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Chemical composition of brines in Miocene evaporite basins of the Carpathian region

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Abstract. The chemical composition of brines in primary inclusions of primary halite from Miocene evaporite formations in the Carpathian region including the Carpathian Foredeep, East Slovakian, Transcarpathian, and Transylvanian basins, have been studied in order to determine the similarities and differences in composition of basin brines. The chemical compositions of fluid inclusions indicate that brines from all basins studied belong to the Na-K-Mg-Cl-SO_4 type and the proportion of the ions was close to modern seawater saturated with NaCl. The slightly decreased content of SO_4 is found in all basins, that is probably caused by the inflow of continental water. An especially low content of SO_4 was typical for evaporite formations in the smallest, East Slovakian basin. The geochemical data on Miocene evaporites of the Carpathian region confirm the idea that seawater was the main source of the salts and had the composition close to modern seawater.

Key words: Miocene, evaporite, salt, halite, fluid inclusions, Carpathian region.

Introduction

The question of genesis of Miocene evaporites in the Carpathian region is still under discussion because of peculiarities of evaporite sequences in that region. Salt-bearing sequences in the Carpathian Foredeep are characterized by a high content of terrigenous material and by the presence of potassium-magnesium sulfate salts, and the East Slovakian basin differs by its small area. Most evaporite sequences have a very complicated tectonic structure and a wide distribution of breccia. In the Transcarpathian and Transylvanian basins, salt diapirs are developed. Data on the chemical compositions of brines in inclusions in sedimentary halite are very important sources of information for revealing evaporite genesis. They permit the reconstruction of the composition of brines in ancient basins, and thus provide information about the source of salts. The results of analyses of fluid inclusions in halite from Miocene evaporites are especially important, because the chemical composition of seawater (as a standard for correlation) at that time is known; it could not differ significantly from modern seawater taking into account the age of these evaporites (*cf.* Holland, 1978).

Up to now, the fluid inclusions in sedimentary halite from several evaporite sections from the Ukrainian Forecarpathian and Transcarpathian regions have been studied in detail (Kovalevich, 1978, 1994; Khrushchov & Petrichenko, 1980; Kityk *et al.*, 1983; Petrichenko, 1988). From the Badenian evaporites of East Slovakia and Transylvania, only a few samples have been investigated (Petrichenko, 1988). In this paper, new geochemical data for these four basins are presented, and the existing information on brine composition in basins and genesis of evaporites in this region are summarized.

For three reasons, we present data on the composition of brine inclusions in halite that has precipitated at relatively early stages of brine saturation: (1) The potash salts were formed only in evaporite sequences of the Forecarpathian basin, and they have been studied in detail (Kovalevich, 1978, 1994; Peryt & Kovalevich, 1997). (2) For reconstruction of seawater composition, in our opinion, it is necessary to use samples from the lowest parts of halite sequences that were formed from brines of relatively low concentration, because further evaporation leads to significant changes in ion ratios up to the complete loss of sulfate ion. Specifically, such a picture of brines evolution has been established for the Permian basin of the Uralian Foredeep (Kovalevich & Petrichenko, 1994). (3) The halite sequences with a relatively low concentration of brine inclusions have been found in all evaporite formations of the region.

Geological setting

The Miocene evaporite basins in the Carpathian region are in Slovakia, Poland, Ukraine and Romania in foremountain and intermountain depressions (Fig. 1; Sonnenfeld, 1974). The ages of evaporite sequences range from 14 to 22 Ma, although the stratigraphic position of some of them is doubtful.

Forecarpathian basin. Evaporite deposits of the Carpathian Foredeep belong to a thick Miocene molasse unit. Questions about the number of evaporite formations in the molasse section, their thicknesses, stratigraphy and tectonics are still being discussed.

According to recent views (Dzhinoridze *et al.*, 1980; Korin, 1992, 1994), there are only two evaporite formations in the Carpathian Foredeep: Vorotyshcha and Tyras of Eggenburgian and Badenian age, respectively. The deposits of both series occur as narrow bands along the entire foredeep. The real thickness of each series is 100-130 m. Salt-bearing parts of these sections are composed of salt breccias, rock salt and lenticular beds of potassium-magnesium salts of chloride-sulfate type in the middle parts of the series. Gypsum-anhydrite rocks are widely developed only in the upper (Tyras) formation, and in the marginal part of the basin they make up the entire formation. Salt deposits of both sequences are

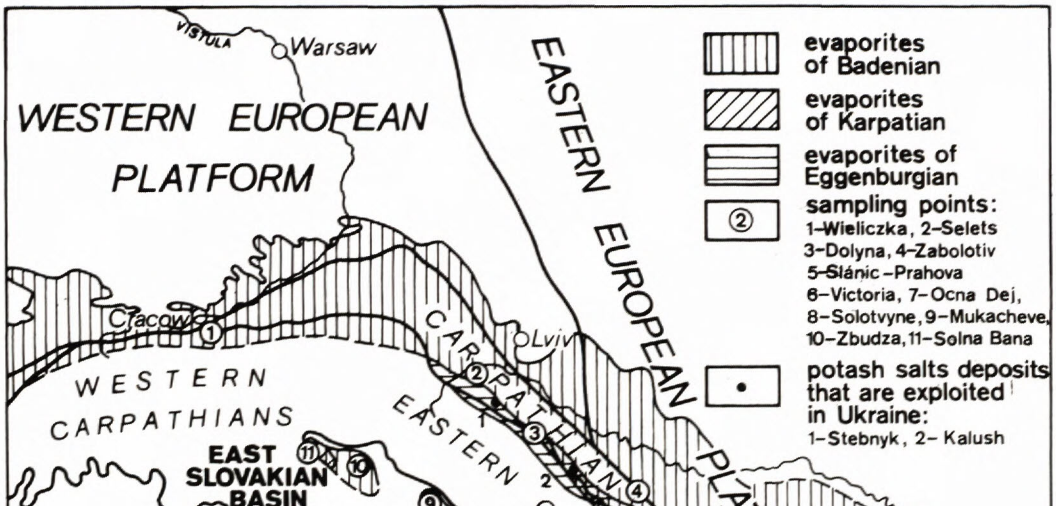

Fig. 1. Occurrence of Miocene evaporites in the Carpathian region (after Garlicki, 1979; Popescu et al., 1973; Stoica & Gherasie, 1981; Panow & Płotnikow, 1996).

pressed into narrow, often recumbent, folds and are offset by reverse faults. Such a complicated folded-thrust construction caused the salt-bearing deposits to be 1000 and more meters thick in parts of the Carpathian Foredeep.

Kainite and langbeinite as well as less frequent sylvite, kieserite and polyhalite are the most common minerals in the potassium-magnesium salt deposits. Within the Carpathian Foredeep more than 10 deposits of potash salts are known and two of them are exploited - Stebnyk and Kalush (Fig. 1).

In the Eggenburgian evaporite formation, the primary sedimentary forms of halite (chevron and hopper crystals) are rare, and in the Badenian evaporites they are widespread. The largest chevron crystals are observed in the Wieliczka rock salt deposit in Poland (15 cm in length). From data on inclusions in halite from the Eggenburgian formation, in this paper we use only those that have been obtained from the lowest parts of underlying rock salt (Ukraine, three boreholes near Dolyna, see Table 1). Several sections without potash salts from the Badenian formation of the Carpathian Foredeep have been studied, particularly in the Wieliczka (Poland), Slanic-Prahova (Romania) and in Selets and Zabolotiv (Ukraine) regions.

Intracarpathian depressions. The smallest is the East Slovakian basin. Two salt formations have been cut by boreholes in the Miocene in this basin (Karoli, 1994).The lower, Solna Bania Formation, is Karpatian age and 300 m thick. It contains a lot of terrigenous material, and its upper part is composed of breccia. In borehole 131 we have studied the sedimentary relics in halite, but the relatively large fluid inclusions suitable for analysis have been found only in one sample. The upper, Zbudza Formation (see Fig.1), is Badenian age and about 200 m thick. The most typical section of the formation includes the rock salt sequence within clayey deposits. In studied sections of rock salt from boreholes Zb-1 and Ep-2, we have found many large chevron crystals of halite.

The Transcarpathian basin is a medium size basin. Rock salts occurring there have a thickness of about 500-600 m (Korenevsky *et al.*, 1977) and belong to the Badenian Tereblin Formation. The older (Karpatian) evaporites (Fig. 1) in that basin consist of sulfates only (Kityk *et al.*, 1983). Two depressions - Solotvyne and Mukacheve - are distinguished within the Transcarpathian basin. In the most complete sections, the Tereblin Formation is subdivided into three horizons: the lower and upper are salt-bearing, and the middle is terrigenous (Kityk *et al.*, 1983). The rock salt deposits have a low content of terrigenous material and are characterized by well-preserved bedding in rocks with chevron relics in halite. Due to tectonic movements, the disharmonic folding has been formed. It is better expressed in the Solotvyne Depression, where the large diapiric structures, that partly or completely cut the capping rocks, are present. One such diapiric structure is the Solotvyne rock salt deposit. The rock salt we sampled for investigation comes from the upper horizon. The section of salts from the Mukacheve Depression has been studied in borehole 6-T near Mukacheve.

The Transylvanian basin is the largest one among the Intracarpathian depressions. The salt-bearing sequence of this basin is similar to those described from the Solotvyne Depression and is also to Badenian. Korenevsky *et al.* (1977) have distinguished three tectonic zones within the Transylvanian Depression: a monoclinal zone (in margins of depression); a zone of salt massifs and diapirs (closer to the centre) and dome-like folds (in the centre). Most of the salt massifs, as a matter of fact, are deposits of relatively clean rock salt. The visible thickness of salt in some massifs is more than 2000 m. In studied samples from the "Victoria" and "Ocna Dej" rock salt deposits, numerous relics of chevron halite have been recorded.

Primary fluid inclusions in primary halite

The specimens were sampled only from bedded rock salt. The thickness of individual layers in sampled sections ranged from several to a few tens of cm. The sizes of halite grains (or crystals) also vary, from 1 mm to 15 cm. We sampled the most coarse-grained varieties of the salt with macroscopic chevron structures except the Eggenburgian Vorotyshcha Formation in the Carpathian Foredeep where we sampled the relatively fine-grained rock salt (with grain sizes less than 8 mm across). By size and structure, the sedimentary forms of halite in studied evaporites show a considerable variability. Structures, with or without rhythmic zonation and sometimes both occurring within the same sample, differ by inclusion sizes and their amount per volume unit of the crystal (Fig. 2-5). In many cases, the processes of recrystallization have led to sedimentary forms preserved only as rare relics. The largest chevron structures were preserved in the Badenian formations of all basins. Inclusions in sedimentary structures are usually one-phase fluid, have a cubic, or close to cubic, shape and are oriented along the growth zones of crystals. The size of inclusions ranges from a fraction of μm to 200-300 μm, but rarely reaches 1 mm. It is important to emphasize that we have found a lot of fluid inclusions with sizes above 100 μm in halite and these are suitable for chemical analyses.

Fluid inclusions in chevron and hopper crystals are the microdrops of brines trapped during the growth of these crystals. Such a concept is shared by most investigators that have studied the process of crystallization of halite sedimentary forms (Valiashko, 1951, 1962; Dellwig, 1955; Raup, 1970; Roedder, 1984). We think that

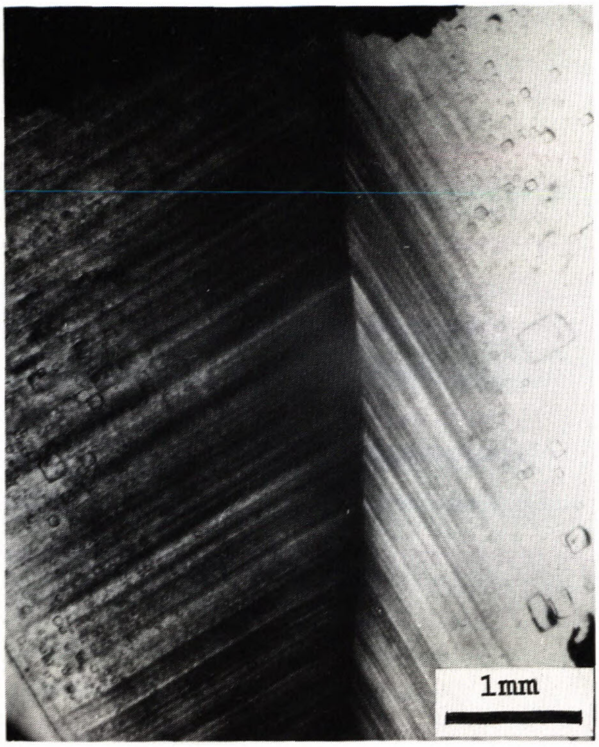

Fig. 2. Chevron structure in halite with asymmetric construction and very thin zonation and minute fluid inclusions. East Slovakia, Badenian, borehole Zb-1, depth 132 m.

this conclusion has been especially substantiated during last years, after obtaining the data about alteration of composition and concentration of inclusion brines in sections coming from many evaporite formations throughout the world (Petrichenko, 1988; Kovalevich, 1990).

In chevron halite from the Mukacheve Depression (borehole 6-T), two-phase gas-fluid inclusions are present (see Fig. 5). The gas phase does not exceed 1% of inclusion volume. It should be emphasized here that a gas phase is present in all inclusions (not depending on their sizes) and the homogenization temperature is similar within every sample from the same depth. We suppose that the gas bubbles result from partial spliting of inclusions due to a high geothermal gradient in the region, and these inclusions are also of use for reconstruction of the chemical composition of brines in basins, considering the small volume of possible loss of brine from inclusions.

The results of chemical analyses of inclusion brines and interpretation

The analysis of inclusion brines was done using the Petrichenko (1973) method of glass capillaries. The contents of K, Mg, SO_4 were determined. The analytical error of the applied method is *ca.* 20% when one measurement is done so, to decrease the error of determination, a few analyses for each compound in inclusion brines in each sample have been carried out. The inclusions over 100 μm across were used for analyses, although the method permits the analysis also of smaller inclusions (about 40 μm). The results are presented in Table 1.

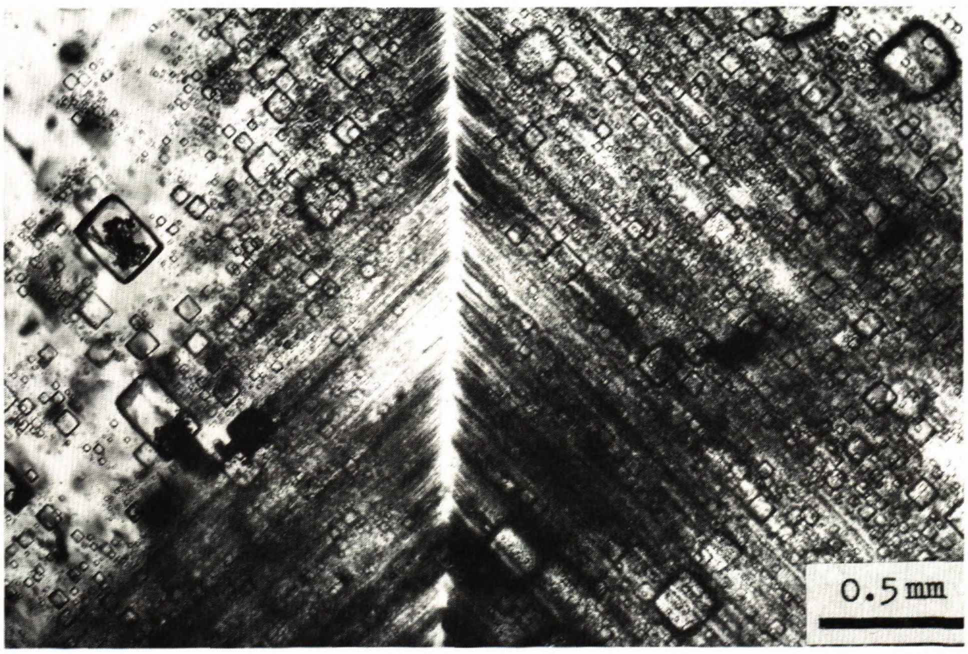

Fig. 3. Fragment of chevron structure in halite with symmetric construction and relatively large fluid inclusions. Carpathian Foredeep, Wieliczka deposit, Badenian.

Fig. 4. Fragment of chevron structure in halite in part with rhythmic zonality. Inclusions are liquid with gas bubbles. Transcarpathians, Mukacheve depression, borehole 6-T, depth 1074 m.

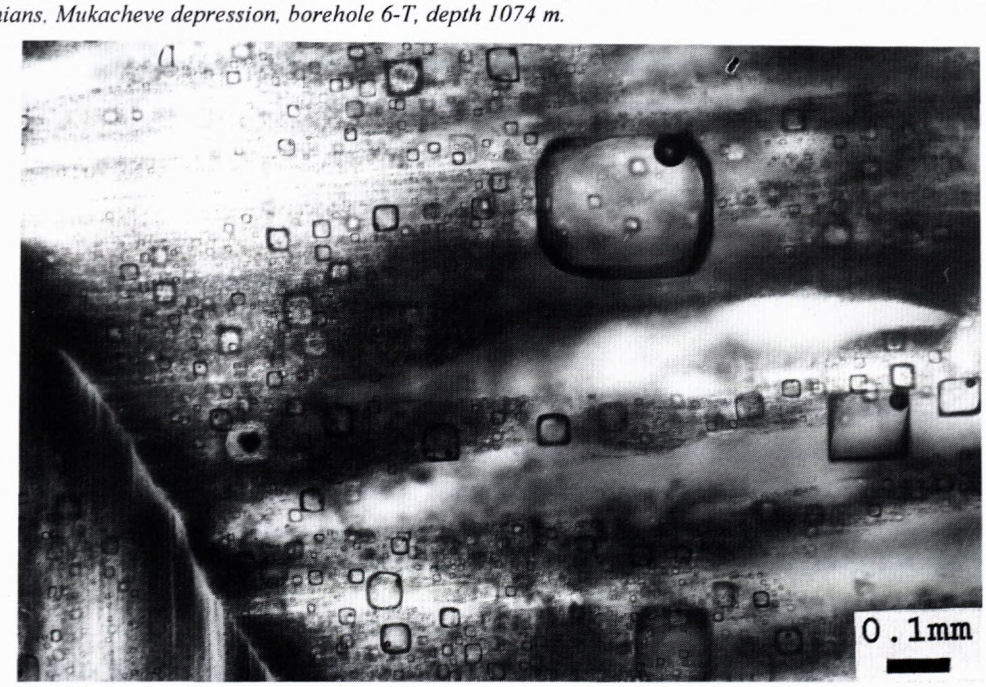

Fig. 5. The detail of chevron structure in halite shown in Fig. 4. The gas phase in inclusions is distinctly seen.

Because of the numerous data, only the average values for separate samples or groups of samples are shown. The grouping of results is applied only when the distinct stratigraphic location of samples in sections is unknown and when the obtained data are similar by total concentration of brines as well as by ratio of ion content. Specifically, the average data are presented for groups of samples from salt diapirs Solotvyne and Slanic-Prahova and for boreholes cutting the Vorotyshcha and Tyras deposits in the Ukrainian part of Carpathian Foredeep.

Considering the data in Table 1, the average contents of ions in brine inclusions in halite from all studied formations (Table 2) have been calculated. We consider these results to correspond to the composition of brines in evaporite basins during crystallization of halite from sampled sections. The data indicate that the brines of all

Table 1. The chemical composition of brine inclusions in primary halite of Miocene evaporite formations of the Carpathian region (g/l of solution)

Location, depth; number of samples	K	Mg	SO_4
FORECARPATHIAN BASIN, VOROTYSHCHA FORMATION, EGGENBURGIAN (UKRAINE, near DOLYNA)			
Borehole Dolyna-9MD, 73-152 m; 5	2.6 (14)*	23.4 (13)	17.0 (16)
Borehole Strutyn-819, 487-518 m; 2	2.3 (5)	28.2 (6)	32.3 (6)
Borehole Jasenovets-17, 319 m; 1	2.0 (4)	26.4 (5)	27.5 (5)
EAST-SLOVAKIAN BASIN, SOLNA BANIA FORMATION, KARPATIAN			
The rock salt deposit Solevar, borehole 131, 374.6 m; 1	0.5 (3)	12.0 (3)	7.2 (3)
FORECARPATHIAN BASIN, WIELICZKA FORMATION, BADENIAN (POLAND)			
The rock salt deposit Wieliczka, 5 samples:			
green salt in breccia	5.1 (3)	18.0 (3)	11.8 (3)
spiza salt	5.5 (3)	20.2 (3)	16.0 (2)
spiza salt	9.7 (2)	26.3 (3)	16.8 (2)
shaft salt	8.0 (5)	20.8 (2)	11.3 (4)
green salt	9.3 (3)	19.3 (3)	17.5 (2)
FORECARPATHIAN BASIN, TYRAS FORMATION, BADENIAN (UKRAINE)			
Borehole Selets-Stupnitsy-348, 117.5-176.0 m; 6	10.6 (25)	22.7 (15)	29.8 (15)
Borehole Selets-Stupnitsy-671, 272-506 m; 13	10.6 (45)	30.9 (19)	24.5 (19)
Borehole Zabolotiv-3847, 660 m; 1**	14.5 (8)	25.8 (8)	31.0 (8)
FORECARPATHIAN BASIN, BADENIAN (ROMANIA)			
The rock salt deposit Slanic-Prahova; 5	6.1 (16)	19.8 (15)	16.1 (12)
EAST SLOVAKIAN BASIN, ZBUDZA FORMATION, BADENIAN			
Borehole Zb-1, 132 m; 1	6.2 (3)	22.8 (2)	10.3 (4)
Borehole Ep-2; 3 :			
depth 236.4 m	4.4 (3)	17.6 (2)	11.7 (3)
depth 238.4 m	5.4 (3)	17.7 (3)	14.0 (3)
depth 239.2 m	5.2 (4)	17.3 (3)	13.7 (3)
TRANSCARPATHIAN BASIN, TEREBLIN FORMATION, BADENIAN (UKRAINE)			
The rock salt deposit Solotvyne; 7	15.5 (40)	28.5 (35)	36.5 (35)
Mukacheve depression, borehole 6-T, 1047.0-1318.0 m; 17***	9.5 (34)	18.0 (34)	20.0 (34)
TRANSYLVANIAN BASIN, BADENIAN (ROMANIA)			
Mine "Victoria", sample P-4	9.0 (4)	20.4 (5)	17.3 (3)
Mine "Victoria", sample P-11	9.3 (5)	14.2 (3)	7.0 (3)
Mine "Victoria", sample P-12	9.8 (2)	24.8 (4)	29.5 (1)
Mine "Ocna Dej", sample P-50	6.8 (2)	13.6 (1)	8.2 (2)

* In brackets - number of analyses; **After Poberegsky (1991); ***After Shaidetska (1997)

basins of the region belonged to the Na-K-Mg-Cl-SO_4 type during the formation of all Miocene evaporite formations, i.e. the same chemical type as modern seawater. The correlation with data on modern seawater evaporation (see Table 2) shows that we have established the brine composition at the initial stages of halite precipitation.

The peculiarities of ion ratios in brines of each basin result when the data are put in the diagram of the seawater system (Fig. 6). All points of composition are located slightly up from the point of modern seawater composition and are scattered in relation to the average value for Miocene basins in the region. The location of points and their scattering show the impact of local paleogeographic conditions on the brine composition in each basin. The most significant alterations took place during the deposition of both formations in the smallest, East Slovakian basin. The essence of these alterations was the decrease of SO_4-ion content (in comparison to modern saturated seawater), which was, probably, caused by sulfate reduction, inflow of surface or underground water and run-off of terrigenous material to the basins. Despite the decreased content of SO_4-ion, seawater was the main source

Table 2. The average composition of brines in Miocene basins of the Carpathian region

Basin, the age of evaporites	Content, g/l K	Mg	SO_4
Forecarpathian, Eggenburgian	2.3	26.0	25.0
Forecarpathian, Badenian	8.5	22.4	19.7
East Slovakian, Karpatian	0.5	12.0	7.2
East Slovakian, Badenian	5.3	18.8	12.4
Transcarpathian, Badenian	12.5	23.2	28.2
Transylvanian, Badenian	8.2	18.2	15.5
The average value	6.2	20.1	18.0
The average value (leveled by Mg content in modern seawater saturated to NaCl)	4.8	15.5	13.9
Modern seawater (saturated with NaCl)	3.3	15.5	21.0

* Calculated from Valiashko (1962).

Table 3. The average composition of brines in Miocene evaporite basins, leveled by magnesium content in modern seawater saturated to the beginning stage of halite precipitation.

	Content, g/l K	Mg	SO_4
Miocene basins	4.8	15.5	13.9
Modern seawater saturated with NaCl	3.3	15.5	21.0

of salts in Miocene basins of the region, and its composition was similar to the modern one. This is also proved by previous investigations of the mineralogy, petrography and geochemistry of salts (Korobtsova, 1955; Khodkova, 1971; Valiashko, 1962), and especially of bromine and some other trace elements (Bilonizhka, 1972, 1975; Garlicki & Wiewiórka, 1981; Kovalevich, 1978, 1994; Malikova, 1967; Slivko & Petrichenko, 1967), as well as isotopic composition of sulfate sulfur (Claypool *et al.*, 1980; Kovalevich & Vityk, 1995).

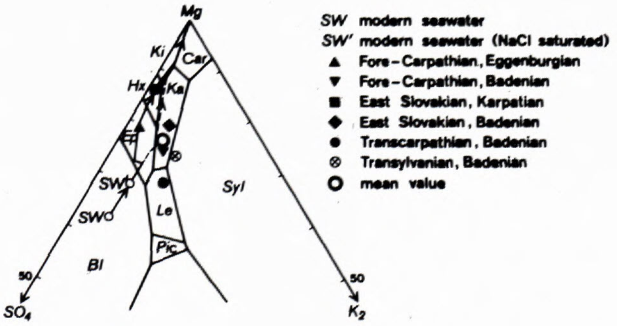

Fig. 6. Analyses of inclusion brines from chevron halite of Miocene evaporites (Carpathian region) plotted on a Jänecke projection of the quinary system Na-K-Mg-SO$_4$-Cl-H$_2$O saturated with respect to halite at 25°C (Eugster et al., 1980). The stability fields of Bl, bloedite; Car, carnallite; Ep, epsomite; Hx, hexahydrite; Ka, kainite; Ki, kieserite; Le, leonite; Pic, picromerite; Syl, sylvite, are indicated.

The location of points in the diagram makes it possible to predict the probable composition of potash salts in new, not yet studied sections of evaporite formations in the region. In case when the brines has reached the higher stage of saturation, the salts may be of complex chloride-sulfate composition, like those found in the Carpathian Foredeep.

We made an attempt to reconstruct the composition of Miocene seawater. For this purpose we calculated the average composition of brines in studied basins, leveled by Mg content with modern seawater, and saturated to the corresponding stage (Table 3). As shown in the table, the brines from Miocene basins differed by the slightly decreased content of SO_4-ion and increased content of K-ion. The Miocene seawater could not significantly differ from modern one, as the residence time of many compounds in seawater was close to or greater than this time (Holland, 1978). Accordingly, the results of analyses of inclusions in primary halite permit reconstruction of the composition of ancient seawater, but with taking into account some alteration of brines within the basin. The most reliable information may be obtained during the study of relatively large basins. In our case they are the Forecarpathian and Transylvanian basins with compositions of brines very close to the composition of modern seawater saturated with NaCl.

Conclusions

The chemical composition of brines in chevron and hopper crystals of halite from bedded rock salt of Miocene evaporite formations in Poland, Slovakia, Ukraine and Romania has been studied. Such basins are located in intermountain and foremountain depressions of the Carpathians: Carpathian Foredeep (Eggenburgian and Badenian), East Slovakian (Karpatian and Badenian), Transcarpathian Foredeep (Badenian) and Transylvanian depression (Badenian).

Results of analyses indicate that the brines of all studied evaporite basins during salt deposition belonged to Na-K-Mg-Cl-SO_4 type. These brines differed from modern seawater saturated to a corresponding stage by slightly decreased content of SO_4. Small differences have been also established in the composition of brines in each basin, that can be explained by peculiarities in local paleogeographic conditions during salt accumulation. Specifically the lowest content of SO_4-ion was characteristic for the smallest, East Slovakian basin. Nevertheless, the results of the analyses permit us to suppose that the seawater with composition close to the modern one was the main source of salts in the Miocene basins.

Acknowledgments

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References

Bilonizhka P.M., 1972: Geochemistry of boron, bromine and iodine in Forecarpathian potash deposits. Lviv, 22 p. (in Russian).

Bilonizhka P.M., 1975: Usage of bromine-chlorine coefficient for revealing the genesis of salt rocks (on example of Forecarpathians). Geologiya i geokhimiya goriuchikh iskopayemykh, 45, 55-62. (in Russian).

Claypool G.E., Holser W.T., Kaplan I.R., Sakai H. & Zak I. 1980: The age curves of sulfur and oxygen isotopes in marine sulfate and their mutual interpretation. Chemical Geology, 28,199-260.

Dellwig L.F., 1955: Origin of the Salina salt of Michigan. J. Sediment. Petrology, 25, 83-110.

Dzhinoridze N.M., Gemp S.D., Gorbov A.F. & Rayevsky V.I., 1980: The laws of distribution and criteria of search of potash salts of the USSR. Mitsniereba, Tbilisi, 374 p. (in Russian).

Eugster H.R., Harvie C.E. & Weare J.H., 1980: Mineral equilibria in the six-component seawater system, Na-K-Mg-Ca-SO_4-H_2O at 25°C. Geochim. Cosmochim. Acta, 44, 1335-1347.

Garlicki A., 1979: Sedymentacja soli mioceńskich w Polsce. Prace Geol. PAN, 119, 67 p.

Garlicki A. & Wiewiórka J., 1981: The distribution of bromine in some halite rock salts of the Wieliczka salt deposit (Poland). Rocznik Polsk. Tow. Geol., 51, 353-359.

Holland H.D., 1978: The chemistry of the atmosphere and oceans. Wiley, New York, 351 p.

Karoli S., 1994: Evaporite facies in the Neogene East Slovakia Basin. Streszczenia referatów międzynarodowego sympozjum "Neogeńskie ewaporaty Środkowej Paratetydy: facje, surowce mineralne, ekologia" we Lwowie, 20-24.09.1994, Warszawa, 9-10.

Khodkova S.V., 1971: Minerals and rocks of Stebnyk potash deposit. In: Materialy po gidrogeologii i geologicheskoy roli podzemnykh vod. Leningrad, 89-91 (in Russian).

Khrushchov D.P. & Petrichenko O.I., 1979: Evaporite formations of central Paratethys and conditions of their sedimentation. Ann. Geol. Pays. Hellen., Tome hors serie, 2, 595-612.

Kityk V.I., Bokun A.N., Panov G.M., Slivko E.P. & Shaidetska V.S., 1983: Evaporite formations of Ukraine: Transcarpathian trough. Naukova dumka, Kiev, 168 p. (in Russian).

Korenevsky S.M., Zakharova V.M. & Shamakhov V.A., 1977: The Miocene evaporite formations of Carpathian foredeep. Nedra, Leningrad, 248 p. (in Russian).

Korin S.S., 1992: Tectonic conditions of formation of potash deposit structure in Boryslav-Pokutsk nappe. Sovetska geol., 12, 20-26. (in Russian).

Korin S.S., 1994: Budowa geologiczna mioceńskich formacji solonośnych ukraińskiego Przedkarpacia. Przegląd Geol., 42, 744-747.

Korobtsova M.S., 1955: Mineralogy of potash deposits of East Forecarpathians. Voprosy mineralogii osadoch. obrazov., 2, 3-137. (in Russian).

Kovalevich V.M., 1978: Physico-chemical conditions of formation of salt in Stebnyk potash deposit. Naukova dumka, Kiev, 100 p. (in Russian).

Kovalevich V.M., 1990: Halogenesis and chemical evolution of the ocean in Phanerozoic. Naukova dumka, Kiev, 154 p. (in Russian).

Kovalevich V.M., 1994: Warunki powstania soli mioceńskich ukraińskiego Przedkarpacia w świetle badań inkluzji. Przegląd Geol., 42, 738-743.

Kovalevich V.M. & Petrichenko O.Yo., 1994: Geochemistry of evaporite sedimentation in a Permian marine basin. ESRI Occ. Publ. 11B, Part III, 41-47.

Kovalevich V.M. & Vityk M.O., 1995: Correlation of sulfur and oxygen isotopes in evaporites with chemical composition of brines of Phanerozoic evaporite basins. Dopov. National. Acad. Nauk Ukrainy, 3, 83-85. (in Ukrainian).

Malikova I.N., 1967: The laws of distribution of rubidium, thallium, and bromine in potash salt deposits. Nauka, Novosibirsk, 150 p. (in Russian).

Panow G.M. & Płotnikow A.M., 1996: Badeńskie ewaporaty ukraińskiego Przedkarpacia: litofacje i miąższość. Przegląd Geol., 44, 1024-1028.

Peryt T.M. & Kovalevich V.M., 1997: Association of redeposited salt breccias and potash evaporites in the Lower Miocene of Stebnyk (Carpathian Foredeep, West Ukraine). Journal of Sedimentary Research, 67, 916–925.

Petrichenko O.I., 1973: Methods of study of inclusions in minerals of saline deposits. Naukova dumka, Kiev, 98 p. (in Ukrainian; transl. in Fluid Inclusion Research Proc. COFFI, 12, 214-274, 1979).

Petrichenko O.I., 1988: Physico-chemical conditions of sedimentation in evaporite paleobasins. Naukova dumka, Kiev, 128 p. (in Russian).

Poberegsky A.V., 1991: Physico-chemical conditions of formation of Badenian sulfate-carbonate deposits of Forecarpathians in connection with sulfur-bearings. Lviv, 20 p. (in Russian).

Popescu Gr., Ciupagea D., Georgescu C., Boltos M. & Motas I., 1973: Privire de ansamblu asupra geologie iformatiunilor saline din Romania. Rev. Petrol. şi Gase, 9, 525-570.

Raup O.B., 1970: Brine mixing: an additional mechanism for formation of basin evaporites. Bull. Am. Assoc. Petrol. Geol., 54, 2246-2259.

Roedder E., 1984: The fluids in salt. Am. Mineralogist, 69, 413-439.

Shaidetska V.S., 1997: Geochemistry of Neogene evaporites of the Transcarpathian Trough in Ukraine. This volume.

Slivko E.P. & Petrichenko O.I., 1967: Accessory lithium, rubidium and caesium in salt-bearing deposits of Ukraine. Naukova dumka, Kiev, 152 p. (in Russian).

Sonnenfeld P., 1974: The Upper Miocene evaporite basins in the Mediterranean Region - a study in paleo-oceanography. Geol. Rundschau, 63, 1133-1172.

Stoica C. & Gherasie I., 1981: Sarea si sarurile de potasiusi magneziu din Romania, Editura Tehnica, Bucureşti, 248 p.

Valiashko M.G., 1951: Structural features of deposits of modern halite. Lvov. Geol. Obshch., Mineralogicheskii Sbornik, 5, 65-74. (in Russian).

Valiashko M.G., 1962: The laws of formation of salt deposits. Moskov. Univ., 396 p. (in Russian).