Numerical modeling of Miocene dyke opening in the Cserhát Hills, Hungary

Dorina Juhász[1], Chiara Lanzi[2], Kitti Váradi[1,3], Márk Szijártó[3], László Fodor[1,4], and Freysteinn Sigmundsson[2]

1-Institute of Geography and Earth Sciences, Department of Geology, Eötvös Loránd University, Budapest, Hungary
2-Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland
3-Institute of Geography and Earth Sciences, Department of Geophysics and Space Science, Eötvös Loránd University, Budapest, Hungary
4-ELKH Research Network, Institute of Earth Physics and Space Science, Sopron, Hungary

Introduction

The Cserhát Hills are located in mid-North Hungary, at the edge of the Pannonian Basin and are parts of the Miocene Inner Carpathian volcanic arc (Fig. 1). The Cserhát Hills is part of the Mátra Andesite Complex and is built up by andesitic cones and by a segmented regional dyke-system(Fig. 2). This study is focusing on this dyke-system, where some of the length of the dykes reach 15 km, and the thickness of 25 m. There are two main striking direction of the dykes, E-W (Fig. 2 a, b, c) and N-S(Fig. 2 d), but even in one set of dyke the segments vary their striking direction (Fig. 2 c). To understand the nature of these dykes, structural geological fieldwork and numerical modelling was carried out. The results of the fieldwork and the numerical modelling help us to understand, when did they open, how much stress was needed to open these dykes, if did they intrude into pre-existing fault-system and what kind of role did they play in the rifting of the Pannonian Basin.

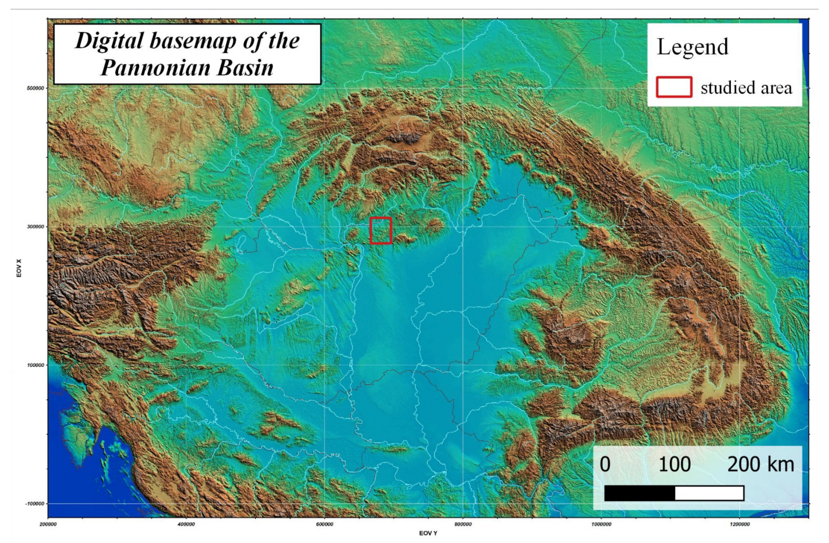

Figure 1. The digital basemap of the Pannonian Basin. The red rectangle shows the Cserhát-

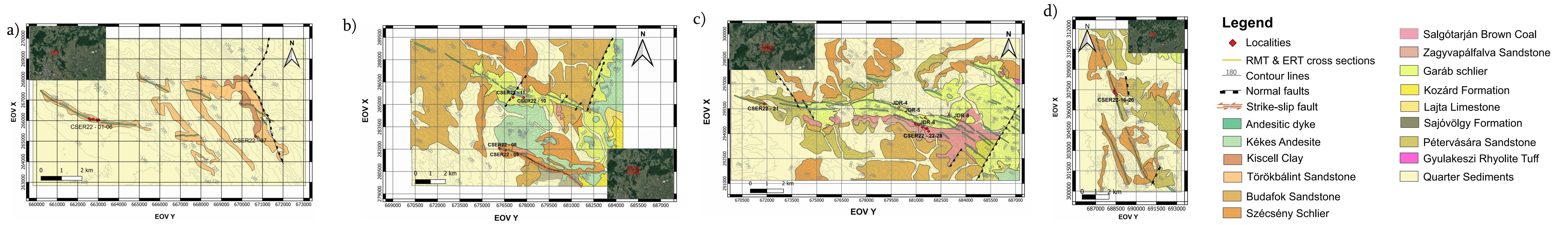

Figure 2. The geological maps of the studied area. The maps were modified after Noszky (1940), Soós (2017) and 1:100000 geological map of the SARA. a) The most southern part of the Cserhát Hills, near Vácduka and Püspökszilágy. b) The area of Bercel and Szanda. c) Northern part of the Cserhát Hills, near Mohora, Cserhátsurány and Herencsény. d) The northernmost part of the Cserhát, it partly belongs to Nógrád.

Methods

- Field work
  - Geological
  - Geophysical
- Numerical Modelling in COMSOL Multiphysics
- Benchmarking against Okada (Okada, 1985)

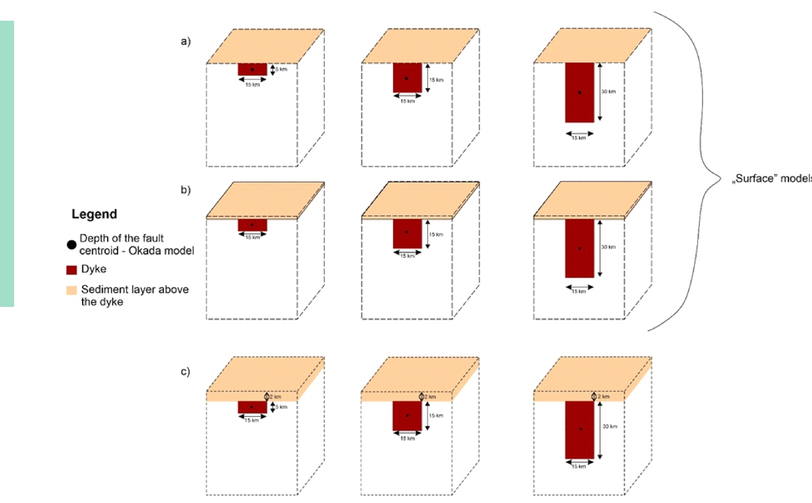

Figure 3. All the different models, what were built up. The a) and b) are the surface models, the difference between them is, on the a) the dykes are not covered by any sediment layer, meanwhile in the b) the dyke is covered by 10 m of sediments. c) the dykes are arrested 2 km below the surface. In the left-handed column the dyke is always 5 km high and 15 km long (”shallow”), in the middle column they are 15 km high (”brittle-ductile”) and in the last one 30 km high (”crust”).

Results I. - Structural evolution

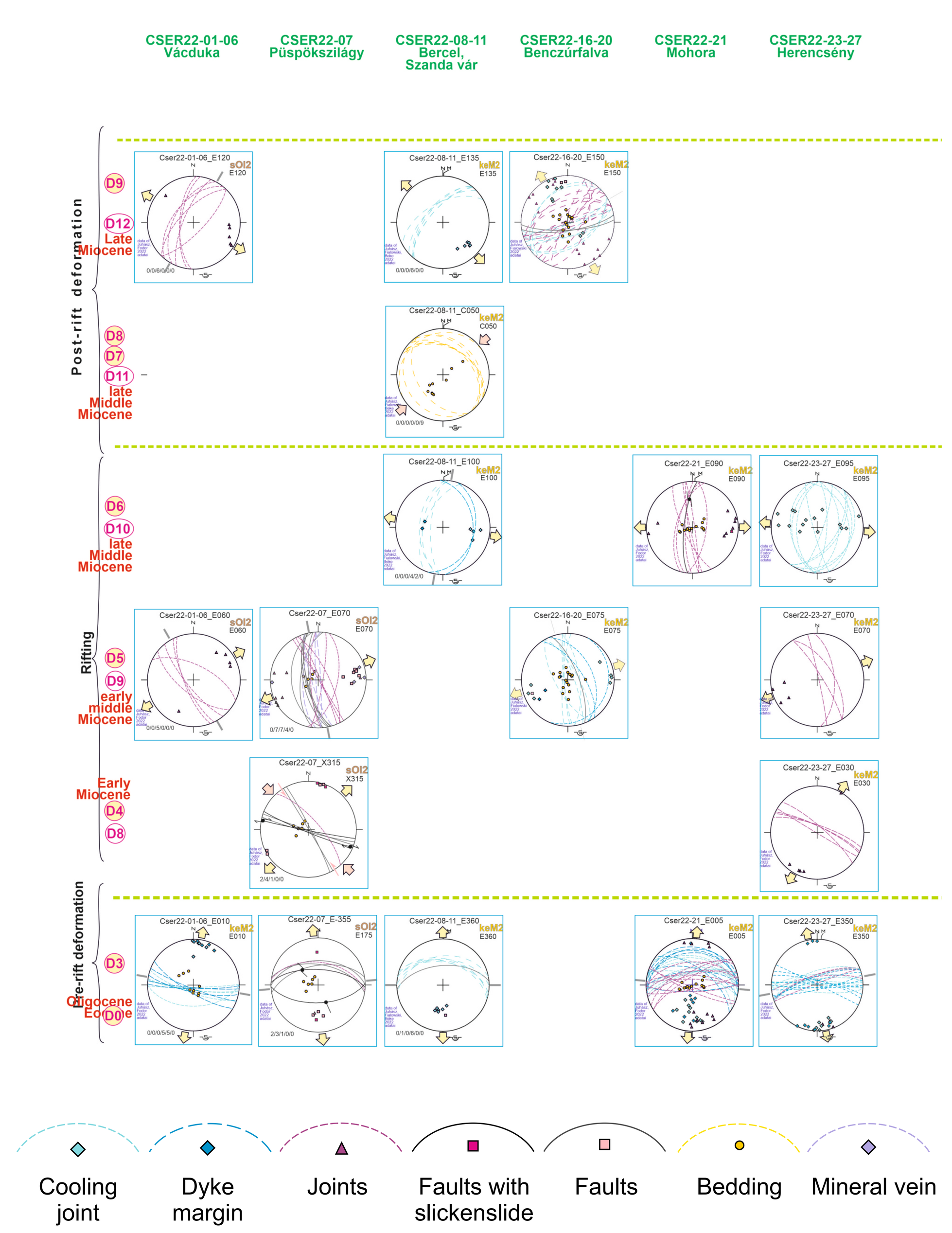

Figure 4. All the measured structural geological data plotted on stereograms. Each column is a different site. Each line shows a different deformation phase, with different stress directions.

Results II. - Stress changes

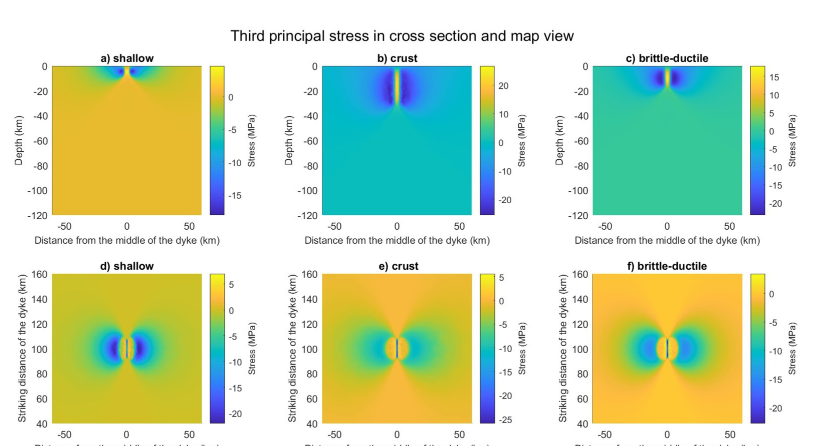

Figure 5. The compressional stress distribution across the dyke (a-c), and on the map view (d-f).

Results III. - Displacement

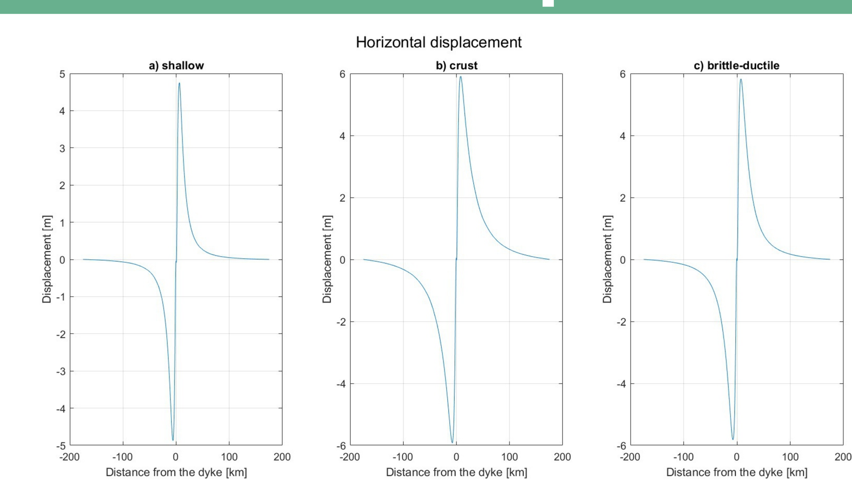

Figure 6. The horizontal displacement in a cross section perpendicular to the dyke.

Discussion and Conclusions

Six different deformation phases are identified in the study area, based on fieldwork . Measurements were carried out on cooling joints in the dykes, dyke margins, joints, faults, mineral veins and bedding. Different phases were separated based on previous research (Beke et al. 2019, Fodor et al. 1999). The locations of the different sites studied are shown on Figure 2.

Main volcanism in the area occcurred during the syn-rift phase, in the early Middle Miocene (Harangi, 2001). During this phase, there is no knowledge of N-S oriented extension. Therefore, we suggest the E-W striking dykes **intruded into a previously developed fault system** as the first deformation phase shows on Figure 4., or where guided by local volcanic systems or effects of topography. On the other hand, **N-S oriented dykes are parallel with the half-graben type normal faults**, which have created the Zagyva Basin (Soós, 2017), a subbasin of the Pannonian Basin.

Due to its back-arc setting, the magma source has been estimated at approximately at 30 km depth. A pathway is required from that depth, but experience from Iceland suggests that below the brittle-ductile transition they may be narrow. Recent rifting epiosodes in Iceland have only led to significant opening above the brittle-ductile transition. hence the suggestion is, the most likely model is, where the Okada source extends to the brittle-ductile boundary. Dykes often get arrested 500-1500 meters below the surface (e.g., Gudmundsson, 2002). We infer the **most appropriate model for the dykes studies is the one where a dyke is arrested 2 km below the surface, and extends to the brittle-ductile boundary.**
We use the numerical models to infer how much stress was required to open the studied dykes in the Cserhát Hills. The third principal stress shows best the co-diking stress change (negative values in the COMSOL software mean compression). **The displacement reacts to the stress change**. The dikes compress the crust adjacent to the dyke. As the diking events may have affected stresses over a **100 km wide zone was deformed due to one diking event** (Fig. 7.), they may have played some role in the widening of the Pannonian Basin.

Field observations

Figure 7. Field observations from three different locations. From left to the right: CSER22-07, at this location the dyke was not found anymore, only the walls of it due to the mining. In the bedrock we were able to measure the dips of faults and bedding. In the middle can be seen the smallest dyke, at the location CSER22-21. The green lines are the cooling joints. On the third we can see the pictures from the location CSER22-16-20. Here the contact between the bedrock and the dyke could be very well followed.

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