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Marine and continental Lower Permian evaporites of the Prypiac' Trough (Belarus)

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Abstract

Sakmarian evaporites which include gypsum, anhydrite, halite, carnallite, kieserite and bischofite occur in the Prypiac' Trough (Belarus) within the lower and upper parts of one lithostratigraphic unit, the Svaboda Suite. The lower part of Svaboda Suite is up to 143 m thick and is composed of rock salt with interbeds of red claystones–siltstones and potassium–magnesium and magnesium–sulfate salts which are correlated with the lowest potassic salts of the Sakmarian Kramators'k Suite of the Dnipro-Donets Basin. These salts originated from precipitation from marine brines. Salts occur in a very limited area, and the occurrence of sulfate facies is much wider. The upper part of the Svaboda Suite (up to 520 m thick) is composed of interbedded mixed halite–siliciclastic and terrigenous deposits. There were two major sources of solutions flowing into the continental basin in which the subsuite was formed: meteoric (and continental) waters, and brines derived from the dissolution of Devonian salts. The distribution of the mixed halite–siliciclastic facies was related to tectonic dislocations that controlled the depocenter and the outflow, from the underlying Famennian deposits, of the major volume of salt into the intensively growing salt domes. Accordingly, the tectonic framework was the major control on the evaporite basin during deposition of the upper part of the Svaboda Suite.

Keywords: Permian; Evaporite geochemistry; Halite; Belarus; Redeposition

1. Introduction

Permian evaporites of marine origin are characterized by the occurrence of giant evaporite basins and the presence of potash salts of chloride–sulfate composition (Zharkov, 1984). The greatest Permian

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evaporite basin occurs in East Europe (Fig. 1), with evaporite deposits extending over an area of 1.5 million km^2 and with a total volume of 1 million km^3 (Zharkov, 1981). The Dnipro-Donets and Prypiac' evaporite basins occur in the SW part of that evaporitic area and are related to the Donbas-Prypiac' rift, which is more than 1300 km long and 70–130 km wide (Ulmishek et al., 1994) (Fig. 1C). The Devonian and younger rocks of the Donbas-Prypiac' rift unconformably overlie the Proterozoic or crystalline basement and may be divided into prerift platform (Middle Devonian to Lower Frasnian), synrift (Middle Frasnian to Famennian), and postrift sag sequences (Lower Carboniferous to Lower Permian), and the overlying platform sequence of post-Early Permian age (Ulmishek et al., 1994; Konishchev et al., 2001).

The postrift sag sequence is relatively thin in the Prypiac' basin and is present in depressions between salt domes. It thins or pinches out on the tops of the domes (Ulmishek et al., 1994) (Fig. 2). Whereas Lower Permian sulfate-bearing deposits are quite widespread in the Prypiac' Trough (Golubtsov and Monkevich, 2001), halite deposits occur in a very limited area in the central part of the basin and are accompanied by potash salts in some places (Kislik et al., 1985; Vysotskiy et al., 1988) (Fig. 1A, C and 3).

The aim of this paper is to characterize sedimentary environments of those poorly known Permian evap-

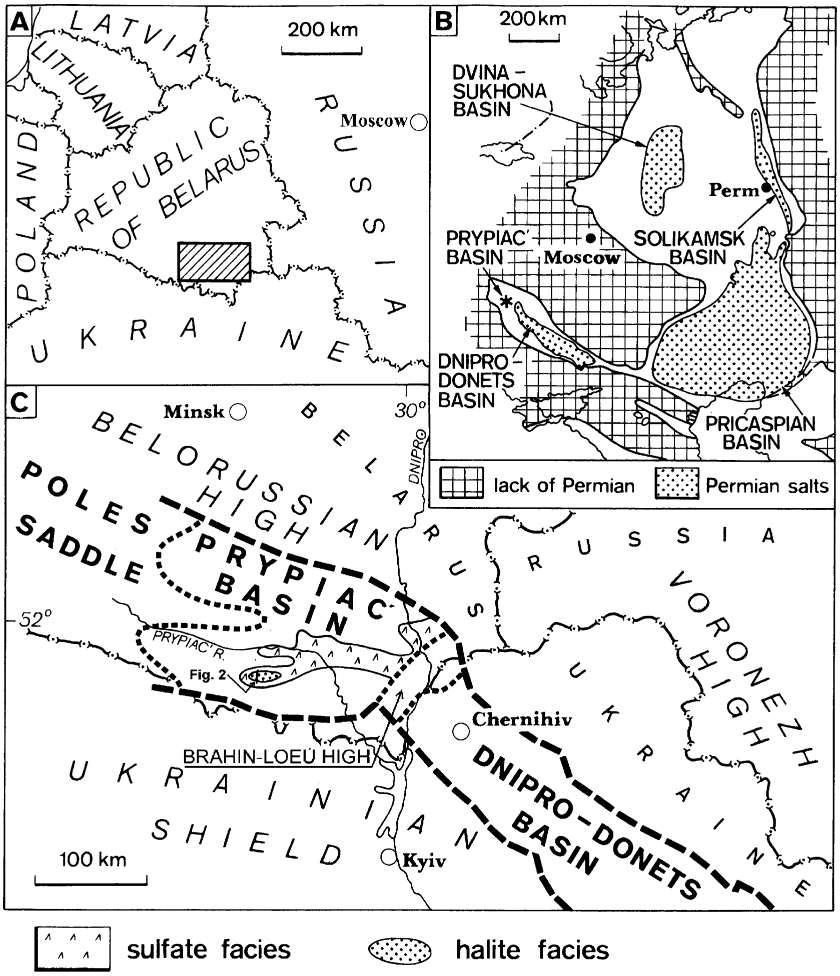

Fig. 1. Location map (A—studied area; the hachured area is shown in Fig. 3; B—East European Permian Basin, after Zharkov, 1984; C—the Prypiac' and Dnipro-Donets basins, after Ulmishek et al., 1994, Fig. 1).

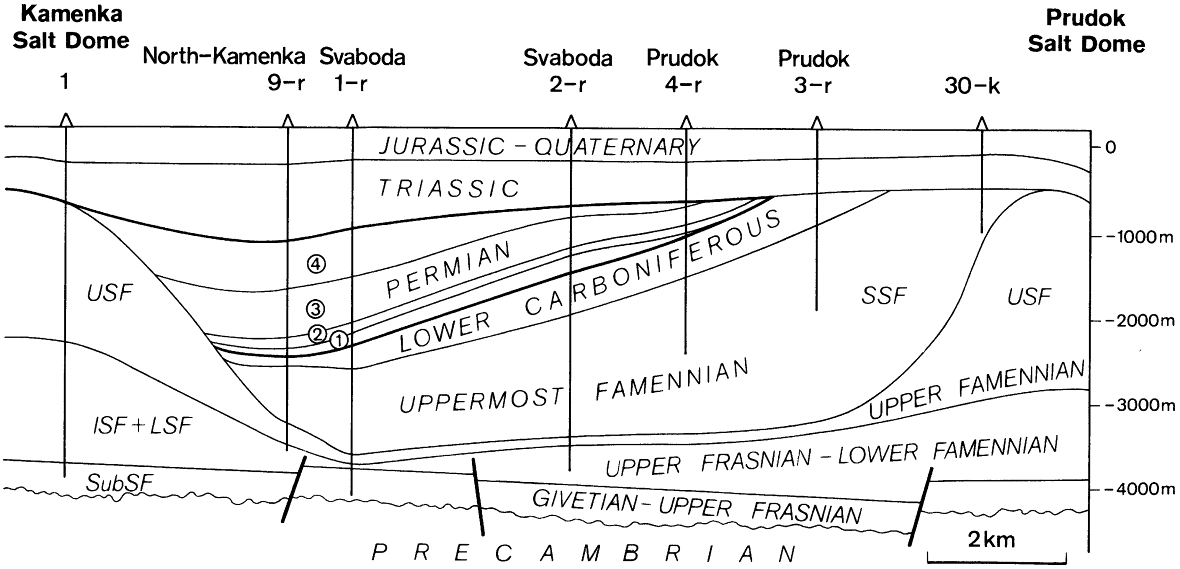

Fig. 2. Geological cross-section through the Prudok and Kamenka salt domes and the Svaboda salt syncline located between the domes (after Konishchev, 2002). ISF—Intrasaliferous Formation, LSF—Lower Saliferous Formation, SSF—Suprasaliferous Formation, SubSF—Subsaliferous Formation, USF—Upper Saliferous Formation, 1—Prudok Suite and lower subsuite of Svaboda Suite, 2—middle subsuite of Svaboda Suite, 3—upper subsuite of Svaboda Suite, 4—younger Permian suites.

orites and to discuss controls on evaporite deposition in the Prypiac' Basin. One such possible control is redeposition of Devonian salt dissolved from diapers piercing the depositional surface in the Early Permian, as was recently concluded for the Sakmarian evaporites of the Dnipro-Donets Basin (Stovba and Stephenson, 2003, p. 1196).

2. Geological setting

The Permian evaporites in the Prypiac' Trough occur between 1000 and 1800 m depth and have been recorded in many boreholes in the area (Fig. 3). In most cases, coring has been sparse and the lithological sections are based on the interpretation of geophysical logs.

The stratigraphy of the Permian deposits in the Prypiac' Trough is summarized in Table 1. Rock salt and anhydrite occur in the Svaboda Suite. The Svaboda Suite is underlain by the upper subsuite of the Prudok Suite. The lower subsuite of the Prudok Suite is composed of red claystones, marls and limestones with sandstone intercalations. The subsuite contains an Asselian microfauna (Monkevich, 1976). The upper subsuite, also assigned to the Asselian (Golubtsov, 1997) although it contains no guide fossils, is up to 20 m thick; at the base of the subsuite conglomerates occur (marker complex A—Fig. 4). The subsuite consists of red claystones and poorly sorted sandstones. In previous stratigraphic interpretations, massive anhydrites with dolomite intercalations have also been included into the upper subsuite, but according to our interpretation they belong to the Svaboda Suite.

The lower (salt-bearing) subsuite of the Svaboda Suite is up to 143 m thick and is composed of rock salt with interbeds of red claystones–siltstones and K–Mg and magnesium–sulfate salts. Considering the occurrence of kieserite and bischofite in the suite, it is correlated with the Sakmarian Kramators'k Suite of the Dnipro-Donets Basin (Lukin, 1988). In the Dnipro-Donets Basin, potassic salts of chloride and chloride–sulfate composition of the Kramators'k Suite (150–900 m thick in the Dnipro-Donets Basin—Korenevskiy et al., 1968) are arranged into five potash-bearing horizons (several meters to 30 m thick), and the potassic horizon in the Prypiac' Basin is regarded as an analogue of the lowest horizon (t_1) in the Dnipro-Donets Basin (Kislik et al., 1985).

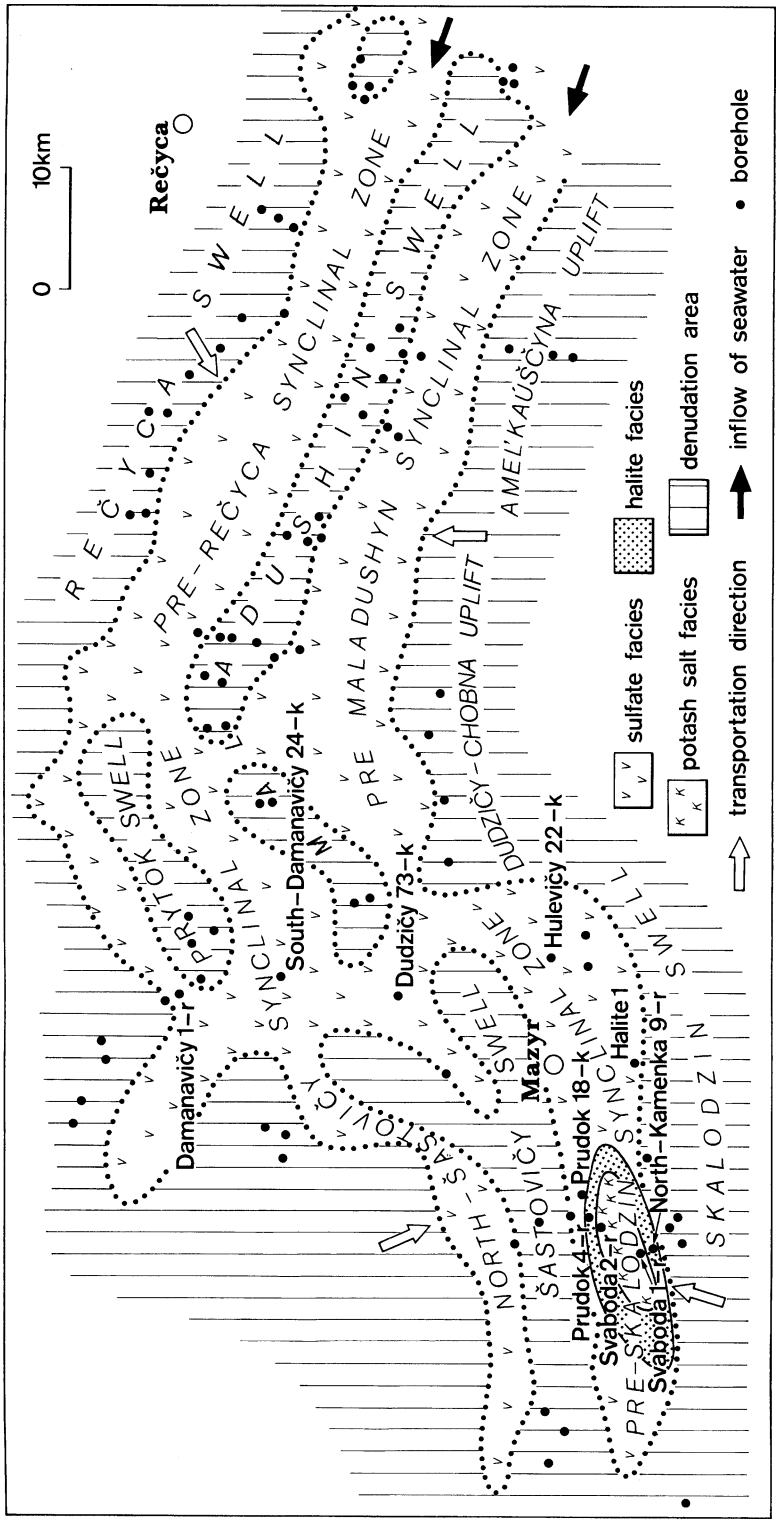

Fig. 3. Distribution of evaporite facies in the Prypiac' Trough.

Table 1
Stratigraphy of Permian deposits of the SE Belarus

Age	Prypiac' Basin		Dnipro-Donets Basin
Tatarian	upper subsuite of Dudzičy Suite		Peresazh (Dronov) Suite
	lower subsuite of Dudzičy Suite		
Kazanian			
Ufimian			
Kungurian			
Artinskian			
Sakmarian	Pre-Dudzičy Suite		
	Svaboda Suite		Kramators'k Suite
Asselian	Prudok Suite	upper subsuite	Slovyans'k Suite
		lower subsuite	Mykytiv Suite
			Kartamysh Suite

The middle (siliciclasic) subsuite of the Svaboda Suite is up to 132 m thick and composed of red and grey sandy and clayey siltstones as well as sandy and silty claystones. The entire subsuite is a marker complex (B in Fig. 4) (Kislik et al., 1985). It contains no fossils and is tentatively ascribed to Sakmarian (Golubtsov and Monkevich, 2001).

The upper (saline) subsuite of Svaboda Suite is up to 520 m thick and composed of interbedded rock salt and sandstones–claystones. In the lack of fossils, it is ascribed to the Upper Permian (Golubtsov and Monkevich, 2001) or Lower Permian (Vysotskiy and Kruchek, 2000); we concur with the latter interpretation (Table 1). The overlying Pre-Dudzičy Suite is up to 545 m thick and differs from the underlying upper subsuite of Svaboda Suite by lacking evaporites; it is also tentatively ascribed to the Sakmarian (Table 1).

From the structural point of view, many tectonic units are distinguished in the Prypiac' Trough (see Fig. 3) which shows the present geological situation. The origin of those units is primarily controlled by thick-skinned extensional events that induced salt movements during the Carboniferous and at the end of Carboniferous–earliest Permian (Stovba and Stephenson, 2003).

3. Materials and methods

We have examined cores and interpreted geophysical logs from six boreholes (Svaboda 1-r, Svaboda 2-r, Prudok 4-r, North-Kamenka 9-r, Halite 1, South-Damanavičy 24-k; Fig. 2). In addition, 20 other boreholes (archival data) have been used for the construction of Fig. 3, including boreholes Damanavičy 1-r, Dudzičy 73-k, Hulevičy 22-k and Prudok 18-k described in detail by Golubtsov (1992). In the Prypiac' Trough, during drilling of oil-exploration wells in the evaporite series, the following log suites have been derived: electric, gamma, neutron-gamma, and caliper log. The standard interpretation of these logs makes it possible to identify the principal rock types present in the sections, and this interpretation was verified by sparse coring (cf. Fig. 4). The cored salts have been chemically studied (nine samples in total). A standard chemical analysis of the solution

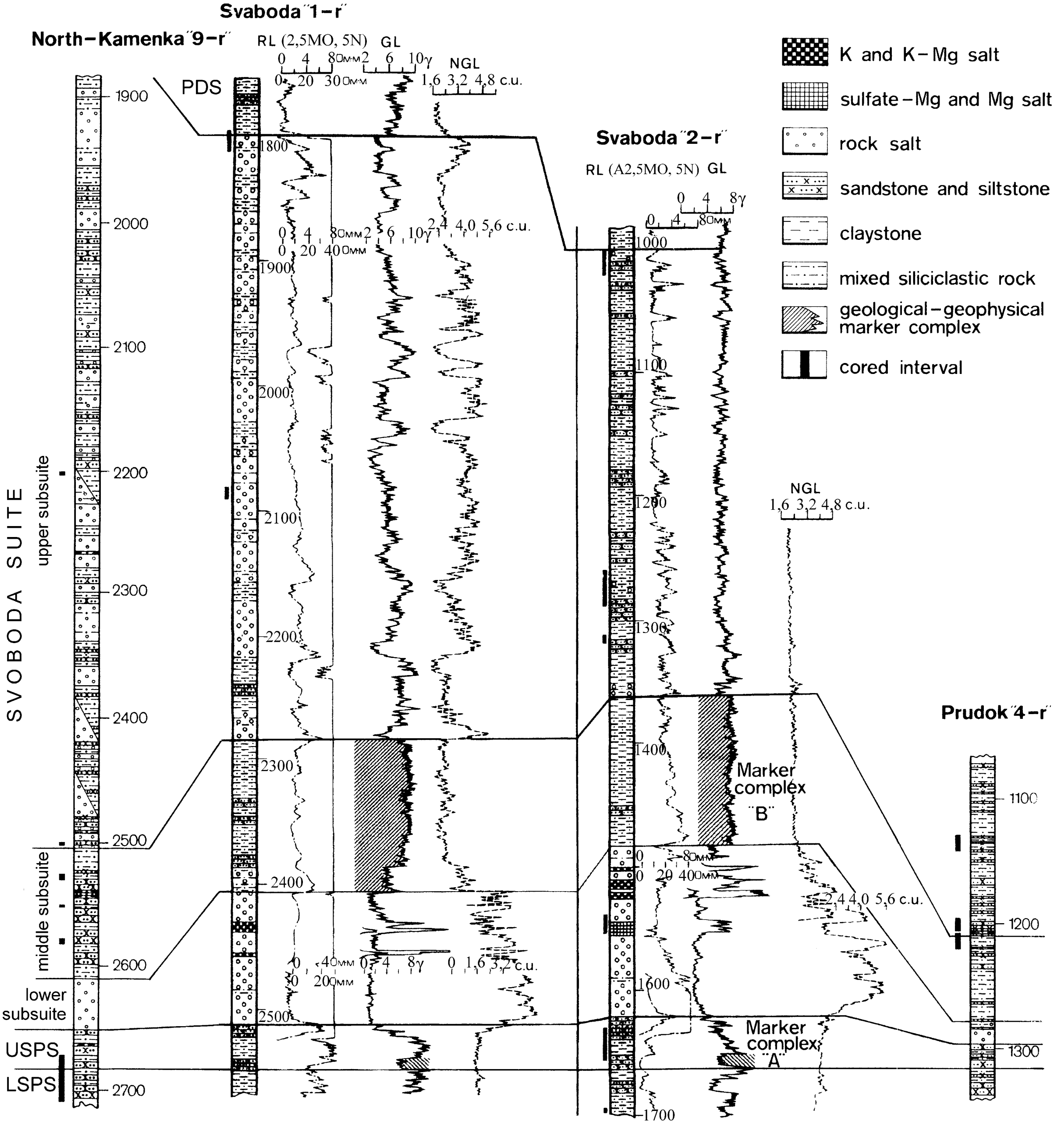

Fig. 4. Sections of Lower Permian salt-bearing sections of the Prypiac' Trough; PDS—Pre-Dudzičy Suite, USPS—upper subsuite of Prudok Suite, LSPS—lower subsuite of Prudok Suite, RL—seeming resistance log, GL—gamma log, NGL—neutron-gamma log, c.u.—conventional units.

obtained as water was extracted from the rock was also applied. The following constituents have been determined: K^+, Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, Br^-, water-insoluble residue, hygroscopic and crystallization water. Those analyses were done by the company *Belarus'kaliy*. Standard granulometric analyses of siliciclastic material have also been done in four samples of the mixed halite–siliciclastic rocks.

Measurements of sulfur isotope ratios of sulfate minerals were carried out in the Institute of Geological Sciences of the National Academy of Sciences of Belarus with a precision of ±0.3‰. Sulfates were first transformed into cadmium sulfide by reduction with graphite. The SO_2 from sulfides, for measuring $^{34}S/^{32}S$ ratio, was obtained by oxidation with copper oxide (Ustinov and Grinenko, 1965). One sample was analyzed for sulfur and oxygen isotopes at the Mass Spectrometry Laboratory, Maria Curie-Sklodowska University, Lublin. The isotopic compositions, $\delta^{34}S$ and $\delta^{18}O$, were analyzed by a dual inlet and triple collector mass spectrometer on SO_2 and CO_2 gases, respectively. The SO_2 was extracted by the method developed in the Lublin laboratory (Halas and Szaran, 1999), whereas CO_2 was prepared by the method described by Mizutani (1971). Typically 8–12 mg of $BaSO_4$ was used in each preparation. The reproducibility of the both delta analysis (two standard deviations) was about 0.16‰.

4. Evaporite lithology

4.1. Lower subsuite of Svaboda Suite

Intercalations of gypsum and anhydrite within variegated terrigenous beds have been recorded in the central and eastern parts of the Prypiac’ Trough. There occur one to seven beds of anhydrite and gypsum (Golubtsov and Monkevich, 2001) each of which are 0.15–1.3 m thick. These sulfate beds occur at the top of cycles composed of sandstones (in one case—conglomerates) at the base, passing into siltstones or claystones and then sulfates or claystones and siltstones with inclusions or veins of sulfates. The gypsum is white in colour, coarsely crystalline, massive, and occasionally with inclusions of variegated clays. Anhydrite is bluish-grey in colour, massive, and homogeneous. The anhydrite facies was recorded in the borehole Halite 1 where a bed 0.9 m of massive, fine crystalline, grey anhydrite occurs which in some places contains idiomorphic dolomite crystals. The $CaSO_4$ content exceeds 90% and reaches 98.3%. The strontium content as measured in several samples is 0.28–0.35%.

The halite facies was studied in the borehole Svaboda 2-r. The rock salt is medium- and coarse-grained, and red in colour owing to admixture of clay material; in the lower part of the subsuite, it is grey in colour. The NaCl content is 80–99%, KCl is 0.06–2.48%, $MgCl_2$ is 0.13–2.79, $CaSO_4$ is 0.29–5.92, and the water-insoluble residue content is 0.1–5.4%. In some places, intercalations (up to 10 cm thick) of cloudy to transparent, coarsely crystalline halite (crystals up to 1 cm in diameter) occur. Siltstone intercalations, characterized by diffuse borders, are common in the rock salt. The primary depositional forms of halite, such as chevron or hopper crystals, are lacking. The bromine content is 110–290 ppm (Table 2).

The petrophysical logs indicate that in the Svaboda 1-r borehole the upper part of the lower subsuite of the Svaboda Suite comprises a potassium-bearing horizon (Fig. 4). It is composed of three beds: a lower K-bearing, middle halite, and an upper K-bearing. Potassium-bearing deposits are presumably sylvinite interbedded with halite. In the Svaboda 2-r borehole, Mg–sulfate rocks have been cored. Chemical, X-ray and thermal studies showed that the rock is mostly kieserite (84.2%) with admixtures of bischofite (13.8%), epsomite, halite and other minerals. The Br content is 500 ppm. In the upper part of the Svaboda Suite, in the lower K-bearing horizon, three parts are distinguished based on geophysical logs: a lower and an upper carnallite units separated by a middle bischofite unit (2 m thick). The upper (K-bearing) horizon is composed of interbedded K-salt (up to 1.5 m thick) and halite. K-salts are built of sylvinite but potassium–sulfate salts can occur as well.

Table 2
Bromide content in Permian rock salt of the Prypiac’ Trough

Subsuite	Borehole	Depth [m]	Sample	Br content [ppm]
Upper	North-Kamenka 9-r	2200.5	Clayey rock	20
		2202.0	salt of	<10
	Svaboda 1-r	1797.0	Haselgebirge	40
		1797.5	type	50
Lower	Svaboda 2-r	1538.9	Rock salt with carnallite inclusions	290
		1538.95	Rock salt	230
		1539.0		180
		1552.9		150
		1553.0		110

In the uppermost part of the lower subsuite of Svaboda Suite in the Svaboda 1-r borehole, mixed halite–siliciclastic rocks occur which show similar geophysical characteristics as the rocks recorded in the upper subsuite of Svaboda Suite (Fig. 4).

4.2. Upper subsuite of Svaboda Suite

The subsuite comprises mixed halite–siliciclastic rocks (Fig. 4). The rock salt shows no bedding and has a brecciated appearance, and it is dirty due to occurrence of sandy, silty and clay material of red colour. The grain size analyses of that material from two samples from the lowermost part of the subsuite in the Prudok 4-r borehole (depth 1029.7–1042.9 and 1096.0–1108.1 m) showed that the content of sand is 29.0–37.2%, silt is 44.4–50.8%, and clay fraction is 18.4–20.2%. In the sand, grains of 0.10–0.25 mm predominate (79.2–80.5%), and quartz constitutes up to 85% of grains; in addition, feldspar (up to 19.5%) and mica (up to 2%) occur, accompanied by ilmenite and garnet. The analysis of two samples from the top of the subsuite in the Svaboda 1-r borehole (depth 1794.5 m and 1809 m) showed the following contents: sand 0.5–78.0%, silt 9.5–46.0, clay 16.0–41.3. Within sand, grains 0.25–0.5 and 0.1–0.25 mm predominate (28.5–44.3% and 61.0–78.1%, respectively). The quartz content reaches 90.5%, and the content of feldspars is 5.5–19.5% and of mica reaches 2%. Heavy minerals are mainly ilmenite and garnet, and authigenic minerals are mostly iron hydroxides (up to 73% of total heavy fraction). Cement is mostly halite and clay, and carbonates comprise 7.5–14.1%, with dolomite predominating over calcite.

The NaCl content in rock salt is 34–90%, the water-insoluble residue exceeds 10%, and the average is 32.8%. The Br content is 20–50 ppm, and in one sample it is below the sensitivity of the method (10 ppm) (Table 2).

5. Isotopic composition of sulfate sulfur

The δ^{34}S values recorded in the lower subsuite of the Svaboda Suite, both in the sulfate lithofacies as well as in anhydrite dispersed in halite (Table 3), are similar to δ^{34}S values from Sakmarian anhydrites of the Dnipro-Donets Basin (11.97–12.63‰; Kovalevych et al., 2002). These are regarded as marine evaporites, and their values correspond to values characteristic for seawater sulfate of the Early Permian (Strauss, 1997). In turn, δ^{34}S values found in anhydrite dispersed in halite from the upper subsuite of Svaboda Suite (Table 3) are higher than those in the lower subsuite. This enrichment could have resulted from (1) input of sulfate ions derived from dissolved Devonian salts (the δ^{34}S values for Devonian salts of the Prypiac' Trough are +22.8±0.37‰—Makhnach, 1989) and/or (2) more intensive sulfate reduction in a more restricted part of the Prypiac' Trough, in which those salts have accumulated.

6. Environmental conditions: interpretation

During the Early Permian, the Prypiac' Trough was a narrow (15–25 km wide) gulf of a major basin that existed in the Dnipro-Donets Basin. The northern limit of the Prypiac' Basin was the Rečyca high, and the southern limit was controlled by three highs: the Skalodzin, Dudzičy-Chobna and Amel'kaúščyna (Fig. 3). Within the basin, several islands existed (the greatest ones were the Maladushyn and Prytok). The main depressions were as follows: the Pre-Rečyca and

Table 3
Isotopic composition of sulfates in the Sakmarian Svaboda Suite of the Prypiac' Trough (1—Institute of Geological Sciences, National Academy of Sciences of Belarus, Minsk; 2—Mass Spectrometry Laboratory, Maria Curie-Sklodowska University, Lublin)

Subsuite	Borehole	Depth [m]	Sample	δ^{34}S (‰)	δ^{18}O (‰)	Laboratory
Upper	North-Kamenka 9-r	2200.5	Anhydrite dispersed	+14.1		1
		2201.8	in halite	+16.3		
Lower	Svaboda 2-r	1540.0		+13.1		
		1547.0		+13.7		
	Mozyr (Halite)	1229.3	Anhydrite	+13.12±0.07	+8.86±0.06	2
	South-Damanavičy 24	641.0	Gypsum	+9.0		1

Pre-Maladushyn lows (where red sulfate-bearing terrigenous deposits with rare carbonate intercalations have been formed), and the Pre-Skalodzin zone where salt-bearing deposits occur (Fig. 3). This structural plan already existed in the Early Permian and was controlled by the salt tectonics, as mentioned earlier (Stovba and Stephenson, 2003).

During deposition of the lower subsuite of Svaboda Suite, the main water source comprised marine brines (Fig. 5A). This is indicated by the high bromide content (110–180 ppm) which is considered characteristic for marine halites (Valiashko, 1956; Holser, 1966, 1979; Kühn, 1968). Similarly, the δ^{34}S values in the anhydrites within the sulfate facies (9.0–13.1‰), as well as those in the halite facies (13.1–13.7‰), suggest a marine origin for the SO_4^{2-} ions. In the most depressed part of the basin (ca. 35 sq. km), the brines reached the phase of carnallite and bischofite concentration. The marine phase of development of the Prypiac' Basin was terminated with the deposition of siliciclastic deposits of the middle subsuite of the Svaboda Suite.

During deposition of the upper subsuite of the Svaboda Suite, the area of occurrence of the salt facies was approximately the same as the area of salt facies during deposition of the lower subsuite of Svaboda

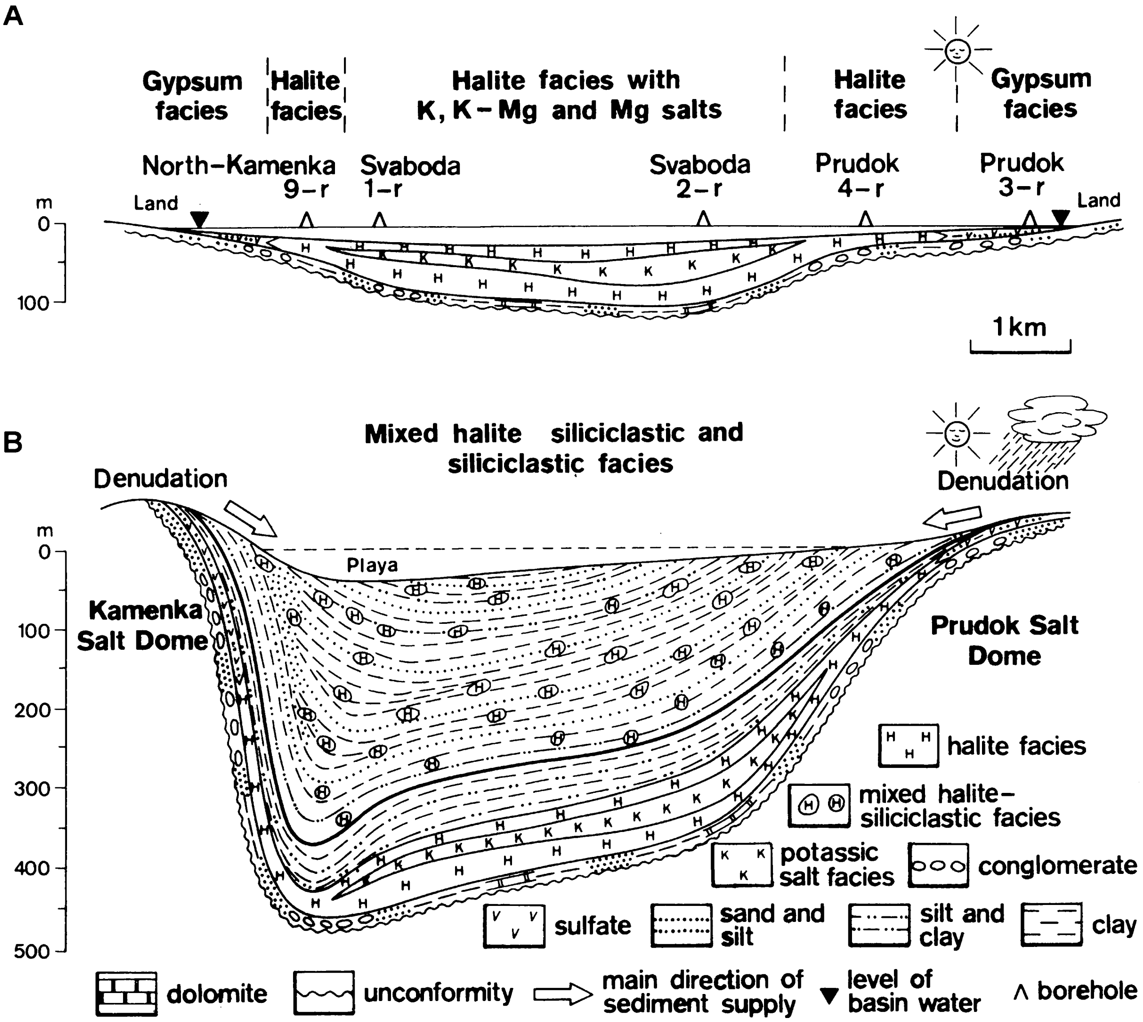

Fig. 5. Accumulation of Lower Permian evaporites in the western part of the Pre-Skalodzin Synclinal Zone (Prypiac' Trough). (A) Marine evaporite basin; (B) continental evaporite basin.

Suite. However, as the sulfate facies was lacking, the area of evaporite deposition was considerably reduced overall (cf. Fig. 1) and restricted to the western part of the Pre-Skalodzin Synclinal Zone (Fig. 3). It should be mentioned that the interpretation of wireline logs suggests that in the eastern part of the Pre-Skalodzin Synclinal Zone, there could be another (although smaller) salt basin. This is shown in Fig. 3, but there are no factual data (no gravity data) confirming such a supposition.

Bromide contents of halite in the upper subsuite of Svaboda Suite (Table 2) show values which are accepted for primary marine halite (40–50 ppm), as well as some lower values. As discussed by Holser et al. (1972), marine halites may be recrystallized or recycled by seawater and this may have given the second cycle salt with bromide contents of 10 ppm (assuming that the parent halite had 75 ppm of Br), whereas the later recrystallization(s) may not have given a Br content in halite lower than 7 ppm. In turn, a Br content in halite recycled by nonmarine water would be expected to be about 3 ppm (Raup and Hite, 1978, with references). Based on the bromide content alone, it is difficult to be certain about the nature of formation waters (whether marine or nonmarine), or recycling marine halites, either Lower Permian or Devonian.

A characteristic feature of the upper subsuite of the Svaboda Suite is the brecciated appearance of deposits. This is interpreted to be analogous to a special facies of claystones found elsewhere in the Permian red beds of Europe and called "Haselgebirge" or "zuber" (Sonnenfeld, 1984). The Haselgebirge claystones have a halite content of 30% and comprise a chaotic mélange of shale, siltstone, sandstone, anhydrite, carbonates, and scarce volcanic rocks embedded in a clayey halite matrix. Spötl et al. (1998) regarded the Haselgebirge facies as recording a complex history of deformations during the late Jurassic closure of the Meliata–Hallstatt trough south of the Northern Calcareous Alps. However, Ślączka (1994) argued that the presence of sedimentary structures similar to those recorded in Wieliczka (where breccias show sedimentary features produced by subaqueous gravity flows of partly unconsolidated saliferous deposits—Kolasa and Ślączka, 1985) indicates that at least some of the breccias are olistostromes. The facies in the Prypiac' Basin differ, from the Austrian Haselgebirge facies, by the lacking pebbles of clayey shales, and show similarity to the zuber facies recorded in the Zechstein. This evaporite facies area was surrounded by alluvial fans and mudflats (cf. Spötl, 1989).The basin itself became a playa lake fed by waters transporting material derived from the erosion of the Devonian (Famennian) and, presumably, also older Permian evaporite-bearing formations. As in other playa-lake deposits (e.g. Bristol Dry Lake Basin, California—Rosen, 1991), thick sections of evaporite-bearing sequences cannot be easily correlated. The distribution of the Haselgebirge facies in the Prypiac' Basin was related to the depocenter (Pre-Skalodzin Synclinal Zone) controlled by the intensively growing salt domes: the Prudok in the north and Kamenka in the south (Figs. 2 and 3).

7. Discussion

The hydrological framework of evaporite basins is complex because the inflowing waters can have different provenance and signatures. Environmental markers provide useful information on the origin of evaporites which is especially useful in the case of recycled evaporites (Taberner et al., 2000). However, the use of different geochemical markers may lead to contradictory conclusions about the environments of evaporite deposition, although geochemical modelling of evaporite sequences provides a useful tool for the interpretation of the main inflows and the source of solutes reaching evaporite basins (e.g. Ayora et al., 1994, 1995; Taberner et al., 2000). There are no primary-sedimentary forms of halite containing primary fluid inclusions in the Permian of Prypiac' Trough which could provide information on the electrolyte composition of the inclusions. Therefore, we use the traditional markers: the bromine content of halite samples and the isotopic composition of sulfates, which lead to the same interpretation: most evaporites of the lower subsuite of Svaboda Suite precipitated from marine brines (Fig. 5A), and evaporites in the upper subsuite of Svaboda Suite formed in a playa environment from waters recycling older evaporites, as shown in Fig. 5B.

The succession of two major depositional environments, marine and continental, as recorded in the

Prypiac' Trough, is common in the fossil record. One example is the Upper Permian Zechstein Basin of Central and North-Western Europe. The majority of the Zechstein sediments were formed during transgressive–regressive carbonate-evaporitic cycles embracing cyclothems from PZ1 to PZ3, in stable arid climate conditions. Subsequently, in the uppermost part of the Younger Clay Halite Na3t of the PZ3, sedimentation in the Zechstein Basin has changed substantially when the stable arid climate has been replaced by alternating humid and dry periods with a general trend toward more humid climate (Peryt and Wagner, 1998). Such climatic conditions promoted the origin of terrigenous-evaporitic climatic cycles in the uppermost Zechstein cyclothems from PZ4a to PZ4e, and in the axial part of the evaporitic basin zuber facies originated (Wagner, 1994). However, in the Zechstein Basin, there was a gradual evolution from a marine evaporite basin into continental one owing to climatic and tectonic changes, whereas in the Prypiac' Basin, there was probably no such major change of environmental conditions. In the Dnipro-Donets Basin, there is evidence of local dissolution of Devonian salt during Permian intervals (Kogan, 1966; Sterlin and Tkhorzhevskiy, 1966; Stovba and Stephenson, 2003), and in the Prypiac' Basin this dissolution was a major source of brine solutions. This is supported by a general geologic situation (Fig. 5B), enriched δ^{34}S isotopes, and decreased bromide contents.

In the Prypiac' Basin, the original marine evaporite condition (characterized by precipitation of salts from brines derived from marine water which inflowed from the Dnipro-Donets Depression) was transformed into a continental evaporite basin with occasional inflow of meteoric (and continental) waters and brines derived from the dissolution of Devonian salts. One mechanism was perhaps the dissolution of salts from rising Devonian diapers as recently suggested by Stovba and Stephenson (2003) for the Sakmarian of the Dnipro-Donets Basin.

8. Conclusions

The lower Svaboda Suite, comprising red claystones interbedded with potassium and magnesium salts that are correlated with the Sakmarian potash salts in the Dnipro-Donets Basin, precipitated directly from Permian marine brines. The upper Svaboda Suite, composed of halite salt and interbedded siliciclastics, formed in a continental basin fed by meteoric (and continental) waters and brines fed from Devonian salt deposits exposed in rising salt domes.

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