



Topo-Transylvania: a multidisciplinary Earth science initiative in Central Europe to tackle local and global challenges

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This special issue is devoted for the Topo-Transylvania initiative, which aims to review the present earth science knowledge of the SE Carpathian area and adjacent Transylvanian Basin, and outlines the future activity planned in the framework of the project.

1 General idea, purpose and outline of Topo-Transylvania project

Topo-Transylvania is a cross-and inter-disciplinary framework initiative that groups several projects aiming to monitor a geodynamically active, complex and critical part of European topography, the internal part of the SE Carpathians area, where a number of ongoing and geologically recent processes (such as large magnitude, intermediate mantle and crustal seismicity, recent volcanism, post-volcanic phenomena, focused geothermal activity) converge in space and time. The project was initiated by the MTA CSFK Geodetic and Geophysical Institute (Hungary), Babes-Bolyai University (Romania) and the National Institute of Earth Physics (Romania), Institute of Geodynamics of Romanian Academy with the cooperation of the Tectonics Group at the Utrecht University (The Netherlands). The project addresses the following scientific objectives: (1) quantify the societal relevance of a geo-tectonically highly active area; (2) coupling deep Earth processes to surface evolution and kinematics; (3) process-oriented understanding of landform evolution and the link with the multi-temporal and spatial scales of relevant processes in a geodynamic active area; (4) supporting decision making with a quantitative and process-oriented analysis of natural hazards; (5) assessing the vulnerability and sensitivity of the target area with respect to geohazards.

The monitoring and modelling of processes in one of the most tectonically active part of European topography will be accomplished by: (1) *monitoring Earth's dynamics* including the up-to-date space geodetic techniques as well as integrating results of ground geochemical and surface geophysical observations; (2) *investigating the lithospheric architecture* by means of seismic tomography based on a dense seismic network, electromagnetic deep-soundings, benefitting from the analysis of available potential field data; (3) *analogue and numerical modelling* will foster a better understanding of the coupling between volcanism

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and tectonics using thermochemical models as well as linking the refined lithospheric architecture with dynamical observation; (4) *natural resources with special consideration of geothermal energy*; (5) *natural (volcanic, tectonic) and anthropogenic (induced and triggered seismicity) hazards* will be studied including effects of climate change (flooding, erosion).

2 Why this area?

The multitude of processes presently active in the SE Carpathians (Fig. 1) and the adjacent part of the Transylvanian Basin make it a key area to understand the rapid changes of continental topography in an important part of the Carpathian–Pannonian system of Central Europe. These relevant active processes are linked with subduction roll-back, break-off and associated basin (de)formation, volcanism, post-volcanic activity (gas emanations, ore mineralization), earthquakes and tectonic movements (e.g., salt diapirism, volcano spreading Szakács and Krézsek 2006; Falus et al. 2008; Ismail-Zadeh et al. 2012; Horváth et al. 2006; Seghedi et al. 2016; Kis et al. 2017). These processes are active or have ceased their impact during the recent evolution of the Carpathians–Transylvanian system). Interesting is the high concentration and frequency of these processes in the restricted area of the SE Carpathians, which allows an integrated study of tectonic plate convergence in the final stages of continental collision, reflecting the evolution of the much larger alpine system (Matenco 2017). The SE Carpathians are also an excellent natural laboratory to investigate and understand the behaviour the lithosphere–asthenosphere system in relationship with

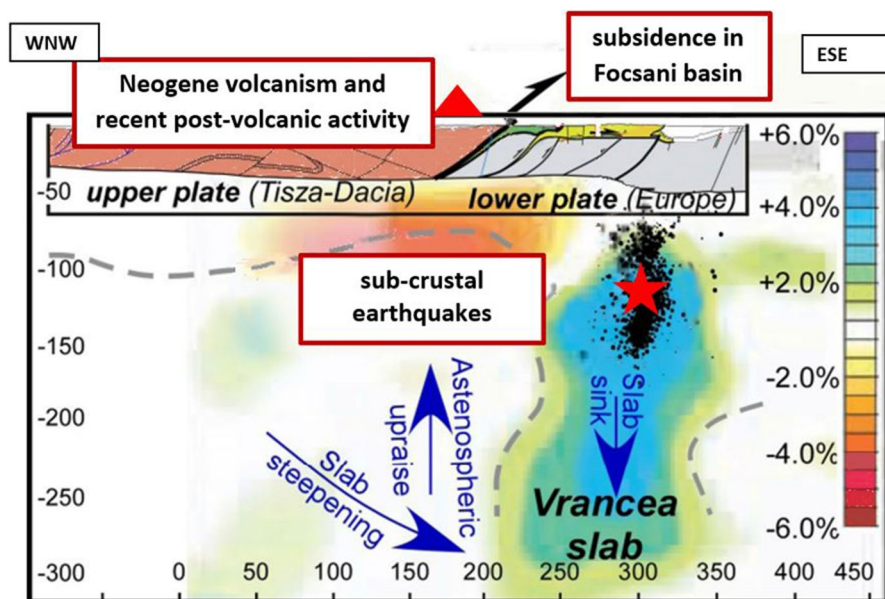


Fig. 1 A schematic figure for the geodynamics of the SE Carpathians. Active deep and surface processes are clearly indicated by the strong intermediate-depth seismicity, volcanic activity and active landform evolution probably triggered by the descending slab. (modified after Martin and Wenzel 2006; Matenco and Andriessen 2013)

large magnitude seismic events associated with significant societal impact. For instance, the 1977 Mw 7.2 destructive Vrancea earthquake resulted in over 1500 victims in a densely populated area. In addition, last volcanic eruptions in the Eastern Carpathians located just at the Carpathian Bend interior took place only ~ 30 ka ago (Seghedi et al. 2016; Karátson et al. 2016), confirming that the link between active tectonics and magmatism. Furthermore, the post volcanic activity transports significant amounts of CO_2 and other volatiles to the surface. These tectono-magmatic processes are also associated with high-intensity geothermal anomalies, micro-seismicity and teleseismic wave attenuation beneath the SE Carpathians volcanic area and the presence of a critical low-velocity crustal anomaly observed in high-resolution seismic tomography (Popa et al. 2012). Since the study area is populated, the monitoring and, eventually, warning of these potential geological hazards (seismic and volcanic) are of prime importance.

3 Expected societal impact and outreach of Topo-Transylvania initiative

The SE Carpathians and the adjacent part of the Transylvanian Basin are the locus of active differential vertical movements of the orogenically thickened and isostatically unbalanced lithosphere, involving uplift in the mountainous part of the bend area and subsidence in the neighbouring Focsani foredeep (Leever et al. 2006; Matenco et al. 2007). Furthermore, the seismogenic Vrancea zone (Fig. 2), one of the most active and hazardous places in Europe, is linked with active geodynamic processes unfolding in the SE Carpathians (e.g., Ismail-Zadeh et al. 2012), active influencing the landform evolution, changing the topography and actively modifying the largest river system of continental Europe (i.e., the Danube) with significant societal impact (Matenco et al. 2016). The research of geological risks is not new in this area as several different research groups and institutions with different

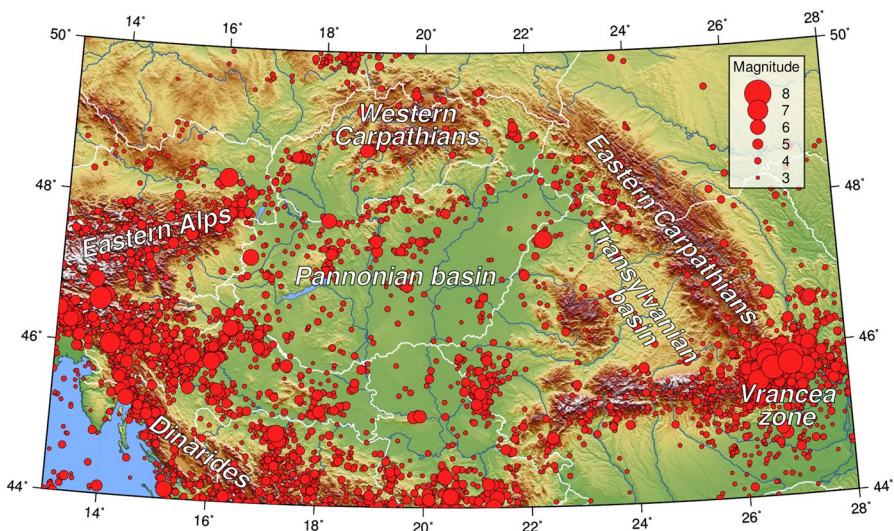


Fig. 2 $M \geq 3$ earthquakes in the Carpatho-Pannonian region occurred between the years 456 and 2015. Sources of data: MTA CSFK GGI Earthquake Catalogue (2018), International Seismological Centre Online Bulletin (2018)

nationalities and expertise have actively carried out research activity on this subject over the past decades. The novelty of the present initiative is to bring together various research groups and scholars of different nationalities and range of expertise in order to get a more comprehensive and holistic image on the geological framework and current geodynamic state of the Carpathian Bend area. In particular, the key motivation is to link deep and surface processes to get a deeper insight into the kinematics of the lithosphere–asthenosphere system in a geologically active segment of the Alpine orogeny. This involves a number of new approaches and methodologies not addressed previously in this area.

The research has great societal importance as the anticipated results may improve our understanding of the link between the geological scale of tectonic processes and the societal scale of the seismogenic cycle, advancing our ability towards prediction of large earthquakes in continental convergence settings (e.g., Dal Zilio et al. 2018). In addition, the monitoring of surface movements provide important constraints to engineering geology, facilitating the planning of human infrastructures (construction and maintenance of buildings, roads and dams). The monitoring of gas emanations of the area could serve as important indicators of potential volcanic activity and risks, which is an additional and practical utilization of the initiative.

The educational outreach of Topo-Transylvania will be considerable given that the investigated area is in the focus of public interest. Practical information such as potential geohazard in the region will also be of great interest to the public and Topo-Transylvania will take a number of measures to communicate the societal-relevant outcomes of the scientific investigation. In particular, Topo-Transylvania strives to raise the public awareness with regard to earthquakes, volcanism and active landscape evolution.

4 Outstanding research questions and available research capacities

The large-scale, multidisciplinary and international collaboration involving a wide range of methods and data sets in Topo-Transylvania takes advantage of a number of major previous initiatives that have targeted the Carpathians–Pannonian System, such as the ESF EURO-PROBE PANCARDI or the ESF TOPO-EUROPE SourceSink projects (Cloetingh et al. 2007; Matenco and Andriessen 2013). Topo-Transylvania covers the entire lithosphere–asthenosphere system from bottom to top opening up new, more holistic research horizons. Besides the societal relevance, the results will contribute to the construction of state-of-the-art analogue and numeric models for understanding the deformation of the lithosphere in the SE Carpathians. The project benefits from, and builds on, the experience gathered previously in the participating institutes.

4.1 Research capabilities available in the Topo-Transylvania initiatives

By exploiting the phase change of microwave satellite images, satellite radar-interferometry offers a unique tool for the continuous monitoring of surface deformation with high accuracy with unprecedented spatial and time resolution. Basics of the method in summarized in Szűcs et al. (2018) (in this issue) as well as a case study is presented based on archive data set for the vicinity of the Ciomadul volcano. With coordinated and systematic observations of the recent satellite mission Sentinel-1 of the ESA Copernicus Earth observation mission new research avenues are foreseen in the detection of small-scale surface deformations.

Szakács et al. (2018) (in this issue) presents a geochronological and geochemical review of the Neogene volcanic activity of the Carpathian–Pannonian region. This study reviews how these data could outline the geodynamic processes acting at the origin of magmatic activity and how these observations maybe reconciled in the light of deep and surface processes. This approach could be successfully applied also to the more refined investigation of the Neogene volcanic activity in the Carpathian Bend area.

Bartha et al. (2018) (in this issue) provides a case study for two Neogene sedimentary basins in the Carpathian–Pannonian region using paleo-stepping method, which allows considering more complex geometries and the effects of lateral movements (compression, folding and inversion in the petroleum systems model). This approach may provide a possible template for a similar investigation of the Transylvanian basin and clearly demonstrates the power, efficiency and limitation of numerical and physical modelling and inversion.

Popa et al. (2018) (in this issue) studied the focal mechanism of earthquakes occurring in the southwest Carpathian Bend area. The results implied the role of broader tectonic trigger mechanism for these regional earthquakes which challenges previous models and may contribute to the development of refined models for Vrancea earthquakes.

Kovács et al. (2018) (in this issue) demonstrated how petrologic and geochemical information from upper-mantle xenoliths could be used to obtain geophysical information (e.g. seismic velocity and anisotropy, viscosity, electromagnetic properties). Based on area specific depth-temperature relationship and equilibrium temperature estimated from upper-mantle xenoliths provisional lithospheric column can be constructed with corresponding geophysical parameters. That concerns the crucial question of validation of geophysical modelling and inversion.

5 Concluding remarks

The immediate benefit of the Topo-Transylvania project is that a new comprehensive model for the behaviour of the lithosphere-asthenosphere system in a complex geological setting could be achieved. This model, in turn, facilitates the explanation of geological processes occurring in the area with special focus on the sustainable utilization of natural resources and geological hazard factors threatening the local society. The ultimate goal is that the emerging new knowledge and synthesis from a geologically still active, populated and, thus, well documented region of Europe could be applied as a template to other areas of the world which are less explored.

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