Stress Propagation and Ongoing Basin Inversion in the Pannonian Region

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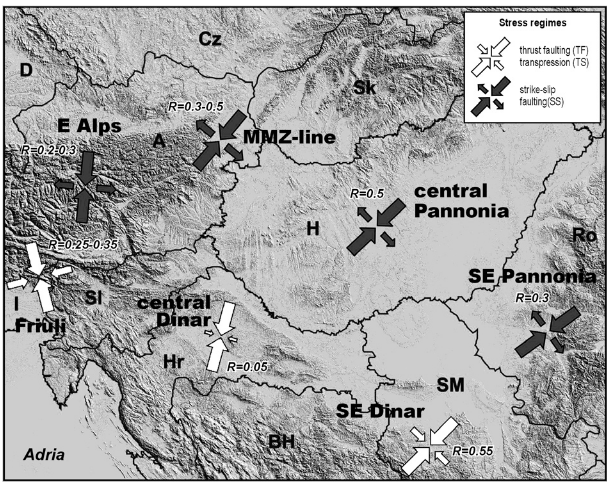
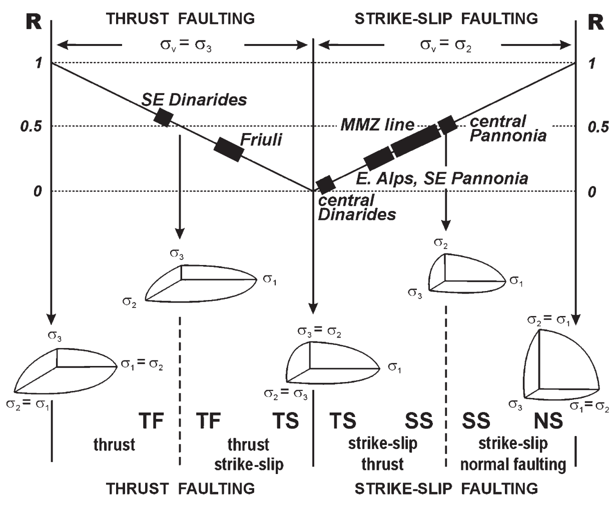
We present a compilation of new data and models on the present-day stress and strain pattern in the Pannonian basin, particularly in its western part, and its tectonic environment, the East Alpine-Dinaric orogens. Extensional formation of the Pannonian basin system within the compressional Alpine belt set off in the early Miocene, whereas its structural reactivation has been taking place since late Pliocene-Quaternary times. Basin inversion is related to changes in the regional stress field from a state of tension controlling basin formation and subsidence, to a state of compression, mainly governed by the convergence between Adria and its buffer, the Alpine belt of orogens. Seismicity indicates that ongoing deformation is mainly concentrated in the contact zone around the Adriatic microplate, where intense contraction is in combination with active strike-slip faulting manifested in an active Dinaric transpressional (dextral) corridor. Stresses and deformation are, however, transferred well into the Pannonian basin, resulting in a complex pattern of ongoing tectonic activity, i.e. a well-defined spatial variation of both the stress and strain fields during the current stage of basin evolution (Fig. 1). From the frontal zone of "Adria-push" in the outer Dinarides towards the interior of the Pannonian basin the dominant style of deformation gradually changes from pure contraction through transpression to strike-slip faulting (Fig. 2). The overall shortening over the entire basin, clearly evidenced by earthquake focal mechanism solutions, GPS data and the results of neotectonic studies, has led, eventually, to the folding of the lithosphere at various scales.

Extensional basin formation resulted in significant weakening of the Pannonian lithosphere, allowing subsequent basin deformation to be localised at crustal discontinuities. The extended, hot and, hence, weak lithosphere underlying sedimentary basins is prone to reactivation under relatively low compressional stresses. Due to its extremely low rigidity and the high level of intra-plate compression concentrated in the thin elastic core of the Pannonian lithosphere, the area exhibits large-scale bending manifested in Quaternary subsidence and uplift anomalies. The Pannonian basin is interpreted as a key example of irregular lithospheric folding, with a wavelength spectrum ranging from a few kilometres (local basin inversion) to hundreds



■ **Fig. 1.** Stress regimes in the Pannonian basin and neighbouring orogens defined by the orientation and relative magnitude of the principal stress axes. See Figure 2 for the specified R values.



■ **Fig. 2.** Dominant style of deformation in various parts of the Panonian basin and its surroundings on the basis of the orientation and relative magnitude of the principal stress axes, the latter expressed by stress ratio R ($R = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$).

of kilometres (whole lithospheric folding). Folding is often associated with differential vertical motions. Significant uplift has been taking place at the basin margins and along several internal basement highs, and accelerated subsidence is in progress in localised depressions at the basin centre.

The importance of late-stage compression in the Pannonian basin for explaining its anomalous topography and intraplate seismicity is interpreted in a more general context of structural reactivation of back-arc basins. Possible sources of compression have been investigated by means of numerical modelling. The state of recent stress and deformation in the Pannonian basin, particularly in its western and southern part, is governed by the complex interaction of plate boundary and intraplate forces. These are the counterclockwise rotation and northward indentation of the Adriatic microplate, as the dominant source of compression, in combination with buoyancy forces associated with an elevated topography, and crustal as well as lithospheric inhomogeneities along the Alpine, Carpathian and Dinaric orogens.

Miocene Danube Basin: Geodynamics and Depositional History

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In a W–E cross section, the Slovakian northern part of the Danube Basin has a character of three depressions – Blatne, Risnovce, and Komjatice, being divided by Povazsky Inovec Mts., and Tribec Mts. horst structures.

By the combination of geodynamic, and paleogeographic history with a depositional history, we are presenting a complex sequence stratigraphic model of the basin.

The Eggenburgian to Ottnangian geodynamic development started under a transpressional regime at the northern margin of the basin, forming wrench fault furrow type depocentres. The Late Ottnangian to Karpatian phase of the initial rifting was forced by the extrusion of the Central Western Carpathian part of the ALCAPA microplate from the East Alpine realm. The transtensional pull apart depocentre system gradually widened. The Early Badenian transtensional rifting, demonstrated by a rapid tectonic subsidence forced the opening of the southeastern part of the basin. A complex wide extensional rifting started during the Middle Badenian, causing the unification of the basin. The deposition of marine sediments took place in whole the basin territory. At the end of the Middle Badenian time the sedimentary record shows the initial emergence of two drab horst structures, and starting partial separation of the mentioned depressions. The Upper Badenian to Sarmatian geodynamic development shows a gradual ceasing of the rifting, i. e. a transition from the synrift stage to a thermal relaxation. The largest Sarmatian accommodation place took place in the central Risnovce Depression, being filled by thick deltaic deposits. The next phase of tectonic subsidence took place only in the southern part of the basin during the Early Pannonian time, being controlled by deep listric faults, dipping to SE. Then the next thermal postrift phase followed. During this Pannonian phase only normal faults at the basin margin controlled the subsidence..The latest Late Miocene to Pliocene extensional phase coincided with the thermal collapse of the Danube Basin, and caused the development of separated sag basins.

The depositional history of the Danube Basin reflects the tectonic, subsidence, and eustatic changes, as well as changes in the sediment supply.

By the analysis of depositional key surfaces, bounding the principal depositional systems tracts, we can roughly reconstruct the succession of depositional sequences within the Miocene infill of the basin. The Danube Basin fill was separated into 7 principal depositional sequences.

The Eggenburgian to Early Ottnangian Sequence Nr. 1 starts by the deposition of alluvial clastics in local depressions of the basement, and later by marine coarse clastics at the toes of marginal rock cliffs. The marine fine clastics show a gradual decrease of salinity at their top.

The Ottnangian to Karpatian Sequence Nr. 2 lower boundary is situated within the coarse fluvial to deltaic clastics, covering the Ottnangian Cibicides-Elphidium Schlier. The transgressive brackish, anoxic to marine deposits are covered by the highstand systems tract related marine neritic ones. The upper boundary of this sequence, deposited at the northern part of the basin displays a subaerial erosion surface.

A distinct geodynamic change caused, that the following Sequence Nr. 3 developed in a new depocentre in the southeastern part of the basin, and its duration is from the latest Karpatian to the Early Badenian. Its lower boundary coincides with the pre-Neogene basement surface. The lowstand continental clastics were flooded and covered by marine sandy clays, related to the transgressive, and highstand depositional systems tracts.

The Middle Badenian Sequence Nr. 4 evolution starts probably before the end of the Early Badenian at the NW edge of the basin. The lowstand deposits are represented by a huge accumulation of alluvial coarse clastics in the local pull apart Blatné Depression. The following flooding covered the whole basin area by transgressive clayey deposits, continuing into similar highstand sandy clays with offlap stacking pattern in their upper portion.

The Upper Badenian Sequence Nr. 5 transgressive portion shows a new depositional onlap on the basin margins, and on the elevated horsts. The transgressive depositional systems of shelf sand ridges are capped by offshore clays during the highstand period of relative sea level change. The final part of this sequence is represented by the deposition of hyposaline facies assemblages, continuing until the earliest Sarmatian time.

At the basin margins, the eroded Badenian strata were incised by fluvial channels, transporting clastic material into fan deltaic systems. They were flooded by a new transgression of the