Foreland of the Romanian Carpathians

Leever, K.A.

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Foreland of the Romanian Carpathians - controls on late orogenic sedimentary basin evolution and Paratethys paleogeography.

Summary

A wealth of information about the history of the Earth and the processes that shaped it is stored in sedimentary basins. For the less poetic: they also contain fresh water reserves and store the hydrocarbons that to date still represent our major energy source; geothermal energy from sedimentary basins is a promising resource. The patterns of sedimentary infill give information about the subsidence and uplift of the earth's surface controlled by mantle-driven processes, as well as sometimes major sea level changes. Environmental and climate changes may be read from the fossil record.

The study of sedimentary basins is therefore justified not only from the curiosity-driven scientific point of view, which traditionally aimed to derive the geological history of a particular region, and in modern Earth Sciences aspires to obtain a quantitative understanding about the interacting processes shaping the Earth. It also, ultimately, helps to answer the demand for energy and provides understanding about variations in our physical environment, in which climate and sea level changes represent some of the major challenges in the 21st century.

That said; the scope of this PhD thesis is the mechanisms controlling the tectonic, sedimentary and paleogeographic evolution of foreland basins in the period during and specifically post-dating the tectogenesis of the adjacent orogen. The evolution of orogen and foreland basins is intimately linked, a relationship that was found to continue even after the end of the major orogenic deformations or nappe stacking events. Uplift and subsidence are tectonically coupled in the orogen-basin system, which also represents a coupled source-sink system. Moreover, the rising orogen represents a barrier determining the paleogeographic evolution of a region and the associated environmental changes. Integration of data from both parts of the system is therefore vital for its comprehensive understanding, and the results presented in this thesis should be seen in the larger framework of research recently conducted on such coupled systems within the Netherlands Research Centre for Integrated Solid Earth Science (ISES) Pannonian-Carpathian programme.

The foreland basins of the Romanian Carpathians are a natural laboratory that features a dynamic late orogenic evolution in all of these aspects. Building on an extensive data set that has become available over the years, the data presented in this thesis give good constraints on the controlling mechanisms. The Carpathians are highly arcuate orogen in central and eastern Europe, extending eastward from the Alps and completing an 180° loop before connecting with the Balkans. During the Tertiary shortening and rotations in the Carpathian chain, its foreland basins on Romanian territory started their evolution on an amalgamated foreland lithosphere of laterally strongly different age and rheology. Paleogeographically, the post-orogenic basin is known as the Dacic Basin, forming an appendix of the Eastern Paratethys.

Within the framework of the late orogenic evolution of the Romanian foreland basins,

this thesis consists of two parts, geographically different and with different emphasis and aims. The subject of the first part of the thesis is tectonic foreland subsidence and the mechanisms controlling it, aiming (1) to determine the influence of lateral variations in lithosphere strength on syn-orogenic basin evolution and (2) constrain the kinematics and define a mechanism for the anomalous post orogenic vertical motions in the foreland of the East and SE Carpathians. Changing paleogeographic relations and associated sea level changes are the subject best represented and studied in the foreland of the South Carpathians. Here, the aims are to determine (3) the signature of the major sea level fall associated with the Mediterranean Messinian Salinity Crisis in the Dacic Basin, and (4) the causes and effects of changing intra-Paratethys connectivity, specifically the controls on the incision of the Danube into its gorges across the Carpathians, and the effects on sediment partitioning between the Dacic and Pannonian Basin.

As for the applied methodology: the results presented in this thesis are largely based on the interpretation of both newly acquired high resolution shallow seismic data and high quality industry lines. Numerical modelling, by parameter studies of lithospheric flexure and the interaction between lithosphere and surface processes, is used as a tool to aid the interpretation of the seismic data and derive the relative importance of controlling mechanisms.

The study area of the first part of the thesis, in front of the East and SE Carpathians, features an amalgamated foreland composed of strongly different pieces of lithosphere. They are of different tectono-thermal age, composition and hence rheology and flexural behaviour. The old East European Craton (EEC) is bordered to the south by the Scythian Platform, which in turn is separated from the Moesian Platform by the Jurassic North Dobrogea orogen. The evolution of the foreland basin during the east-ward displacement and accretion of the Carpathian flysch belt was studied by 2D elastic flexural modeling. The topographic load migrated towards and across the lateral transition in lithosphere strength from the EEC to the Moesian Platform, oblique to the Carpathian deformation front. The parameter study pointed out that a strength transition in the foreland of an accreting orogen will result in a step-wise widening of the evolving foreland basin. The foreland-ward migration of its shoreline (and flexural bulge) may occur at a rate of up to 4 times the migration rate of the belt, depending on the gradient of the transition. A strength transition of ~100 km width explains the geometry of the Sarmatian foredeep, much wider in the north than in the south. Furthermore, concentration and amplification of bending stresses is predicted along the strength transition. Such a flexural bending-induced 'collapse' along a zone of lithospheric strength contrast could explain the extensional faulting along the Peceneaga-Camena fault system.

The most striking feature of the East Carpathian foreland is the Focşani Depression adjacent to the SE Carpathian Bend Zone. In a region of ~60 x 120 km, up to 6 km of sediments accumulated in the aftermath of continental collision during Pliocene-Quaternary times. They are presently outcropping adjacent to the belt, steeply dipping away from it. Interpretation of newly acquired and depth converted high resolution shallow seismic lines allowed detailed mapping of the geometry of the strata on this western basin flank adjacent to the orogen. From a kinematic reconstruction, three stages of foreland subsidence were recognized. The first, Late Miocene stage, was related to 'normal' foreland basin evolution during orogenic loading. The second stage, which lasted from latest Miocene to Pliocene, featured generalized subsidence over an area that comprised part of the present-day elevated belt. This subsidence was most likely driven by the pull of the seismogenic 'Vrancea slab'. In the third and final Quaternary stage, the basin was inverted. In response to ~5km of shortening, uplift of the orogen was partly accommodated by steep reverse basement faults. As a result of the uplift of the belt, the sediments on the western flank were tilted into a sub-vertical position while subsidence continued further eastward, accommodating up to 2 km of sediments. This inversion stage coincides with the regional inversion of the Pannonian-Carpathian domain, and occurred at an exaggerated amplitude in comparison with the inversion of the Pannonian Basin due to the slab pull and the adjacent rigid EEC. These observations led to the conclusion that post-collisional tectonic movements in an orogen and its adjacent foreland basin, related to intraplate stress and the presence of a remnant slab, are capable to induce significant deformations overprinting the existing patterns of nappe emplacement.

The second part of this thesis focuses on the foreland of the South Carpathians, where the rotation of the overriding Tisza-Dacia plate along the western margin of the Moesian Platform led to the extensional opening of the Getic Depression. Followed by Sarmatian transpression, it resulted in an up to ~500m deep basin that was progressively filled by prograding clastic shelf systems during the Late Miocene-Pliocene. These represent a sensitive recorder of base level changes. In its extreme west, the Danube enters the basin at the Iron Gates, after transversely crossing the South Carpathians over a distance of ~90km in its deeply incised gateway. In this part of the thesis, basin evolution is approached from a paleogeographic perspective, with a focus on the signature of the Mediterranean Messinian Salinity Crisis (MSC) in the Dacic Basin. The expression of the connectivity between the water masses of the Paratethys sub-basins and between Paratethys and the Mediterranean, and its control on both accommodation space and sediment supply is the key issue. The combination of basin-scale seismic sequence stratigraphic interpretation and surface mass transport modelling was found to provide a potentially powerful tool to constrain paleogeography in addition to the traditional biostratigraphic methods. Good age constraints on the deposits, either from biostratigraphy or preferably absolute, remain a prerequisite.

>From the sequence stratigraphic interpretation of a large composite seismic section (>200km) covering the western Dacic Basin, the large Mediterranean sea level changes associated with the MSC were shown to have affected the Dacic Basin as well. The sea level changes in the Dacic Basin related to this event amount to 100's of meters, largely exceeding glacio-eustatic values in rate and magnitude. A Middle Pontian sea level fall of 200m could be attributed to the MSC. It exposed the entire shelf, greatly reducing the sediment accumulation area and increasing the apparent sedimentation rates. A large lowstand wedge developed, prograding into the remnant ~300m deep basin. During the lowstand, the sea was kept at a constant level by the elevation of the Scythian pathway, the barrier with the Black Sea in the east. The subsequent Late Pontian sea level rise, coeval to the Zanclean

deluge, re-flooded the entire basin at least to its present-day margins.

The major Messinian sea level change observed on the seismic data points at communication between Paratethys and the Mediterranean, and led to questions on intra-Paratethys connectivity. The causes and effects of changing connectivity between the Pannonian and Dacic Basins by way of the Danube Gateway were further explored by numerical modelling. Besides sea level changes, a number of other factors were addressed that potentially influence the connectivity and resulting sediment partitioning between the two basins: barrier geometry and uplift rate, and lithosphere rigidity. The most important result of the modelling is that the connectivity between two basins exerts control on accommodation as well as on supply which, as such, were found to be mutually dependent.

The modelling showed that a fluvial connection between two large sedimentary basins that are separated by an elevated barrier will only be established if the upstream lake level is able to rise to the top of the barrier. In the model, the upstream (Pannonian) basin has the largest sediment source area, while the downstream (Dacic) basin is in open connection to sea level. Capture and adaptation of the river gradient across the barrier to a subsequent downstream base level lowering will result in an upstream lowering of the lake level. The counteracting effect of isostatic rebound is reduced by lateral differences in erodibility, controlled by tectonic structuring, allowing the connecting river to incise relatively deeply in its gateway. The resulting sediment partitioning between the basins is controlled primarily by the accommodation space in the upstream basin, which in turn is a function of the lake level and subsidence. The rigidity of the lithosphere is the most important parameter influencing the sediment partitioning, controlling both the timing and the rate of the bulk sediment shift. A strong lithosphere will lead to a fast and sudden shift while for a weak lithosphere the response is more gradual. The capture event itself will not lead to a strong downstream change in sedimentation rates, unless it coincides with or triggers the completion of the infill of the upstream accommodation space, which may occur for a large elevation difference between the basins. Locally, at the inlet in the downstream basin, an increase in sedimentation rates due to capture is predicted.

The fluvial connection between the Pannonian and Dacic Basins, after open water communication was disrupted by the Sarmatian uplift of the Carpathian barrier, was most likely re-established during the Meotian, as suggested by the increased sedimentation in front of the Iron Gates, and the low salinity of Lake Pannon during the endemic Pannonian stage. Calculations of a water balance for the Pannonian drainage area also argue for an early reconnection. The 200m Messinian sea level fall in the Dacic Basin resulted in deeper fluvial incision into the Danube gateway, which caused the lowering of the Pannonian lake level. The connection was permanent from then on; the lowered barrier may even have allowed the subsequent rising sea level to penetrate into the Pannonian Basin. The lowering of the Pannonian lake level marked the end of the 2nd order 'Late Miocene sequence', accellerated the final infilling of the basin and increased the sedimentation rates into the Dacic Basin. The downstream increase in sedimentation rates was only gradual due to the low lithosphere rigidity and ongoing subsidence and generation of accommodation space in the upstream Pannonian Basin. The ongoing Pannonian subsidence additionally allowed the accommodation of large volumes of fluvial or shallow lacustrine sediments.