Magneto-structural and mineralogical study of tectonic gouge

Магнито-структурно и минераложко изследване на тектонска глина

Ayre Keskineva[1], Neven Georgiev[1], Kalin Naydenov[2], Neli Jordanova[3], Diana Jordanova[3], Louisa Dimowa[4]
Айре Кескинева[1], Невен Георгиев[1], Калин Найденов[2], Нели Йорданова[3], Диана Йорданова[3], Луиза Димова[4]

[1] Sofia University "St. Kliment Ohridski", 15 Tzar Osvoboditel Blvd., 1504 Sofia, Bulgaria;
E-mail: ayre.keskineva@murgana.org
[2] Geological Institute, BAS, Acad. Georgi Bonchev str., bl. 24, 1113 Sofia, Bulgaria
[3] National Institute of Geophysics, Geodesy and Geography, BAS, Acad. Georgi Bonchev str., bl. 3, 1113 Sofia, Bulgaria
[4] Institute of Mineralogy and Crystallography "Acad. Ivan Kostov", BAS, Acad. Georgi Bonchev str., bl. 107, 1113 Sofia, Bulgaria

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Introduction

The kinematic analysis of brittle failures and fault zones meets a serious problem when the fault surfaces are lacking lineation fabrics related to the movements along the faults. A presence of several generations of lineations on the fault surfaces is another problem of the kinematic analysis. In such cases, the interpretations assume either a change in the orientation of the regional stress field in a frame of a single tectonic phase, or a presence of different in age, superimposed structures. Since even minor movements along faults can cause formation of lineations, it is of primary importance to define the lineation that is related to the major translations along the fault surfaces. Often, due to the rheological contrast between the gouge domains and their host within the fault zone, the clay layers and their bounding surfaces can be easily reactivated. The latter may occur not only due to tectonic, but also due to gravitation driven processes. Thus, the surfaces of the gouge domains may show a lineation pattern inconsistent with the fault kinematics at the time of gouge formation. In these cases, even with the presence of asymmetry structures, the kinematic analysis is impossible.

Thick domains of tectonic gouge are formed due to considerable translations along faults in the upper 4 km of the lithosphere. In a single-phase fault zone, the synkinematic phyllosilicates and that comprise the gouge domains, will show a shape preferred orientation related to the stress field applied. When a major reactivation of a fault zone affects older gouge domains, one would expect that the clasts and the minerals will reorient progressively. To obtain quantitative information of the orientation of planar and linear structures in rocks that do not contain macroscopic lineations and foliations, the method of Anisotropy of Magnetic Susceptibility (AMS) is successfully applied (Jelinek, 1981). Therefore, the AMS approach has long been applied in studies of magmatic units. However, the contribution of this technique to the structural analysis of fault rocks with complicated foliation/lineation patterns or without visible structures is still largely underestimated. In this work, we present an integrated AMS and meso- to micro-scale structural study of a brittle fault zone, containing several layers of 5 to 30 cm thick tectonic gouge aiming to show the applications of this approach in a complicated tectonic setting.

Methodical approach and results

The sampling sites were selected in a way to compare data obtained by both field observations and AMS technique. Further control on the structural development of the gauge domains was obtained by studies of polished samples and a microstructural analysis. Oriented samples were collected at places where the gouge domains surfaces contained striation lineations. For studying the tectonic gouge mineralogy, critical for the interpretations of the results, X-ray powder diffraction analysis (PXRD) and thermomagnetic analysis were applied.

The magnetic studies showed that all samples have a very low susceptibility, typical for rocks dominated by paramagnetic minerals. PXRD analysis of the gouge showed that the main mineral phases are chlorite, illite and a small amount of pyrite. The axes of the magnetic susceptibility ellipsoid have average values for K_1 – 1.011 to 1.024, for K_2 – 1.007 to 1.009 and for K_3 – 0.967 to 0.983. Because of the low susceptibility, two steps of slow heating in oxygen environment respectively up to 400 and to 650 °C were applied in order to enhance the magnetic signal by high-temperature formation of new magnetic phases (alteration products that mimic the initial grains' distribution). The thermomagnetic analysis indicate that heating up to 360–380 °C resulted in minor changes in the mineralogy of the samples, related to the formation of small amounts of pyrrhotite at the expense of pyrite. The PXRD analysis shows presence of pyrite in some of the samples and a small amount of pyrrhotite in some of the heated ones, which suggest that formation of pyrrhotite at the expense of pyrite is possible. Heating at higher temperatures showed a formation of titanium bearing phases (at 400–420 °C) and magnetite (at 580 °C). Little or no changes in the shape of the magnetic susceptibility ellipsoid were detected in the samples heated up to 400 °C. However, in some samples, changes in the K values were noted. Heating up to 650 °C led to crystallization of magnetite, which increased the magnetic susceptibility with an order of magnitude. The magnetic axes determined showed an increase in K_1 up to 1.070–1.051, and in K_2 up to 1.008–1.020 whereas K_3 values decreased to 0.915–0.977. Thus, the oblate shape of the magnetic ellipsoid, defined by the new K-values, became more pronounced. Microscopic observations revealed development of penetrating slightly curved (S-shaped) cataclastic foliation, as well as synthetic R- and Y-shear planes, the latter being parallel to the boundaries of the gouge domains. The clear magnetic planar fabric was obtained from a bulk AMS analysis and therefore cannot distinguish between these synkinematic foliations. The obtained magnetic foliation is slightly oblique to the field-measured boundaries of the tectonic gouge domains and we may assume that its orientation is largely controlled by mineral alignment along the R- or S-planes. In either case, due to the synkinematic character of the two planar structures, the obtained orientation of the magnetic foliation is perfectly applicable for the kinematic studies and the interpretations of the tectonic gauge development. The relation between the magnetic foliation and the boundaries of the tectonic gouge domains are consistent with dextral kinematics of the fault zone, obtained on the field.

Some of the heated samples (up to 650 °C) showed also an increase in the K_1/K_2 ratio probably as a result of a heat induced magnetite crystallisation along elongated Fe-hydroxide or illite aggregates. This has a major importance for the structural analysis of the fault zone because prior to the laboratory heating the samples did not show clear orientation of a magnetic lineation. Field studies of the fault zone revealed the presence of two generations striation lineations. The earlier one is gently plunging to sub horizontal and is associated with dextral strike-slip shearing, whereas the later lineation is sub vertical, interpreted as a result of the reactivation of the fault zone as a normal-fault. The AMS analysis revealed development of magnetic lineation that is either parallel or slightly oblique to the earlier strike-slip related striation lineation observed on the field. The normal-fault reactivation did not, therefore, obliterate or distort significantly the magnetic ellipsoid. Some angular differences between the magnetic and the field-measured strike-slip lineations were detected by the AMS results. This might correspond to the bulk character of the magnetic analysis in which the magnetic linear fabric averages the lineations that are associated with S-, Y- and R-planes within the gouge domains.

Conclusions

Field and microstructural analyses showed that the studied brittle shear zone recorded two highly oblique senses of movements and it is suggested that the major shearing event had a dextral strike-slip kinematics. The frequent lack of strike-slip related striation lineation and more important, the superimposed normal-fault movements that formed a second generation of striation lineation on the walls of the soft tectonic gauge domains and fault zone surfaces, hindered the field- and hand-specimen scale kinematic analysis and questioned its reliability. This study shows that the application of the AMS analysis on tectonic gouge can strongly contribute to addressing those important problems. It was demonstrated that the normal-fault reactivation of the studied fault zone was of insignificant scale with respect to the fabric development within the tectonic gouge domains. The magnetic fabric of the gouge coincides and is directly controlled by the orientation of the meso-scale penetrative linear and planar structures. This was then used to confirm that the tectonites were formed in a dextral strike-slip setting. Moreover, this study demonstrates that, by applying simple heating experiments, the AMS record of tectonic gouges can be enhanced without altering the orientation of the principal susceptibility axes which allowed for a well-motivated and better interpretation of the shape of the magnetic susceptibility ellipsoid. Clearly, the most important result of the AMS study is the possibility to identify the orientation of the synkinematic linear fabric, which here is interpreted to resemble the maximum stretching direction. The obvious application of this is the possibility to support a microstructural and meso-scale kinematic analyses by providing the orientation of the finite stretching direction in gouge domains where striation lineation did not develop or several generations of lineations were formed, or where secondary processes obliterated the linear fabric. The AMS analysis can therefore be used as a tool to identify the kinematic framework of large fault zones especially in cases of a presence of thick gouge domains.

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References

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