Analogue modeling of the evolution of Polish Outer Carpathians

Making Mountains

MARTA RAUCH-WŁODARSKA
Institute of Geological Sciences, Wrocław
Polish Academy of Sciences
ndrauch@cyf-kr.edu.pl

The world has become immersed in computers and their capabilities to simulate reality, yet in certain cases nothing can take the place of traditional methods and tools

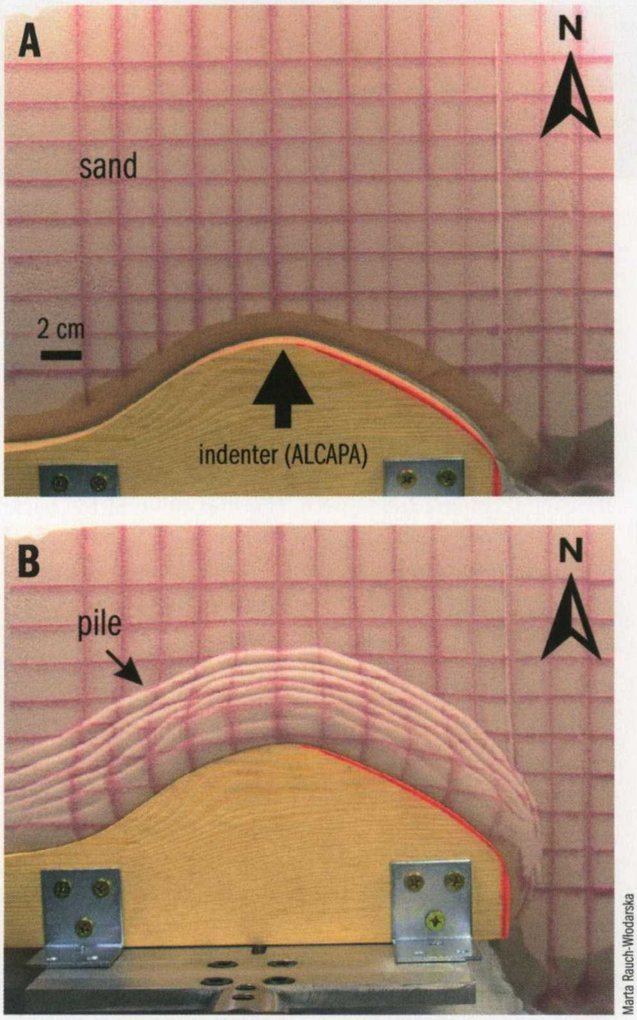
Mountains have fascinated mankind since time immemorial. Yet one does not have to travel to the Himalayas to appreciate the powerful forces that created them - it suffices to climb Poland's own Beskid mountains and look at the rocks one passes. Once sea-floor sediments, they are now far above sea level, set upright, and heavily folded. Geological study of the Polish Outer Carpathians, underway since the turn of the 20th century, has focused on identifying how that came to pass.

Nearly 100 years of research has enabled us to precisely identify the geological structure of the Carpathians, based on which we can now reconstruct all the stages of their evolution. First the Carpathian Basin was formed, where sediments accumulated in the Cretaceous and Neogene. Next those sediments were consolidated, deformed, and uplifted, where they are now subject to weathering and erosion. Although our knowledge is now considerable, debate is still underway on the precise mechanism by which the Outer Carpathians formed. Various theories can be tested in a simple way using the method of analogue modeling, which involves making physical simulations of how a given geological structure or entire orogen was formed.

Geological bulldozer

The Polish Outer Carpathians are an orogen shaped as a large arc convex towards the north, composed of sedimentary rocks dating from the late Jurassic to the early Miocene (ca. 150-20 million years ago). These rocks were folded and cut by many faults. The deformations are thought to have begun in the Oligocene (ca. 34 million years ago), in the southern portion of the Carpathian Basin, with their front later shifting northwards. These sediments were cut away from the substratum in the form of large slices, called "nappes," and pushed forward forming a pile. That pile of nappes is called the Carpathian accretionary wedge. Five such nappes have been distinguished within the Polish part of the Carpathians, the oldest being the Magura Nappe, lying furthest to the south.

Efforts to reconstruct the evolution of the Outer Carpathians now widely adopt a collision-type model, according to which the Carpathian accretionary wedge was formed when the African and Euroasiatic continents collided with one another. There were also smaller continental fragments in the area of the collision, including the ALCAPA block, encompassing today's Tatra Mountains



Analogue model of the emergence of the Outer Carpathians. The movement of the indenter simulates the shifting of the ALCAPA block northward: A) initial state, B) final state, an accretionary wedge having formed in front of the indenter

BE&W

The way in which the nappes (rock sheets) forming the Polish Outer Carpathians were shaped still largely remains a mystery

and Podhale region. The two large continents drawing closer to one another likewise affected such smaller plates, causing them to move and rotate.

The Outer Carpathians are widely believed to have arisen as a consequence of the movement of the ALCAPA block, which like a gigantic bulldozer pushed off Carpathian sediments into a gigantic pile. Discussion is currently underway about the nature of this block's motion: did it move consistently in a single direction or change direction, and did it rotate during such motion or not?

Mountains of sand

Analogue modeling, a method of broad application in the world, is frequently used to better comprehend mechanisms of geological deformation and to reconstruct the evolution of fold-and-thrust belts and accretionary wedges. In the special type of analogue modeling used to study these phenomena, called indentation modeling, a rigid block (indenter) is pressed into a prepared layer, usually composed of sand. During such an experiment a structure analogous to an accretionary wedge forms along the front of the moving indenter. The outcome of indentation modeling depends on various parameters such as the type of material, the friction of the substratum, the thickness of the layer of material, the dip of the front face of the indenter, and its shape. The indenter is usually pressed in one direction, with complex paths of motion only being tested rarely.

The analogue modeling method, although known in Poland, has not been very popular among Polish researchers, mainly due to the absence of a special experimental table. Such a computer-controlled device has now been built as part of a project financed by the Polish Committee for Scientific Research (KBN), at the newly established Analogue Modeling Laboratory of the Institute of Geological Sciences in Wroclaw. The device is unique because it can perform both typical experiments where the indenter moves in a single direction, as well as more unusual configurations where the indenter changes direction during the experiment or moves in a constant direction but simultaneously rotates.

The Laboratory is currently testing various theories of the Polish Outer Carpathians' formation. The results to date have shown that the simplest scenario, with the indenter moving in a constant direction, produces a wedge with an internal structure that does not correspond to that of the Outer Carpathians. When the indenter is pressed precisely northward, the wedge so obtained exhibits longitudinal symmetry, but such symmetry is observed in the Carpathians only in the Magura nappe. This suggests that the pressing motion should be more complex. Research is still underway, testing to date indicates that the best results are obtained with the indenter put into anti-clockwise rotation while simultaneously moving to the northeast. ■

Further reading:

Rauch M. (2005). Preliminary results of analogue modeling of the Paleogene and Neogene evolution of the Western Outer Carpathians (Poland). Proceedings of the 3rd Meeting of the Central European Tectonics Group (CETG). *GeoLines, 19*, 98–99.

Fodor L. & Csontos L., Bada G., Györfi I., Benkovics L. (1999). Tertiary tectonic evolution of the Pannonian basin system and neighbouring orogens: a new synthesis of paleostress data. [In:] Durand B., Jolivet L., Horváth F. & Séranne M. (Eds.). The Mediterranean Basins: Tertiary Extension within the Alpine Orogen. *Geological Society, London, Special Publications, 156*, 295–334.

Mulugeta G. (1988). Modeling the geometry of Coulomb thrust wedges. *Journal of Structural Geology, 10 (8)*, 847–859.