EXTENSIONAL REACTIVATION OF A FORMER COMPRESSIONAL FAULT ZONE: AN EXAMPLE FROM THE EASTERN PART OF THE ZLATITSA GRABEN

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ABSTRACT. The formation of the grabens and the uplift of the Stara Planina Mountain are morphological features, related to the translations along the normal faults, situated along the southern foot of the mountain. Most often, the normal fault zone is rather well expressed as a prominent mountain front, thus indicating active tectonics along the normal fault zone. The subject of this study is the easternmost part of the fault zone in the Zlatitsa graben. The area provides good outcrops of rocks that are situated along the mountain front and thus it can be assumed that complete profiles along the normal fault zone can be observed. The structural analysis of the related tectonites indicates evolution that is more complex. Within the fault zone, two different parts are characterized in terms of thickness, as well as related tectonites. Within the western part, a several-meter-thick cataclasite zone affects the Paleozoic gneisses. Numerous folds, as well as some slip planes indicate an earlier, probably severely overprinted, phase of compressional top-to-the-north shear. The easternmost parts of the zone are characterized by 1-2 m thick fault core surrounded by brecciated and silicified granitic host rocks. Rare Riedel shears within the fault core indicate extensional shearing. However, our data are incompatible with the interpretation of this fault zone as a product of only extensional tectonics. Based on: 1/ the presence of folded cataclasites; 2/ the presence of sporadic top-to-the-south slip surfaces; 3/ large thickness of the fault zone and evidence for an intensive hydrothermal alteration, it can be argued that the studied zone represents an older compressional fault zone reactivated during the youngest tectonic face. These results are in line with the data from the Karlovo graben and the western part of the Zlatitsa graben.

Keywords: Zlatitsa graben, normal fault, fault zone, reactivation, tectonic inheritance

ЕКСТЕНЗИОННА РЕАКТИВАЦИЯ НА КОМПРЕСИОННИ РАЗЛОМНИ ЗОНИ: ПРИМЕР ОТ ИЗТОЧНАТА ЧАСТ НА ЗЛАТИШКИЯ ГРАБЕН

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РЕЗЮМЕ. Издигането на Стара планина и формирането на грабени в южното подножие са породени от транслациите по система от разседи в южния Старопланински склон. В повечето случаи тези разседи са морфоложки изразени като ясно обособен планински фронт, което наред с други геоморфоложки белези индикира съвременната активност на разсяданията. Обект на настоящото изследване е източната част на разседната зона, в района на изток от с. Антон, където има много добра разкритост на скалите от участъка на планинския фронт и са достъпни почти пълни профили през разломната зона. Проведените структурни изследвания индикират сложна еволюция на скалите от тектонската зона, маркираща планинския фронт. Получените данни са несъвместими с интерпретацията на разломната зона, като структура породена само от екстензионни срязвания. Аргументите за това са: 1/ наличие на нагънати катаклазити; 2/ присъствие на спорадични южновергетни срязвания; 3/ значителната дебелина на разломната зона и белезите за интензивна хидротермална промяна. На базата на тези факти, считаме че изследваната тектонска зона представлява екстензионно реактивирана компресионна зона. Тези резултати потвърждават аналогични изводи, направени при изучаването на разседните сегменти в Карловско и западната част на Златишкия грабен.

Ключови думи: Златишки грабен, разсед, разломна зона, реактивация, тектонско унаследяване

Introduction

In recent years, significant advances have been made in understanding the tectonic evolution of the Zlatitsa-Etropole area in the Stara Planina Mountain and situated along the southern mountain foot of the Zlatitsa graben (recent overview in Antonov et al., 2010a, 2010b; see also Gerdzhikov et al., 2012; Kunov et al., 2017; etc.). These studies demonstrate that the contemporary structure of the area is defined by several tectonic phases, of major importance being the Variscan, Early Alpine (J3-K1), Late Alpine (Pc-Eo) and post-Late Oligocene extensions. From an orogenic point of view, within a very narrow E-W trending belt locked between the Vezhen pluton and the Zlatitsa graben (width in map view between 6,5 and 0,3 km), structures can be observed that attributed to these tectonic phases of different age. Besides, in the area to the NE of the village of Anton, these structures are overlapping (e.g. Antonov et al., 2010). This spatial proximity and even overlapping is an indicator for possible structural inheritance and reactivation. Such ideas have been proposed earlier (Bonchev, Karagyuleva, 1961), but solid structural arguments for this supposition are not available. Here we present results of our structural studies of the easternmost part of the fault zone that coincides with the normal fault zone controlling the formation of the Zlatitsa graben. These data indicate prolonged structural evolution and are incompatible with the interpretation of the fault-related rocks along the mountain front as a product of a single tectonic event.

Geological setting

The Zlatitsa graben is part of the system of grabens situated along the southern margin of the Stara Planina Mountain (e.g. Tsankov et al., 1996; Roy et al., 1996). The basin is elongated in E-W direction and has a length of about 35 km. Situated between the Stara Planina and the Sredna Gora Mountains, the basin can be characterized as inter-montane (Fig.1), filled by a continental succession without a well-studied thickness. From a structural point of view, this extensional structure is controlled mainly by a south-dipping fault that is traced along the southern slope of the Stara Planina Mountain. This normal fault (referred to as the Zlatitsa graben normal fault – ZGNF) has a pronounced geomorphological expression as it is marked by a prominent mountain front (term defined in Bull and McFadden, 1977) with mean slope angles between 18–34°. Along with other qualitative and quantitative tectonic geomorphological characteristics (Mishev et al., 1962; Gerdxhikov et al., 2012), this is strong argument for the contemporary activity of the fault zone. Importantly, low-temperature FT geochronological data indicate that the extension along this fault zone initiated in Late Oligocene time (Kunov et al., 2017).

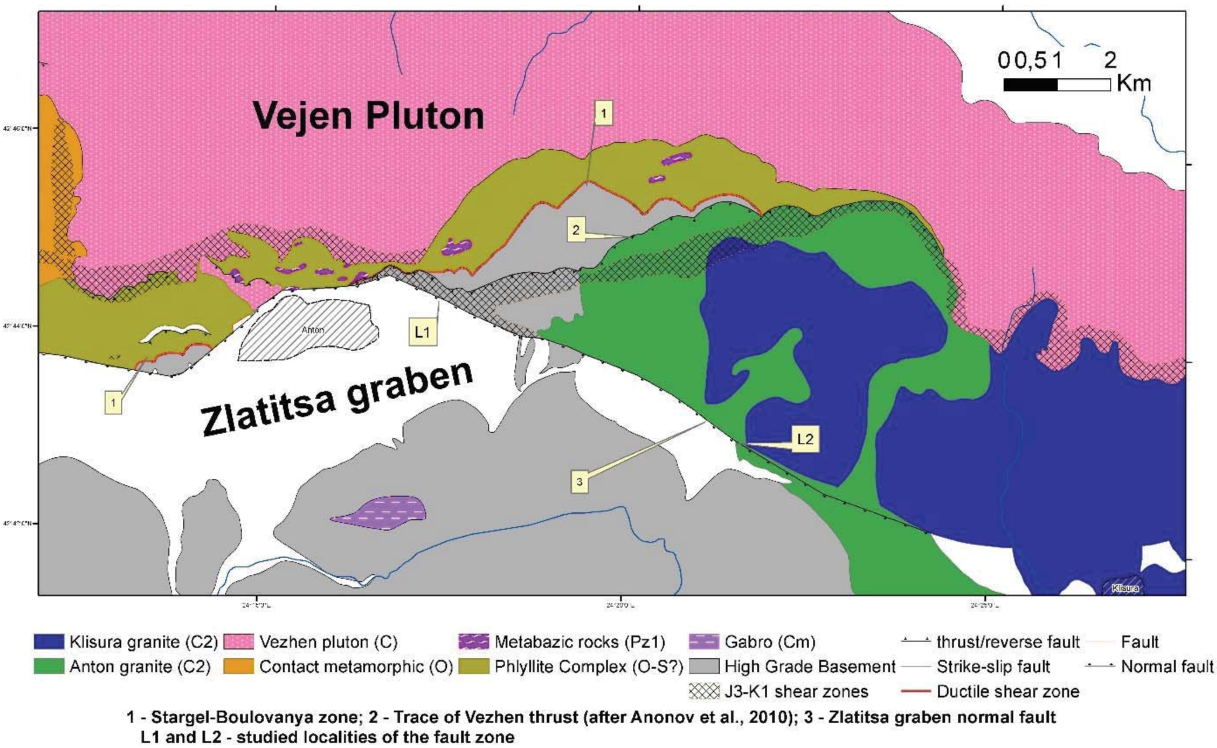

Fig. 1. Geological map of the Zlatitsa graben with the location of the studied part of the Zlatitsa graben normal fault

On the basis of the Zlatitsa graben normal fault trace in map view, three geometrical segments (in the sence of Peackok et al., 2016) can be defined – western(~11 km), central (14.5 km) and eastern (12.5 km). The subject of the current research is the well-outcropped eastern segment of the Zlatitsa graben normal fault. Here, the zone is completely hosted within the Variscan basement and is at least partially covered by Quaternary alluvium, delluvium, and colluvium deposits. The Variscan basement is represented by metamorphic rocks and granitoids. In the metamorphic basement, two complexes are distinguished that differ in grade and evolution: the high-grade basement (the Central Srednogorie High-Grade metamorphic complex – Gerdzhikov et al., 2008; the Pirdop Complex – Antonov et al., 2010) and the low-grade phyllite dominated complex (Phyllite formation, Antonov et al., 2010).

The area to the northeast of the village of Anton (Fig. 1) is a real tectonic knot that telescopes four tectonic zones which differ in age (Antonov et al., 2010). The Variscan Stargel-Boluvanya zone and the Early Alpine north-vergentmetre-decametre scale shear zones are with a penetrative character. The translations along the Variscan zone led to the juxtaposition of the high- and low-grade basement units and to the creation of the regional-scale, stable, south-dipping planar fabric. While the Stargel-Boluvanya zone is well-mapped (e.g. Antonov et al., 2010), the extent of the Early Alpine shear zones is not yet well-known. They are traced as east-west striking lens-like high-strain domains, mainly hosted within the gneissic basement. Traditionally, the Vezhen thrust is regarded as a representative of the Late Alpine north-vergent compressional structure (Bonchev and Karagyuleva, 1963; Antonov et al., 2010). It is important to note that the existence and the exact trace of this structure are topics of debate (e.g. Gerdzhikov et al., 2008; Antonov et al., 2010). The latest contribution (Antonov et al., 2010) suggested the NE trend of this zone and its possible merger/connection with the other tectonic zones along the mountain front that coincides with the Zlatitsa graben normal fault.

New structural geological studies were carried out in this segment that allowed us to revise the previously reported (Glabadanidu et al., 2012) architecture and significance of the fault zone.

Fault zone structure and related tectonites

The studied segment of the Zlatitsa graben normal fault strikes east-southeast (115^o) and dips moderately at 30-40^o to the south. Outcrop conditions are highly variable. From the village of Anton to the valley of the Vartopska river, the whole zone, or at least the upper parts of it, are covered by colluvium or alluvium sediments. To the east, the zone is completely hosted in the Late Variscan granites, yet there are no perfect outcrop conditions along the zone. Field data indicate that the thickness and characteristics of the zone are highly dependent on the type of the protoliths. Thus, in the western part, where the zone cuts the Variscan gneissic basement, the zone is represented by up to 10 m of a brecciated and strongly cataclastically reworked rock volume. To the east, the zone cuts through more competent granitoids and here the thick damage zone hosts a comparatively narrow fault core.

Fault zone in the gneissic basement

Two large outcrops in the westernmost part of the studied area provide nice opportunities to study the fault zone that coincides with the mountain front. In both of them, the fault-related rocks are covered by alluvium or colluvium. We interpret these rocks as an exhumed footwall of the Zlatitsa graben normal fault. Most probably the youngest fault strands are covered and masked by Holocene sediments. Locality 1 (at 24.29065, 42.73946) represents a deca-meter scale 3D outcrop along the slopes of a deeply incised river valley. The footwall consists of two micas, often highly weathered, and fractured gneisses. Most often the foliation is strongly folded, but in places with more consistent orientation, foliation dips to the southwest (200-230^o/50-60^o). Two domains are distinguished within the fault zone: heterogeneously faulted and ultracataclastic (Fig. 2).

In domain 1, the gneisses are strongly fractured and host several levels of black cataclasites to ultracataclasites. The black color of the strongly cataclastically reworked gneisses is due to the extreme crushing of the rock mass, along with processes of diffusive mass transfer and growth of chlorite. In the ultracataclastic domain 2, the dominant rock type is represented by chlorite-rich cataclasites and ultracataclasites that host clasts of the protolith that are sized of up to a decimeter. Cataclastic and ultracataclastic tectonites are strongly affected by centimeter- meter-scale folding. The orientation of the fold axes displays some spread, but the main NW-SE trend can be detected (Fig. 3a). A possible reason for this spread is the presence of numerous centimeter-scale shear zones and slip surfaces that are abundant in the ultracataclastic domain. Importantly, the orientation of these structures differs in terms of strike and dip to the mean orientation of the eastern segment of the Zlatitsa graben normal fault (Fig. 3b). It was not possible to detect linear fabric on the shear surfaces. Structures as Riedel shears and C-S mesoscale mélanges (Kusky, Bradley, 1999) indicate that most of them are extensional, yet such features also point to the presence of compressional, top-to-the-north, NE shear.

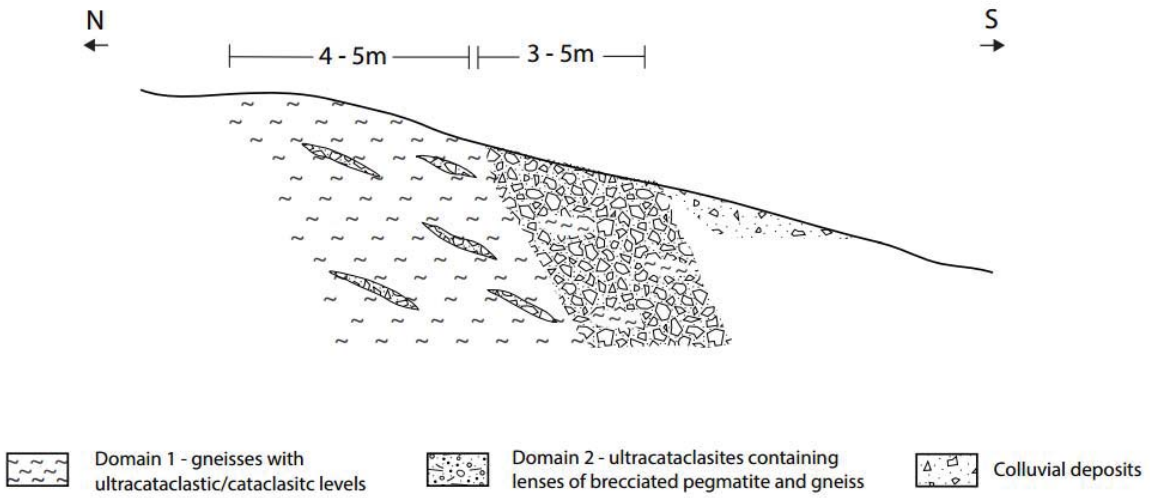

Fig.2. Overview of the main components of the fault zone developed in the gneissic basement from Locality 1

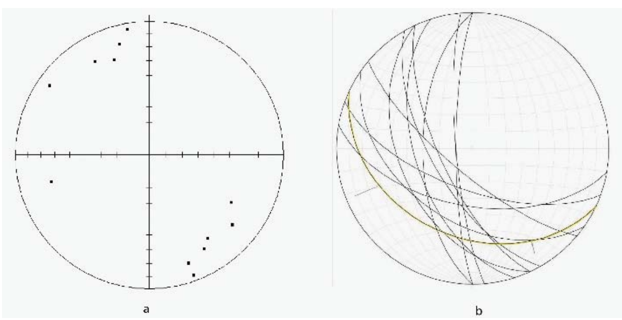

Fig.3. Stereo-plots. a) fold axes from Locality 1; b) slip surfaces from the ultracataclastic domain (Locality 1). Arrows mark the great circle representing the orientation of the eastern segment of ZGNF. Equal area, lower hemisphere

About 250 m eastwards (at 24.29271, 42.73863), there are good outcrops of a heterogeneously faulted domain from Locality 1. They are covered by colluvium, so the upper parts of the fault zone are masked. Again, the brecciated and cataclastically reworked gneisses are affected by folds with axes trending NW-SE. Non-penetrative Riedel shears (slip planes) as well as imbricated shear-bounded lens fragments indicate compressional, north-vergent shear (Fig. 4).

Fig.4. Folded cataclasites (folded surfaces underlined by dash white line) and slip planes indicating N-vergent shear. North is to the left

Fault zone in the granite

For the purpose of the description of the zone, we can define three elements: footwall zone, fault core and hanging wall zone. This cross-sectional architecture is centered on the identified in the field single, narrow zone built up of breccias, cataclasites, and gauge. The type locality of the fault core is easily accessible on the main road E-871 (Locality 2, at, 42.71829; L2 in Fig. 1) where the zone strikes 125^{o} and dips 40-45^{o} to the south.

The footwall of the zone is well-outcropped. Here, the intensity of the brittle overprint varies from rather weak to very strong. In weakly deformed parts, the protholite is affected by a network of fractures and weak brecciation and does not display strong hydrothermal overprint. The intensively overprinted parts of the footwall are brecciated, dissected by discrete south-dipping fault, and often silicified. Usually, it is difficult to obtain a clear view of the original fabric of these rocks. Still, at a few places, it is clear that the brittle zone overprints foliated to weakly foliated granites. In the uppermost part of the footwall, there are 2-4 m thick levels of brecciated and strongly silicified granite with extremely fine-grained grey-greenish matrix.

The hanging wall is often covered by colluvium and more rarely by alluvial deposits. The immediate hanging wall is built by the same granites. They are also strongly brecciated and contain planes that shallowly (35^{o}) dip to the southslip, trending 100^{o}.

The core of the zone is about 1 m thick and is characterized by great heterogeneity. The dominant lithology is represented by cohesive, matrix-supported, grey-greenish tectonite that contains angular or oval-shaped clasts with long axes of up to several centimeters. A coarse cataclastic foliation that is co-planar with weak color layering is observed. Due to the heterogeneity of these tectonites, their precise classification is almost impossible. According to the classification of Woodcock Mort (2008), they fit within the categories of chaotic breccias and cataclasites. Both types of tectonites do not show systematic spatial relations either to the cataclastic foliation, or to other structural discontinuities. Most probably their "mixing" is the result of a heterogeneous strain distribution. The uppermost level of these grey cataclastic rocks is a rather strong and resistent ot erosion. It forms a pronounced "crust" that preserves the fault core from erosion. The strong cohesion of this rock type is due to the presence of calcite cement and abundant calcite veins. Microfabric studies reveal the intensive influx of carbonate-rich fluids into the strongly fractured rock mass.

Another type of tectonite is dark grey to black ultracataclasite that forms 2-3 irregular layers (up to 25cm thick) parallel to the cataclastic foliation. The ultracataclasite is affected by strong foliation that corresponds to closely spaced mesoscale fractures and shear surfaces. On the scale of the specimen, these tectonites are clast-free. Clasts that vary in size are observed in thin sections. Some of them are well-rounded, a feature suggesting very strong attrition. Some clasts are overgrown by newly formed chlorite that is also abundant in the matrix. The foliation is defined by sub-parallel alignment of 1) elongation of newly grown phyllosilicate phases; 2) lensoidal clasts of the protholite; 3) vaguely defined pressure solution seams marked by enrichment of insoluble constituents; 4/ elongated beards of phyllosilicates upon clasts.

While the distinguished tectonite types (grey chaotic breccias, grey cataclasites and black ultracataclasites) most often interlayer parallel to the cataclastic foliation, there are field relations that suggest mutually cross-cutting relations. We observed decimeter-meter-scale blocks of the breccias embeded into the black ultracataclasites, as well as presence of black ultracataclasite clasts into grey breccias. All these relations are documented in a single large outcrop with areal extent of >1 000m^{2}. Most probably they are the result of a protracted period of successive slip events occurring in different conditions of fluid availability and strain rate. Of course, it cannot be excluded that they result from overlapping products of different tectonic phases.

During the first inspection of the outcrop in 2005, we recorded the existence of polished surface/s with almost down-dip lineation (160/30). Later field work was not able to record again these data. In down-dip sections, orthogonal to the foliation, available along several 1-1.2 m deep gullies, we observed Riedel shears that are steeper (40–50°) to the cataclastic foliation and in some cases displace the faint layering within breccias. Because we were unable to observe any marks on the fault/shear surfaces,these Riedel shears are the only kinematic indicator that confirms the extensional character of the shearing.

Discussion

Were the tectonites, localized along the mountain front, formed during the single tectonic phase?

It is well known that brittle faults often record long history and, once formed, they are mechanically weak zones that accommodate later strain increments (e.g. Holdsworth et al., 1997). Besides, it is demonstrated that previously existing structural anisotropy exerts strong control on the geometry of faulting in the continental crust (Buttler et al. 2008). These possibilities are still unrecognized in the case with the fault network in the studied area.

The data reported in this contribution refer to the fault-related rocks situated immediately on the mountain front. They can be regarded as a result of a single tectonic phase related to post-Oligocene extensional tectonics. Yet, field data argue for re-appraisal of this most conventional idea. There are data and arguments that motivate a negative answer to the posed question.

First, the obtained data from the fault zone in the gneissic basement - such as the large thickness of the zone, the existence of folds affecting cataclasites, as well as the presence of north-vergent shears - are incompatible with the interpretation of the studied fault zone as completely related to the extensional movements related to the Zlatitsa graben normal fault. Most probably, the studied tectonites represent an old compressional zone related to a Late Alpine compression.

Second, despite of the fact that it is not that conclusive, the data from the tectonite fabric in the granite basement are also incompatible with the simplest tectonic scenario. Arguments supporting this view can be the significant width of the zone and the data for very strong fluid infiltrations not only in the fault core, but in the brecciated host rocks, too.

Third, the reported features of the fault zone within the granite basement bear a strong similarity with the observed features along the normal fault at the same tectonic-geomorphological position from the neighboring Karlovo graben. The normal fault along the southern slope of the StaraPlanina Mountain in the Karlovo area is most often represented by cataclastic rocks that are up to 1-2 m thick, strongly hydrothermally altered (silicified or carbonatization), and resistant to weathering. Due to their mechanical properties, the normal fault is often marked by the upper surface of these altered rocks that appear on the crust. A similar crust is present at the uppermost levels of the studied segment of the Zlatitsa graben normal fault where the zone cuts the granite basement. Importantly, a detailed field work along the southern foot of the Stara Planina Mountain in the area of the Karlovo graben clearly demonstrated that the normal fault zone, controlling the contemporary uplift, reactivates Late Alpine thrust surfaces (Balkanska and Gerdzhikov, 2010). Data from the western part of the graben (between the villages of Bunovo and Chelopech) also clearly indicate extensional reactivation of a former south-dipping compressional fault array that is rather wide in this part (Dotseva et al., 2016).

Conclusions

The mountain front in the eastern part of the Zlatitsa graben is marked by a complex and long-living tectonic zone. This conclusion is in line with the suggestions of Tsankov et al. (1996) and the data from the neighboring Karlovo graben (Vangelov et al., 2010; Balkanska and Gerdzhikov, 2010).

In the light of our new results, it can be concluded that the application of the classical tripartite model of the fault zone architecture (Chester et al., 1993) cannot be applied to the Zlatitsa graben normal fault. It is obvious that the model of the fault architecture that was previously reported by us (Glabadanidu et al., 2012) is too simplistic. Structural data clearly indicate the extensional character of the last movements in the fault core in the granite basement. The specific features for the zone are the lack of pronounced lineation, as well as meso-and macro-scale corrugations and polished fault mirrors.

Despite being well-outcropped, we did not find incohesive tectonites along the studied geometric segment of the Zlatitsa graben normal fault. This can be explained by the migration of active fault strands toward the interior of the graben, thus exhuming the main fault zone along the mountain front. Thus, we follow the model of Stewart and Hancock (1988) of the “intrafault-zone hanging wall collapse”.

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