

## Rb–Sr and K–Ar Isotopic Systems of the Upper Devonian Sediments in the Pripyat Trough, Belarus

M. I. Bujakaite<sup>a</sup>, V. I. Vinogradov<sup>a,†</sup>, N. S. Petrova<sup>b</sup>, N. D. Mikhailov<sup>b</sup>,  
D. O. Gertsev<sup>a</sup>, D. I. Golovin<sup>a,†</sup>, and Yu. V. Kushcheva<sup>a</sup>

<sup>a</sup>*Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*  
e-mail: bujakaite@ginras.ru

<sup>b</sup>*Belarussian Research Geological-Prospecting Institute, ul. Kuprevicha 7, Minsk, 220141 Belarus*

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**Abstract**—The results of Rb–Sr and K–Ar isotope studies of the Famennian upper salt and suprasalt complexes sampled from the core material of exploratory boreholes drilled at the northwestern margin of the Pripyat Trough (Belarus) are presented. The suprasalt and saliferous portions of the sequence define an age of approximately 470 Ma. Despite multiple reworking of the material, we interpret this value as preservation of the provenance “memory.” Regardless of the Sr content in sample, the strontium isotope ratios obtained for low-Rb minerals (celestine, carbonate, and halite) varies throughout the section within 0.7083–0.7095, indicating the preservation of some primary features of the matter. The lowest isotope values obtained are slightly higher than those inferred for the upper Famennian. This fact confirms the concept that the studied complex was formed in a shallow-water setting. Data on sylvites show that the present-day isotopic characteristics of potassium salts were formed significantly later.

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### INTRODUCTION

Isotopic studies were carried out in the Laboratory of Isotope Geochemistry and Geochronology (Geological Institute of the Russian Academy of Sciences) for sedimentary complexes of the Riphean rocks in the Bashkirian anticlinorium (Vinogradov et al., 2001), Vendian rocks of the Russian Platform (Vinogradov et al., 2005), and Precambrian rocks of the Irkutsk amphitheater (Vinogradov et al., 2006). The aim of these works was to reveal the role of secondary post-sedimentary processes in the formation of sedimentary material in the geological history using the methods of isotope geochemistry. Isotopic methods are most suitable for the identification of such transformations, whereas data on the radioactive isotopic systems can likely be used as a measure of geological time.

Previous study of sedimentary complexes formed in different geodynamic settings suggested the following conclusion: the development stages preserved in the memory of the Rb–Sr isotopic system mark the timing of postsedimentary alteration of rocks rather than their deposition. Obviously, the degree of rock alteration increases with age. Hence, the study of older-to-younger rock complexes allows us to trace the trend of decrease in the transformation of their isotopic characteristics.

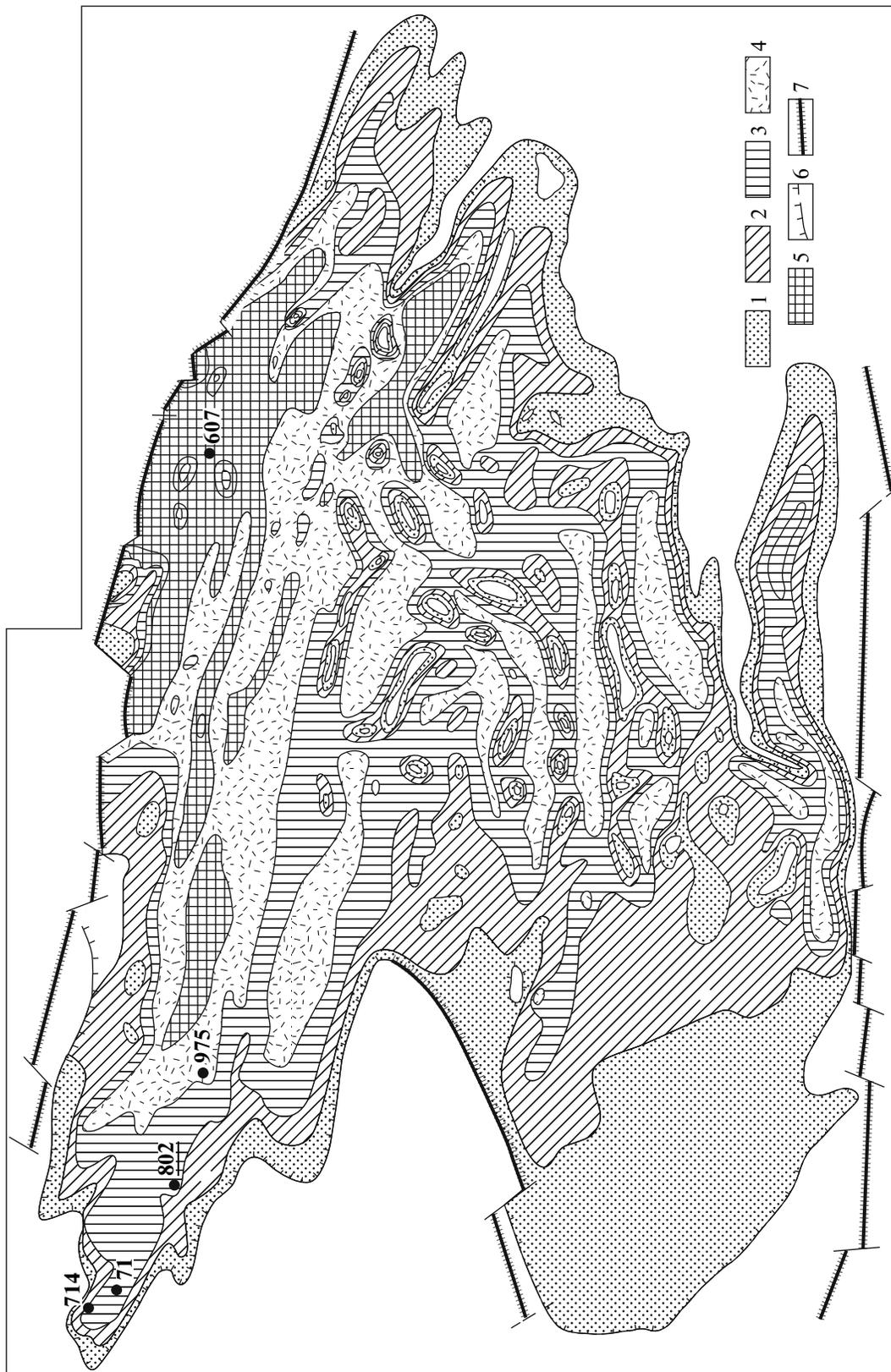
In this work, we continue the isotopic study of the transformation of sedimentary matter in the geological history using the Upper Devonian saliferous sequences of the Pripyat Trough as example. Halogenic rocks are least resistant to epigenetic transformations due to high solubility of salt rocks. However, the formal (Ordovician) age obtained in our work seemed to be older than their stratigraphic (Devonian) age. Therefore, we believe that the isotopic system of these rocks was not completely reset and they preserved some provenance memory.

### UPPER DEVONIAN SALT COMPLEX OF THE PRIPYAT TROUGH

The Pripyat Trough contains the following Upper Devonian units (from the bottom to top): subsalt terrigenous (lower Frasnian), subsalt carbonate (middle–upper Frasnian), lower saliferous (upper Frasnian), intersalt (lower Famennian), upper saliferous (middle–upper Famennian), and suprasalt (upper Famennian) (*Devonskie ...*, 1982).

Isotopic studies of the Upper Devonian rocks of the Pripyat Trough were started from the suprasalt sequence (Petrova et al., 2010). In the present work, we report data on the upper saliferous sequence (location of sampled boreholes is shown in Fig. 1). The upper saliferous sequence unites the Famennian rocks of the Lebedyan, Oressk, and lower Streshino horizons. Its total thickness varies from 70 to 3000 m (aver-

<sup>†</sup> Deceased.



**Fig. 1.** Location of the studied boreholes in the Pripyat Trough. (1–5) Fields of rhythmic units of the K-bearing subformation: (1) I–II, (2) III–IV, (3) V–VI, (4) VII–VIII, (5) IX–X; (6) domain of rock salt of the K-bearing subformation; (7) marginal faults (*Devonskie ...*, 1982).

age 1300–1400 m). The sequence is divided into the lower halite and upper K-bearing (clay–halite) subsequences. The complex is overlain by the Famennian suprasalt sediments, the lower part of which is considered a zone related to the underground leaching of the upper salt sequence.

In the generally accepted model of the Devonian potassium chloride sedimentation in the Pripyat paleorift, a significant role belongs to the clastogenic rocks, which are products of the erosion and weathering of basement exposures, rocks of previous sedimentation cycles, and volcanic activity.

In terms of structure, the K-bearing associations of the middle–upper Famennian formation of the Pripyat Trough are ascribed to the asymmetric subtype of the rhythmic type, with rhythmicity manifested in the combination of nonsalt (lower) and salt (upper) rocks (Kopnin, 1987).

In terms of location between the underlying and overlying sedimentary sequences, this formation is close to the Kungur Formation of the Solikamsk basin, Eocene–Oligocene Formation of the Upper Rhine graben, Carboniferous Paradox Formation, Carboniferous Olinda Formation of the Amazon basin, and Kungur Formation of the Upper Pechora basin. The non-salt matrix reveals some differences: in particular, the Eocene–Oligocene formation of the Upper Rhine graben is mainly composed of carbonate–anhydrite rocks, whereas the middle–upper Famennian sequence of the Pripyat Trough is dominated by clay and marl.

The upper Famennian sediments are made up of rhythmically alternating beds of rock salt and non-salt (carbonate–clayey, clayey, carbonate–sulfate, and terrigenous) rocks. The K-bearing subformation contains potash horizons (p.h.). Lithostratigraphic section with locations of the studied samples is shown in Fig. 2.

Salts account for approximately 45–60% of the sequence and their content decreases toward the marginal parts of the subformation domain. Salt members (5–10 to 45–50 m thick) consist of rock salt, while the potash horizons comprises sylvinite, sylvite–carnallite, and carnallite rocks.

Thickness of non-salt rocks (denoted by even numbers in the section) varies from 5–10 to 36–40 m, reaching maximum in units 8 and 20. Non-salt units are mainly represented by the clay–carbonate rocks (clays, clayey marls, marls, clayey dolomites, and limestones), with the less common terrigenous (sandstones, siltstones) and sulfate (clayey anhydrites, anhydrites) rocks. Proportions of the rock types are variable. Sulfate and sulfate–carbonate rocks are mainly confined to the lower part of subformation (rhythmic beds I and II). Above potash bed III, thickness of the clay–anhydrite interbeds decreases, while the amount of sulfate–carbonate rocks increases in the rhythmic bed II (*Devonskie ...*, 1982).

Determination of the lithological composition of saliferous formations within large chemogenic–sedimentary systems and the sources of detrital material in the sedimentary infill of potash subformation in the Pripyat intracontinental rift remain an urgent problem.

Interest to this problem is not accidental, because the volume of clay–carbonate material in the Devonian saliferous rocks of the Pripyat Trough is often equal to that of salt sediments, and their accumulation rates are comparable. The grain size spectrum of detrital material is dominated by the pelite- and silt-size particles. Moreover, the main clay mineral is hydromica of 1Md polytype with minor Mg-chlorite and mixed-layer minerals. The share of detrital material, which was delivered with air or water flows due to volcanic activity during salt accumulation, in the potash subformation is yet unclear.

The amount and thickness of terrigenous rocks increase toward marginal zones of the K-bearing subformation, especially in the depressions. Gravelstones, conglomerates, and breccias are developed in the uplifted areas.

As mentioned above, isotopic study of the Upper Devonian rocks of the Pripyat Trough was started in the suprasalt sequence at the margin of the sedimentation basin (Starobinsk deposit, borehole 71) (Petrova et al., 2010). In this work, the results of the study of the upper saliferous sequence are reported.

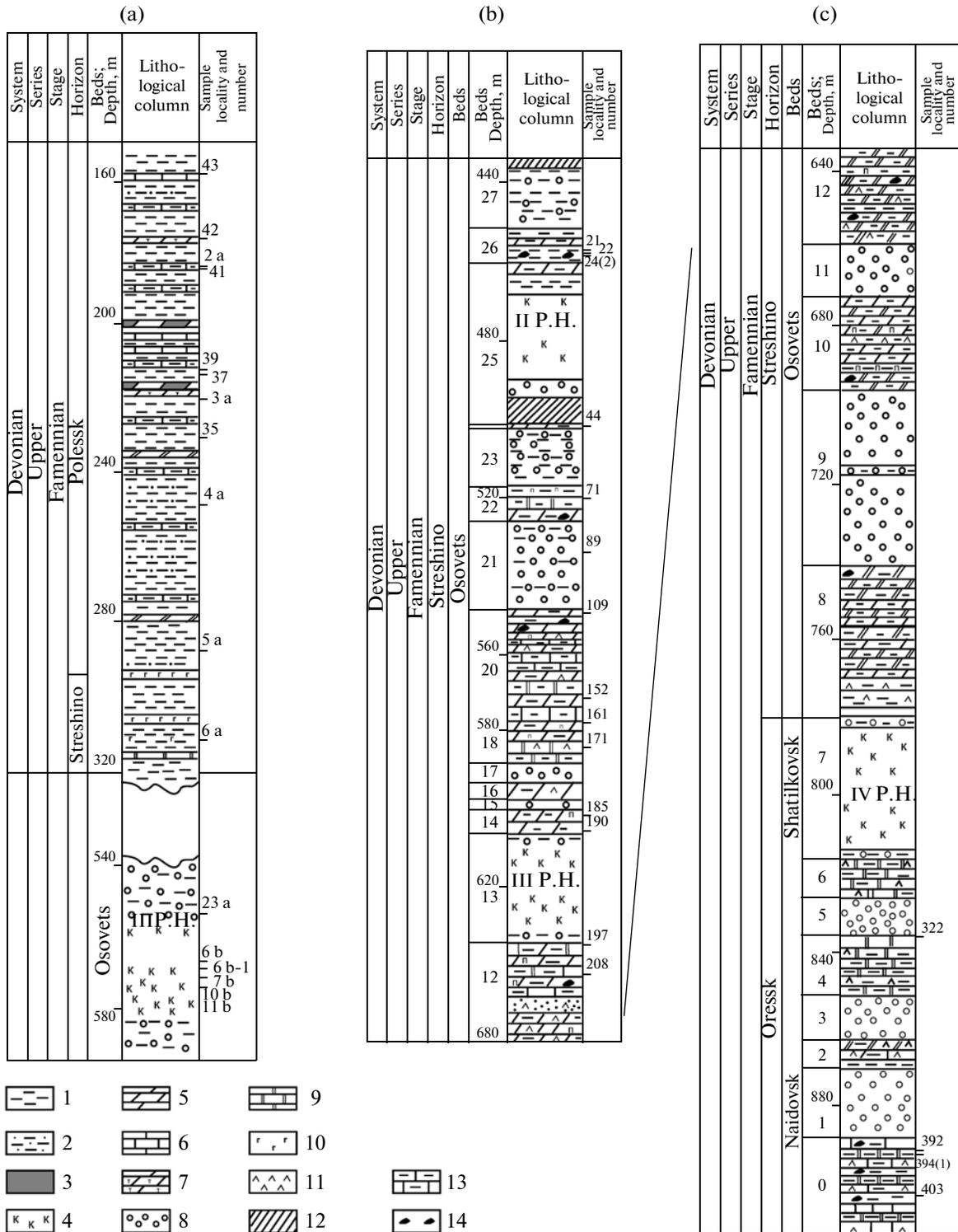
Lithological studies (description of thin sections, mineralogical and X-ray analysis) revealed that the clastic material was mainly formed by rapid redeposition of the older sediments transported from a provenance composed of diverse rocks. Height gradient required for the movement of sedimentary masses was provided by large-amplitude faults in the area.

## MATERIALS AND METHODS

The aim of our work in such comprehensively studied region was to determine the degree of geochemical preservation or transformation of the initial composition of rocks. Specificity of our approach to this problem was as follows: we attempted to trace changes in the isotopic characteristics of rocks in the salt and nonsalt interbeds in a single sequence for one or several closely located boreholes.

We studied the saliferous sequence of borehole 71 supplemented with the section of borehole 714. Our previous results on the upper suprasalt complex were supplemented with the data on borehole 802 (Petrova et al., 2010) (Fig. 2).

In the previous work, we presented our data on the stable (O, C, S) and radiogenic (Sr) isotopes in sediments of the suprasalt sequence. In this work, we report only Rb–Sr and K–Ar data on these rocks. Data on stable isotopes will be published in the forthcoming papers.



**Fig. 2.** Lithostratigraphic section with locations of the studied samples. (a) Borehole 802; (b) borehole 71; (c) borehole 714. (1) Clay, (2) siltstone; (3) combustible shale, (4) potassium salt; (5) marl; (6) limestone; (7) tuffaceous marl; (8) rock salt; (9) dolomite; (10) gypsum; (11) anhydrite; (12) core is absent; (13) clayey limestone; (14) CaSO<sub>4</sub> nodules.

According to our Rb–Sr analysis method, sedimentary rocks are studied in two stages. Study of the silicate constituent of marls in the first stage can allow

one to find some temporal signatures and initial Sr isotope ratios, which provide insight into geochemical conditions in the sedimentation basin.

**Table 1.** Rb–Sr data on the silicate constituent of marls in nonsalt interbeds of the upper salt sequence and in the suprasalt sequence of Devonian sediments of the Pripyat Trough

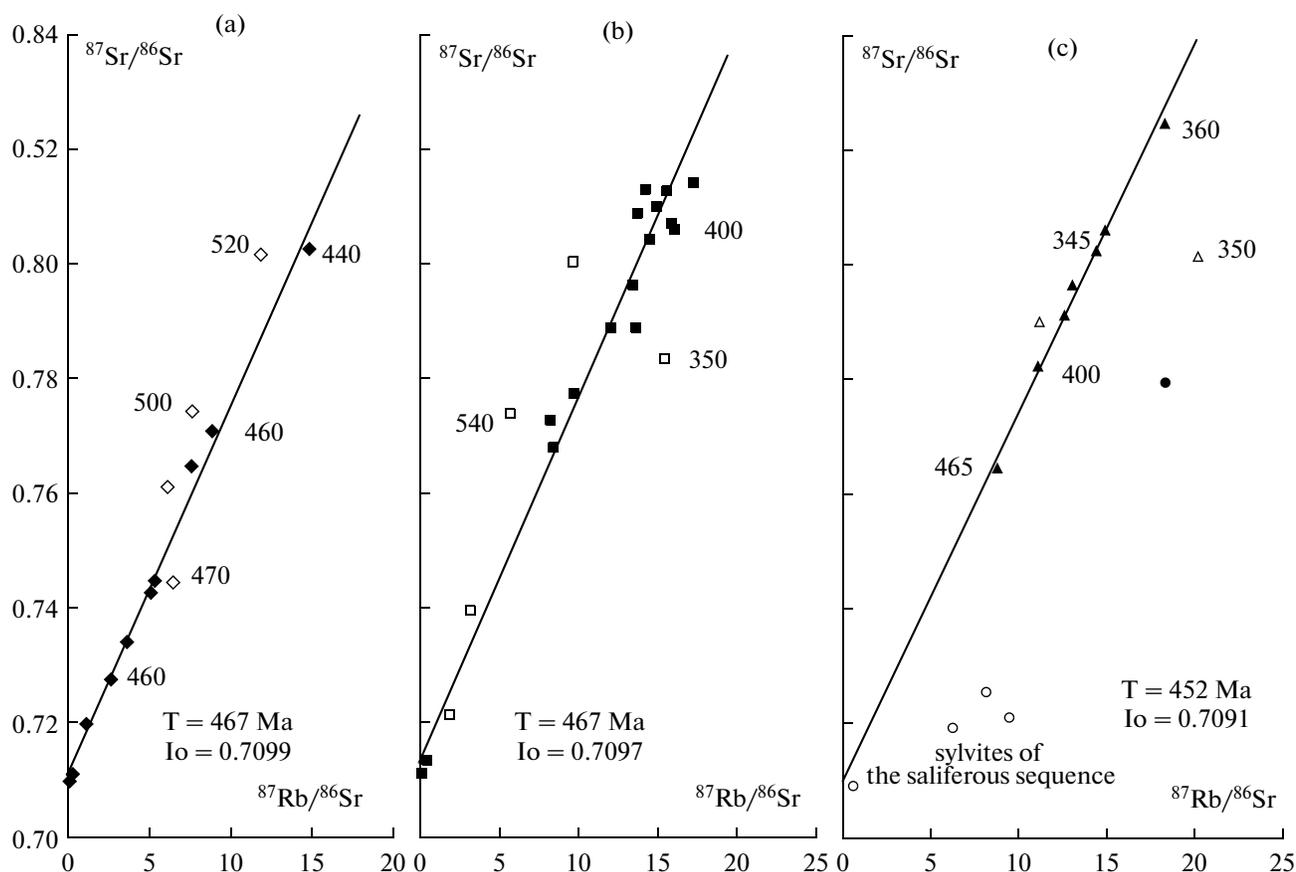
Sample no.	Depth, m	Rb, ppm	Sr, ppm	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	Rock
Upper salt sequence (borehole 71)						
21	457	148	56.4	7.64	0.7645	Clay
22	457.6	135	76.5	5.11	0.7424	Clay
24(2)	458	195	86.5	6.55	0.7438	Carbonate clay
44	502	158	173	2.65	0.7273	Carbonate clay
71	520	153	401	1.10	0.7196	Clayey dolomite
89	534	157	74.0	6.18	0.7609	Clayey dolomitic marl
109	550	162	61.6	7.66	0.7740	Clayey calcareous marl
152	572	170	136	3.62	0.7337	Clayey dolomitic marl
161	578	168	2160	0.225	0.7106	Clay
171	584	182	98.4	5.36	0.7442	Clayey dolomitic marl
185	602	218	42.7	14.9	0.8022	Carbonate clay
190	606	194	47.7	11.9	0.8013	Clayey marl
197	635	189	6680	0.082	0.7096	Carbonate clay
208	643	176	57.8	8.90	0.7705	Dolomitic calcareous clay
Subsalt sequence (borehole 802)						
42	169	174	34.8	14.4	0.8023	Mudstone-type clay
2A	174	316	44.3	20.8	0.8006	Clay
41	175	170	37.8	13.2	0.7970	Tuffaceous marl
39	212	136	35.6	11.2	0.7902	Kerogen-bearing clay
37	212.5	211	48.6	12.7	0.7913	Tuffogenic marl
3A	220	196	38.1	15.0	0.8058	Carbonate clay
4A	247	171	44.9	11.1	0.7824	Mudstone-type clay
5A	286	179	58.6	8.86	0.7645	Carbonate clay
6A	308	162	25.8	18.4	0.8243	Platy calcareous clay

The subsequent study of carbonate and, if possible, Rb-free sulfate, components of rocks provides additional independent data on the geochemical conditions and geological interpretation of the temporal signatures. Comparison with the K–Ar data makes it possible to refine the interpretation.

We studied marls and clays of nonsalt interbeds in the saliferous sequence. The nonsilicate (carbonate and sulfate) component of sample was separated and removed from the silicate constituent by dissolution in 2N HCl. Then, the silicate component of marls and clays was decomposed. Further, Rb and Sr fractions were separated by the chromatographic method. It is highly possible that minimal amounts of high-Sr minerals (celestine) could be preserved in the silicate component. The carbonate component was extracted from marls by the following procedure. Samples were treated with water on a vibration table to remove the possible sulfate admixture. The presence of sulfates was checked by reaction with barium chloride. After drying the samples, the carbonate portion was

extracted by dissolution in 2N HCl and analyzed with ion-exchange chromatography. The measurements were conducted on a MAT-260 mass spectrometer. The Sr isotopic composition and Rb and Sr contents were determined by the isotope dilution method. The measurement errors ( $\pm 0.0002$  for  $^{87}\text{Sr}/^{86}\text{Sr}$  and no more than 1.5% for  $^{87}\text{Rb}/^{86}\text{Sr}$ ) were controlled by measurements of the ISG standard (Vinogradov and Chernyshev, 1987).

The content of radiogenic Ar was analyzed by the isotope dilution method in 10–40 mg aliquots with a MI 1201IG mass spectrometric complex. Samples were melted at temperatures of 1600–1800°C. The content of radiogenic Ar was measured accurate to 1%. The fraction of atmospheric Ar was within 5–10%. The K concentration was measured with an accuracy less than 1% using an AAS-3 atomic absorber in the chemical-analytical laboratory of the Geological Institute of the Russian Academy of Sciences (I.V. Kislova, analyst). Error in the calculated K–Ar age (2.5–3.5%) was controlled by the convergence of



**Fig. 3.** Rb–Sr diagrams for the silicate constituent of marls, clays, and clayey carbonates. (a) Saliferous sequence of borehole 71; (b) suprasalt sequence of borehole 71 (Petrova et al., 2010); (c) suprasalt sequence of borehole 802. Open symbols denote samples omitted from age calculations. Numbers in plots denote the K–Ar datings of samples.

replicate measurements and reproducibility of the analyses of standard samples. Ages were calculated using the following constants:  $\lambda_e = 0.581 \times 10^{-10} \text{ yr}^{-1}$ ,  $\lambda_\beta = 4.962 \times 10^{-10} \text{ yr}^{-1}$ ;  $^{40}\text{K}/\text{K} = 1.167 \times 10^{-4}$  (Steiger and Jäger, 1977).

## RESULTS

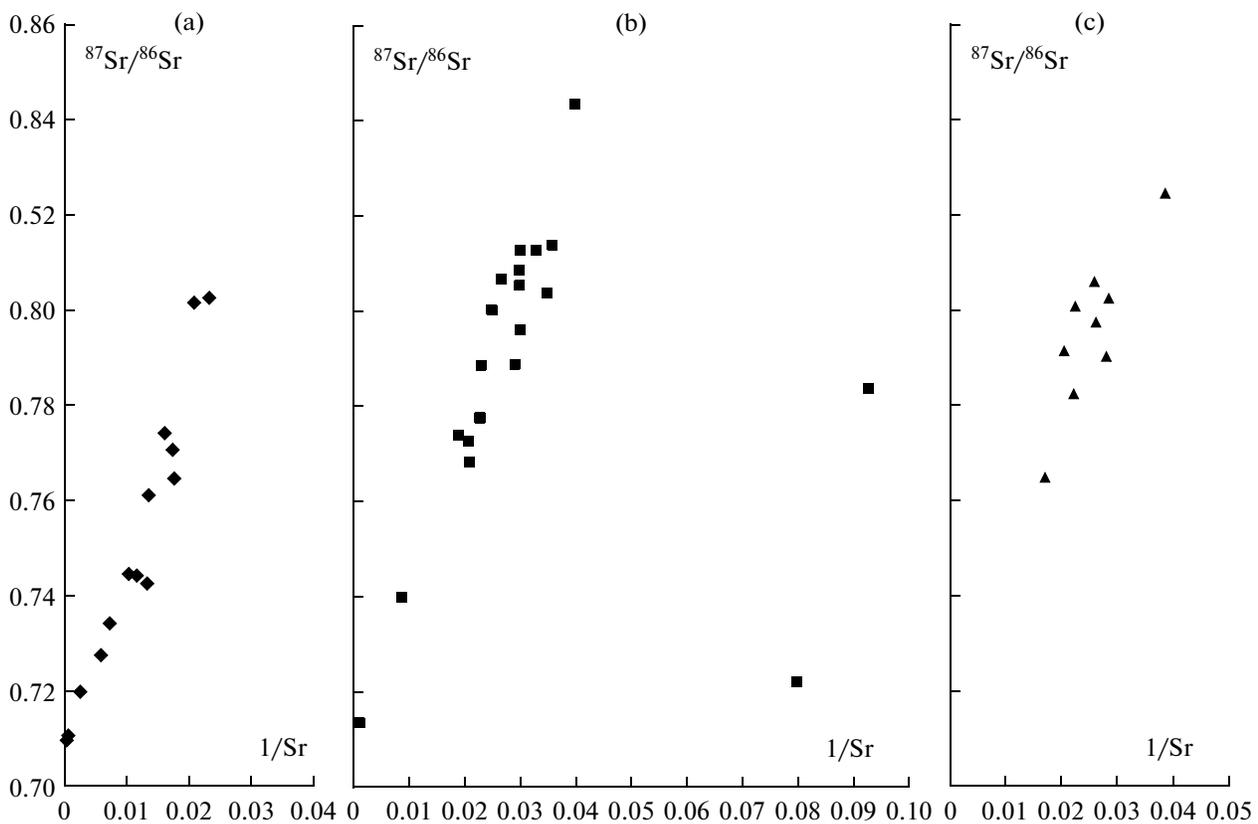
**Silicate component.** Rb–Sr systems were studied in the clay component of marl in all parts of the section: suprasalt sequence (boreholes 802 and 71) and upper salt sequence (borehole 71) (Table 1, Fig. 3). It is seen in Figs. 3a–3c that data points (with rare exceptions typical of sedimentary rocks) are grouped around lines with similar slope and initial ratio. Of course, these lines are not isochrons, but data points show a comparatively insignificant scatter around them. Their slope corresponds to the Ordovician value (452–473 Ma) with the initial Sr ratio of 0.7091–0.7099, whereas the stratigraphic age of this sequence is Upper Devonian (Famennian, 365–360 Ma).

Strong argument is required to interpret the dependences obtained as age data rather than mixing line. The simplest way to establish the presence or absence

of these dependences is plotting the  $^{87}\text{Sr}/^{86}\text{Sr}$  versus  $1/\text{Sr}$  diagram. The results of this test are shown in Fig. 4, where data points also define linear trends. It is naturally difficult to estimate the geological interpretation significance of these trends (Figs. 3, 4) for the considered multicomponent system.

It is very useful to apply a second geochronometer to substantiate the age interpretation. We studied the K–Ar isotopic system in the marl. We obtained the following results. Among the temporal signatures (Table 2, Fig. 3), many values are significantly older than the Famennian and some values correspond to the Ordovician. In the saliferous part of the section, the K–Ar dates are closest to the Rb–Sr values. Moreover, the suprasalt part of borehole 802 contains samples with the Devonian isotopic age. In other words, the K–Ar data are consistent and sufficiently similar with the Rb–Sr data. In our opinion, this is a serious argument in support of the validity of age interpretation.

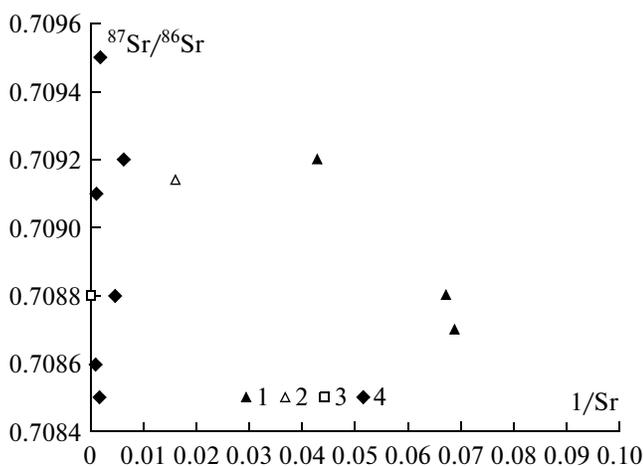
Note that the silicate component of marl is extracted in the course of Rb–Sr isotopic measurements by treatment in 2N HCl in order to remove the easily soluble carbonates and sulfates. It is suggested that this procedure does not destroy the silicate con-



**Fig. 4.**  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio versus  $1/\text{Sr}$  diagram for the silicate constituents of marls. (a) Saliferous sequence (borehole 71); (b, c) supra-salt sequence: (b) borehole 71, (c) borehole 802.

stituent of the sample. As to the K–Ar isotopic study, samples are usually washed only in water, because it is generally believed that the presence of carbonates does not affect the age estimates. However, we checked the

above assumption and revealed that the influence is notable in our case, probably, due to sample heterogeneity because of small weight of aliquot (10 mg) during the Ar isotopic analysis. This issue deserves further study, but it is beyond the scope of the given work.



**Fig. 5.**  $^{87}\text{Sr}/^{86}\text{Sr}$  versus  $1/\text{Sr}$  diagram. (a) Halite, (2) carnallite; (3, 4) nonsilicate constituent of marls and clays: (3) celestine, (4) carbonate.

*Carbonate constituent.* The initial Sr isotope ratio provides insight into the sediment formation or transformation environment. The parameters characterizing sedimentation settings or subsequent stages of transformations in the Rb–Sr system are deciphered from the rocks and minerals with the lowest Rb content in order to minimize the effect of gradual accumulation of  $^{87}\text{Sr}$ . Therefore, it is reasonable to compare the initial Sr isotope ratios obtained for the clayey material of marls with the isotope ratios in their carbonate part. For this purpose, we selectively analyzed the Sr isotopic composition in the carbonate component of marls and clayey carbonates in the entire suprasalt and salt sequence (Table 3). The results suggest the following conclusions.

First, isotope ratios in the carbonate component of marls and clayey carbonates vary from 0.7091 to 0.7083. Initial ratios in the linear dependences are slightly higher, but they overlap the isotope ratios in the carbonate component within the limit of accuracy (approximately 0.001).

Second,  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio shows no correlation with the Sr content in sample (Fig. 5), indicating the absence of contamination by the radiogenic Sr. Measurement in one celestine-bearing sample containing 4% Sr yielded the Sr isotope ratio of 0.7088 and confirmed this conclusion.

Third, the isotope ratio decreases with depth in the saliferous part of the section, except for sample 403 (borehole 714).

Fourth, all measured  $^{87}\text{Sr}/^{86}\text{Sr}$  values are higher than the seawater ratio, which is 0.70807 for the early Famennian (Van Geldern et al., 2006),  $0.7082 \pm 0.0001$  for the beginning of Famennian (Veizer et al., 1999), and  $0.70815 \pm 0.00003$  for the Famennian (Brand, 2004). It should be noted that determinations of  $^{87}\text{Sr}/^{86}\text{Sr}$  in the biogenic carbonates at the Frasnian–Famennian boundary are scanty, and accuracy of their age assignment is low. The figure adopted from (Veizer et al., 1999) in (Petrova et al., 2010) shows that the Sr isotope ratio in the Famennian is determined by extrapolation of the trend. Note that some authors have reported  $^{87}\text{Sr}/^{86}\text{Sr}$  values higher than those in (Veizer et al., 1999). For example, the study of two sections at the Frasnian–Famennian boundary in South China (Chen et al., 2005) showed that the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio varies from 0.7082 and 0.70915 in the boundary zone and further decreases to 0.7088. In the work dedicated to the isotopic study of the Upper Devonian carbonate rocks of West Siberia (Izokh, 2009), the Famennian limestones are characterized by the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.7086 and 0.7087. Note that plots of the Sr isotope ratio are based on the lowest Sr ratios for the given time. Therefore, we believe that the data presented in (Chen et al., 2005) and (Izokh, 2009) provide no grounds for revision of the conclusions in (Veizer et al., 1999).

Thus, our data presumably indicate that the saliferous sequence was formed in a basin with the Sr isotopic composition differing from that in seawater. The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio in the saliferous sequences turned out to be higher than in seawater because of the influence of continental circulating solutions, which can homogenize the Sr isotope ratio over the entire section. This possibility was also demonstrated for other saliferous basins (Hardie, 1996; Holland et al., 1996).

*Salts (Rb–Sr system).* We studied the Sr isotope systems in several salt samples: three halite samples and two sylvite samples from the saliferous part of borehole 802 (the so-called third potash horizon), one sylvite sample from borehole 975, and one carnallite sample from borehole 607. Isotope ratios obtained for the halite samples (0.7088, 0.7087, 0.7092) do not differ from the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio in the carbonate constituent of the marls. Celestine in the suprasalt sequence (sample 29) (Petrova et al., 2010) yielded an isotope ratio of 0.7088 and extremely high Sr content (4%). These results are important, because the Sr content in halites (Table 3) is 10n ppm. This value is several orders of magnitude lower than those in carbonates (aside

**Table 2.** Results of K–Ar studies of the Devonian marls from the Pripyat Trough

Sample no.	K, %	Ar, mm <sup>3</sup> /g	T/(Ma)	Treatment
Suprasalt portion (borehole 802)				
2a	6.94	0.104	350	HC1
2a	6.54	0.117	410	H <sub>2</sub> O
4a	7.07	0.122	395	HC1
5a	7.69	0.159	455	HC1
5a	4.4	0.0907	465	H <sub>2</sub> O
6a	7.04	0.11	360	HC1
6a	3.75	0.068	416	H <sub>2</sub> O
42	5.73	0.0857	345	HC1
42	3.89	0.066	390	H <sub>2</sub> O
Suprasalt portion (borehole 71)				
48	2.58	0.039	350	HC1
50	5.17	0.0895	398	HC1
80B	1.11	0.0271	540	HC1
Upper salt sequence (borehole 71)				
22	7.80	0.132	386	HC1
22	3.94	0.0715	415	H <sub>2</sub> O
24(2)	5.24	0.112	480	HC1
24(2)	4.25	0.0878	465	H <sub>2</sub> O
44	6.98	0.119	390	HC1
44	5.64	0.115	460	H <sub>2</sub> O
109	5.14	0.115	495	HC1
185	6.47	0.125	435	HC1
185	5.87	0.113	438	H <sub>2</sub> O
185	5.95	0.1167	445	H <sub>2</sub> O
190	6.21	0.125	455	HC1
190	4.43	0.103	517	H <sub>2</sub> O
208	6.31	0.122	435	HC1
208	4.63	0.0932	455	H <sub>2</sub> O

from celestine), indicating a similar source of solutions for different parts of the section. The nature of brines circulating throughout the studied section (suprasalt and salt sequences of the trough) is of great interest, since both chemical and isotopic characteristics of the brines reflect the degree of link between the evaporite and open marine basins.

In the  $^{87}\text{Rb}/^{86}\text{Sr}$ – $^{87}\text{Sr}/^{86}\text{Sr}$  diagram (Fig. 2a), data points of sylvite are plotted significantly lower than those of clays from the marls. The formal age value is within 100–120 Ma with a scatter of initial Sr values within 0.7084–0.7088. Similar cases were noted for evaporates from other regions (Chaudhuri and Clauer, 1992) and interpreted as evidence in favor of the loss of radiogenic Sr and Ar during the latest recrystallization in different tectonometamorphic processes.

**Table 3.** Sr and Rb contents and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio in the carbonate constituent of marls and in salts

Borehole no.	Sample no.	Depth, m	Horizon	$^{87}\text{Sr}/^{86}\text{Sr}$	Sr, ppm	Rb, ppm	$^{87}\text{Rb}/^{86}\text{Sr}$
Carbonates							
802	43	159	Polessk	0.70904	—	—	—
802	42	169	Polessk	0.70909	—	—	—
802	41	175	Polessk	0.7088	214	1.9	0.026
802	37	212.5	Polessk	0.7091	811	7.2	0.026
802	35	235	Polessk	0.70886	—	—	—
802	4a	247	Polessk	0.7090	—	—	—
71	80b	172	Polessk	0.7092	170.4	5.0	0.085
71	78	252	Polessk	0.7095	635	32.4	0.15
71	68b	371	Polessk	0.7086	1380	10	0.02
71	29*	425	Polessk	0.7088	>40 000	40	<0.001
71	22	458	Streshino	0.7085	600	5.2	0.020
71	44	502	Streshino	0.70889	—	—	—
71	71	520	Streshino	0.70861	—	—	—
71	109	550	Streshino	0.70893	—	—	—
71	171	584	Streshino	0.70902	—	—	—
71	197	635	Streshino	0.70868	—	—	—
714	322	834	Oressk	0.70869	—	—	—
714	392	890	Oressk	0.70842	—	—	—
714	394 (1)	891	Oressk	0.70834	—	—	—
714	403	894	Oressk	0.70932	—	—	—
Halites							
802	23.A	554	III p.h., USB	0.7087	14.4	0.16	0.032
802	6B-1	567	III p.h., CCB	0.7088	15.9	0.46	0.084
802	10B	572	III p.h., LSB	0.7092	23.4	1.34	0.165
Sylvites							
802	7B	569	Streshino, III p.h., USB	0.7194	8.55	18.6	6.32
802	11B	572	Streshino, III p.h., LSB	0.7210	10.1	33.0	9.49
975	5501	835	Streshino, III p.h. LSB	0.7254	7.45	21.1	8.21
Carnallite							
607	41	550	Polessk 0–15 p.h.	0.70914	62.4	14.1	0.65

Note: (LSB) Lower sylvinitic bed; (USB) upper sylvinitic bed; (CCB) clay–carnallite bed; (\*) celestine; (–) not determined.

## DISCUSSION

Thus, we can make the following conclusion based on the data mentioned above. Since the formation of rocks and during their subsequent geological evolution, their Sr and Ar isotopic systems partially preserved the provenance memory despite the unambigu-

ous influence of circulating solutions and other post-sedimentary alterations. Although indicated in the classical monograph (Faure, 1986) and in (Krasnobaev et al., 1986), this possibility was not studied so far in our works. Study of mudstones from the Ushakovskaya and Mot formations, as well as the silicate constituent of marls from the overlying Usol'e and

Bel'sk formations, from the Lower Cambrian saliferous rocks in the Irkutsk amphitheater yielded an age of  $580 \pm 20$  Ma (Vinogradov et al., 2006), which can be interpreted now as the provenance memory.

Of course, it would be incorrect to interpret the Ordovician age value as a direct indication of the provenance age, although this temporal signature was obtained for all three units of the section. Note that difficulties in interpreting the whole-rock age data on sedimentary rocks are discussed in (Clauer et al., 1992).

According to the existing concepts, rocks of the considered marginal zone of the Pripyat Trough are attributed to erosion of the Precambrian (rather than Ordovician) rocks during the accumulation of a thick sedimentary sequence in the rift graben (Makhnach et al., 1994). In this connection, the obtained data may be interpreted as the result of partial transformation of rocks during their evolution. This assumption is confirmed by the existence of a linear trend (Fig. 4), which could be explained by the mixing of clastogenic and authigenic components during the formation of the Rb–Sr isotopic system. Therefore, our data probably define an incomplete homogenization of the isotopic system rather than a certain temporal mark. The Ordovician value is consistent well with the presence of a long-term pre-Devonian interval, which is recorded in the Lower Paleozoic sections over the entire Baltic region.

Similar  $^{87}\text{Sr}/^{86}\text{Sr}$  values in the carbonates, halites, and celestine indicate that the saliferous complex was reworked by solutions. However, this process was not recorded in the Rb–Sr and K–Ar isotopic systems. The rocks were likely reworked in a shallow-water closed basin.

This conclusion is confirmed by the comparison of our initial Sr ratios with the values for the Famennian seawater. In order to understand the significance of this comparison, we should take the following point into account: the Sr isotope ratio in seawater was significantly modified during the Devonian; as mentioned above, the value available for the stratigraphic age of the rock complex was obtained by extrapolation; study of the Sr isotope balance in (Cendon et al., 2008) revealed the possibility of significant differences in the Sr isotopic composition between the shallow sea and oceanic water environments. Higher Sr isotope ratios in evaporite systems are likely related to the multiple recycling of brines.

## CONCLUSIONS

Thus, the Sr and Ar isotopic systems of marls from the saliferous and suprasalt sequences of the Pripyat Trough retained some provenance memory. Our data probably indicate incomplete homogenization of the isotopic system rather than a definite temporal signature. The saliferous complex was likely formed in a

shallow-water closed basin with the Sr isotopic composition differing from that in oceanic water.

Data presented in this work are preliminary ones. They should be confirmed by additional independent studies. However, they are of much interest even in the present form.

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