation is 0-30°.

atexites developed at the expense of leucocratic gneisses. Its relations with the granodiorite could not be seen in the field. The granodiorite is invaded by a dense network of dykes involving granitoids that are generally coarse-grained and leucocratic, either porphyric or equigranular, together with pegmatitic and aplitic veins. The dykes are pervasively foliated and most of them lie concordantly to the foliation in the host granodiorite. Many meter-thick granitic sills display a sharp symmetrical strain gradient with a dm-thick ultramylonitic zone, occupying the core of the sill. We take this feature as an indication that these intrusions have been emplaced during regional shearing, considering that rapid yet progressive cooling has led the core of each sill to become the weakest layer at once, in which more strain could have accumulated. Deformation does not seem to be significantly lasted after the emplacement of the dykes, unlike along the NRES (see below). The granitic dykes are probably connected with the much larger body of leucocratic granite (Shpaniovitsa body of Valkov et al., 1989) that is found further west inside the RRB. On its eastern margin (next to "Stankovo Baraki"dam), at a distance of about 100 m across, the intrusion shows a progressive transition from weakly foliated granite to C-S protomylonites and mylonites at the contact with the hosting granodiorite. This also documents the syn-kinematic character of the intrusion. Single-grain $^{40}Ar/^{39}Ar$ dating of synfolial muscovites from a sample of these mylonites yielded a well-defined plateau age at 34.8±0.2 Ma (2s), interpreted as dating mylonitization. Stretching lineations in the earlier granodiorite, the various dykes and along the margin of the leucocratic intrusion, all show a regular NW-SE to NNW-SSE trend. Kinematics indicators in the zones of highest strain consistently document top-to-NW/NNW shearing.

Close to the mountain front, a strip of metamorphic rocks marks the margin of the RRB. The contact itself is a 50 m-thick zone in which intimate interlayering between the RRB granitoids (including the medium-grained granodiorite) and the host rocks is observed. Fine-grained dark metadioritic gneisses (with a Late Permian-Early Triassic protolith age according to von Quadt and Peycheva, 2005) and rare marbles constitute the host rocks. The strip where the "third" shear zone of Dimov and Georgiev (2000) is located merely coincides with the ductile shear zone of the NRES. As a result, the rocks invariably display mylonitic to ultramylonitic fabrics. The stretching lineation trends NNW-SSE to N-S, and kinematic indicators document top-to-north shearing. Like the granodiorite in the RRB, the metamorphic strip hosts numerous granitic and pegmatitic dykes, but unlike in the granodiorite, many of these dykes display strong boudinage and tight to isoclinal folding, which indicates that intense deformation persisted after dyke emplacement. This difference with the case in the RRB implies that the dykes in the strip are generally older than in the RRB or(/and) that deformation went on longer within the strip. The latter is consistent with our interpretation of the NRES as reflecting strain localization during extensional exhumation, a view confirmed by the concordant high-strain brittle overprint found at the top of the strip (see below). Due to the very low dip of foliations, the shear zone appears to be wide in map view (700 m along the road Sestrimo-Chaira), nevertheless its actual thickness is not more than 100 m.

The upper (northern) contact of the strip of host rocks is always sharp. Along the Oshliak river (west of Sestrimo) and the Kriva river (just south of Sestrimo), the contact is marked by steep, probably recent faults striking 110-130°. Only in the valley of Sestrimska river the low angle normal fault zone typical of the NRES could be observed (at N42.201, E23.924). There, the fault zone consists of ultracataclasites 3-5 m thick developed at the expense of ultramylonitic gneisses, pegmatites and marbles, which in turn grade downward into the typical mylonitic strip of host rocks. In contrast, the hangingwall rocks are featured by lack of regular mylonitic fabric. They are strongly faulted and have a lower-grade appearance, consisting of fine-grained gneisses, schists and marbles as well as more locally, medium-grained amphibolites. Several meter-thick pegmatitic dykes are also found in the hangingwall but unlike in the footwall they are weakly foliated and cut at a high angle the schistosity of the metamorphic host. Also, the granitic dykes seem restricted to the footwall only.

The Sestrimo area is the nortwesternmost one that allows direct observation of the NRES. Further west, the structures are obscured by post-Late Eocene (-Oligocene?) thrusting along the northern margin of the Raduil-Sestrimo basin. Nevertheless, the extensional shear zone probably extends as far as around the village of Mala Tsarkva, as indicated by the deformation pattern in the granitoids along the northern margin of the RRB. There, most intrusions display a solid-state fabric. Leucocratic granites, previously reported as isotropic (e.g. Chavcha body of Valkov et al., 1989) are generally the least strained bodies, yet they locally show typical C-S fabrics and dm-thick mylonitic bands with similar kinematics as in the more pervasively strained mesocratic intrusions. Again, the stretching lineation trends N-S and kinematic indicators document top-to-north shearing.

Finally, our observations are consistent with a composite character of the RRB (Valkov et al., 1989; Kamenov et al., 1998; von Quadt, Peycheva, 2005) with broadly an older generation of mesocratic granodiorite(s) and a later generation of leucocratic granites with swarms of pegmatitic and aplitic veins. Fabrics and structural patterns further allow documenting the synkinematic character of at least some of the leucocratic intrusions, as described above. U-Pb geochronological data recently reported for samples of these intrusions from within the NRES indicate crystallization ages around 37.5 to 43.5 Ma (von Quadt, Peycheva, 2005), thus roughly constraining the timing of top-to-north extensional shearing. Besides, our $^{40}Ar/^{39}Ar$ age at 34.8±0.2 Ma provides a tight time constraint for top-to-NW/NNW shearing further south in the footwall of the NRES. Therefore, at that time, extensional shearing was still active at some depth —probably not more than 0.3-0.5 km — beneath the main shallow-dipping shear zone, possibly because the coeval emplacement of a large intrusion weakened temporarily this part of the footwall. Alternatively, strain localization along the NRES had not yet occurred at 35 Ma, in which case the quoted U-Pb ages do not date top-to-north localized shearing but the emplacement of early intrusions predating strain localization. At variance with the case of the leucocratic granites, there is no clear indication that the older generation of granodiorite(s) was also syn-kinematic. The ubiquitous gneissic lamination seen in all visited outcrops is more in line with the granodiorite(s) having been emplaced before extensional shearing, or eventually in an early stage of it. In the latter case, taking into account available U-Pb data (von Quadt, Peycheva, 2005), extension would have already been active at 66-70 Ma. However, due to the lack of structural evidence, we do not favor this hypothesis.

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Северозападният сегмент на Севернородопската екстензионна система и асоцииращите структури в гранитоидите на Рило-Родопския батолит

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Резюме. В района на с. Сестримо се разкрива северозападния сегмент на коровомащабната Севернородопска екстензионна система (СРЕС). Зоната се подстила от силно деформираните гранитоиди на Рило-Родопския батолит (РРБ), докато в нейния обхват се разкрива сравнително тънко ниво от вместващите батолита метаморфити. Горната граница на СРЕС се маркира от полегато разседно нарушение, което в повечето локалитети е преработено от проявите на кватернерната екстензия. На северозапад зоната се покрива от олигоценски и кватернерни седименти, или трасирането ѝ се маскира от пост-еоцен-олигоценските навличания. За евентуалното продължение на СРЕС на СЗ се съди по широко застъпените наложени структури в РРБ. Данните от структурния анализ се съгласуват добре с наличните изотопни датировки и отбелязваме присъствието на (1) ранна гранодиоритова фаза с гнайсов строеж и белези за високотемпературни деформации (късно кредни) и (2) синтектонски в широк смисъл гранитоиди, които се характеризират с фина шистозност и често проявен S/C строеж (късно еоценски). $^{40}Ar/^{39}Ar$ анализ на мусковит от милонитна зона в РРБ индикира късноеоценска възраст (34.8±0.2 Ma) на пластичните деформации в лежащото крило на СРЕС. По целия северен ръб на Рила от с. Сестримо до с. Мала Църква, гранитоидите на РРБ запечатват насочени към север екстензионни деформации.