Salt Tectonics in Compressional Settings: Comparison of the S Pyrenees and the N Carpathians

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Evaporites in general, and rock salt in particular, are of key importance for evolution of fold-and-thrust belts, as evaporitic layers often form preferred levels of detachments within the orogenic wedge. The combined effects of the foredeep basin morphology during deposition of evaporites and distribution of the surrounding non-evaporitic depositional systems influence the position, extent and thickness of the foredeep evaporitic successions. The continuous forward propagation of the thrust front often result in forward and upward migration of the evaporitic units.

The Carpathians and the Pyrenees belong to the Alpine – Himalayan orogenic belt formed by the closure of the Tethys Ocean. At present, the frontal part of the S Pyrenees is well exposed, whereas front of the Polish Carpathians is mostly buried, especially in their central segment described below. In both the S Pyrenees and N Carpathians, the foredeep evaporitic layers constitute the principal detachment levels for the late development of both fold-and-thrust systems, with a strong coupling between tectonics and sedimentation and vice versa.

The external folded domain of the Southern Pyrenees is detached above several middle Eocene to middle Oligocene foreland syntectonic evaporitic layers (e.g. Vergés et al. 1992). The position, extent and thickness of these evaporites as well as the shape of the southwards transported Pyrenean thrust front constrain the position, geometry and trend of the series of detached anticlines in the Ebro Basin. The most important foreland detachment is located above the middle Eocene, 300-m thick Cardona salts on top of which a trend of continuous NE-SW trending anticlines developed (e.g. Sans and Vergés 1995). The tip line of the Pyrenean shortening corresponds in this region to a backthrust with NW vergence. Towards the SW boundary of the Cardona salt basin, the detachment climbs to the about 1,000 m thick middle Oligocene Barbastro evaporites. Above the ramp, the Barbastro and Sanaüja anticlines developed with their forelimb detached as a backthrust along the overburden – evaporites contact (Sans et al. 1996, Sans and Vergés 1995).

The Outer Carpathians are genetically linked to the Carpathian foredeep basin that developed in front of the advancing orogenic wedge (for recent summary see Oszczypko et al. 2005). Presently, in front of the Outer Carpathian flysch (pre-Miocene) units, a zone of deformed foredeep deposits exists of variable width, reaching max. 10 km in the area located between Kraków and Tarnów. Undeformed foredeep infill preserved in front of the Carpathians consists of the Upper Badenian – Sarmatian siliciclastic succession, with important evaporitic level at its bottom. Major detachments of this Miocene thrust system are related to the upper Badenian evaporites. Within the frontal part of the triangle zone of the Wojnicz slice two evaporitic horizons overlap laterally, one being uplifted by passive backthrusting of the Biadoliny slice, and another being preserved in its autochthonous position beneath the triangle zone (cf Krzywiec et al. 2004). Such configuration suggests that in this area two overlapping evaporitic horizons were deposited, contrary to previous models assuming single evaporitic level developed within the entire basin.

Using Cardona model proposed for the S Pyrenean front as well as triangle zone model proposed for the Tarnów sector of the Polish Carpathians, a new conceptual model for the Wieliczka sector (S from Kraków) was developed. In this part of the frontal Carpathians famous Wieliczka salt mine is located within the strongly deformed Miocene evaporitic zone in front of the flysch Carpathian nappes. Previously published cross-sections of the Wieliczka salt mine (Tołwiński 1956) suggest that also in this area triangle zone might have developed, and that the entire salt mine might be located within the core of this zone. Formation of the Wieliczka triangle zone and associated backthrust might have been controlled by lateral facies changes of the evaporitic unit – transition from thick salt-dominated domain to thin anhydrite-dominated domain. Additional control on both evaporitic facies distribution as well as tectonic style and location of backthrusting could have been exerted by morphology of the pre-evaporitic basement.

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Role of Basement Tectonics in Evolution of Salt Diapirs: the Mid-Polish trough Versus the Dead Sea Basin

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During the extensional basin subsidence, salt layers underlying a thick sedimentary overburden can start to flow, giving rise to the development of a variety of halokinetic structures, such as salt diapirs, salt pillows and salt walls. Salt flow can be triggered by extensional faulting of the sub-salt "basement" (Koyi et al. 1993), as well as by thin-skinned extension of the post-salt sedimentary cover (Vendeville and Jackson 1992a, b). In intracontinental settings salt structures are particularly often related to sub-salt fault zones as in such basins localised extension and subsidence is associated with significant faulting within the pre-salt basement.

The Mid-Polish Trough (MPT) formed the axis of the Polish Basin which belonged to the Permian-Mesozoic system of West- and Central-European epicontinental basins (Ziegler 1990). During the Permian, the MPT formed the easternmost part of the Southern Permian Basin. Prior to its Late Cretaceous – Paleocene inversion, the MPT was filled with several kilometres of Permian and Mesozoic sediments, including thick Zechstein salts. The presence of these Zechstein salts gave rise to the development of a complex system of salt structures in the central and northwest segments of the MPT.

Recently completed regional analysis of seismic reflection data from the entire territory of the Mid-Polish Trough allowed to formulate some rules concerning relative roles of the basement, cover and salt tectonics. Using results of interpretation of seismic data basin-scale sub-Zechstein basement fault pattern responsible for the Mid-Polish Trough subsidence and inversion was proposed together with its role for development of salt structures (Krzywiec 2004a, b, 2006a, b). Basement extension has resulted – since the Triassic – in initiation of salt pillows. In some areas, peripheral (i.e. located outside the zone of maximum subsidence) fault zones formed within the Mesozoic sedimentary cover. Within the central (Kuiavian) segment of the basin very intense extension and faulting led to development in Late Triassic of the salt diapir that extruded onto the basin floor and was covered by uppermost Triassic and Jurassic deposits. During Late Cretaceous inversion salt structures present within the Mid-Polish Trough have been reactivated, both due to basement mobility (uplift of the basement block along reverse faults) as well as compressional stress field acting within the sedimentary cover. Compressional reactivation is best observed for the Drawno – Człopa – Szamotuły salt structure system (Krzywiec 2006b). In this area compression resulted in active diapirism, and growing diapir caused development of numerous unconformities in its vicinity that document consecutive stage of its development. During inversion within peripheral parts of the Mid-Polish Trough salt pillows were formed entirely related to the Mid-Polish Trough inversion and related lateral salt flow. Growth of such salt structures is documented by local thickness variations of the Upper Cretaceous deposits. Analysis of seismic data provided also information on Cenozoic reactivation of selected salt structures. Within the Drawno – Człopa salt structure system extensional reactivation of their topmost parts is observed. Similar activity connected with significant localised subsidence and deposition of brown coal seams has been described above the Damasławek salt diapir (Krzywiec et al. 2000).

A similar interaction between basement faulting, a thick salt layer and its supra-salt sedimentary cover was documented in many other basins, with good example provided by the Dead Sea Basin. This basin is a continental depression located within the rift valley that accompanies the Dead Sea Transform (DST). It is widely agreed that the basin is a rhomb-shaped pull-apart graben that was formed due to the left-lateral displacement along the segmented DST. The basin is bounded on the east and west by a series of oblique-normal (basinwards) faults, which suggest that the basin underwent active transtensional rifting.

Within the Dead Sea basin, the presence of thick Pliocene salt and active Quaternary normal faulting resulted in the development of numerous salt structures (e.g. Sedom and Lisan diapirs) and in different degrees of decoupling between the thick-skinned basement tectonics and the thin-skinned cover tectonics (cf. Al-Zoubi and Ten Brink 2001, Al-Zoubi et al. 2001, Larsen et al. 2002). The location of the Sedom salt diapir was dictated by the existence of oblique-normal faults in the margins of the basin. Presently, salt entirely pierced its overburden and extruded on the surface where it presently forms Mount Sedom with surface expression up to 200 m (Weinberger et al. 1997, Weinberger et al. 2006a). The present uplift rate of Mount Sedom,