Evaporites of Ukraine: a review

S. P. HRYNIV, B. V. DOLISHNIY, O. V. KHMELEVSKA,
A. V. POBEREZHSKYY & S. V. VOVNYUK

Institute of Geology and Geochemistry of Combustible Minerals, National Academy of Sciences of Ukraine, Naukova 3A, 79053 Lviv, Ukraine
(e-mail: Sophia_Hryniv@ukr.net, igggk@ah.ipm.lviv.ua)

Abstract: The results of geological and lithological–geochemical investigations of the Devonian, Permian, Jurassic and Miocene evaporite deposits of Ukraine are presented in review. The main regions of evaporite distribution are the Dnipro–Donets depression, Carpathian (Forecarpathians, Transcarpathians) and Foredobrogean regions. The data on tectonics and stratigraphy are presented and information on lithology, the mineralogical and geochemical study of gypsum, anhydrite, rock and potash salts are summarized. The rich mineral composition of the Miocene evaporites in the Carpathian Foredeep (more than 20 salt minerals) is demonstrated, and the unique superimposed hydrothermal mineralization in the rock salt of salt domes from the Dnipro–Donets depression is presented (containing about 40 high- and mid-temperature hydrothermal minerals). In particular, the results of brine inclusion studies in evaporite minerals suggest that seawater was the main source of most of the salts. The brines in both the Miocene and Permian evaporite basins are classified as the Na–K–Mg–Cl–SO_4 (SO_4-rich) chemical type and the Jurassic and Devonian belong to the Na–K–Mg–Ca–Cl (Ca-rich) type. Temperature of solutions during halite precipitation shifted from 25 to 43 °C, while during the stage of potash salt sedimentation it apparently increased to 40–83 °C.

Ukraine possesses Devonian, Permian, Jurassic and Neogene evaporite deposits located in several areas: the Dnipro–Donets depression (D, P), the Foredobrogean trough and western margin of the East European platform (J), the Carpathian Foredeep, the Transcarpathian trough and the Crimea (N) (Fig. 1). Some of the deposits are widespread (e.g. the Devonian evaporites in the Dnipro–Donets depression are distributed over area of about 40,000 km^2) and also are quite thick (Zharkov 1984); another, the Miocene gypsum of Kerch peninsula, has a more restricted distribution and is relatively thin. Small evaporite deposits of Silurian age present in Volyno–Podoliya (Markovskiy *et al.* 1979) and those of Jurassic age, present in the Crimea (Borisenko *et al.* 1974), are not well studied and are not reviewed here.

Evaporites of Ukraine are represented by gypsum, anhydrite and both rock salt and potash salts. In the Carpathian Foredeep saline deposits are characterized by a very rich mineral composition – potash deposits contain about 20 potassium–magnesium, mostly sulphate, minerals. In the rock salt of salt domes of the Dnipro–Donets depression a unique superimposed hydrothermal mineralization has developed.

A brine inclusion study in sedimentary halite provided the data and stimulated the understanding of geochemical principles of marine salt formation evolution (Petrichenko 1988) – changes from SO_4-rich, Ca-poor chemical type to the SO_4-poor, Ca-rich chemical type that have been outlined by Petrichenko and are tied in with an influx of subsurface $CaCl_2$-rich brines into the evaporite basins during orogenesis. Such changes of brine inclusion composition apparently were connected with the evolution of seawater during the Phanerozoic (Kovalevich 1988, 1990). In the Phanerozoic seawater chemistry oscillated between the Na–K–Mg–Ca–Cl and Na–K–Mg–Cl–SO_4 types. From the Cambrian to Carboniferous and from the Jurassic to middle Paleogene the Na–K–Mg–Ca–Cl type prevailed, while in Permian and Triassic as well as starting in the middle Paleogene until the Recent the ocean was of the Na–K–Mg–Cl–SO_4 type (Kovalevich 1988; Kovalevich *et al.* 1998). A similar series of research studies concerning secular changes in the chemical composition of seawater based on the results of brine inclusions study is also noted in the western geological literature (Lowenstein *et al.* 2001, 2003; Horita *et al.* 2002), though the problem of secular changes in the chemical composition of seawater during the Phanerozoic from the results of another investigation (chemical composition of potash salts, mineral composition of carbonates) has been considered and is still widely discussed (e.g. Holland 1972, 1984, 2003; Holland *et al.* 1986; Hardie 1996). Besides being of general scientific interest, the observations pertaining to secular changes in

From: SCHREIBER, B. C., LUGLI, S. & BĄBEL, M. (eds) *Evaporites Through Space and Time.* Geological Society, London, Special Publications, **285**, 309–334.
DOI: 10.1144/SP285.18 0305-8719/07/$15.00

Fig. 1. Location map of evaporite deposits in Ukraine (after Kruglov & Tsypko 1988). I, Devonian evaporites of the Dnipro–Donets depression; II, Permian evaporites of the Dnipro–Donets depression; III, Jurassic evaporites: a, Forecarpathian region; b, Foredobrogean trough; IV, Miocene evaporites: a, b, Carpathian Foredeep (a, Bilche-Volytsya zone and adjacent part of East European platform; b, Sambir and Boryslav-Pokuttya zones); c, Transcarpathian trough; d, Kerch peninsula.

the chemical composition of seawater have a practical application in that they represent a predictor for the determination of the mineral resources connected with evaporites.

In Ukraine these mineral resources include gypsum, rock and potash salts, native sulphur, celestite, brines and mineral–medicinal waters. In most areas having evaporites, oil and gas deposits also are present.

The majority of investigators adhere to the opinion of general principles of classic theory of salt formation that connects the origin of evaporites with evaporation of seawater (Borchert 1959; Valyashko 1962), although alternative points of view have also been presented. These other concepts suggest that salt-saturated hot brines form under the Earth's crust (Sozanskiy 1973) or that exhalation–sedimentary formation of salt deposits is very important (Dzhinoridze 1980).

The results of most of the investigations of evaporites in Ukraine, their geology, composition and origin have been published in Russian and Ukrainian journals (and books) and have not been readily available for foreign scientists. Though recently a good deal of information has been published in English, the goal of this review is to summarize in a single paper the main data on geology, mineralogy, petrography, geochemistry and origin of evaporite deposits in Ukraine. Because this paper is merely a short review, it only permits us to touch on the general aspects of the deposits, but here we outline some of the more significant deposits and their references.

Devonian and Permian evaporites of the Dnipro–Donets depression

Devonian and Permian evaporites are widespread in Ukraine in the Dnipro–Donets depression. This area is located in southeastern part of the East European platform between the margin of the Ukrainian Shield, along the SW, and the Voronezh High to the NE (Fig. 2). In the NW the depression continues along the Prypiat' trough (in Belarus territory), which is separated from the Dnipro–Donets depression by the Chernihiv–Brahin High. To the SE the depression ends in the Donbas Foldbelt.

Geotectonically the depression is a complicated graben with a northwestern extension, in which the hypsometric level of basement is gradually lower in the southeastern direction. The shape and size of Dnipro–Donets depression is controlled by the evolution of marginal faults that have been traced by seismic investigations and penetrate both the granitic and basaltic layers of the Earth's crust (both upper and lower lithosphere) and apparently reach down to the mantle. The length of this depression is about 500 km, and the width ranges from 80 km in the NW part to 120 km to the SE. The thickness of sedimentary cover changes from 3–4 km in the NW to 10–17 km in the SE.

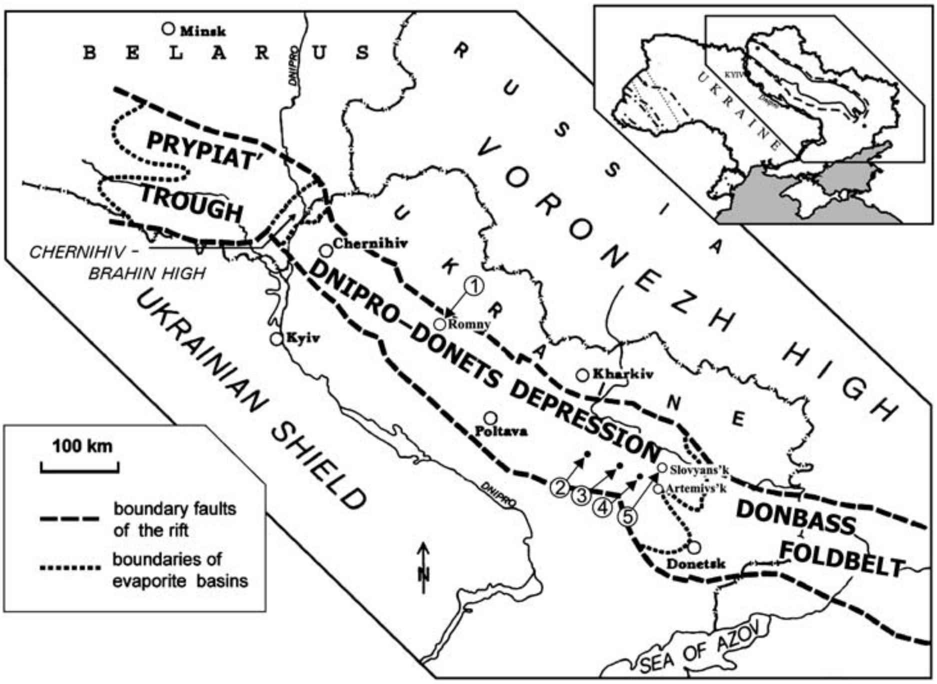

Fig. 2. Location map of the Dnipro–Donets depression (after Ulmishek *et al.* 1994). Salt domes: 1, Romny; 2, Bilyayivka; 3, Berets'k; 4, Bantyshevo; 5, Slovyans'k.

The fill is composed of sedimentary rocks of the Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene and Quaternary ages and consists of the terrigenous–carbonate, sulphate and saline deposits, sometimes with layers of tuffaceous rocks. Rock salt (halite) is present mainly in the Upper Devonian (Frasnian and Famennian stages) and in the Lower Permian (lower part).

The sedimentary series in the Dnipro–Donets depression is mainly controlled and determined by basement offsets, which penetrate the sedimentary series, and by disharmonic displacements of the Devonian and Permian salts (Kityk 1970). The basement has a complicated fault-block structure: numerous horsts displaced with vertical amplitude up to 1–2 km. In the sedimentary cover offset along most faults gradually declines from bottom to top and passes into zones of plastic deformation that warped the evaporite sections. These warps lead to disharmonic dislocation of the entire sedimentary sequence.

The plastic deformation of the salt rocks led to the origin of many uplifts in the sediments overlying the salt series. Cores of these uplifts, as a rule, pierce the overlying deposits and sometimes form surface outcrops. In some cases the uplift of overlying rocks is not significant and takes place without true diapirism. The salt domes in the Dnipro–Donets depression form disharmonic folds, which are composed of both undersalt and oversalt structures with salt cores. Diapirism of overlying deposits, formed by salt cores, leads to their destruction and the formation of diapiric and solutional breccias of different thicknesses that vary from place to place.

The first geological investigations of the depression began in the early eighteenth century. These studies were connected mainly with salt springs near the town of Tor (presently called Slovyans'k), which were used as a source of kitchen salt (Novik *et al.* 1960). In 1701 richer springs were found along the Bakhmut River, and this in turn caused the development of an industrial salt centre in the town of Bakhmut (presently called Artemivs'k). In the 1840s the salt-making factories were initiated, and they, in turn, stimulated research for associated fuel resources, e.g. coal.

In 1831 the Petrovsk coal deposit, and in 1870s the rock salt deposit in shallow horizons near towns Slovyans'k and Artemivs'k, were opened. In the 1930s Shatskiy (1931) projected the existence of salt domes near Isachka and Romny on the base of correlation of the lithological peculiarities of rocks from two different parts of the depression. This hypothesis was successfully tested by drilling in the Romny area (1932) and in 1936 in this area oil was discovered in the oversalt rocks. Later, all of the territory of Dnipro–Donets depression was gradually investigated. Salt domes became the object of great interest for geologists as sources for rock salt as well as for oil and gas, sulphur, coal and gypsum. Additionally, some of them were found to contain polymetallic sulfides, fluorite, mercury and others ore manifestations.

Devonian evaporites

The Upper Devonian evaporite deposits in the Dnipro–Donets depression (Fig. 3) are recognized in sediments of both the Frasnian and Famennian stages and are widespread (Vysotskiy *et al.* 1988).

Upper Frasnian In the initial bedded occurrence the Upper Frasnian salt deposits are uncovered in the NW and near the margins of the depression, and in the inner part they are dislocated by processes of salt domes forming. The plastic deformation of the salt rocks led to the origin of many uplifts in the oversalt series, such as brachyanticlines, salt domes and stocks. In these salt uplifts the salt roof may be located at a depth of 40–1000 m, but in zones between the domes it occurs at 3500–4500 m (Vysotskiy *et al.* 1988). The thickness of this salt formation ranges from several hundreds to 1200 m and within the salt uplifts it reaches over 2500 m.

The salt formation is represented by interbedded layers of rock salt (5–20 to 70–100 m thick) and non-saline rocks (2–10 to 20–40 m thick). At the base of the salt formation carbonate, igneous and rarely terrigenous rocks are present (Galabuda 1970). The salt-bearing section in addition to rock salt may contain rocks such as anhydrite, carbonate, terrigenous deposits, volcanic tuff, diabase and basalt.

Sulphate rocks in these deposits are grey, yellowish and white, microgranular, laminated, commonly with breccia-like textures, and sometimes include carbonates and bitumen.

Rock salt is light and dark grey, orange and red, fine- and coarse-grained, sometimes

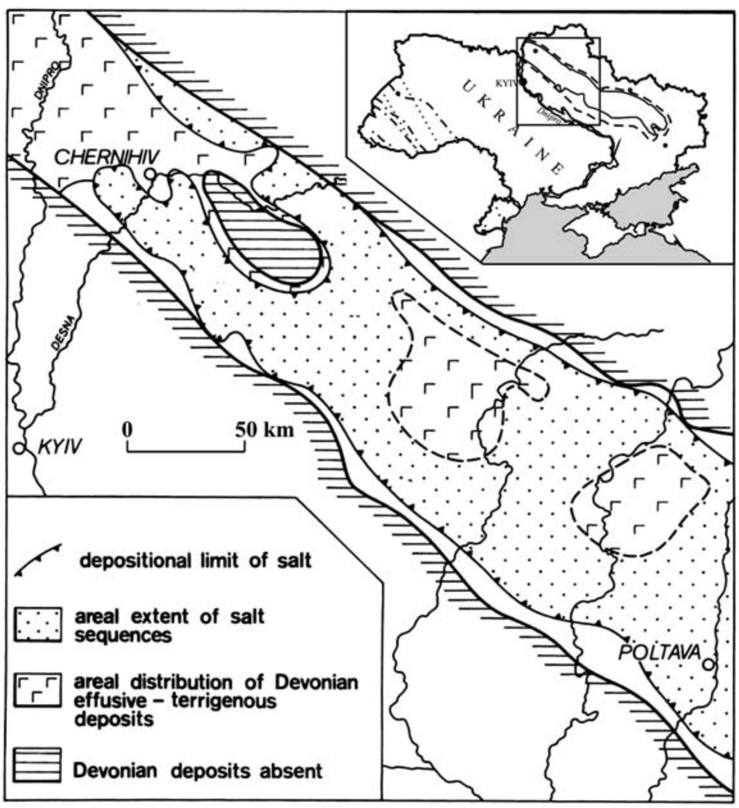

Fig. 3. Scheme of distribution of Devonian rock salt areas in the NW and central parts of the Dnipro–Donets depression (after Zharkov 1984).

mega-crystalline; however, generally isometric grains of 2–10 mm prevail. The texture is massive, laminated, in the cores of salt domes – deformed with flattened grains. The water-insoluble residue is composed of anhydrite, gypsum, calcite, dolomite, ankerite, quartz, feldspar and clays.

In the salt diapirs, as a rule, rock salt contains fragments of layers and blocks of anhydrite, terrigenous, clayey-carbonate and igneous rocks. The latter are made up of diabase and gabbro-diabase. Within the contact with igneous rocks the rock salt is strongly altered, apparently melting (Petrichenko & Shaidetskaya 1977; Petrichenko 1989). The thickness of such melted zones does not exceed several meters.

Potash-bearing salts The most complete data concerning the potash-bearing salts of the Upper Frasnian age were obtained from the Romny salt stock (Korenevskiy *et al.* 1968; Vysotskiy *et al.* 1988). There are two potash-bearing horizons, which are strongly deformed. The initial thickness of the upper one reaches a thickness of 4 m, and the lower is 18 m. The lithological section of the upper horizon is rhythmic. One rhythm is usually composed of three parts: (1) clayey-carbonate or clayey-carbonate–anhydrite rock (0.5–3 cm thick); (2) rock salt (2.5 cm); and (3) sylvinite or rock salt with sylvite (from 1.2 to 8 cm).

The lower horizon is represented by fine- and middle-grained sylvite–halite rock and rock salt with layers of reddish sylvinite. The bromine content in the Frasnian rock salt is 50–150 ppm.

Famennian Salt formation of the Famennian stage is located near the margins of the Dnipro–Donets depression. Its thickness is variable and varies from 0 to 320 m. In the arches of salt structures it is minimal and on the flanks the thickness increases. Salt formation is composed of rock salt interbedded with marls, anhydrites and terrigenous and igneous rocks (Zharkov 1984). The bromine content in the rock salt is 60–130 ppm.

Rock salt in domes is made up of light to dark grey halite with a heterogeneous structure – large salt crystals commonly form separate segregations within a thin- and middle-grained mass. Crystal sizes usually are 2–3 cm, but sometimes reach 5–6 cm. This rock salt contains hydrothermal authigenic minerals, which were first studied in the evaporites by Dolishniy (1976, 2000). The content of water-insoluble residue ranges from less than 1% up to several percent, 1–3% on average.

Minerals are distributed unevenly and form accumulations, where one or other minerals are more common. Such distribution of minerals sometimes causes a spotty colouration in the salt. For example, in borehole cores some intervals of rock salt from the Slovyans'k structure are reddish because of presence of large amounts of thin plates of hematite; in the Bantyshevo dome the salt is green due to the presence of small crystals of tourmaline. Authigenic minerals are typical of high-temperature association (scapolite, albite, muskovite, sphene, microcline, clinozoisite and others), rare minerals (tunisite, dawsonite, juwelite) and some ore minerals (Table 1).

Almost all studied minerals are euhedral crystals, and rounded ones are not present. Some minerals are commonly present as a xenogenic phase within the gas–liquid inclusions in halite. The minerals are present as separate crystals, and in intergrowths as well as monomineralic aggregates, microdruses and crusts. Crystal sizes range from 0.1 to 3 mm, rarely 4–5 mm, on average 1–2 mm.

The origin of superimposed secondary authigenic mineralization in salt domes is related to the broad development of hydrothermal activity in the region. Thermal fluids moved up along the tectonically 'released' zones around salt domes and poured out along microcracks of salt bodies as well as in porous diapiric breccias. The comparison of the authigenic mineral composition in salt from one side and in breccia zones (Kuznietsova *et al.* 1968; Kuznietsova 1970) from another appears to confirm the correctness of such conclusions (Dolishniy 1976, 2000).

The presence of hydrothermal mineralization occurred in three linear zones parallel to the extension of graben: two near the edge and one zone along the central axis. Almost all ore trends are located in breccias of salt domes and are made up of magnesite, galenite, sphalerite, pyrite, pyrotite, chalcopyrite, hematite, ilmenite, titanomagnetite, parisite, fluorite, scapolite, tourmaline, garnet, rutile etc. (Kuznietsova 1971). Based on chemical and spectral analyses the increased content of Co, Ni, Cu, Ba, Mo, Hg and the transition elements, etc. has been determined (Kuznietsova 1971, Khrushchov 1980). Small layers of coal and organic matter also have been noted. In the caprock of the Romny dome there are industrial sulphur deposits. Fluid inclusion investigations in the Slovyans'k dome (Zatsikha *et al.* 1973) showed that hydrothermal processes occurred over a wide scale of temperature, from 500 to 100 °C and lower. Some geochemical peculiarities of the Devonian salts are compared with Permian ones at the end of the Permian evaporites description.

Permian evaporites

The Lower Permian deposits are spread across most of the Dnipro–Donets depression (Fig. 4), but their total volume is smaller than that of the Devonian age. The depth of Permian base ranges from 700

Table 1. *Distribution of minerals in the water-insoluble residues of rock salt from some salt domes in SE part of Dnipro–Donets depression (Dolishniy 1976, 2000)*

Minerals	Saltdome structures			
	Slovyans'k	Bantyshevo	Berets'k	Bilyayivska
Sulphur	3		3	2
Pyrite	2	1	2	2
Pyrrhotite		4		
Molybdenite	4			
Galenite		4		
Sphalerite	4	4		4
Wurtzite				4
Quartz	1	1	1	1
Rutile	4	3		
Anatase		4		
Brookite		4		
Leucoxene		4		
Magnetite		4		
Hematite	3		3	3
Hydrous ferric oxide	3		3	3
Dolomite	1	1	1	1
Calcite	1	1	1	1
Siderite	4			
Ankerite	4			
Rhodochrosite	4			
Dawsonite	3			
Tunisite	2	3		
Anhydrite	1	1	1	1
Barite	3			
Celestite	3			3
Scapolite		3		
Albite	4	3		3
Muscovite	3	2	4	4
Phlogopite		3		
Tourmaline	4	3		4
Microcline		3		
Sphene		4		
Apatite		4		
Fluorite			4	
Juvelite	4			
Anthraxolite	4			3
Clinozoisite		4		
Pumpellyite		4		
Tremolite(?)				

Note: 1, major minerals; 2, minor; 3, rare; 4, single occurrence.

to 5000 m (Vysotskiy *et al.* 1988). The total thickness of the Lower Permian evaporite formation is from 300 m in the NW to 1650 m in the SE part of depression and the Permian deposits are actually exposed at the surface here (Fig. 5). Within the Permian of Ukraine lies the largest rock salt deposit, the Artemivs'k.

Within this depression, the Lower Permian deposits are subdivided up the section to four suites: Kartamysh, Mykytiv, Slovyans'k and Kramators'k. The lowest one (a thickness of 10–1200 m) is represented mainly by terrigenous deposits with dolomite layers. Mykytiv suite (10–300 m) is composed of clay, carbonates, anhydrite and rock salt. This salt is from several to 80 m thick. In the Slovyans'k suite salt thickness increases from 15 m in the NW part of the depression to 900 m in the SE. The uppermost suite, Kramators'k, is 150–900 m thick and consists of 90% salt. Bromine content in rock salt from the three salt-bearing suites ranges from 32 to 85 ppm (Korenevskiy *et al.* 1968; Zharkov 1984).

Also potash salts (of chloride and chloride–sulphate composition) and bischofite are present in some second-order depressions. There are five potash-bearing horizons (up to 30 m each) with

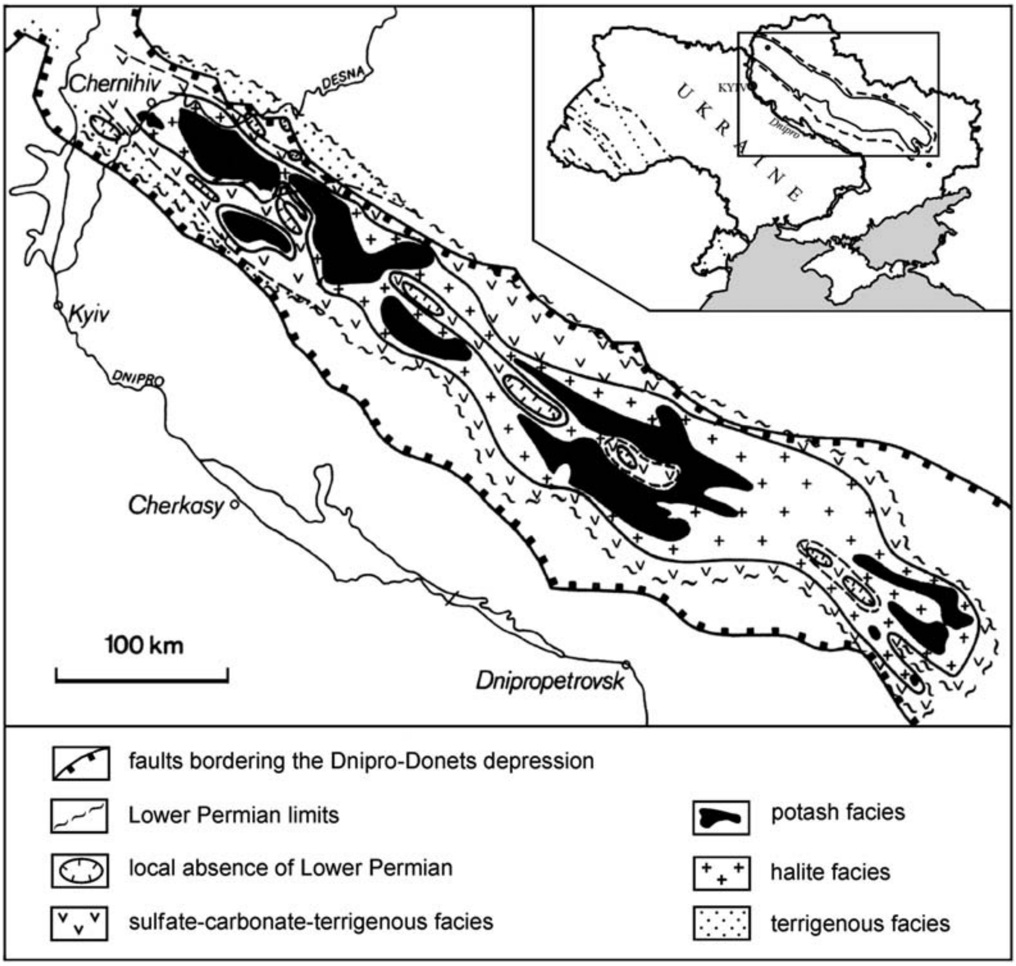

Fig. 4. Location map of the Permian evaporites in the Dnipro–Donets depression (after Zharkov 1984).

bischofite mineralization. Also present are separate layers having very complicated compositions. They are made up of carnallite, carnallite–bischofite, kieserite–carnallite, carnallite–kieserite and carnallite–halite rocks. In the kieserite-bearing rocks sulfoborite and ascharite are present (Khrushchov 1971; Galitskiy 1972; Korenevskiy *et al.* 1980; Vysotskiy *et al.* 1988).

The physical–chemical depositional conditions of the Devonian and Permian salt formations (based on data from studies of fluid inclusions in halite) are described in many publications (Petrichenko *et al.* 1974*a*; Kovalevich 1985; Shaidetskaya 1990; Kovalevych & Petrychenko 1994; Petrichenko & Shaidetska 1998; Kovalevych *et al.* 2002; Petrychenko & Peryt 2004).

Based on these investigations, the Devonian salts were formed from solutions of Na–K–Ca–Mg–Cl (Ca-rich) chemical type and the Permian from solutions of Na–K–Mg–Cl–SO_4 (SO_4-rich) type. These differences have permitted stratigraphical differentiation for the twin-salt structures of the Permian and Devonian age in the Dnipro–Donets depression (Petrychenko *et al.* 1976*b*), using the ultramicrochemical analysis of brine inclusions in halite (Petrichenko 1973). Based on the fluid inclusion studies the temperature of salt-forming solutions in the Devonian and Permian evaporite basins at the stage of halite precipitation did not exceed 43 °C, elevated up to 60–65 °C in the sylvite stage in the Devonian and up to 78–83 °C on carnallite and 65–77 °C on bischofite stages in the Permian (Petrichenko 1988). The temperature of diagenetic transformations of the rock salt in the Permian deposits was 45–55 °C and that of potash rocks is estimated to have been 75–82 °C.

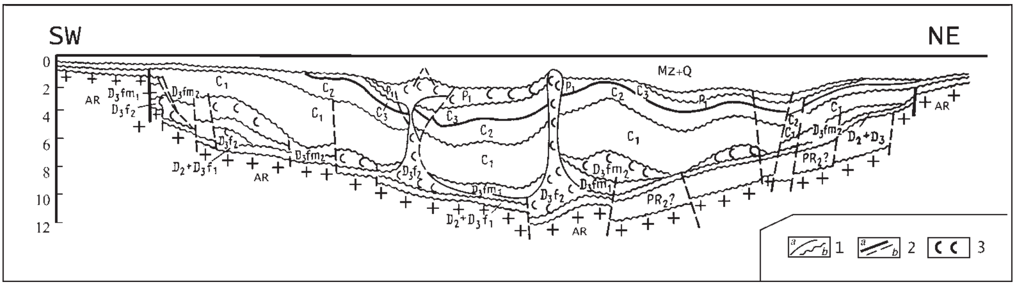

Fig. 5. Schematic geological section across the Dnipro–Donets depression (after Kruglov & Tsypko 1988). 1, boundaries (a, geological, b, of unconformable bedding of rocks); 2, faults (a, marginal, b, other faults); 3, rock salt.

Upper Jurassic evaporites

Upper Jurassic evaporite deposits are broadly spread across the western and southwestern slope of the East European platform in Poland, Ukraine, Moldova and Romania (Fig. 6). In Ukraine they are distributed in the Forecarpathian region (Carpathian Foredeep and the slope of the East European platform) and in the Foredobrogean trough.

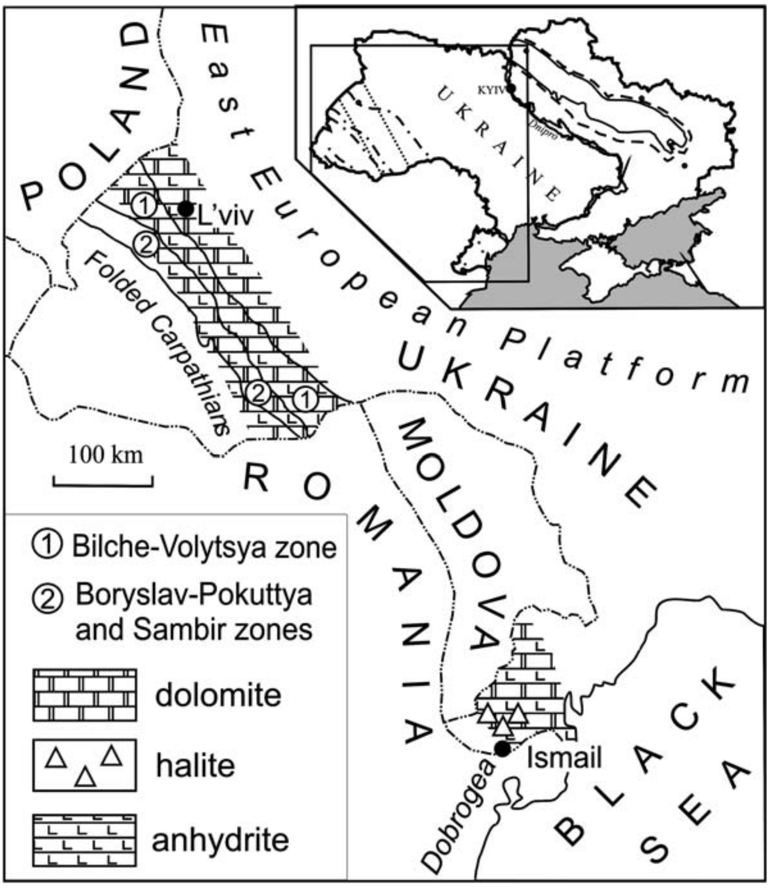

Fig. 6. Schematic map of distribution of Jurassic evaporites, western and southwestern slope of East European platform (after Khmelevskaya 1997). I, Forecarpathian region; II, Foredobrogean trough.

Forecarpathian region

In the territory of the Forecarpathian region of Ukraine Jurassic evaporites are located in the basement of the Bilche–Volytsya zone of the Carpathian Foredeep and the adjacent part of Volyno–Podoliya region (Stryy Jurassic trough). During Jurassic time the Stryy trough was developed on the western and southwestern slope of the East European platform. It has a triangular shape that extended SE toward NW but showed an asymmetric construction, with a NE limb that was gentle and extended and the SW was steep and short, complicated by faults (Glushko 1968).

Jurassic deposits transgressively overlap the eroded and truncated surface of the Paleozoic (Anastasieva 1957) and are represented by all units, Lower, Middle and Upper Jurassic with a total thickness >2500 m. On the Ukrainian territory they are spread as a wide band (60–100 km) from Poland at NW to Romania at SE (Dulub *et al.* 2003).

Evaporite deposits are recognized in the Rava–Ruska suite of Kimmeridgian age, and their thickness varies from 20 to 250 m (Garetskiy 1985). They are made up of interbedded dolomites, dolomitic limestones, terrigenous rocks (sand- and siltstones), massive and bedded anhydrite, anhydrite breccia and gypsum (Korenevskiy 1982).

Anhydrite is white, light and dark grey, pink, brownish and commonly multicoloured due to admixtures, and the structure is fine-grained, while the texture is massive or irregular. Some anhydrites with thin clayey or carbonate veins have a cellular texture (Khmelevska 1993; Chmielewska 1995). The thickness of individual anhydrite layers in the section ranges from several centimetres to 7 m (Anastasieva 1958).

Anhydrite breccia is composed of oval nodules of dark grey or pink anhydrite cemented by brown or grey fine-grained dolomite or mudstone. Anhydrite nodules range in size from 2–3 mm to 5 cm. Breccias occur in the upper part of sulphate-carbonate suite and are 12–25 m thick. They are intrastratal formations interpreted as possible subaqueous slumps and collapse deposits (Sandler & Vorona 1955).

Gypsum rocks have a restricted distribution and are present as lenses and layers up to 1 m thick, filling cavities and veins in breccia-like carbonate–clayey and clay deposits. The gypsum is white, grey and brownish and commonly contains significant carbonate and clayey admixtures. In some cases the veins and cavities are filled by parallel-fibrous gypsum (satin-spar) (Anastasieva 1958).

The formation of these evaporite deposits apparently took place in lagoons separated from sea only by underwater barriers. Such conditions provided a lateral transition from anhydrite to carbonate rocks (Dulub *et al.* 1986).

Foredobrogean trough

In the SW Ukraine, near the Black Sea, the Upper Jurassic evaporite deposits accumulated within the Foredobrogean Mesozoic trough, located between Dobrogea and the platform. It is composed of both Triassic and Jurassic deposits. The trough has an asymmetric construction, where the limb adjacent to Dobrogea is steep and that near the platform – sloping (Romanov & Slavin 1970).

The Jurassic rocks are formed into gentle folds with small amplitude. In the central part of trough thickness of Jurassic rocks is greatest, up to 2500 m (Glushko 1968). Evaporites have been recognized in the Kongaz suite of Kimmeridgian age and are composed of carbonate, clastic, sulphate and halite rocks. The total thickness of this suite ranges from 15 to 445 m (Sliusar 1971; Romanov 1976; Korenevskiy 1982; Garetskiy 1985).

The sulphate rocks in the trough are composed of anhydrite, mixed gypsum–anhydrite and gypsum. Near the salt body their thickness reaches 250 m. The anhydrite is white, grey and brown, and usually fine-grained, massive and relatively pure (97–99% calcium sulphate). Among the admixtures are carbonates, celestite and pyrite. Some anhydrite includes the detrital carbonized remains of shells (Khmelevskaya 1990*a*). As a result of gypsification, mixed gypsum–anhydrite rocks are present and characterized by presence of rosette-like gypsum aggregates within the massive anhydrite.

Gypsum may be fine-grained but there also are coarsely crystalline varieties. Fine-grained gypsum is grey, blue, brownish, multicoloured with massive or irregular patchy textures. Coarsely crystalline gypsum is uncoloured, yellow and grey and forms veins and layers in fine-grained gypsum or anhydrite. Crystals of gypsum are lens-shaped, platy or columnar and may reach 7 cm in size.

Rock salt is located in a restricted area near Izmail (Butkovskiy *et al.* 1976); its maximal thickness does not exceed 80 m. It is composed of white and grey halite, medium- to coarse-grained, slightly recrystallized, with thin layers and aggregates of anhydrite. The NaCl content ranges from 93 to 98%. The water insoluble portion of the salt consists of authigenic minerals – anhydrite, carbonates (calcite and dolomite), quartz, celestite, fluorite and pyrite and terrigenous ones – quartz, rarely garnet, tourmaline and biotite. Clay minerals include hydromica and chlorite (Khmelevskaya 1990*b*). Euhedrality is the distinguishing feature for authigenic minerals.

On average the bromine content of the rock salt ranges from 27 to 63 ppm and is 35 ppm. Fluid inclusion investigation showed that rock salt was composed of both sedimentary (primary) and recrystallized halite (Khmelevska 1993; Khmelevskaya 1997). Based on ultramicrochemical analysis of brine inclusions in halite (Petrichenko 1973) it appears that salt-forming solutions were of Na–K–Ca–Mg–Cl composition (Ca-rich type). The maximum concentration determined for the potassium-ion in brine inclusions in halite was 15.5 g l^{-1} and this value was too low to expect any primary potash salt sedimentation (Petrychenko *et al.* 1976*a*).

The Upper Jurassic Foredobrogean evaporite basin was formed within the northern continental margin of the Tethys ocean, parallel to the Dobrogea land mass. It was apparently deposited in a lagoon or arm of the sea, which united several isolated basins having different rates of bottom subsidence and concentration of seawater. Only in the most subsident part of the evaporite basin the conditions were favourable for rock salt accumulation.

Miocene evaporites

Miocene evaporite deposits in Ukraine are distributed in the Carpathian region (Carpathian Foredeep and Transcarpathian trough) and in the Crimea on the Kerch peninsula (see Fig. 1). The archeological findings show that salt in the Forecarpathian and Transcarpathian areas has been mined for a long time. In the Transcarpathian rock salt was first quarried in the first to third centuries, and later it was again mined in the second part of the nineteenth century (Kityk *et al.* 1983).

In the Forecarpathian the salt production was widespread and this geographic area was given the name 'Halychyna' (from the Greek 'galos' for salt). At the end of the nineteenth century the potash deposits were discovered and their exploitation was begun (Korenevskiy & Donchenko 1963).

The Miocene evaporite deposits of the Forecarpathian are potash-bearing and the Stebnyk and Kalush-Holyn' industrial potash fields are located there. At the present time their exploitation is conducted only in the Dombrovo quarry of Kalush–Holyn' deposit. Another 10 deposits are explored here of which the largest one is Markova–Rosilna (Fig. 7).

The results of investigations of these evaporites were published by Polish and Austrian geologists before the second World War as well as in later studies and have been summarized in the following reviews (Byhovier *et al.* 1941; Lazarenko *et al.* 1962; Korenevskiy & Donchenko 1963; Dolenko 1975).

Carpathian Foredeep

For this complicated region the peculiarities of evaporites are described separately for sulphate (gypsum–anhydrite) deposits and for the rock salt of the Bilche–Volytsya zone and potash-bearing deposits of the Boryslav–Pokuttya and Sambir zone.

The Carpathian Foredeep in Ukraine territory extends from NW to SE as a band of 25–60 km wide and about 300 km long (see Fig. 7) and is located along the boundary of the Folded Carpathians and East European platform. It occurs on folded flysch as well as on the platform basement and is filled by thick chemogenic–terrigenous formation of the Miocene molasse. In the SW it is bounded by the Carpathian overthrust and to the NE by a system of faults in which the basement rocks have a step-like subsidence towards the Carpathians.

The Carpathian Foredeep is subdivided on the Boryslav–Pokuttya, Sambir and Bilche–Volytsya zones (Vul *et al.* 1998). In the Boryslav–Pokuttya and Sambir zone the folded flysch deposits of the Cretaceous and Palaeogene age are conformably overlapped by the complex of the lower and upper molasse. In the Bilche–Volytsya zone, only the upper molasse is present and it lies on the Mesozoic platform basement with a sharp break and an angular unconformity. Within the platform portion, the Miocene deposits are present at 10–200 m depths below the surface, and in the foredeep they subsided under the overthrust of the Sambir zone and are at depths of 1200–2200 m. The Boryslav–Pokuttya zone has been thrust to the NE and forms a sheet of 25 km amplitude. The Sambir zone is stripped from its basement and thrust onto the Badenian–Sarmatian deposits of the Bilche–Volytsya zone; near the Kalush–Holyn' deposit the thrust amplitude is 8–12 km (Korenevskiy & Donchenko 1963).

The correlation of different stratigraphic schemes for the Neogene areas of the Eastern and Western Paratethys in Western regions of Ukraine can be seen (Fig. 8) in the review by Vyalov (1980), and the stratigraphic scheme of the Miocene molasse of the Carpathian Foredeep is shown in Figure 9. The number and stratigraphic position of evaporite deposits in the Miocene section have not been fully explored and remain uncertain. The number and stratigraphic position of evaporite deposits in the Miocene section have not been fully explored. It remains uncertain whether there are two (Dzhinoridze 1980), three (Klimov 1977; Khrushchov 1980) or four (Korenevskiy *et al.* 1977) evaporite formations. According to different researchers, Markova–Rosilna and Stebnyk deposites could belong to the Lower- and Upper-Vorotyshcha subsuites respectively (Klimov 1972; Korenevskiy *et al.* 1977), or to the undivided Vorotyshcha suite (Dzhinoridze 1980), while Kalush–Holyn' and a number of other deposits are related to the Upper-Stebnyk

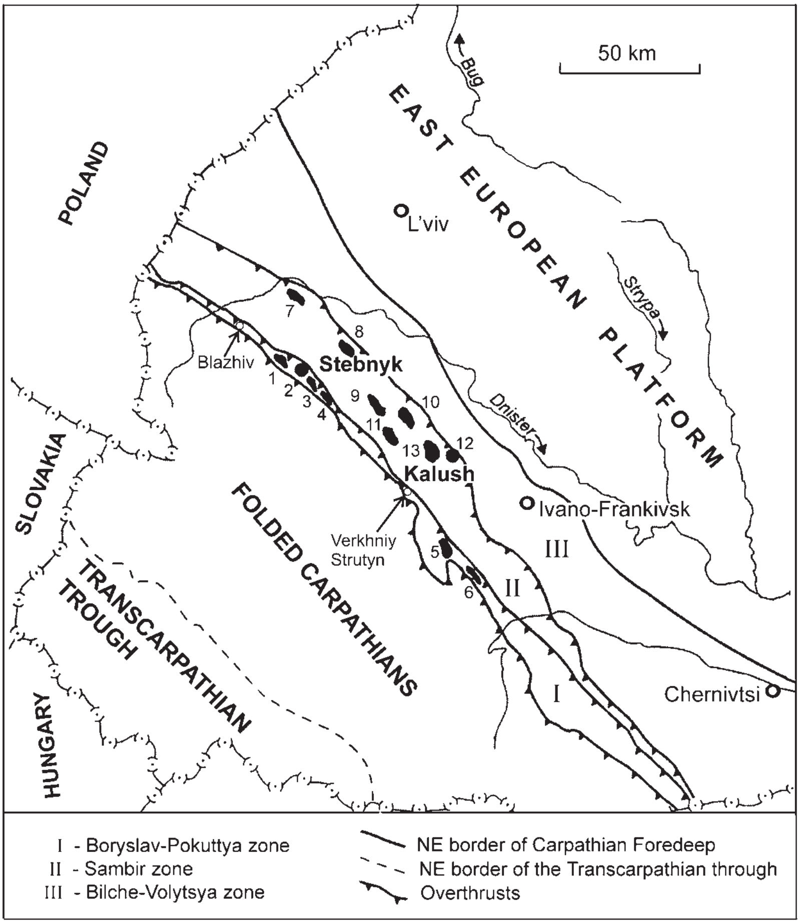

Fig. 7. Location map of potash-bearing deposits in the Carpathian Foredeep. I, Boryslav-Pokuttya zone: 1, Boryslav; 2, Stebnyk; 3, Dobrohostiv; 4, Ulychne; 5, Rosilna; 6, Markova. II, Sambir zone: 7, Bilyna-Velyka; 8, Nezhukhiv; 9, Morshyn; 10, Tura Velyka; 11, Trostyanets'; 12, Kalush; 13, Holyn'. III, Bilche–Volytsya zone.

subsuite (Klimov 1972; Korenevskiy *et al.* 1977; Khrushchov 1980) or to its facial analogue, the Lower-Balytska one (Skvortsova 1964; Klimov 1977), or to the Tyras suite (Dzhinoridze 1980). In this paper we accept that evaporite deposits belong to the Vorotyshcha (Eggenburgian) and Tyras (Badenian) suites (Dzhinoridze 1980).

In our opinion the most certain view concerns the Badenian age of Kalush–Holyn' deposits. This was first put forward by Polish geologists (Kuźniar 1939) and later supported by the studies of foraminifera microfauna (Dzhinoridze 1976) and nannoplankton (Andreyeva-Grigorovich & Kulchytskiy 1985; Andreyeva-Grigorovich *et al.* 2003). Salt-bearing deposits from Bilyna Velyka and Nezhukhiv, Morshyn, Tura Velyka, and Trostyanets' (see Fig. 7) are considered to be coeval with Kalush–Holyn' deposit (Korenevskiy *et al.* 1977).

The deposits of the Lower-Vorotyshcha subsuite form a band in Boryslav–Pokuttya zone and extend along the Carpathian thrust. They are composed of saline clays with intercalated strata of sandstones and siltstones, anhydrite and rock salt. In some areas (Boryslav, Markova–Rosilna potash deposits, Dobrogostiv, Ulychne fields; see Fig. 7) they are represented by salt-bearing breccia with layers of potash salts. Their thickness varies from 100 to 900 m.

The deposits of the Upper-Vorotyshcha subsuite are spread only in zone from Blazhiv to Verkhniy Strutyn, within the Stebnyk deposit and they are composed of a thick sequence (700–1000 m) of saline clays and salt-bearing breccia with layers of

Western Paratethys, regional stage: Old scheme	Western Paratethys, regional stage: New scheme	Transcarpathian trough, suites	Forecarpathian deep, suites	SW margin of East Europian platform	
Sarmatian S. Str.	Sarmatian S. Str.	Lukove	Dashava	Upper Volyn' horizon	
		Dorobratove		Lower Volyn' horizon	
Upper Tortonian	Badenian	Darolyn	Kosiv	Holohory substage	Buhliv beds
		Neresnytsya			Vyshgorod beds
		Tyachiv			
		Shandrove			Ternopil' beds
		Solotvyna			Pidhirtsi beds
Lower Tortonian		Tereblya	Tyras		Tyras gypsum
		Talabor	Bohorodchany	Opillya substage	Kryvchytsi horizon Roztocha horizon Narayiv beds
		Novoselytsya			Baranove beds
Upper Helvetian	Karpatian		Balych	Berezhany beds	
Lower Helvetian	Ottnangian		Stebnyk	Nahoryany beds	
Burdigalian	Eggenburgian	Burkalo	Vorotyshcha		
Aquitanian	Egerian	Nehrove			
Chattian			Polyanytsya		

Fig. 8. Regional stages scheme for Miocene of Western Ukraine (after Vyalov 1980).

potash salts (Korenevskiy *et al.* 1977). The Upper-Vorotyshcha subsuite is separated from the Lower Vorotyshcha by clays, sandstones, gritstones and conglomerates of Zagorsk suite that is 100–400 m thick. In recent papers the Zagorsk suite is described as an olistostrome horizon, and the Vorotyshcha suite is not subdivided into the Upper and Lower parts (Dzhinoridze 1980; Kulchytskiy 1986; Korin' & Mosora 1990).

The Tyras suite in Sambir zone of the Foredeep is potash-bearing (Dzhinoridze 1980) but in the Bilche-Volytsya zone it is composed mainly of gypsum and anhydrite. In the Sambir zone the Kalush–Holyn' potash deposit and Bilyna Velyka, Nezhukhiv, Morshyn, Trostyanets' and Tura Velyka all belong to the Tyras suite (Dzhinoridze 1980). It consists of salt-bearing breccia, rock and potash salts. Their thickness in Kalush syncline reaches 300–350 m and in Holyn' *c.* 600–800m. In the Bilche–Volytsya zone the Tyras suite is composed of gypsum, anhydrite and rock salt with terrigenous (clay and sandstone) and carbonate (limestone and marl) rocks; its thickness ranges from 20 to 50 m, sometimes up to 70 m. In Kolomyya depression where the rock salt is known among the anhydrites, the thickness increases to 246 m, and in the Bratkivtsi area up to 347 m (Korenevskiy *et al.* 1977).

Gypsum-anhydrite deposits and rock salt of the Bilche–Volytsya zone

Evaporite deposits of Tyras suite in Bilche–Volytsya zone of the Carpathian Foredeep (Fig. 10) contain large industrial resources of native sulphur and are represented by three complexes: carbonate, sulphate and chloride.

The carbonate complex is composed of sulphate–carbonate, commonly celestite-bearing rocks, secondary metasomatic and sulphur-bearing limestones. The results obtained due to the petrographical and mineralogical investigations of this complex are in agreement with the idea that proposes a metasomatic origin for the limestones from this sulphur-bearing series and the epigenetic origin for celestite, with wide development of superimposed mineralization and intensive leaching of the rocks. Geochemical investigations of the composition of intracrystal solutions and of brine inclusions in calcite from limestones showed an elevated content of calcium hydrocarbonate and potassium chloride in comparison to seawater.

The sulphate complex on 95% consists of chemogenic deposits represented by gypsum, gypsum–anhydrite and anhydrite rocks. It is subdivided into the lower autochthone (*in situ*) and upper allochthone (reworked, clastic) parts. The lower part

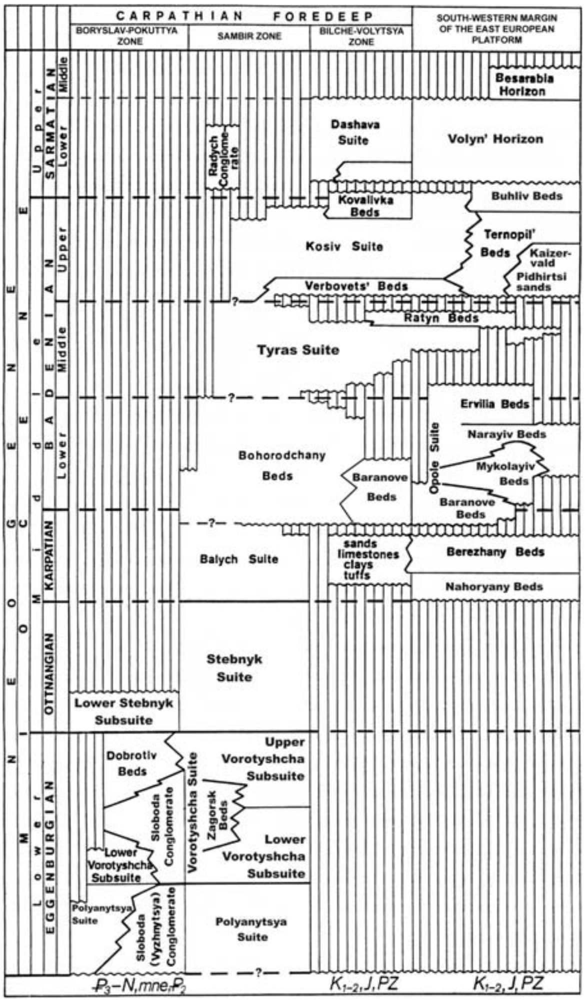

Fig. 9. Stratigraphic scheme of Miocene in the Carpathian Foredeep (after Petrichenko *et al.* 1994).

is locally distributed in tectonic depressions within the Ukraine territory. Within the autochthonic sulphate sequence there are three section types (Peryt 2001), two of which are present in Ukraine. The first one is composed of stromatolitic gypsum and is typical for the NE margin of the basin (up to 15 km wide). The second type of gypsum section forms a zone (40 km wide) near the central part of basin and is composed of stromatolitic gypsum in its lower part and of saber-like gypsum in the upper part (Poberezhskyy *et al.* 2002; Peryt *et al.* 2004*a*). The correlation of these facies zones is based on recognized key horizons in the primary sedimentary gypsum. The typical key horizon is 20–40 cm thick and is composed of wavy layers of fine-grained gypsum and it is present across a very broad area of the Bilche–Volytsya zone. Another important correlative marker is the contact between the autochthonic and allochthonic (clastic) gypsum and this evidences a significant alteration in the history of basin evolution (Peryt 1996). Correlation between the facies zones evidences the contemporaneous origin of coarse-crystalline and stromatolitic gypsum. It is considered that the near-shore facies associations were formed under sabkha conditions (Peryt 1996; Bąbel 2004, 2005a, *b*), and during the whole time of existence of the basin only two periods of elevated brine concentration are noted (Kasprzyk 1999).

The question of the correlation of the sulphate and chloride sedimentation in the region remains unresolved, particularly concerning possible genetic connections between these strictly chemogenic deposits and the time of their sedimentation

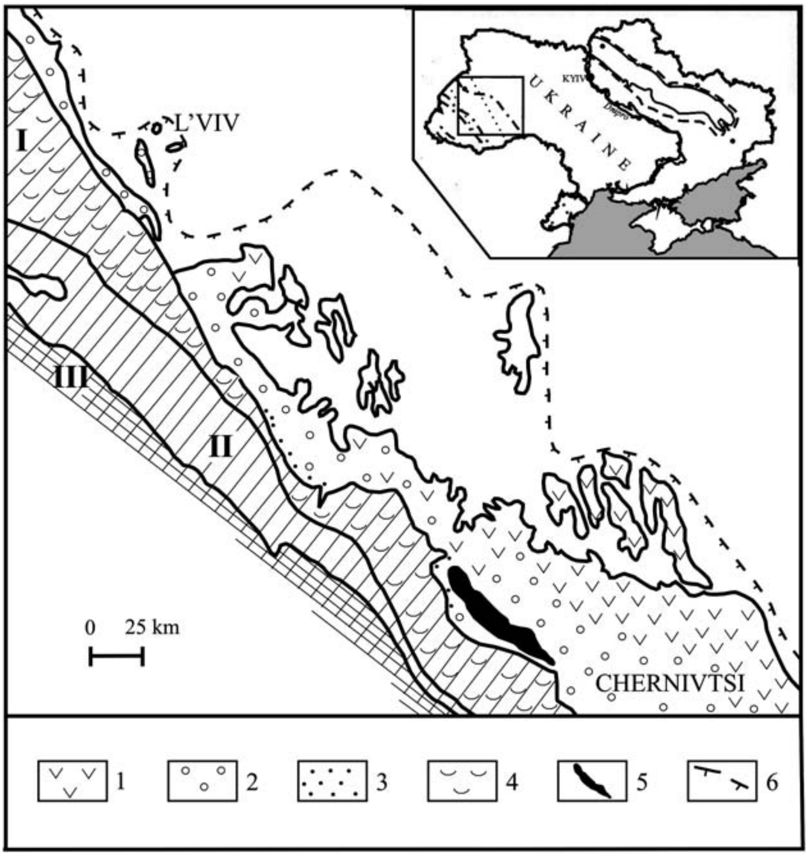

Fig. 10. Location scheme of sulphate and chloride complexes of Tyras suite in Bilche–Volytsya zone (SE part) of the Carpathian Foredeep and adjacent part of East European platform (after Kityk *et al.* 1979). I, Bilche–Volytsya zone; II, Boryslav–Pokuttya and Sambir zones; III, Folded Carpathians. 1, sedimentary gypsum; 2, epigenetic gypsum; 3, gypsum–anhydrites; 4, anhydrites; 5, rock salt; 6, NE boundary of distribution of sulphate complex.

(Panow & Płotnikow 1996; Petrichenko *et al.* 1994; Wyszyński 1939). It has been assumed, but remains uncertain, that the gypsum sequences correspond only to the upper part of evaporite complex, the origin of which was related to a mixed continental-marine evaporite basin at the end of the Badenian time (Petrychenko *et al.* 1997; Poberezhskyy 2000).

Anhydrite deposits are massive or layered rocks, and commonly with intercalations of clay lamina. $CaSO_4$ content is about 94–96% and different admixtures and clays compose 4–6% of the total. Gypsum–anhydrite mixes apparently resulted from incomplete dehydration of gypsum (or incomplete hydration of secondary anhydrite) and sometimes are marked by inherited lithologic structures, relics of coarse-crystalline sabre-like gypsum crystals for example.

Petrographical study of coarse-crystalline gypsum showed that, during its dehydration, bassanite originated first, and then anhydrite. Bassanite forms as crystals of prismatic, needle, plate and rod-like shapes. It is typical that many fluid inclusions (less than 1–3 μm) occur in the gypsum around bassanite crystals. These inclusions are formed from water released during gypsum–bassanite alteration. (Petrichenko & Poberezhskyy in Matkovskyy *et al.* 2003). The water-insoluble residue from single crystals of coarse-crystalline gypsum is composed of chlorite, montmorillonite, mica, kaolinite, euhedral quartz, dolomite and calcite.

The chloride complex is composed of rock salt containing both primary and recrystallized halite. Three varieties of primary halite are distinguished: pyramidal hopper crystals, chevrons and cubic hopper crystals. This last structure was first described by Raup (1970) and demonstrated the mixing of differentiated brines. The bromine content in these salt deposits varies from 20 to 60 ppm (Petrichenko *et al.* 1974*b*). The water-insoluble residue consists of authigenic anhydrite, gypsum, bassanite, quartz, dolomite, magnesite and calcite. The clay fraction contains hydromica and chlorite.

Potash salts of the Forecarpathian region

Potash-bearing deposits of the Carpathian Foredeep generally are composed of kainite, langbeinite and kainite–langbeinite rocks; to a lesser extent they have sylvinite beds; other salts are found as admixtures and form rare accumulations of potash rocks.

The successions of potassic deposits are best studied in the Stebnyk and Kalush–Holyn' areas. The potassic salts occur repeatedly in the section and this repetition formerly was considered to have formed as the result of sporadic refilling, concentration and repeated sedimentation of different salts in small lagoons. In the Stebnyk deposit there are 14 distinct layers (lenses) (Kudryavtsev 1971; Korenevskiy *et al.* 1977); in the Kalush–Holyn' deposit such lenses are united into four potash horizons for the Kalush syncline; and in the Holyn' area they may variously be divided into nine (Korenevskiy & Donchenko 1963) or into six separate deposits (Korenevskiy *et al.* 1977). In the papers of Dzhinoridze and Korin' an idea has been proposed concerning the thrust–slice constructs of these evaporite deposits. The number of thrust–slices determines the thickness of the salt-bearing sequence and the number of potash lenses. Thus, using that proposal the multi-stage and lens-like bedding of potash layers resulted not from numerous repetition of sedimentation but from thrust-fold construction (Dzhinoridze 1980), and this point of view is clearly reflected in the section of Stebnyk deposit (Fig. 11). The true unfolded thickness of salts in Stebnyk deposit is estimated to have been 100–125 m (Korin' 1992). Before the processes of thrust tectonics in the Forecarpathian region only two strata of potash salts were recognized, the lower one of chloride composition (sylvinite) and the upper of sulphate (kainite–langbeinite) composition (Dzhinoridze 1980; Korin' 1992). This point of view is also supported by lithological investigations; the comparison of lithological sections of some potash layers shows their identity (Hryniv 1985).

Based on their compositions the Vorotyshcha and Tyras potash-bearing deposits of the Carpathian Foredeep, which are best studied in Kalush–Holyn' and Stebnyk deposits, have many comparable features such as sulphate composition of salts, significant content of clays, and also that the enclosing rock for potash salts is a clayey, salt-bearing breccia. This breccia is composed of clay and siltstone detritus cemented by halite that is thus far considered as a rock of sedimentary origin (Polikarpov 1974; Peryt & Kovalevych 1997), but may be the result of crushing of the rocks due to migrating brine and gases during late diagenesis and catagenesis, and more importantly, during repeated periods of strain during overthrust formation (Khodkova 1980). In the Kalush–Holyn' deposit the salt-bearing sequence is somewhat different and begins with a basal anhydrite.

The industrial potash deposits are composed of kainite, langbeinite, kainite–langbeinite, sylvinite, polyhalite and carnallite rocks (Lobanova 1956) with layers of rock salt or interbedded clays and

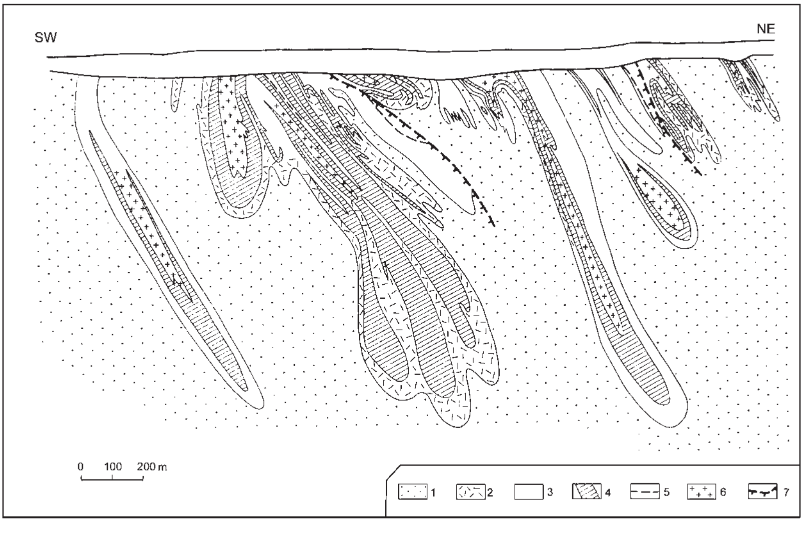

Fig. 11. Geological cross section through the Stebnyk potash-bearing deposits (after Korin' 1992). 1, Terrigenous deposits below evaporites; 2, salt breccia with sylvite; 3, salt breccia; 4, kainite–langbeinite bed; 5, kainite admixture; 6, rock salt; 7, overthrust zones.

rock salt. In the areas of salt-bearing breccia the polyhalite–anhydrite layer occurs along the contact with the potash salts beds.

Kainite rocks are yellow, grey-yellow, mainly fine-grained, commonly clayey, bedded, with the thickness of the layers being 5–10 cm.

Langbeinite rocks are pink, massive, crystalline-grained with a small clayey admixture. In the opinion of Lobanova (1956) kainite and langbeinite are primary minerals precipitated in the evaporite basin. However, Valyashko (1962) and Khodkova (1971) considered them as a result of reactions of metastable minerals (epsomite, hexahydrite, kainite) and burial solutions during early diagenesis.

Kainite–langbeinite rocks contain a mixture of kainite, langbeinite, sylvite, kieserite, halite and water-insoluble residue in approximately equal amounts, 10–15%, and have a breccia-like texture and are considered to be the breccia of sulphate minerals cemented by chloride minerals (Khodkova 1971).

Polyhalite rocks are found in several varieties. The grey clayey polyhalite rock occurs in potash rocks as persistent layers of 5–10 cm thickness. Red polyhalite rock forms layers of 1–3 cm to 1.5–3 m thick in areas where potash deposits pinch out. Two component polyhalite–anhydrite layers of 1–30 cm thick occur in a salt-bearing breccia near the contact with potash salts. Though the crystallization of polyhalite from solution is possible and has been tested experimentally, the gypsum crystallization and its transformation into polyhalite during a stage of early diagenesis are considered as a more reliable possibility for grey polyhalite (Valyashko 1962). Polyhalite–anhydrite layers were formed *de novo* at sulphate geochemical barrier due to the reaction of burial sedimentary sulphate solutions from potash deposits and metamorphosed calcium chloride solutions from salt-bearing breccia (Hryniv 1990).

Carnallite rocks are uneven in thickness and extension beds, which occur in the places of tectonic dislocation of the salt sequence. In the Forecarpathian region the origin of carnallite is connected with altered burial sedimentary brines (Povsten & Povsten 1980).

In potash-bearing deposits and salt-bearing breccia closely related to them, there are occurrences of laterally persistent layers of rock salt (5–10 cm thick, rarely 20 cm). These may have been formed in an evaporite basin as primary precipitates due to salting out, i.e. mixing of solutions of different concentration (Kovalevich 1977; Hryniv 1982). There is, however, another view on their origin, that they are layer-like bodies that were formed during diagenesis (Khodkova 1971).

Potash-bearing deposits of the Carpathian Foredeep contain more than 20 salt minerals. The main rock-forming minerals are halite, sylvite, kainite, langbeinite, kieserite and polyhalite, rarely leonite or carnallite, rare minerals include bassanite and kalistrontite (the last one being the third finding in the world). Anhydrite in salt-bearing breccia is a common admixture, and it occurs rarely in potash rocks. A separate group is formed by the hypergene minerals of the weathering zone (from the gypsum-clayey cap): schoenite (picromerite), epsomite, hexahydrite, glaserite, astrakhanite (bloedite), loeweite, vanthoffite, glauberite, mirabilite, tenardite, syngenite (kaluschite) and gypsum. The results of mineralogical investigations and the vast literature on evaporite minerals are summarized in the monograph *Minerals of Ukrainian Carpathians* (Matkovskyy *et al.* 2003).

In early publications the main minerals were considered to be sedimentary (Korobtsova 1955; Lobanova 1956); in later works their origin was recognized to be connected with reactions between unstable sedimentary minerals and the brines from stages of both early and late diagenesis (Valyashko 1962; Khodkova 1971; Gemp 1979; Kovalevich 1982). A sedimentary origin of kainite and one variety of langbeinite, however, is not excluded (Petrichenko 1988). The origin and transformation of salt minerals is also connected to the thermodynamic metamorphism stage of the region (Gemp 1979; Dzhinoridze 1980), which took place during the overthrust-forming processes in the Carpathians and Carpathian Foredeep. The Radiometric age (K–Ar) of langbeinite from Kalush–Holyn and Stebnyk deposits ranges from 13.63 to 14.65 Ma and shows the regional heating and recrystallization of potash-bearing deposits during overthrust-forming (Wojtowicz *et al.* 2003).

The pelitic fraction of the water insoluble residue of salts is represented by hydromica and chlorite with admixture of quartz and carbonates; in some cases feldspar is present (Yarzhemskaya 1954; Bilonizhka *et al.* 1966). Based on data of absolute ages the hydromica is mainly terrigenous (reworked) (Bilonizhka & Kostin 1977). Kaolinite is present in subsalt deposits and disappears in salt-bearing sequence, and this apparently is a result of its transformation under the aggressive environment of saline solutions (Bilonizhka 1991). In the pelitic fraction from the clayey gypsum cap, except for hydromica and chlorite, the mixed-layered phase hydromica-montmorillonite is also present. This is evidence of the degradation of part of hydromica during leaching of evaporites by surface water over long periods of time (Oliyovych *et al.* 2004).

In the potash rocks from Lower Vorotyshcha subsuite the mineral chambersit (a manganese boracite) has been found in the Stebnyk and Markova–Rosilna deposits. In the heavy fraction of water-insoluble residues from potash-bearing salts it is associated with anhydrite, barite, breinerite and rarely dolomite (Slivko 1979). In salt breccia from Upper Vorotyshcha subsuite luneburgite has been found (Matkovskyy *et al.* 2003).

The marine genesis of the Miocene salts is supported by the results of a study of the trace elements: Li, Rb and Cs (Slivko & Petrichenko 1967), Rb, Tl and Br (Malikova 1967), B, Br and J (Bilonizhka 1972). By isotope data, $\delta^{34}S$ of anhydrites from Vorotyshcha and Tyras suites is in the typical range for the Neogene sulphates of marine origin (Kovalevych & Vityk 1995).

The bromine content in the halite (397 analyses) (Kovalevich 1979) has been studied for all saline deposits of the Carpathian Foredeep. In halite from those deposits without potash salts the bromine values range from 10 to 100 ppm (on average 56 ppm); in halite from salt breccia with potash salts the bromine content is 30–230 ppm (on average 120 ppm), and in halite from potash beds it is 70–300 ppm (on average 170 ppm).

In the minerals from the potash deposits the bromine content ranges are: in kainite 800–2300 ppm; in sylvite 1410–2660 ppm; in carnallite 1520–2450 ppm (Bilonizhka 1970).

The brines of Vorotyshcha and Tyras salt-forming basins (based on investigation of brine inclusions from sedimentary halite) belong to a Na–K–Mg–Cl–SO_4 (SO_4-rich) chemical type. Seawater was a main source of salts and based on the chemical composition it was close to the modern seawater and but differed somewhat, based on a lower content of the sulphate-ion (Kovalevich 1978; Kovalevich & Petrichenko 1997; Galamay 1999; Poberezhskyy & Kovalevych 2001).

The temperature of solution in the Miocene basins of this region at the stage of halite sedimentation was about 25 °C (Kovalevich 1978; Galamay 2003), and at the potash salt stage of sedimentation these solutions were stratified and due to greenhouse effect their lower portion heated up to 40–60 °C. At the stage of catagenesis the temperature rose to 70 °C and such elevated values have a regional character (Kovalevich 1978).

Transcarpathian trough

The Transcarpathian trough is a sag structure filled with a thick sequence of the Neogene molasse (Fig. 12). It formed at the boundary of the folded Eastern Carpathians and the Hungarian (or Pannonian) median mass and was separated from them by deep faults of the Transcarpathian (Laz'ko & Rezvoy 1962) or Utiosovo–Marmaroshsky (Slavin & Khain 1965) and Pripannonsky (Merlich & Spitkovskaya 1965). The trough extends from NW to SE and is about 150 km long and 20–30 km wide.

Crossfaults (anticarpathian extension faults) caused the separation of the trough into second-order

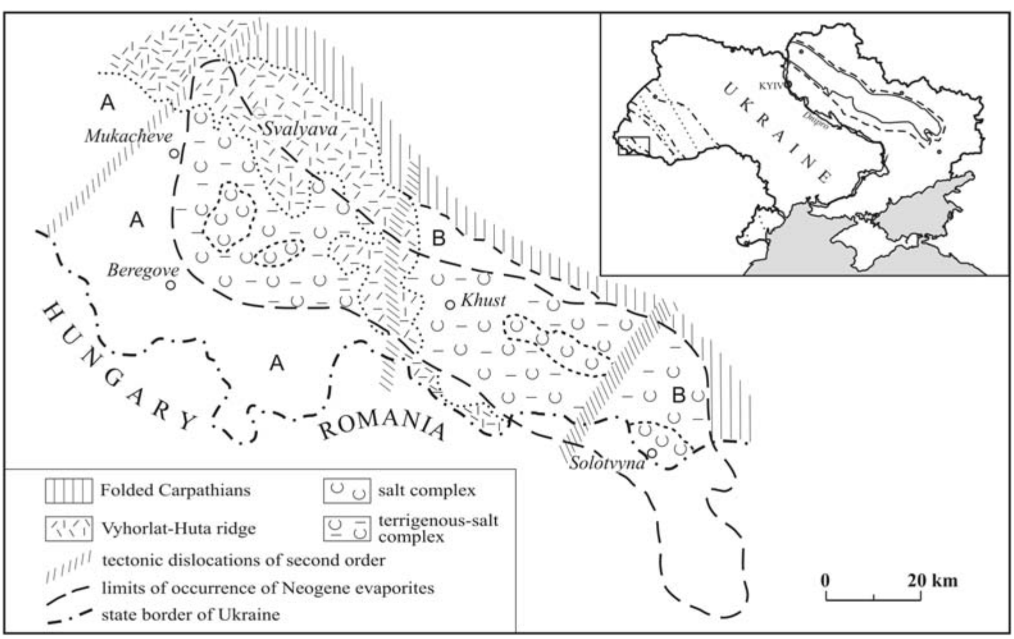

Fig. 12. Location map of Miocene evaporites in Transcarpathian trough (after Kityk *et al.* 1983). (A) Mukacheve depression; (B) Solotvyna depression.

structural–tectonic units and the major units are the Solotvyna and Mukacheve depressions, divided by the Khust fault (Kityk *et al.* 1983).

Neogene deposits in the Transcarpathian trough lie with an angular and stratigraphic unconformity upon Paleozoic, Mesozoic and Paleogene formations. In the Miocene section evaporite deposits are present in the Tereblya suite. They are in turn overlapped by rocks of the Upper Miocene, Pliocene and Pleistocene.

Disharmonic dislocations which are typical for the salt-bearing deposits of Transcarpathian trough result in the development of diapiric salt bodies with the degree of deformation of overlying deposits from insignificant rise to entire penetration and outcrop. In the central part of Solotvyna depression there are large short, broad, anticlinal domes (diapirs) with open piercement-type cores. In the Mukacheve depression these disharmonic dislocations are less marked, and the salts do not penetrate the overlying deposits (Kityk *et al.* 1983).

Evaporite deposits of Tereblya suite are composed of rock salt with an admixture of clayey material and anhydrite, saline and argillaceous clays, and rare tuffs.

The rock salt is pure, usually white, but sometimes grey with layers of clays and gypsum–anhydrites. In areas of outcrop it is overlapped by grey viscous clays (named 'palah') which are the residue of rock salt weathering. The most widespread rock salt in the Solotvyna deposit is pure with a NaCl content of 93.67–99.34% and a water insoluble residue of 0.8–2.0%. The content of bromine is typical for a marine-sourced water at the halite stage (100–110 ppm on average), but in some areas its content is distinctly lower, *c*. 10ppm, which suggests that the halite is recrystallized (Kityk *et al.* 1983).

The clayey minerals of salt-bearing deposits in Solotvyna are represented by hydromica and Mg–Fe chlorite with admixture of dolomite, calcite and anhydrite (Bilonizhka 1979; Kityk *et al.* 1983). Rock salt in the Svalyava region underlies the sheet of Pliocene volcanic rocks of the Vyhorlat–Huta ridge and its pelitic fraction contains the mixed layered chlorite–Mg–montmorillonite close to corrensite composition (Kityk *et al.* 1983).

The brines that had concentrated during halite sedimentation in Transcarpathian salt basin (based on data from fluid inclusions from the sedimentary halite) belong to the Na–K–Mg–Cl–SO_4 (SO_4-rich) chemical type and by ratio of K and Mg were close to the modern seawater saturated to the halite stage. The halogenesis had not reached a high stage of concentration and finished in the halite range (Shaidetskaya 1997).

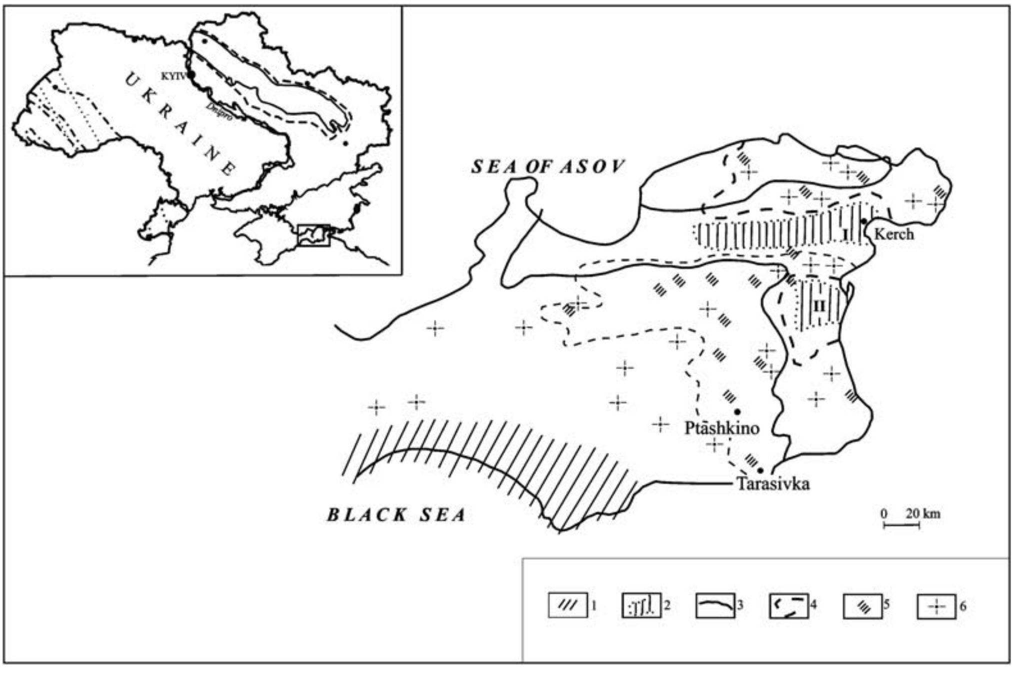

Fig. 13. Paleogeographic scheme of Kerch peninsula in Chokrakian time (after Peryt *et al.* 2004*b*). 1, Land; 2, relatively deep-water part of Chokrakian sea; 3, shore line of late Tarkhanian sea; 4, assumed boundary of area of late Chokrakian gypsum accumulation; 5, areas where late Chokrakian gypsum or metasomatic limestones were found; 6, mud volcanoes active in Chokrakian.

Kerch peninsula (Crimea)

The presence of evaporites in the Miocene deposits of Kerch peninsula (Fig. 13) is well known and mentioned in many papers devoted to the geology and mineral resources of this region. Evaporites are represented by gypsum and are present in all stages of the Middle and Upper Miocene. The largest gypsum deposits are located near Ptashkino (Elkedgi–Eli) and Tarasivka (Tchekur–Koyash). Research on sulphur as an industrial mineral largely governed the development of evaporite investigation in the area of the Kerch peninsula.

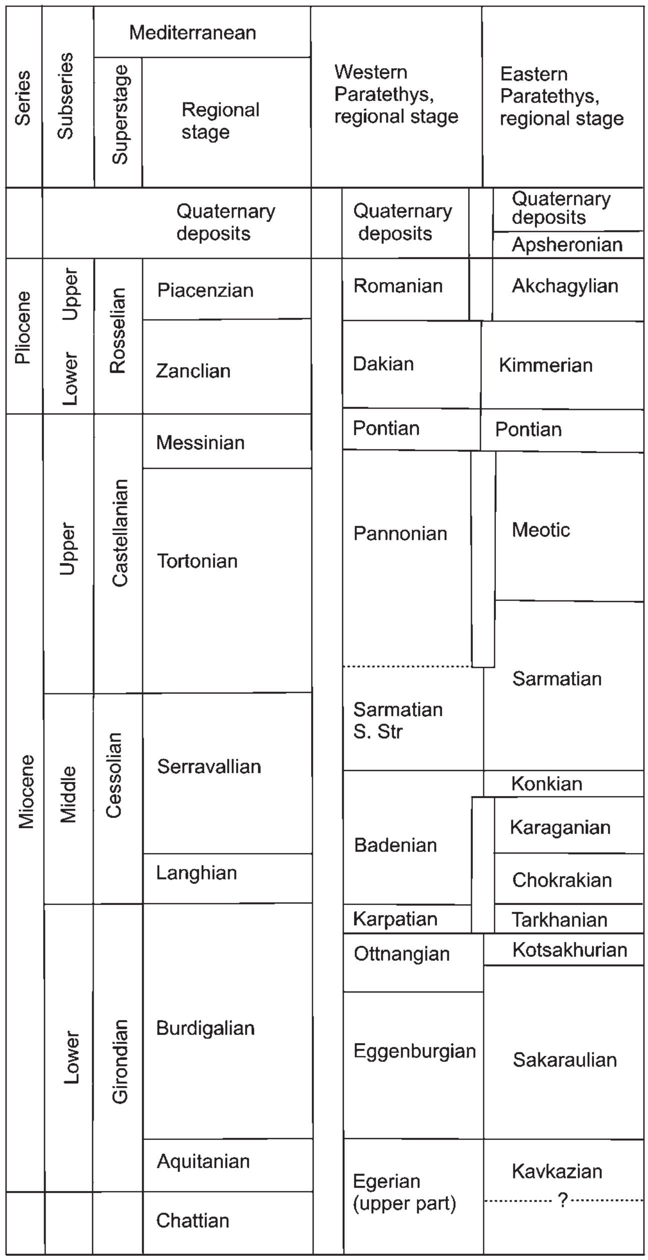

Fig. 14. Regional stages correlation scheme of Eastern Paratethys, Western Paratethys and Mediterranean (after Nevesskaya *et al.* 1984).

The Miocene evaporites in this region are not uniformly distributed. They are absent in the southwestern plain and in the majority of the uplifts. In the eastern part of the peninsula they overlap the Maikop Oligocene to Lower Miocene clays without a visible break. To the west they are separated by an erosion surface and the Tarkhanian stage is missing from the section. At last case the angular unconformity, sometimes significant, is noticed between Maikop (Oligocene) and Miocene layers.

Gypsum as a rule forms small lenses and layers up to several centimetres thick and is only present in the lower part of the Middle Miocene. The age of these layers has been determined as Chokrakian (Arkhangelskiy *et al.* 1930), Upper-Chokrakian (Ishchenko & Kisieliov 1967; Pavlenko *et al.* 1974), Karaganian (Shniukov *et al.* 1971; Nevesskaya *et al.* 1984) or Chokrakian–Karaganian (Muratov 1960). It is most likely that a Chokrakian age is correct for these evaporites (Peryt *et al.* 2004*b*; Kityk *et al.* 1979). If this age assignment is correct then the gypsum-bearing deposits of Kerch peninsula are coeval to the Tyras gypsum-bearing sequence of the Forecarpathian region and this in turn supports the synchronous conditions of gypsum sedimentation in the basins of the Eastern and Western Paratethys.

In the Ptashkino and Tarasivka deposits, gypsum crops out as a strata about 0.9 m thick and the thickness increases toward the east into the subsident area up to 6.25 m (Sobolevskiy 1970). Gypsum occurs in two layers. The lower one composed of fine-grained gypsum is accompanied by clayey and clay–carbonate material, but the upper layer is mainly composed of coarsely crystalline gypsum.

Based on the morphology of crystals and internal structure the coarse-crystalline gypsum of Chokrakian horizon is similar to that of the Tyras suite of the Forecarpathian (Fig. 14). The Kerch gypsum contains more solid inclusions and is less transparent and is enriched by biogenic material. The crystallization of coarse-crystalline gypsum took place in conditions within the field of gypsum stability. Possibly that was connected with lower temperature (30 °C) and water concentration in the Chokrakian basin in comparison to Tyras basin (Kulchetskaya 1987; Peryt *et al.* 2004*b*).

Conclusions

Evaporite deposits are widespread in Ukraine and are located in the Dnipro–Donets depression (Devonian, Permian), western and southwestern slope of the East European platform (Jurssic), Carpathian Foredeep, Transcarpathian trough and the Crimea (Neogene). The majority of investigators (including the authors of this review) consider them to be mostly of marine origin. The largest evaporite deposits of Devonian and Permian age are present in the Dnipro–Donets depression. They are presented mainly by rock salt.

Upper Devonian (Frasnian and Famennian) evaporites are represented by anhydrites, rock and potash salts (sylvinite). Bedded salts, as well as dislocated salts (brachianticlines, salt domes and stocks), are well known. Rock salt in some domes contains rich superimposed hydrothermal mineralization. In it water insoluble residues, there are about 40 high- and middle-temperature minerals such as scapolite, albite, muskovite, sphene, microcline, clinozoisite and others, and rare minerals – tunisite, dawsonite, juwelite. Bromine content in rock salt of Frasnian stage is 50–150 ppm and of the Famennian stage 60–130 ppm. These salts were formed from solutions of Na–K–Ca–Mg–Cl (Ca-rich) chemical type. The temperature of these solutions during the stage of halite precipitation did not exceed 43 °C, and was elevated to 60–65 °C on sylvite stage.

Lower Permian evaporites in the Dnipro–Donets depression are composed of anhydrite, rock salt, potash and magnesium salts (composed of carnallite, kieserite and bishofite). Rock salt also forms salt domes but the halite has less thicknesses than Devonian deposits. In some cases Devonian salts pierced the Permian ones creating so-called twin-salt structures (Petrychenko *et al.* 1976*b*). The stratigraphical differentiation in such structures is possible only with the help of the ultramicrochemical analysis of brine inclusions in halite (Petrichenko 1973). Permian salts were formed from solutions of Na–K–Mg–Cl–SO_4 (SO_4-rich) chemical type while the Devonian salts were Na–K–Ca–Mg–Cl (Ca-rich). The bromine content in halite of Permian deposits was 32–85 ppm. The temperature of salt-forming solutions on stage of halite precipitation did not exceed 43 °C, but was elevated to 78–83 °C for carnallite and to 65–77 °C in the bischofite stages. The temperature of diagenetic transformations of rock salt in the Permian deposits was 45–55 °C and of potash rocks, 75–82 °C.

Upper Jurassic evaporite deposits in Ukraine are distributed within western and southwestern slopes of the East European platform in the Forecarpathian and Foredobrogean regions. Throughout most of the territory they are represented by anhydrites and gypsum and only in a restricted area, near Izmail, they contain rock salt. The bromine content in this rock salt is 27–63 ppm. Salt was formed from solutions of Na–K–Ca–Mg–Cl (Ca-rich) chemical type and at temperatures of less than 40 °C. The maximal determined concentration of potassium-ion in halite was 15.5 g l^{-1} and this value was too low to expect potash salt sedimentation.

Neogene (Miocene) evaporite deposits in Ukraine are distributed in the Carpathian Foredeep, and Transcarpathian trough and in Crimea (Kerch peninsula). In the Carpathian Foredeep they are located in the Bilche–Volytsya, Sambir and Boryslav–Pokuttya zones. In the Bilche–Volytsya zone they are represented by gypsum, anhydrites and the rock salt of the Tyras suite (Badenian) and large industrial resources of native sulphur are connected with them. Potash salts of the Carpathian Foredeep are related to Vorotyshcha suite (Eggenburgian), which are located in the Boryslav–Pokuttya zone and to the Tyras suite (Badenian) in the Sambir zone. They have many similar features, such as large number of potash lenses in the section, which results from the folded-thrust construction of the evaporite deposits; most of these salts are sulphates with a high clay content. The main potash rocks are of kainite, langbeinite and kainite–langbeinite composition. In the potash deposits and in their weathering zone there are more than 20 salt minerals. Bromine content in halite of the Carpathian Foredeep for deposits without potash salts ranges from 10 to 100 ppm (on average 56 ppm); that in halite from salt breccia with potash salts ranges fom 30 to 230 ppm (on average 120 ppm); and that in halite from potash beds ranges from 70 to 300 ppm (on average 170 ppm). In the minerals from the potash deposits bromine content ranges are: in kainite 800–2300 ppm; in sylvite 1410–2660 ppm; and in carnallite 1520–2450 ppm.

The brines of Vorotyshcha and Tyras salt-forming basins (based on data from brine inclusions in an investigation of sedimentary halite) belong to the Na–K–Mg–Cl–SO_4 (SO_4-rich) chemical type. The temperature of halite formation in the Miocene basins of Forecarpathian region was about 25 °C at the halite stage. During the stage of potash salts sedimentation these solutions became highly stratified and due to a greenhouse effect the bottom (formative) layer of basin brines was heated up to 40–60 °C. During a later stage of burial and catagenesis the temperature rose to 70 °C and such elevated values had a clear regional distribution.

In the Transcarpathian area the Miocene evaporites of the Tereblya suite (Badenian) are represented by rock salt, which occurs in a bedded series or is present in salt domes. Bromine content in these rock salts is typical of the marine-sourced halite stage of evaporation and is 100–110 ppm, but in some areas its content is distinctly lower (as low as 10 ppm), which indicates the recrystallization of halite. The brines during halite sedimentation in the Transcarpathian salt-forming basin (based on data of fluid inclusions from sedimentary halite) belong to the Na–K–Mg–Cl–SO_4 (SO_4-rich) chemical type. Here the salt formation (halogenesis) had not reached the highly evaporated stages (potassic salts) and apparently ended within the halite stage.

In the Kerch peninsula Miocene evaporites deposits of the Chokrakian stage are represented only by small lenses and layers of gypsum. The gypsum-bearing deposits of Kerch peninsula are coeval to the gypsum-bearing sequence of the Forecarpathian region.

The data presented above illustrate that evaporite deposits of Ukraine have been studied comprehensively with geological, lithological, mineralogical, petrographic and geochemical methods. Large-scale sampling and thorough investigation of inclusions in primary sedimentary halite deposits demonstrate that the brine inclusions in Devonian and Jurassic evaporites of Ukraine were formed from solutions of Na–K–Ca–Mg–Cl (Ca-rich) chemical type and that Permian and Neogene evolved from a Na–K–Mg–Cl–SO_4 (SO_4-rich) water type. This, in turn, is in good agreement with the well-documented secular variations of seawater chemistry during the Phanerozoic.

We thank O. Petrychenko and V. Kovalevych for critical comments and suggestions, and B. C. Schreiber and M. Bąbel for their remarks on an earlier version of this paper.

References

ANASTASIEVA, O. M. 1957. Some data about the Upper Jurassic sections of Volyno-Podoliya plate. *Geologicheskiy sbornik L'vovskogo geologicheskogo obshchestva*, **4**, 155–162 [in Russian].

ANASTASIEVA, O. M. 1958. Upper Juassic anhydrites and gypsums in the south-western margin of Russian platform. *Voprosy mineralogii osadochnyh obrazovaniy*, **5**, 47–55 [in Russian].

ANDREYEVA-GRIGOROVICH, A. S. & KULCHYTSKIY, A. Ya. 1985. Concerning a problem about the age of the saliferous series of Kalush–Holyn deposit. *In*: KITYK, V. I. (ed.) *Evaporites of Ukraine*. Naukova Dumka, Kiev, 176–181 [in Russian].

ANDREYEVA-GRIGOROVICH, A. S., OSZCZYPKO, N., SAVITSKAYA, N. A., ŁĄCZKA, A. & TROFIMOVICZ, N. A. 2003. Correlation of Late Badenian salts of the Wieliczka, Bochnia and Kalush areas (Polish and Ukrainian Carpathian Foredeep). *Annales Societatis Geologorum Poloniae*, **73**, 67–89.

ARKHANGELSKIY, A. D., BLOKHIN, A. A., MENNER, V. V., OSIPOV, S. S., SOKOLOV, M. I. & CHEPIKOV, K. R. 1930. Brief description of the oil fields in the Kertch peninsula. *Trudy glavnogo geologo-razviedochnogo upravleniya*, **13** [in Russian].

BĄBEL, M. 2004. Badenian evaporite basin of the northern Carpathian Foredeep as a drawdown salina basin. *Acta Geologica Polonica*, **54**, 313–337.

BĄBEL, M. 2005*a*. Event stratigraphy of the Badenian selenite evaporites (Middle Miocene) of the northern Carpathian Foredeep. *Acta Geologica Polonica*, **55**, 9–29.

BĄBEL, M. 2005*b*. Selenite-gypsum microbialite facies and sedimentary evolution of the Badenian evaporite basin of the northern Carpathian Foredeep. *Acta Geologica Polonica*, **55**, 187–210.

BILONIZHKA, P. M. 1970. Content of bromine in salt minerals of potash deposits of Forecarpathians. *Voprosy mineralogii osadochnyh obrazovaniy*, **8**, 126–133 [in Russian].

BILONIZHKA, P. M. 1972. *Geochemistry of Boron, Bromine and Iodine in the Forecarpathian Potash Deposits.* L'vivskyy universytet, L'viv [in Russian].

BILONIZHKA, P. M. 1979. About the mineral composition of carbonates and clays of the Solotvyna rock salt deposit (Transcarpathians). *In*: KITYK, V. I. (ed.) *The Questions of Geology and Geochemistry of Saliferous Deposits.* Naukova Dumka, Kiev, 53–61 [in Russian].

BILONIZHKA, P. M. 1991. The transformation of terrigenous clay minerals in the saliferous process. *Mineralogichnyy zbirnyk*, **45**, 2, 51–56 [in Ukrainian].

BILONIZHKA, P. M. & KOSTIN, V. A. 1977. Origin of hydromicas from salt deposits of the Carpathian Foredeep (based on their absolute ages). *In*: KITYK, V. I. (ed.) *Geology and Geochemistry of Salt-bearing Formations of Ukraine.* Naukova Dumka, Kiev, 53–65 [in Russian].

BILONIZHKA, P. M., VYNAR, O. N. & MELNIKOV, V. S. 1966. About the mineral composition of clay from potash salt deposits of the Forecarpathian. *Voprosy mineralogii osadochnyh obrazovaniy*, **7**, 147–158 [in Russian].

BORCHERT, H. 1959. *Ozeane Salzlagerstatten*. Gebr. Borntrager, Berlin.

BORISENKO, L. S., KROPACHEVA, S. K., PIVOVAROV, S. V. & VASILEVSKAYA, A. E. 1974. First discovery of the Upper Jurassic saliferous deposits in the Crimean mountains. *Doklady AN SSSR*, **219**, 933–935 [in Russian].

BUTKOVSKIY, YU. M., TUREVSKAYA, E. S. & BELIAEV, V. U. 1976. Foredobrogea as Upper Juassic evaporite basin. *Izvestiya VUZov. Geologiya i razviedka.* **2**, 25–30 [in Russian].

BYHOVIER, N. A., VOLGDIN, A. G. & MATVIEYEV, A. K. 1941. Geological investigations. *In*: BYHOVIER, N. A. (ed.) *Geology and Mineral Resources of the Western Regions of USSR*. Gosgeoltehizdat, Moskva-Leningrad, 21–40 [in Russian].

CHMIELEWSKA, E. W. 1995. Litologia kimerydzkich ewaporatow poludniovo-zachodniego sklonu platformy wschodnioeuropejskiej. *Przegland Geologiczny*, **43**, 928–930 [in Polish].

DOLENKO, G. N. (ed.) 1975. Ukrainian SSR (western regions). Period 1918–1945. *In*: TIHOMIROV, V. V. (ed.) *Geological Investigations of USSR*, **31**. Naukova Dumka, Kiev, 1–350 [in Russian].

DOLISHNIY, B. V. 1976. Composition of rock salt insoluble residue from Bantyshevskiy salt stock (northwestern Donbass). *Geologiya i geokhimiya goriuchyh kopalyn*, **47**, 27–30 [in Ukrainian].

DOLISHNIY, B. V. 2000. Hydrothermal mineralization of salt domes from south-eastern part of Dnieper–Donets depression. *Geologiya i geokhimiya goriuchyh kopalyn*, **4**, 56–61 [in Ukrainian].

DZHINORIDZE, N. M. 1976. About the age of salt-bearing deposits of Holyn in Forecarpathian. *Doklady AN SSSR. 227*, **4**, 932–935 [in Russian].

DZHINORIDZE, N. M. 1980. Carpathian potassium-bearing region. *In*: DZHYNORIDZE, N. M., GEMP, S. D., GORBOV, A. F. & RAYEVSKIY, V. I. (eds) *Regularities of Distribution and Exploration Criteria for Potassium Salts in the USSR*. Izdatelstvo Metsniereba, Tbilisi, 73–159 [in Russian].

DULUB, V. G., BUROVA, M. I., BUROV, V. S. & VISHNIAKOV, I. B. 1986. *Explanatory Report to the Regional Stratigraphic Scheme of Jurassic Deposits of the Carpathian Foredeep and Volyno-Podoliya Margin of the East European Platform.* Leningrad [in Russian].

DULUB, V. G., ZHABINA, N. M., OGORODNIK, M. E. & SMIRNOV, S. E. 2003. *Explanatory Report for the Regional Stratigraphic Scheme of Jurassic Deposits of Forecarpathian (Stryy Jurassic basin).* L'viv [in Ukrainian].

GALABUDA, N. I. 1970. Geological construction of Frasnian salt formation of Dnieper–Donets depression. *Geologiya i geokhimiya goriuchyh kopalyn*, **50**, 59–68 [in Ukrainian].

GALAMAY, A. R. 1999. The conditions of the Badenian rock salt formation of fore- and intermountain depressions of the Carpathians. *Geologiya i geokhimiya goriuchyh kopalyn*, **1**, 55–66 [in Ukrainian].

GALAMAY, A. R. 2003. The temperature of halite crystallization in the Badenian evaporite basins of the Carpathian region. *Geologiya i geokhimiya goriuchyh kopalyn*, **1**, 130–139 [in Ukrainian].

GALITSKIY, I. V. 1972. Cyclicity of saliferous, deposits of Lower Permian Kramatorska suite of Dnieper-Donets depression. *In*: KALEDA, G. A. (ed.) *Lithology and paleography of Paleozoic deposits of Russian platform.* Nauka, Moscow, 249–255 [in Russian].

GARETSKIY, R. G. 1985. *Sedimentation and paleogeography of the western part of East European platform in Mesozoik*. Nauka i tekhnika, Minsk [in Russian].

GEMP, S. D. 1979. The role of secondary processes in formation of the mineral composition of potash salts in Forecarpathian. *In*: RAYEVSKIY, V. I. (ed.) *Geological and Mineralogical–Petrographic Estimation of the Distribution, Quality of the Ores and Conditions of Exploitation of Potash Deposits*. VNIIG, Leningrad, 73–91 [in Russian].

GLUSHKO, V. V. 1968. *Tectonics and Oil-and-Gas Content of the Carpathians and adjacent Foredeeps*. Nedra, Moscow [in Russian].

HARDIE, L. A. 1996. Secular variations in seawater chemistry: An explanation for the coupled secular variation in the mineralogies of marine limestones and potash evaporites over the past 600 m.y. *Geology*, **24**, 279–283.

HOLLAND, H. D. 1972. The geologic history of sea water an attempt to solve the problem. *Geochimica et Cosmochimica Acta*, **36**, 637–651.

HOLLAND, H. D. 1984. *The Chemical Evolution of the Atmosphere and Oceans*. Princeton University Press, Princeton, NJ.

HOLLAND, H. D. 2003. The geologic history of seawater. *Treatise on Geochemistry*, **6**, 583–625.

HOLLAND, H. D., LAZAR, B. & MCCAFFREY, M. A. 1986. Evolution of the atmosphere and oceans. *Nature* **320**, 2733.

HORITA, I., ZIMMERMANN, H. & HOLLAND, H. D. 2002. Chemical evolution of seawater during the Phanerozoic: implications from the record of marine evaporites. *Geochimica et Cosmochimica Acta*, **66**, 3733–3756.

HRYNIV, S. P. 1982. Rock salt of salting out origin of Kalush–Holyn deposit. *In*: KITYK, V. I. (ed.) *Geology and Geochemistry of Non-Metallic Mineral Resources*. Naukova Dumka, Kiev, 41–47 [in Russian].

HRYNIV, S. P. 1985. To a question of Kalush-Holyn potash salt deposit correlation. *In*: KITYK, V. I. (ed.) *Evaporites of Ukraine.* Naukova Dumka, Kiev, 44–50 [in Russian].

HRYNIV, S. P. 1990. Conditions of anhydrite-polyhalite beds formation of potash salt deposits of Forecarpathian. *In*: MERZLIAKOV, G. A. (ed.) *Conditions of Formation of Potash Salt Deposits.* Nauka, Novosibirsk, 181–189 [in Russian].

ISHCHENKO, D. I. & KISIELIOV, M. V. 1967. To the question about the geological construction and formation of gypsum deposits of Crimea. *Geologichnyi zhurnal*, **27**(1), 68–76 [in Ukrainian].

KASPRZYK, A. 1999. Sedimentary evolution of Badenian (Middle Miocene) gypsum deposits in the northern Carpathian Foredeep. *Geological Quarterly*, **43**, 449–465.

KHMELEVSKA, O. V. 1993. Physico-chemical conditions of salt accumulation in the Upper Jurassic evaporite basin of Foredobrogea. *Geologiya i geochimiya goriuchyh kopalyn*, **(2–3)**, 83–83; 98–102 [in Ukrainian].

KHMELEVSKAYA, E. V. 1990*a*. About the matter composition of rocks of the Upper Jurassic evaporite formation of the south-western slope of East European platform. *In*: PETRICHENKO, O. I. (ed.) *Geology and Geochemistry of Salt-bearing Deposits of Oil-and-gas Content Provinces.* Naukova Dumka, Kiev, 143–152 [in Russian].

KHMELEVSKAYA, E. V. 1990*b*. Authigenic mineral-impurities in the Upper Jurassic rock salt of Foredobrogea and Middle Asia. *Mineralogicheskiy sbornik*, **44**, 1, 75–77 [in Russian].

KHMELEVSKAYA, E. V. 1997. Upper Jurassic evaporites of the south-western slope of East European platform. *Slovak Geological Magazine*, **3**(3), 213–216.

KHODKOVA, S. V. 1971. Minerals and rocks of the Stebnik potassium salt deposit. *In*: KHODKOV, A. E. (ed.) *Materials on Hydrogeology and Geological Role of Subsurface Waters.* Izdatelstvo Leningradskoho universiteta, Leningrad, 82–91 [in Russian].

KHODKOVA, S. V. 1980. About the nature of salt-bearing breccias of Eastern Forecarpathian. *In*: KITYK, V. I. (ed.) *Lithology and Geochemistry of Salt-bearing Series.* Naukova Dumka, Kiev 69–77 [in Russian].

KHRUSHCHOV, D. P. 1971. *Lithology and Potash-bearing of Salt Deposits of Dnieper–Donets depression*. Naukova Dumka, Kiev [in Ukrainian].

KHRUSHCHOV, D. P. 1980. *Lithology and Geochemistry of Saliferous Formations of the Carpathian Foredeep.* Naukova Dumka, Kiev, [in Russian].

KITYK, V. I. 1970. *Salt Tectonics of Dnieper–Donets Depression.* Naukova Dumka, Kiev [in Russian].

KITYK, V. I., POLKUNOV, V. F. & STEPANENKO, O. T. 1979. *Construction and Regularity of Distribution of Native Sulfur Deposits of the USSR*. Naukova Dumka, Kiev [in Russian].

KITYK, V. I., BOKUN, F. N., PANOV, G. M., SLIVKO, E. P. & SHAIDETSKAYA, V. S. 1983. *Halogenous Formations of Ukraine: Transcarpathian Trough.* Naukova Dumka, Kiev [in Russian].

KLIMOV, M. A. 1972. The manufacturing potash-bearing of the Lower Vorotyshcha suite and the prospects for further potash salts exploration in the Forecarpathian basin. *Trudy Vsesoyuznoho instituta galurgii*, **60**, 148–162 [in Russian].

KLIMOV, M. A. 1977. The prospects of potash-bearing of Kalush salt bearing formations in the Inner zone of the Carpathian Foredeep. *In*: KITYK, V. I. (ed.) *Geology and geochemistry of Salt-bearing Formations of Ukraine.* Naukova Dumka, Kiev, 14–22 [in Russian].

KORENEVSKIY, S. M. 1982. Upper Jurassic salt bearing deposits of Ukraine and Moldaviya. *Litologiya i poleznyye iskopaemyye*, **4**, 107–116 [in Russian].

KORENEVSKIY, S. M. & DONCHENKO, K. B. 1963. Geology and conditions of formation of potash deposits of Soviet Forecarpathians. *Trudy Vsesoyuznoho geologicheskoho instituta N.S.*, **99**, 3–153 [in Russian].

KORENEVSKIY, S. M., BOBROV, V. P., SUPRONIUK, K. S. & KHRUSHCHOV, D. P. 1968. *Saliferous Formations of North-western Donbass and Dnieper–Donets Depression and their Potash-bearing.* Nedra, Moscow [in Russian].

KORENEVSKIY, S. M. & ZAHAROVA, V. M. & SHAMAHOV, V. A. 1977. *Miocene Saliferous Formations of the Carpathian Foredeep.* Nedra, Leningrad [in Russian].

KORENEVSKIY, S. M., VAKATCHUK, G. I., ZAHAROVA,V. M., KHRUSHCHOV, D. P. & SHAMAHOV, V. A. 1980. Correlation of sections, potash salts content and lithofacies complexes of Kramatorska suite of Dnieper–Donets depression. *Geologicheskiy zhurnal*, **40**(5), 48–56 [in Russian].

KORIN', S. S. 1992. Tectonic conditions of formation of potash deposit structure in the Boryslav-Pokutsky nappe. *Otechestviennaya geologiya*, **12**, 20–26 [in Russian].

KORIN', S. S. & MOSORA, T. M. 1990. The structure of the Vorotyshcha saliferous formations of the Forecarpathian (by example of Boryslav facies). *In*: PETRICHENKO, O. I. (ed.) *Geology and Geochemistry of Salt-bearing Deposits of Oil-and-gas Content Province.* Naukova Dumka, Kiev, 86–92 [in Russian].

KOROBTSOVA, M. S. 1955. Mineralogy of potash deposits of the Eastern Forecarpathian. *Voprosy mineralogii osadochnyh obrazovaniy*, **2**, 3–137 [in Russian].

KOVALEVICH, V. M. 1977. Rock salt of 'salting-out' origin in the Miocene saliferous deposits of the Eastern Forecarpathians. *In*: KITYK, V. I. (ed.) *Geology and Geochemistry of Salt-bearing Formations of Ukraine*. Naukova Dumka, Kiev, 48–53 [in Russian].

KOVALEVICH, V. M. 1978. *Physico-chemical Conditions of Salt Formation in the Stebnik Potassic-salt Deposit.* Naukova Dumka, Kiev [in Russian].

KOVALEVICH, V. M. 1979. The possibile utility of bromine content in halite as a prospecting criterion on potash salts in Forecarpathian. *In*: KITYK, V. I. (ed.) *The Questions of Geology and Geochemistry of Halogenous Deposits*. Naukova Dumka, Kiev, 35–44 [in Russian].

KOVALEVICH, V. M. 1982. Genesis of langbeinite in potassium salts of the Carpathian Foredeep based on study of inclusions of mineral-forming solutions. *In*: KITYK, V. I. (ed.) *Geology and Geochemistry of Non-metallic Mineral Resources*. Naukova Dumka, Kiev, 32–41 [in Russian].

KOVALEVICH, V. M. 1985. Physico-chemical conditions of salts accumulation of Lower Permian saliferous formations of Dnieper–Donets depression. *In*: KITYK, V. I. (ed.) *Evaporites of Ukraine.* Naukova Dumka, Kiev, 33–44 [in Russian].

KOVALEVICH, V. M. 1988. Phanerozoic evolution of ocean water composition. *Geochemistry International*, **25**, 20–27.

KOVALEVICH, V. M. 1990. *Salt Deposition and Chemical Evolution of the Ocean in Phanerozoic*. Naukova Dumka, Kiev [in Russian].

KOVALEVICH, V. M. & PETRICHENKO, O. I. 1997. Chemical composition of brines in Miocene evaporite basins of the Carpathian region. *Slovak Geological Magazine*, **3**, 173–180.

KOVALEVICH, V. M., PERYT, T. M. & PETRYCHENKO, O. I. 1998. Secular variation in seawater chemistry during the Phanerozoic as indicated by brine inclusions in halite. *Journal of Geology*, **106**, 695–712.

KOVALEVYCH, V. M. & PETRYCHENKO, O. YO. 1994. Geochemistry of evaporite sedimentation in a Permian marine basin. *Earth Sciences and Resources Institute Occasional Publications*, **11B**, 41–47.

KOVALEVYCH, V. M. & VITYK, M. O. 1995. Correlation of sulfur and oxygen isotopes in evaporites with chemical composition of brines of Phanerozoic evaporite basins. *Dopovidi NAN Ukrainy*, **3**, 83–85 [in Ukrainian].

KOVALEVYCH, V. M., PERYT, T. M., CARMONA, V., SYDOR, D. V., VOVNIUK, S. V. & HALAS, S. 2002. Evolution of Permian seawater: evidence from fluid inclusions in halite. *Neues Jahrbuch für Mineralogie Abhandlungen*, **178**(1), 27–62.

KRUGLOV, S. S. & TSYPKO, A. K. (eds). 1988. *Tectonics of Ukraine.* Nedra, Moscow [in Russian].

KUDRYAVTSEV, U. E. 1971. Some new data about the geological structure of Stebnik potash salt deposit. *In*: KHODKOV, A. E. (ed.) *Materials on Hydrogeology and Geological Role of Subsurface Waters.* Izdatelstvo Leningradskoho universiteta, Leningrad, 71–79 [in Russian].

KULCHETSKAYA, A. A. 1987. *Genesis of gypsum and anhydrite from sedimentary rocks of Ukraine (on the basis of the data of fluid inclusions studies).* Ph.D. thesis, Institut Geohkimii i Fiziki Mineralov, Kiev [in Russian].

KULCHYTSKIY, A. YA. 1986. *Geology and conditions of origin salt-bearing molasse deposits of Forecarpathian and Transcarpathian Neogene Foredeeps.* L'vivskyy universytet, L'viv [in Russian].

KUZNIETSOVA, S. V. 1970. *Mineralogy and some questions of genesis of mercury and lead-zinc ore-displays of north-western part of Donbass*. Ph.D. thesis, Institut Geohkimii i Fiziki Mineralov, Kiev [in Russian].

KUZNIETSOVA, S. V. 1971. About ore mineralization of north-western Donbass. *Mineralogicheskiy sbornik L'vovskogo universiteta* **25**, 2, 111–123 [in Russian].

KUZNIETSOVA, S. V., SOFRONOV, I. L., SKARZHYNSKIY, V. I. & ENTELIS, I. D. 1968. Main features of geological structure and endogenous ore mineralization of northwestern margin of Donbass. *Geologicheskiy zhurnal*, **24**(4), 32–44 [in Russian].

KUŹNIAR, Cz. 1939. Złoże solne w Kałuszu. *Prace Państwowego Instytutu Geologicznego*, **111**(3) [in Polish].

LAZARENKO, E. K., GABINET, M. P. & SLIVKO, O. P. 1962. *Mineralogy of Sedimentary Formations of the Forecarpathian.* Vydavnytstvo L'vivskoho universytetu, L'viv [in Ukrainian].

LAZ'KO, E. M. & REZVOY, D. P. 1962. About the tectonic nature of Carpathian 'cliff zone' range. *Visnyk L'vivskoho universytetu*, **1**, 60–65 [in Russian].

LOBANOVA, V. V. 1956. Questions of petrography of potash deposits of the eastern Forecarpathian. *Trudy Vsesoyuznoho instituta galurgii*, **32**, 164–214 [in Russian].

LOWENSTEIN, T. K., HARDIE, L. A., TIMOFEEFF, M. N. & DEMICCO, R. V. 2003. Secular variation in seawater chemistry and the origin calcium chloride basinal brines. *Geology*, **31**, 851–860.

LOWENSTEIN, T. K., TIMOFEEFF, M. N., BRENNAN, S. T., HARDIE, L. A. & DEMICCO, R. V. 2001. Oscillations in Phanerozoic seawater chemistry: evidence from fluid inclusions. *Science*, **294**, 1086–1088.

MALIKOVA, I. N. 1967. *The Regularities of Distribution of Rubidium, Thallium and Bromine in Potash Salt Deposits.* Nauka, Novosibirsk [in Russian].

MARKOVSKIY, V. I., KOTYK, V. A. & BEREZHYNSKAYA, L. F. 1979. Silurian evaporites of Volyno–Podoliya. *In*: KITYK, V. I. (ed.) *The Questions of Geology and Geochemistry of Saliferous Deposits.* Naukova Dumka, Kiev, 118–128 [in Russian].

MATKOVSKYY, O. I., BILONIZHKA, P. M. *ET AL.* 2003. *Minerals of the Ukrainian Carpathians. Borates, Arsenates, Phosphates, Molybdates, Sulphates, Carbonates, Organic Minerals and Mineraloids*. Vydavnychyy tsentr LNU, L'viv [in Ukrainian].

MERLICH, B. V. & SPITKOVSKAYA, S. M. 1965. The peculiarities of Neogene magmatism of deep faults of the Transcarpathian. *Geologicheskiy sbornik L'vovskogo geologicheskogo obshchestva*, **9**, 55–68 [in Russian].

MURATOV, M. V. 1960. *Short Studies of Geological Structure of the Crimea Peninsula.* Gosgeoltekhizdat, Moscow [in Russian].

NEVESSKAYA, L. A., GONCHAROVA, I. A. *ET AL*. 1984. The regional stratigraphic scale of the Neogene of East Paratethys. *Sovetskaya geologiya*, **9**, 37–49.

NOVIK, E. O., PERMIAKOV, V. V. & KOVALENKO, E. E. 1960. *The History of Geological Research of Donets Coal Basin (1700–1917).* Izdatelstvo AN USSR, Kiev [in Russian].

OLIYOVYCH, O., YAREMCHUK, Ya. & HRYNIV, S. 2004. Clays of saliferous deposits and weathering zone of

Kalush–Holyn potash salt deposit (Miocene, Forecarpathians). *Mineralogichnyy zbirnyk*, **54**(2), 214–223 [in Ukrainian].

PANOW, G. & PŁOTNIKOW, A. 1996. Badeńskie ewaporaty ukraińskiego Przedkarpacia: litofacje i miąższość. *Przegląd Geologiczny*, **44**, 1024–1028 [in Polish].

PAVLENKO, V. V., KROPACHEVA, S. K. & POLTORAKOV, G. I. 1974. Regularities of native sulphur occurrence in Kerch peninsula. *Sovetskaya geologiya*, **8**, 149–152 [in Russian].

PERYT, T. M. 1996. Sedimentology of Badenian (middle Miocene) gypsum in eastern Galicia, Podolia and Bukovina (West Ukraine). *Sedimentology*, **43**, 571–588.

PERYT, T. M. 2001. Gypsum facies transitions in basin–marginal evaporites: middle Miocene (Badenian) of West Ukraine. *Sedimentology*, **48**, 1103–1119.

PERYT, T. M. & KOVALEVYCH, 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**, 913–922.

PERYT, T. M., POBEREZHSKYY, A. V., JASIONOWSKI, M., PERYT, D., PETRYCHENKO, O. Y., LYZOON, S. O. & TURCHYNOV, I. I. 2004*a*. Correlation of Badenian sulphatic deposits in the Dnister river region. *Geologiya i geokhimiya goriuchyh kopalyn*, **1**, 56–69 [in Ukrainian].

PERYT, T. M., POBEREZHSKYY, A. V., PERYT, D., JASIONOWSKI, M. & DURAKIEWICZ, T. 2004*b*. Post-evaporitic restricted deposition in the Middle Miocene Chokrakian/Karaganian of East Crimea (Ukraine). *Sedimentary Geology*, **170**, 21–36.

PETRICHENKO, O. I. 1973. *Methods of Study of Inclusions in Minerals of Saline Deposits*. Naukova Dumka, Kyiv [in Ukrainian; translated in *Fluid Inclusions Research Proc. COFFI*, **12**, 214–274, 1979].

PETRICHENKO, O. I. 1988. *Physico-chemical Conditions of Sedimentation in the Evaporite Palaeobasins*. Naukova Dumka, Kiev [in Russian].

PETRICHENKO, O. I. 1989. *Epigenesis of Evaporites*. Naukova Dumka, Kiev [in Russian].

PETRICHENKO, O. I. & SHAIDETSKAYA, V. S. 1977. Mineralogical-geochemical peculiarities of rock salt of Kaplintsevsky salt dome (Dnieper-Donets depression). *In*: KITYK, V. I. (ed.) *Geology and Geochemistry of Salt-bearing Formations of Ukraine*. Naukova Dumka, Kiev, 84–94 [in Russian].

PETRICHENKO, O. I. & SHAIDETSKA, V. S. 1998. Chlorek wapnia w solankach górnodevońskich basenów ewaporatowych ryftogenu prypećko-dnieprowsko-donieckiego w swietle badań inkluzji w halicie. *Przegląd Geologiczny*, **46**, 689–699 [in Polish].

PETRICHENKO, O. I., SLIVKO, E. P. & SHAIDETSKAYA, V. S. 1974*a*. About conditions of formation Devonian rock salt of Dnieper-Donets depression. *In*: LAZARENKO, E. K. (ed.) *The Perspectives of Prospecting Minerals in Dnieper–Donets Depression*. Naukova Dumka, Kiev, 110–123 [in Russian].

PETRICHENKO, O. I., KOVALEVICH, V. M. & TCHALYY, V. N. 1974*b*. Geochemical environment of salt-formation in the Tortonian evaporite basin of north-western Forecarpathians. *Geologiya i geokhimiya goriuchih iskopaemyh*, **41**, 110–123 [in Russian].

PETRICHENKO, O. I., PANOW, G. M., PERYT, T. M., SREBRODOLSKIY, B. I., POBEREŻSKIY, A. W. & KOWALEWICZ, W. M. 1994. Zarys geologii mioceńskich formacji ewaporatowych ukraińskiej części zapadliska przedkarpackiego. *Przegląd Geologiczny*, **42**, 734–737 [in Polish].

PETRICHENKO, O. I., PERYT, T. M. & POBEREGSKI, A. V. 1997. Peculiarities of gypsum sedimentation in the Middle Miocene Badenian evaporite basin of Carpathian Foredeep. *Slovak Geological Magazine*, **3**(2), 91–104.

PETRYCHENKO, O. Y. & PERYT, T. M. 2004. Geochemical conditions of deposition in the Upper Devonian Prypiac' and Dnipro–Donets evaporite basins (Belarus and Ukraine). *Journal of Geology*, **112**, 577–592.

PETRYCHENKO, O. Y., SHAIDETSKA, V. S. & KOVALEVICH, V. M. 1976*a*. New geochemical criterion for potash salt prospecting. *Dopovidi AN URSR, Ser. B*, **6**, 512–515 [in Ukrainian].

PETRYCHENKO, O. Y., SLYVKO, O. P. & SHAIDETSKA, V. S. 1976*b*. Mineralogical–geochemical illustration of distinctions of rock salt of different ages. *Dopovidi AN USSR, Ser. B*, **9**, 778–781 [in Ukrainian].

POBEREZHSKYY, A. V. 2000. Physico-chemical conditions of gypsum sedimentation in the Badenian evaporite basin of Carpathian Foredeep. *Geologiya i geokhimiya goriuchyh kopalyn*, **4**, 38–55 [in Ukrainian].

POBEREZHSKYY, A. V. & KOVALEVYCH, V. M. 2001. Chemical composition of sea water in Cenozoic (by data of fluid inclusions research in sedimentary halite). *Mineralogichnyy zbirnyk*, **51**(2), 90–109 [in Ukrainian].

POBEREZHSKYY, A. V., PERYT, T. & PETRYCHENKO, O. Y. 2002. Facies and physico-chemical analysis of gypsum sedimentation conditions in the Badenian basin of Carpathian region. *Mineralogichnyy zbirnyk*, **52**(2), 106–110 [in Ukrainian].

POLIKARPOV, A. I. 1974. About some mineralogical peculiarities and origin of terrigenous and halogenous–terrigenous rocks of Eastern Holyn of Kalush–Holyn potash salts deposits. *Trudy Vsesoyuznoho instituta galurgii*, **68**, 65–72 [in Russian].

POVSTEN, E. F. & POVSTEN, G. M. 1980. Carnallite as indicator of faults in saliferous deposits of the Forecarpathian. *In*: KITYK, V. I. (ed.) *Lithology and Geochemistry of Salt-bearing Series*. Naukova Dumka, Kiev, 65–69 [in Russian].

RAUP, O. B. 1970. Brine mixing: an additional mechanism for formation for basin evaporites. *Bulletin American Association Petroleum Geologists*, **54**, 2246–2259.

ROMANOV, L. F. 1976. *Mesozoic Speckled Deposits of Country between Dniestr and Prut*. Shtiintsa, Kishinev [in Russian].

ROMANOV, L. F. & SLAVIN, V. I. 1970. Tectonic position and origin of the Jurassic Dobrogea Foredeep. *Vestnik Moskovskogo universiteta*, **5**, 77–87 [in Russian].

SANDLER, N. M. & VORONA, G. P. 1955. Short lithological description of the Upper Jurassic deposits of Western regions of the USSR. *Naukovi zapysky*

L'vivskoho naukovo-pryrodnychoho muzeyu AN URSR, IV, 55–58 [in Ukrainian].

SHAIDETSKAYA, V. S. 1990. The conditions of chemogenic sedimentation in Late Devonian salts-forming basins of Dnieper-Donets depression. *In*: PETRICHENKO, O. I. (ed.) *Geology and geochemistry of Salt-bearing Deposits of Oil-and-gas Content Province.* Naukova Dumka, Kiev, 101–106 [in Russian].

SHAIDETSKAYA, V. S. 1997. Geochemistry of Neogene evaporites of the Transcarpathian Trough in Ukraine. *Slovak Geological Magazine*, **3**, 193–201.

SHATSKIY, N. S. 1931. To a question about origin of Romny gypsum and rocks of Isachkovsky Hill in Ukraine. *Bulleten Mosovskogo obshchestva ispytateley prirody, otdelenie geologiyi*, **9**(39), 3–4, 156–163 [in Russian].

SHNIUKOV, E. F., NAUMENKO, P. I. & LEBEDEV, U. S. 1971. *The Mud Volcanism and Ore Formation.* Naukova Dumka, Kiev [in Russian].

SKVORTSOVA, K. V. 1964. About the tectonic structure of Kalush–Holyn potash salts deposit. *Trudy Vsesoyuznoho instituta galurgii*, **45**, 23–32 [in Russian].

SLAVIN, V. I. & KHAIN, V. E. 1965. The role of tectonic ruptures in construction and evolution of the Eastern Carpathians. *In*: *Materials of VI Congress of Carpathian-Balkan Geological Association: Contributions of Soviet geologists.* Naukova Dumka, Kiev, 255–276 [in Russian].

SLIUSAR, B. S. 1971. *Jurassic Deposits of North-western Part of Near-Black Sea Region*. Shtiintsa, Kishinev [in Russian].

SLIVKO, E. P. 1979. Questions about the possibility of correlation of potash salt deposits using their authigenic minerals. *In*: KITYK, V. I. (ed.) *The Questions of Geology and Geochemistry of Halogenous Deposits*. Naukova Dumka, Kiev, 61–76 [in Russian].

SLIVKO, E. P. & PETRICHENKO, O. I. 1967. *Accessory Lithium, Rubidium and Caesium in Salt Deposits of Ukraine.* Naukova Dumka, Kiev [in Russian].

SOBOLEVSKIY, YU. V. 1970. Gornostaivske showing of the native sulfur in Kerch peninsula. *Dopovidi AN URSR, Ser. B*, **9**, 789–792 [in Russian].

SOZANSKIY, V. I. 1973. *Geology and Origin of Salt Deposits*. Naukova Dumka, Kiev [in Russian].

ULMISHEK, G. F., BOGINO, V. A., KELLER, M. B. & POZNYAKEVICH, Z. L. 1994. Structure, stratigraphy and petroleum geology of the Pripyat and Dniper–Donets basins, Byelarus and Ukraine. *In*: LANDON, S. M. (ed.) *Interior Rift Basins.* American Association Petroleum Geologists Memoirs, **59**, 125–156.

VALYASHKO, M. G. 1962. *Geochemical Regularities of Origin of Potassium Salt Deposits.* Izdatelstvo Moskovskoho universiteta, Moscow [in Russian].

VUL, M. Y., DENEGA, B. I., KRUPSKYY, Y. Z., NIMETS, M. V., SVYRYDENKO, V. G. & FEDYSHYN, V. O. (eds). 1998. *Atlas of Oil and Gas Fields of Ukraine in Six Volumes. Vol. IV: Western Oil-and-Gas-bearing Regions.* Vydavnytstvo Tsentr Europy, L'viv [in Ukrainian].

VYALOV, O. S. 1980. Stratigraphic scheme of the Neogene deposits of the west regions of USSR. *Paleontologicheskiy sbornik*, **17**, 93–96 [in Russian].

VYSOTSKIY, E. A., GARETSKIY, R. G. & KISLYK, V. Z. 1988. *Potash-bearing Basins of the World*. Nauka i tekhnika, Minsk [in Russian].

WOJTOWICZ, A., HRYNIV, S. P., PERYT, T. M., BUBNIAK, A., BUBNIAK, I. & BILONIZHKA, P. M. 2003. K/Ar dating of the Miocene potash salts of the Carpathian Foredeep (West Ukraine) application to dating of tectonic events. *Geologica Carpatica*, **54**, 243–249.

WYSZYŃSKI, O. W. 1939. Przedgórze okolic Kosowa. *Przemysł Naftowy. (Lwów).* **14**, 7–13 [in Polish].

YARZHEMSKAYA, E. A. 1954. Composition of salt rock clays. *Trudy Vsesoyuznoho instituta galurgii*, **29**, 260–314 [in Russian].

ZHARKOV, M. A. 1984. *Paleozoic Salt Bearing Formations of the World*. Springer, Berlin.

ZATSIKHA, B. V., PETRICHENKO, O. I., DOLISHNIY, B. V. & LAS'KOV, V. A. 1973. Genetic peculiarities of mineral formation in Slaviansk mercuric deposits. *Mineralogicheskiy sbornik L'vovskogo universiteta*, **27**(4), 326–332 [in Russian].