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Speleo-morphology and tectonic processes – What can be seen in slowly deforming regions?

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Abstract

There are a lot of methods used to determine tectonic process active in a region, and they vary depending on the purpose of the research. However, a number of them cannot be used in slowly deforming regions, because the effects of active tectonic process on the rocks in such regions could be negligible. This is especially true for the recently active tectonics in such regions, since most of the recently active tectonic structures never reach the surface. Because of that, studying tectonic structures inside karst caves can give valuable information about active tectonic processes. Here, we present evidence about the youngest and recently active faults in the area of the central part of the Carpatho-Balkan orogen, located in Eastern Serbia, based on data from the karst cave Mala Bizdanja. Age of activity of faults mapped inside the cave was determined based on indicators of faults that cut speleothems, forming fault breccias that incorporate broken speleothems, and based on speleogenetic considerations. Also, samples for radiometric dating have been collected, that will help to quantify fault activity rate. Preliminary results show that the research area is characterized by strike-slip tectonics, with recently active NW-SE-trending sinistral faults, suspected to be also seismically active.

Résumé

Spéléo-morphologie et processus tectoniques – Que peut-on voir dans les régions qui se déforment lentement ? Une myriade de méthodes est utilisée pour déterminer un processus tectonique actif dans une région. L'application de chaque méthode dépend de l'objectif de la recherche. Cependant, beaucoup d'entre elles ne peuvent pas être utilisées dans des régions à déformation lente car les effets du processus tectonique actif sur les roches peuvent être négligeables. Cet effet est particulièrement vrai dans les régions qui ont subi une activité tectonique récente, où la plupart des structures actuelles n'atteignent pas la surface. Pour cette raison, l'étude des structures tectoniques à l'intérieur des cavités karstiques peut fournir des informations précieuses sur les processus tectoniques actifs. Ici, nous présentons des preuves sur les failles les plus jeunes et récemment actives dans la partie centrale de l'orogène carpatho-balkanique, située dans l'est de la Serbie, à partir des données obtenues dans la grotte Mala Bizdanja. L'âge d'activité des failles cartographiées à l'intérieur de la cavité a été déterminé sur la base d'indicateurs de failles qui coupent des spéléothèmes, formant des brèches de failles qui incorporent des spéléothèmes brisés, et sur la base de considérations spéléogénétiques. Des échantillons pour datation radiométrique ont également été collectés, ce qui permettra de quantifier le taux d'activité des failles. Les résultats préliminaires montrent que la zone de recherche est caractérisée par une tectonique décrochante, avec des failles sénestres récemment actives orientées NW-SE et proposées comme étant également actives sur le plan sismique.

1. Introduction

Methods to determine tectonic processes in a region vary depending on the purpose of the research but are generally characterized by mapping of tectonic structures and interpreting them in the context of the tectonic process(es) responsible for their activation. However, if one would like to determine recently active tectonic process, available data dramatically decrease, since most of the tectonic structures that are recently active never reach the surface. This is especially true for the regions with slow tectonic deformation, where tectonic deformation does not produce prominent evidence, or if so, they are occasionally eroded. Because of that, studying of tectonic structures inside caves can give valuable information about active tectonic processes.

One of such regions of slow tectonic deformation is located in the central Balkan Peninsula, in the region of Carpatho-Balkan orogen, situated in Eastern Serbia (Fig. 1). This orogen represents the western part of the Carpatho-Balkan orogenic chain, extending in the north to the Romanian Southern Carpathians and in its southeastern part to the Balkan massif in Bulgaria. In its central part, in Eastern Serbia, Carpatho-Balkanides are made up of a system of east-vergent nappes, that have been formed in Early

Cretaceous and were multiplicatively activated during their geological history (SCHMID *et al*. 2020). This activity led to the formation of faults that are favorably oriented in respect to the main thrust system. It is suspected that some of these fault systems are also active in recent times (for discussion see MLADENOVIĆ *et al*. 2019).

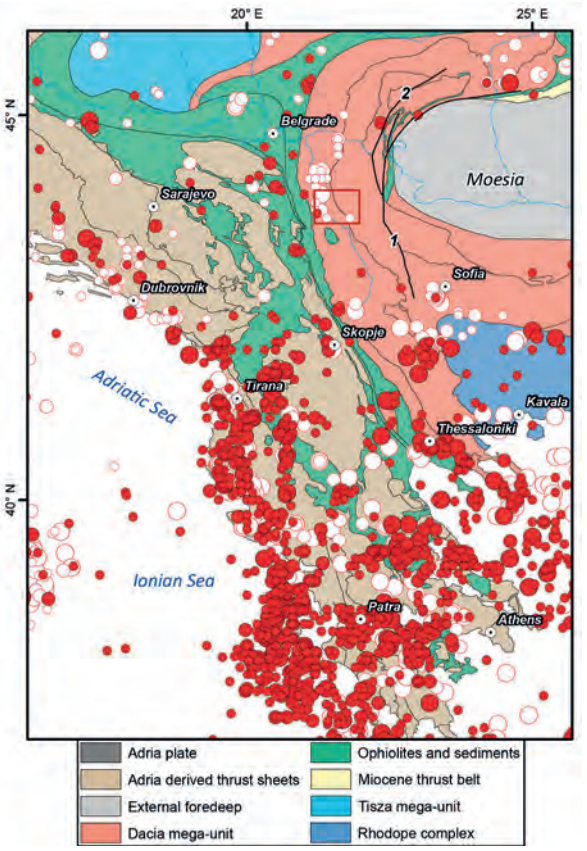

Figure 1: Tectonic map of the wider Balkan Peninsula (after SCHMID et al. 2020), with positions of historical (white circles) and instrumentally located earthquakes (red circles) based on the results of the SHARE project. Immediate research area is marked with red rectangle.

Relatively complex geological structure as well as relatively long time during which the whole area has been exposed on the surface, have both led to the intensive karst process and development of surface and underground karst forms. Because of that, investigation of deformation structures on the field surface is relatively difficult, but investigation of these structures inside the karst caves can give a lot more information.

In this paper, we present evidence about neotectonically active faults that were mapped inside the Mala Bizdanja Cave, situated in the westernmost part of the Carpatho-Balkan orogen (Fig. 2). Vicinity of the research area is characterized by modest seismic activity, and according to earthquake focal mechanisms, recently active tectonic process in the wider area can be characterized as strike-slip, with maximal stress axis oriented NNE–SSW (MLADENOVIĆ *et al*. 2014). The main fault systems that are active in recent times are sinistral faults oriented NW–SE, and dextral faults, generally oriented NE–SW, as well as their secondary structures.

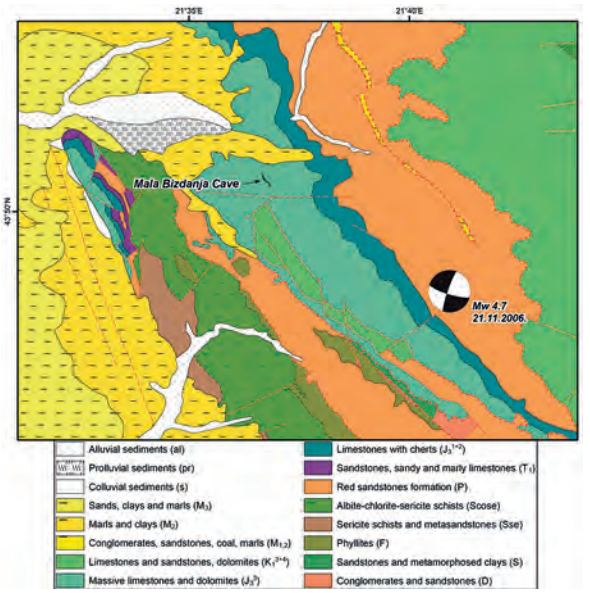

Figure 2: Geological map of the wider research area, based on the General geological map of SFRY.

The Mala Bizdanja Cave is approximately 1 km long, mostly horizontal cave with vertical entrance. It is situated high in the vadose zone, with mild seasonal percolation through the relatively thin overlying caprock. The cave is elongated in the NW–SE direction and located near the suspected seismically active NW–SE-trending sinistral fault (Fig. 2; see also MLADENOVIĆ *et al*. 2014). This cave was extensively explored by members of the Students' Speleological and Alpinistic Club (ASAK) from Belgrade. During these field campaigns, a lot of broken speleothems have been recorded inside the cave, which gave rise to the ideas of tectonic investigation, especially when taking in mind its position in the context of local and regional geology.

2. Methods

Base for tectonic investigations in the Mala Bizdanja Cave was a detailed map of the cave, completed by ASAK team, during numerous field campaigns of topographic surveying of the cave passages. Topographic survey of the cave was performed following standard techniques and using digital compass equipped with laser distance-meter, Leica x310. During these field campaigns, speleologists mapped a lot of broken speleothems, passages guided by structural planes (bedding planes, joints, fault planes). During these investigations, we tried to map not only structures, but also more clear evidence of their neotectonic activity, as well as to try to quantify slip along the supposed active faults. For that reason, we took test sample for U-series radiometric dating to be carried out at the Johannes Gutenberg University in Mainz, Germany.

3. Results and discussion

During tectonic investigations, we succeeded to map a lot of evidence of neotectonic activity inside the Mala Bizdanja Cave, some of which are shown on the Fig. 3.

The most indicative example of the neotectonic activity inside the cave is represented by broken speleothems, as shown on Fig. 3a. Here, the subhorizontal joints developed along the h0l (conjugate joints) systems cut draperies.

Structures shown on Fig. 3b represent fault plane and secondary structures (Riedel shears), along which an extensive fault breccia has been developed. Fault breccias developed on this location, as well as on several other locations inside the cave, often incorporate broken speleothems as clasts inside the tectonic sediment, indicating thus neotectonic activity of these faults.

Fault plane evident on Fig. 3c has well developed striations that indicate two generations of slip along this fault. Older, and less prominent, striations point to reverse slip, which is expected in the research area, most probably active during Oligocene and Miocene complex rotation of the whole area around the rigid Moesian promontory (for detailed discussion see MLADENOVIĆ *et al*. 2019). Clear cross-cutting relationship of the striations along this fault plane indicate that the younger slip along this WNW–ESE-trending fault is sinistral. Although we cannot guarantee for its neotectonic activity, it is evident that this fault belongs to the system of seismically active faults in this area, as shown by the earthquake focal mechanism, presented on the Fig. 2 (also, for detailed discussion on recent tectonic activity in the wider research area see MLADENOVIĆ *et al*. 2014).

Cave passage shown on Fig. 3d is clearly guided by tectonic structures – the main course of the passage is developed along the WNW – ESE-trending fault, and it was widening by mechanical erosion of water running along the Riedel shears related to this fault. According to the orientation of these Riedel shear joints, it can be concluded that the main guiding fault of this passage is also sinistral.

The most promising location for potential radiometric dating of speleothems is shown on the Fig. 3e. This is well developed fault plane trending NNE–SSW, on which striations indicate normal slip. On this location, several "layers" of flowstone are developed. Striations are probably developed on more of these layers, however, we found the youngest ones developed on the second youngest layer of flowstone. Because of that, we sampled the youngest and the second youngest layer for U-series radiometric dating. However, our test samples suffered from low concentrations of uranium, so we were unable to calculate the age of these samples, and hence to try to determine the youngest activity of this fault.

Figure 3: Typical neotectonic elements inside the Mala Bizdanja Cave. See the main text for detailed explanations.

Figure 3f shows cave column that is broken along joints belonging to the h0l system, thus indicating shear along the zone located near the area where the column is located. Although during previous research the shear zone has not been found, it certainly points to the neotectonic activity of this zone.

4. Conclusion and future work

Results of investigation of neotectonically active faults based on tectonic mapping inside the Mala Bizdanja Cave, located in the westernmost part of the Carpatho-Balkan orogen in Eastern Serbia, indicate that neotectonically active faults in the research area most probably belong to the system of WNW–SSE-trending left lateral faults, and NE–SW-trending right lateral faults. This is also in accordance with earthquake focal mechanisms in this area, indicating thus also their recent activity.

Strike-slip tectonic regime in this area most likely result from far-field stress generated by the collision of the Adriatic microplate, the Moesian promontory and the tectonic units in-between. Such stress field is shown to be highly heterogeneous even in this relatively small research area, so local areas of transtension and transpression have also been very important in controlling the recent fault kinematics. The reason for this probably lies in the fact that most of the faults that are active in recent times are reactivated structures, that have been active during previous very intensive periods of tectonic activity.

Future work in this area should consist of more detailed mapping of tectonic structures, and finding locations to sample speleothems for dating, which would certainly be of high importance in determining fault dynamics in this area. Also, it would be useful to map the surface above the cave and try to determine faults and their kinematics also applying this methodology.

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