High-resolution morpho-tectonic profiling across an orogen

Necea, D.

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1 Introduction, scope and outline of the thesis

1.1. Geological introduction

Mountains, with different shapes and various altitudes, have drawn people's attention since the ancient times, when caves were used as shelters for living and protection. Multiple hypotheses have been proposed over the last two centuries to explain the process of mountain building (orogeny), which is best explained in the context of plate tectonics theory. Orogenic belts form at the convergent plate boundaries, where lithosphere plates collide. The denser (oceanic) plate undergoes subduction beneath either continental or oceanic lithosphere. When the oceanic lithosphere, bounded by two continental masses, has been completely consumed, the two continents will collide. The overriding plate is strongly deformed, which will generally lead to development of topography. This topography is continuously exposed to surface processes, from where large amounts of material are removed through erosion, ultimately revealing the orogenic core. Therefore, the mountain range becomes source area for the adjacent sedimentary basins.

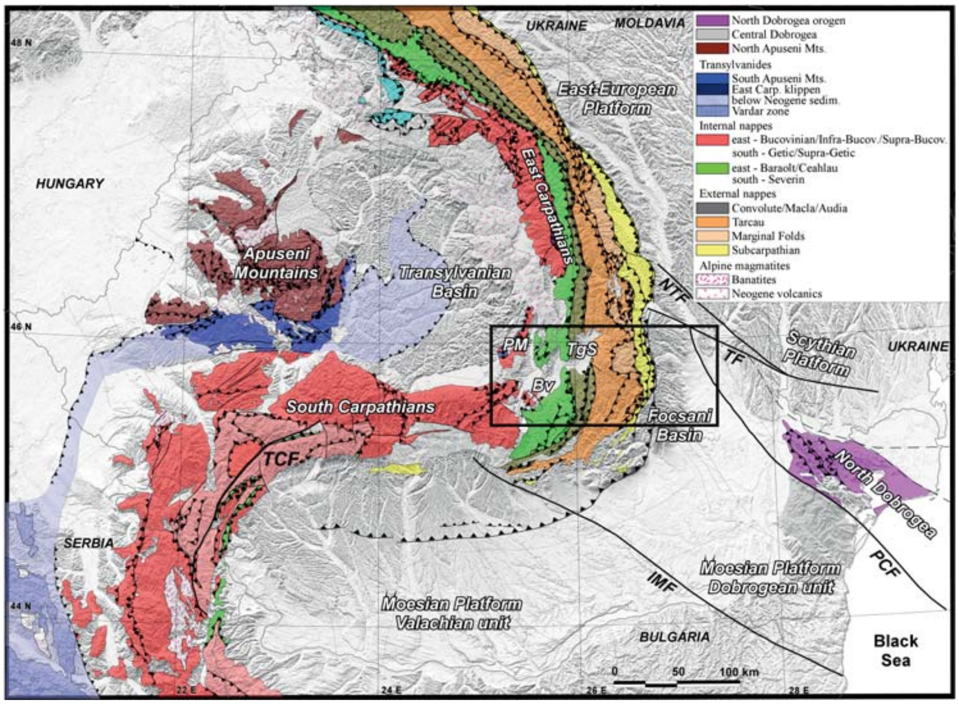
The overall evolution of an orogen through time and the driving mechanism(s) can been constrained by quantifying the amplitude, timing and rate of vertical motions in the orogen itself and the adjacent basins by means of geomorphology and various dating methods. The amounts of eroded material across the orogen and deposited in the adjacent basins help to derive the mechanical model of subduction-collision tectonics of an Alpine-type compressional orogen (Beaumont et al., 1996). This can be characterized by three distinct convergent tectonic stages: (1) subduction with single vergence deformation, (2) a transition from subduction to collision and (3) continental collision with double (or single) vergence deformation. The evolution of an orogen, as for instance described by such a subdivision, might be controlled by a combination of tectonics, surface processes and climate change (Willett et al., 2006; Reiners and Brandon, 2006).

The SE Carpathians (Fig. 1.1), the focus of this research, were chosen to study formation of an orogen as a result of plate convergence and continental collision. This orogen is marked by a characteristic foredeep basin and post-collisional deformations. The SE Carpathians are part of the highly curved Alpine-Carpathian orogenic system. The Carpathian orogen has formed in response to the Middle Triassic to Quaternary evolution of several continental blocks (e.g. Tisza to the south-west, Dacia to the south-east and ALCAPA to the north; Csontos and Vörös, 2004) and the East European/Scythian/Moesian platforms to the north, east and south (Visarion et al., 1988). During the Mesozoic, these blocks have been separated by the Transylvanides (west and south) and the Ceahlău-Severin (east and north) oceanic domains, respectively (Săndulescu, 1984). The Cretaceous evolution is linked to the closure of the Transylvanides domain, when shortening and continental collision took place between the Tisza and Dacia blocks, culminating in the intra-Albian. Coeval deformation took place in the Bucovinian nappes, which were emplaced eastward over the external Ceahlău-Severin units (Fig. 1.1; Săndulescu, 1988). During the Paleogene, the Carpathian orogen was apparently inactive for ~40 Ma (Săndulescu, 1988; Ştefănescu et al., 1988). The Neogene evolution of the SE Carpathians is linked to the final closure of the Ceahlău-Severin ocean. Its eastern passive continental margin was entirely subducted in the Late Miocene (~11 Ma), when the Carpathian nappe emplacement ceased due to the continental collision with the Moesian platform (Fig. 1.1; Matenco and Bertotti, 2000 and references therein). Subsequently, two distinct periods of deformation have been recognized (Necea et al., 2005; Leever et al., 2006; Matenco et al., 2007). The first period was marked by a Latest Miocene-Pliocene general phase of subsidence, while the second one by the Quaternary shortening of 5 km. They can be explained by the interplay between the pull-down effect of an inherited slab, locked during the Late Miocene collision (Vrancea slab) and the Quaternary inversion acting in the entire Carpathian-Pannonian system (Matenco et al., 2007).

1.2. Scope of the thesis

This research was conducted in the framework of two programs, namely Sonderforschungsbereich 461 (SFB461: Strong Earthquakes - a Challenge for Geosciences and Civil Engineering) carried out at the University of Karlsruhe (Germany) and Netherlands Research Centre for Integrated Solid Earth Science (ISES) carried out at the Vrije Universiteit Amsterdam (the Netherlands), respectively. SFB461 focused on the deep lithospheric processes and their surface expression in the Vrancea active seismic zone of the SE Carpathians. The contribution of this thesis to the SFB461 was to quantify the amplitude of

Figure 1.1



Regional geology of the Romanian Carpathians. The black rectangle corresponds to the studied area, the bending zone of the SE Carpathians. PM-Perşani mountains; Bv-Braşov and TgS-Târgu Secuiesc basins; NTF-New Trotuş fault, TF-Trotuş fault, IMF-Intramoesian fault and TCF-Timok-Cerna fault (from Săndulescu, 1984, in Matenco et al., 2007).

vertical movements and processes controlling landscape evolution during the last phases of orogenic evolution (Late Pliocene-Quaternary, i.e. the last 3 Ma) by mean of tectonic geomorphology and luminescence dating. This PhD then continued within the scope of ISES, which has the Pannonian basin-Carpathians system as one of its natural laboratories for quantifying neotectonic and landscape forming processes (Cloetingh et al., 2003). Initially, the objective of this PhD within the ISES program was to derive and quantify the amplitude and timing of vertical movements taking place in the aftermath of the Late Miocene continental collision by applying low-T thermochronology. In a later stage, the study area was extended, geographically from the external Carpathian nappes up to the Transylvanian basin across the orogen and temporally, from the Late Pliocene to the Early Cretaceous, respectively.

1.3. Outline of the thesis

Amplitude, timing and kinematics of shortening events taking place in the SE Carpathians have been quantified during this study following a 175 km long W-E geological transect. The profile starts in the Transylvanian hinterland basin, crosses the orogenic system, the eastward tilted strata of the Focşani foreland basin and ends in the flat-dipping Holocene deposits in the central part of the basin (Fig. 1.1).

Chapter 2 describes the geomorphological analyses and focuses on the last phases of orogenic evolution recorded during the Quaternary in selected key areas (e.g. along the Putna and Milcov rivers which cross-cut from west to east the external orogenic nappes and the adjacent foreland basin).

Despite the good control on the amplitude of deformation described in Chapter 2, there is less information on its timing. For this reason, this study introduces in *Chapter 3*, three different dating methods applied to different time scales: Infrared Stimulated Luminescence (IRSL) to Middle Pleistocene-Holocene and Apatite Fission Track (AFT) and (U-Th)/He thermochronology to Cretaceous-Quaternary. The IRSL method helped to generate a new set of age data for the Middle Pleistocene-Holocene loess sequences deposited on river terraces and overlapping tilted bedrock surfaces (i.e. monocline structure), both in the internal nappes and intramontane basin and at the orogen-foreland transition zone. The results are presented in Chapter 4. Geological data in the SE Carpathian orogen provide an incomplete chronology of different orogenic events, particularly the Middle Cretaceous (Aptian-Albian) shortening of the internal nappes, the Paleogene quiescence, the Miocene thrusting of the external units and the Quaternary deformation of the orogen-foreland transition zone. The (AFT) and (U-Th)/He methods constrain the timing and magnitude of the above mentioned events and are further discussed in *Chapter 5*.

Chapter 4 combines the geomorphological results with time constraints provided by IRSL dating applied to loess sequences to derive the loess deposition, indirectly terrace formation time, rate and amplitude of river incision and dominant contributing processes. This data integration applies to the internal and external orogenic nappes and the sedimentary fillings of the adjacent Braşov intramontane and Focşani foreland basins.

Chapter 5 depicts the amplitude, timing and kinematics of shortening for each tectonic unit and the evolution is subdivided in accordance with the recognized and above outlined main tectonic phases. The findings from the AFT and (U-Th)/He thermochronological dating are discussed and interpreted by two shortening phases, late Early Cretaceous to Late Miocene and Latest Miocene to Present.

Chapter 6 integrates the geomorphological, luminescence and thermochronological results to derive the three successive orogenic stages and driving mechanisms of mountain building characterizing the SE Carpathians. The three stages are: Hauterivian? to Earliest Oligocene subduction, Oligocene to Late Miocene subduction to collision and Latest Miocene to Present post-collision. This chapter also points out about glaciation influence on river incision and terrace formation.