THE ONSET AND THE TERMINATION OF THE BADENIAN SALINITY CRISIS IN CENTRAL PARATETHYS: THE STATE OF THE ART

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Badenian evaporites in the Polish and Ukrainian parts of Carpathian Foredeep show a regular spatial facies pattern. The correlation of different Badenian evaporite facies is difficult (if possible et all), but there are no problems in the case of particular evaporite facies zones. The correlation is based on the occurrence of characteristic marker beds, as well as the observations made in areas transitional between the facies zones.

Key words: Badenian, evaporites, Central Paratethys, Carpathian Foredeep

The age and correlation of evaporites occurring in different parts of the Badenian Carpathian Foredeep Basin, and hence the reconstruction of basin history during deposition of evaporites, are subject to controversies. Recent study of calcareous nannoplankton indicates that the Badenian sulfates of the Carpathian Foredeep represent the lower part of the NN6 zone (D. Peryt, 1997, 1999).

Badenian evaporites in the Polish and Ukrainian parts of Carpathian Foredeep show a regular spatial facies pattern. The greatest facies variation the marginal sulfate platform was recorded in the Ukrainian part of the basin. There are three main types of gypsum section (Peryt, 2001). The first one consists entirely of stromatolitic gypsum and is characteristic of the area bordering the nearshore sulfate facies limits. The second type of gypsum section is located further towards the basin center. This type is characterized by the occurrence of stromatolitic gypsum in the lower part of the section and sabre gypsum in the upper part. The third type occurs in still further basinward locations and is composed of giant gypsum intergrowths in the lower part, overlain by stromatolitic gypsum, sabre gypsum and clastic gypsum units. The Badenian sulfate section in the marginal sulfate platform can be divided into two parts, although in many cases, especially in West Ukraine, the upper part is absent,

having been deposited only locally, in tectonically-controlled troughs (Peryt, 2001). The gypsum of this upper, clastic part of the section consists of detritus derived from erosion of the lower part of gypsum section, and possibly of primary precipitates.

The anhydrite sections in central part of the Carpathian Foredeep consist mainly of interbedded laminated anhydrite and anhydrite breccia. These facies display features characteristic of redeposited sediments such as distortions due to slumping, erosional boundaries, and graded-bedded laminae (Peryt, 2000).

The best recognized facies changes of Badenian salts come from the historical Wieliczka salt mine where two units are distinguished. The lower unit (stratiform deposit - bedded part) is a complex of strongly folded, deformed and overthrusted salt beds interbedded with anhydrite and anhydritic clays. The upper unit (boulder deposit) is developed as coarse breccia composed mainly of salt clay with blocks of coarse-grained salt. The deposits of the boulder and stratiform units have been identified as facies varieties (Garlicki, 1979). The boulder unit deposits precipitated in a more shallow evaporite basin situated closer to the Carpathian border, and the stratiform unit deposits accumulated in the deeper and more distal part of the subbasin. Both facies exhibit sedimentary structures indicating that most of the halite layers have been formed from redeposition by gravity mass movements.

Autochthonous gypsum facies (crystalline gypsum, stromatolitic and massive alabastrine gypsum) were deposited in two main environments (Peryt, 1996). One variety of crystalline gypsum (giant gypsum intergrowths) precipitated from highly concentrated brines in moderate water depths at the initial stage of gypsum precipitation. Other varieties of autochthonous gypsum facies represent very shallow subaqueous gypsum deposited in a vast brine pan characterized by a facies mosaic that reflected an interplay of concentrated brines from the central part of the evaporite basin, diluted brines resulting from the influx of continental meteoric waters, and local evaporation of a restricted shallow water body. Accordingly, the salinity oscillated (Peryt, 1996; Rosell et al., 1998). A facies continuum, microbial gypsum – grass-like selenite – skeletal selenite - sabre gypsum, indicates increasing salinity of the brine with time. The sabre gypsum unit contains an intercalation of gypsarenitic, mostly laminated gypsum, which is correlated with the limestone intercalations recorded in some outcrops. The inflow waters were normal marine, as indicated by the presence of marine fossils in the limestones, so in such cases gypsum precipitation resumed once the entire brine again became supersaturated with gypsum. The nearshore

facies association distinguished by Kasprzyk (1999) originated in sabkha environment.

Basin-marginal Badenian evaporites formed in a standing body of water, as well as in desiccated environments subject to floods. The lateral persistence of thin beds over large areas with only minor changes in thickness and facies indicates that they formed on broad, very low relief areas which were affected by rapid transgressions that led to major changes in brine chemistry.

The anhydrite sections in central part of the Carpathian Foredeep display features characteristic of redeposited sediments. A great deal of redeposition combined with the in situ brecciation suggest that the triggering mechanism for redeposition could be earthquakes. They generated mass flows and eventually turbidites, so that earlier deposited grains could be redeposited. The redeposition processes played also a very important role during the deposition of halite and associated siliciclastics (Ślączka and Kolasa, 1997; Bukowski, 1997).

Halite and associated deposits in the central part of the Badenian evaporite basin show the same facies successions and marker beds can be traced across and between individual basins (Garlicki, 1994). It is usually assumed that the depth of those basins was a few hundred of meters (Garlicki, 1979), and such a conclusion is supported by geochemical data (Gaweł, 1965; Kovalevich, 1997). Marine incursions were related to the extrabasinal factors, and based on rapid facies changes, it seems that the Badenian evaporite basin was located in a depression in which the brine top level was located below the contemporaneous sea level. Accordingly, during sea-level rises new marine water could enter this depression and bring with it a temporary pulse of marine fauna.

Although the correlation of different Badenian evaporite facies is difficult (if possible et all), there are no such problems in the case of particular evaporite facies zones. The correlation between facies zones of the marginal sulfate platform was based on the occurrence of characteristic marker beds, as well as the observations made in areas transitional between the facies zones. The marker beds seem to reflect events that may be related to sudden and widespread changes in water chemistry, which in turn imply major changes in basin hydrology (Peryt, 2001).

Physical stratigraphic relationships between sulfates occurring in the marginal sulfate platform and sulfates from sulfate basin are uncertain. The correlation of particular halite cyclothems, units and marker beds was done for the Polish part of

the Carpathian Foredeep basin (Garlicki, 1979, 1994). However, the relation of the areas of halite and sulfate deposition remains enigmatic. In some boreholes in the inner zone of the Ukrainian part of Carpathian Foredeep sulfates occur in the lower and upper parts of the evaporite sequence and halite in its middle part. Petrichenko et al. (1997) suggested that gypsum deposits in the marginal parts of the basin correspond only to the upper part of the evaporite sequence in those boreholes.

The estimated duration of the Badenian evaporite deposition of the Central Paratethys was 20,000 – 35,000 (Garlicki, 1979; Petrichenko et al., 1997). The scenario of events leading to the deposition of widespread evaporites, being a synchronous event, in the Badenian is not established in detail. It is assumed that the interrupted communication of the Paratethys with the ocean was a consequence of eustatic sea-level fall, possibly related to climatic cooling. Such a conclusion resulted from the isotopic studies of Badenian foraminifers occurring below and above evaporites that indicated the lowest temperatures in a part of the Badenian section where evaporites occur (Gonera et al., 2000). Quantitative reconstructions of the Middle to Late Miocene climate evolution in the southern Carpathian Foredeep Basin in NW Bulgaria (Ivanov et al., 2002) indicated the existence of warm, subtropical climate during the Badenian, with mean annual temperature between 16 and 18^{o}C and mean annual precipitation between 1100 and 1300 mm; however, small climate fluctuations existed as well. However, a tectonic closure of connection with the Tethys could contribute to the origin of salinary crisis as well.

In some places in the marginal sulfate platform area, a thin sandy or marly coquina layer (Ervilia Bed) occurs below the gypsum sequence. This layer containing fauna almost exclusively composed of two mollusk species (*Modiola hoernesi* Reuss and *Ervilia pusilla* Philippi), is attributed to restricted water circulation and density stratification that followed sea level fall and an increase in salinity, as those species are particularly adapted to an increased salinity and low oxygenation (Kowalewski, 1966). The density, brine stratification, once established, continued during the gypsum precipitation in the marginal sulfate platform zone and during the deposition of halite-bearing series.

Sedimentological and geochemical data indicate “cannibalisation” of evaporites throughout the most time of evaporite deposition. Primary shallow-water evaporites from the margin of evaporite basin that was adjacent to the Carpathian orogen have gone and were deposited in deep-water settings. The orogen was also controlling the

sedimentary history in the basin foreland as indicated by the shoreward migration of the sabre gypsum facies in the Ukrainian part of the Carpathian Foredeep basin during the course of Badenian gypsum deposition. A general transgressive sequence of evaporites as found in the marginal sulfate platform results from the migration of facies zones that was induced by the nappe movement. Another result of the influence of the Carpathian orogen for the evaporite deposition was the supply of continental water as well as brines from the orogen.

The cannibalization at the end of gypsum deposition in the marginal sulfate platform was accompanied by the block-tectonics that resulted in the creation of bathymetric difference at least a few ten of meters as indicated by the occurrence of Ratyn Limestone on stratigraphically different parts of the gypsum section. It was accompanied by a change in the hydrology of the Central Paratethys that was tectonically-driven, and possibly related to the block tectonic phase manifested in the marginal part of the Carpathian Foredeep Basin. The change in hydrology implied the dilution of brines by inflowing marine water and this terminated the Badenian salinity crisis.

References

Bukowski, K., 1997, Sedimentation of clastic strata associated with Miocene salts in Wieliczka (Southern Poland): Slovak Geological Magazine, v. 3, p. 157-163.

Garlicki, A., 1979, Sedymentacja soli mioceńskich w Polsce: Prace Geologiczne 119, p. 1-66.

Garlicki, A., 1994, Porównanie osadów solnych Górnego Śląska i okolic Wieliczki: Przegląd Geologiczny, v. 42, p. 752-753.

Gaweł, A., 1965, Dekrepitacja soli z Wieliczki i Barycza: Sprawozdania z Posiedzeń Komisji Nauk PAN, Oddział Kraków: 482-p. 485.

Gonera, M., Peryt, T.M., and Durakiewicz, T., 2000, Biostratigraphical and palaeoenvironmental implications of isotopic studies (^{18}O, ^{13}C) of middle Miocene (Badenian) foraminifers in the Central Paratethys: Terra Nova, v. 12, p. 231-238.

Ivanov, D., Ashraf, A.R., Mosbrugger, V., and Palamarev, E., 2002, Palynological evidence for Miocene climate change in the Forecarpathian Basin (Central Paratethys, NW Bulgaria): Palaeogeography, Palaeoclimatology, Palaeoecology (in press).

Kasprzyk, A., 1999, Sedimentary evolution of Badenian (Middle Miocene) gypsum deposits in the northern Carpathian Foredeep: Geological Quarterly, v. 43, p. 449-465.

Kovalevich, V.M., 1997, Inkluzje fluidalne w soli kamiennej z Bochni: Przegląd Geologiczny, v. 45, p. 822-825.

Kowalewski, K., 1966, Trzeciorzęd Polski Południowej. Tom I. Stratygrafia trzeciorzędu południowego obrzeżenia Gór Świętokrzyskich i Roztocza. Część IV. Miocen odcinków południowo-sandomierskiego, tarnobrzeskiego i chmielowsko-baranowskiego i ich stosunek do obszarów sąsiednich: Biuletyn Państwowego Instytutu Geologicznego 189a, 143 p.

Peryt, D., 1997, Calcareous nannoplankton stratigraphy of the Middle Miocene in the Gliwice area (Upper Silesia, Poland): Bulletin of the Polish Academy of Sciences, Earth Sciences, v. 45, p. 119-131.

Peryt, D., 1999, Calcareous nannoplankton assemblages of the Badenian evaporites in the Carpathian Foredeep: Biuletyn Państwowego Instytutu Geologicznego 387, p. 158-161.

Peryt, T.M., 1996, Sedimentology of Badenian (middle Miocene) gypsum in eastern Galicia, Podolia and Bukovina (West Ukraine): Sedimentology, v. 43, p. 571-588.

Peryt, T.M., 2000, Resedimentation of basin centre sulphate deposits: Middle Miocene Badenian of Carpathian Foredeep, southern Poland: Sedimentary Geology, v. 134, p. 331-342.
Peryt, T.M. 2001, Gypsum facies transitions in basin-marginal evaporites: middle Miocene (Badenian) of West Ukraine: Sedimentology, v. 48, p. 1103-1119.
Petrichenko, O.I., Peryt, T.M., and Poberegsky, A.V., 1997, Pecularities of gypsum sedimentation in the Middle Miocene Badenian evaporite basin of Carpathian Foredeep: Slovak Geological Magazine, v. 3, p. 91-104.
Rosell, L., Orti, F., Kasprzyk, A., Playà, E., and Peryt, T.M., 1998, Strontium geochemistry of Miocene primary gypsum: Messinian of SE Spain and Sicily and Badenian of Poland: Journal of Sedimentary Research, v. 68, p. 63-79.
Ślączka, A., and Kolasa, K., 1997, Resedimented salt in the Northern Carpathians Foredeep (Wieliczka, Poland): Slovak Geological Magazine, v. 3, p. 135-155.