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"BAZHENOVITES" ON THE NORWEGIAN CONTINENTAL SHELF

V.M.Gavshin and V.A.Zakharov

The Late Jurassic - Early Cretaceous marine high-carbonaceous planktonic deposits covering the territory of more than one million square kilometeres in the central part of the Western Siberian plate and being known as "bazhenovites" pinch out northward. However quite similar deposits occur approximately 2,500 km north-westward in the Barents Sea within the limits of the Norwegian continental shelf. Here their base is somewhat lower in the stratigraphic scale so that they comprise larger stratigraphic interval. Planktonic deposits of the Norwegian continental shelf like bazhenovites of the Western Siberian plate are enriched to a more considerable extent by Mo, U, V, Cu, Zn, Ni, As, Sb, Se, Ag in comparison to normal clay. As it has been established as the result of studying deep-water sediments of the Black Sea, this is the association of the chemical elements that accompanies the organic matter penetrating into sediments from marine water. The alternative (clastophilic) association related to terrigenous material reflects the integral composition of the sources. Bazhenovites of the Norwegian continental shelf as compared to that of the Western Siberian plate are particularly rich in organic matter (V, Zn, Sb, Ag).

In the whole complex of the problems of global correlation of geological processes the study of "black shales" distribution in the sequences of the stratisphere takes an important place. If their formation associates with autochthonous planktonic sedimentation, then did it occur in different parts of the World Ocean at the same time and in strictly definite epochs or did it take place during the whole geological history in sedimentary basins which recurrently appeared in different places independently of each other? The answer to this question requires detailed correlation of the stratigraphic position and material composition of the largest "black shale" and "dominikoid" formations.

Interesting perspectives in this direction arose from boring on the Norwegian continental shelf in the Barents Sea that exposed Jurassic and Early Cretaceous high-carbonaceous rocks, indistinguishable by the major patterns from that of the Bazhenov suite of the Western Siberian plate situated approximately 2,500 km south-eastward.

The Bazhenov suite was identified for the first time by F.G.Gurari in 1959 as a member [18]. Subsequently it developed into the huge geologic body occupying the territory more than 1 mln. km^2 with average thickness of 28 m [14]. The rocks predominating in the suite are very typical by their habit: first they were described as "black and brownish-black mudstones, often platy, bituminous, with lot of fish remains, crushed shells of buchias, ammonites and rostrum of belemnites ..." [18]. However, it became clear later that the name "mudstones" is not at all adequate to their composition that varied within wide limits due to changeable content of three basic components: clayey material, sapropelic organic matter and biogenic silica [11, 12, 21]. In typical occurrence these deposits rich in organic matter are non-calcareous, hydrophobic and distinguished by higher radioactivity among country rocks.

In the discussion about the name for these rocks nothing better has been proposed up to now than the term "bazhenovites" suggested by N.B.Vassoevich [3]. The appearance of the new term in this case is justified entirely by typical habit and peculiar material composition of the rocks in the Bazhenov suite as well as by their global distribution; however abroad they would be undoubtedly named as "oil shale".

Autochthonous planktonic organic matter has been accumulated in epicontinental marine basin with normal salinity during the Volgian time and continued into the Early Berriasian; the bazhenovites are 28 m thick and comprise from the bottom to the roof 12 ammonite zones, which corresponds to 10-12 Ma. Slow warping of the basin floor was not compensated under the conditions of minimum supply of terrigenous material from the source areas, the sea depth was not less than 400 m and could reach 500-700 m [1, 10, 15, 21]; hydrogen sulfide contamination of the floor water is supposed but not proved [21].

The investigations of the Bazhenov suite were especially intensive after the commercial reserves of free oil has been discovered just in this very geological body in 1968 [14]. In 1984 the bibliography for "the Bazhenov suite" included already 354 references and since then the number of publications on this subject rose to a large degree. In 1971 I.I.Pluman showed that high radioactivity of bazhenovites is actually fully determined by uranium [17] (or, to be more precise, by its products of decay). Subsequently the sapropel organic matter from the Bazhenov suite was found to be followed along with uranium by Mo, As, Sb, Zn, V, Ni, Au, Ag, Cu, Ba, Se, Br; other elements associate mainly with terrigenous material [6].

The reasons of origin of two geochemical associations become evident if we appeal to the investigation of abyssal ooze of the Black Sea. In sapropelic ooze which N.M.Strakhov considered to be "subfossil pyroschist horizon" [19], organic carbon is accompanied by Mo, U, V, Cu, Ni, As, Sb, Br, i.e., these very "organophilic" elements, which are concentrated in bazhenovites. In this case they no doubt deposited from the marine water, which shows little difference in minor elements composition in comparison to that of the ocean. The alternative "clastophilic" geochemical association is related to the terrigenous material and reflects the integral composition of sources [8]. Apparently sapropel ooze of the Black Sea are recent homologues by its chemical composition to the bazhenovites which are distributed, we believe, not only within the limits of the Western Siberian plate (Fig. 1).

On the Norwegian continental shelf of the Barents Sea bituminous mudstones are exposed in the well 7430/10-U-I at a depth of 43.90-67.60 m. They show similarity with the rocks of the Bazhenov suite in many parameters, though the rocks of the lower portion differ from those of the upper one in this 25 m thick unit. The interval of 67.60m to 57.00 m comprises black to dark-grey thin-bedded occasionally earthy mudstones with uneven bedding surface, in places they are very similar to compact clays. They show rare thin (of shell thickness) concentrations of burried in situ shells of the bivalve mollusks-buchias, tentacle hooks of cephalopods (Onychites), the remains of the ammonites and rare fragments of fish bones. The interval 57.00m to 43.90m is characterized by black rock in places with brownish tint, thin bedded with even bedding surface. It contains abundant fragments of fish skeletons, closely scattered valves and the fragments of buchia shells and very rare impints of ammonite shells.

Five samples of these rocks were available (almost regularly distributed throughout 25 m interval) in order to answer the question how close they stand to bazhenovites by chemical composition. All analyses were made at the Institute of Geology and Geophysics, Siberian Branch of the Academy of Sciences of the USSR: X-ray fluorescent analysis was performed by A.D.Kireev, apparatus neutron activation analysis by V.S.Parkhomenko and atomic absoption analysis by L.N.Smertina. Metrological characteristics obtained from physical analyses accomplished for standard samples have been published in [4, 8, 16]. The analyses for bazhenovites and sapropel ooze from the Black Sea were made in 1979 and 1984 also by V.S.Parkhomenko and L.N.Smertina, respectively; statistical estimates were published before [6] became more complete and precise. The apparatus neutron activation analysis evaluates the amount of silver in pulse/s, however the amount of silver in two samples was

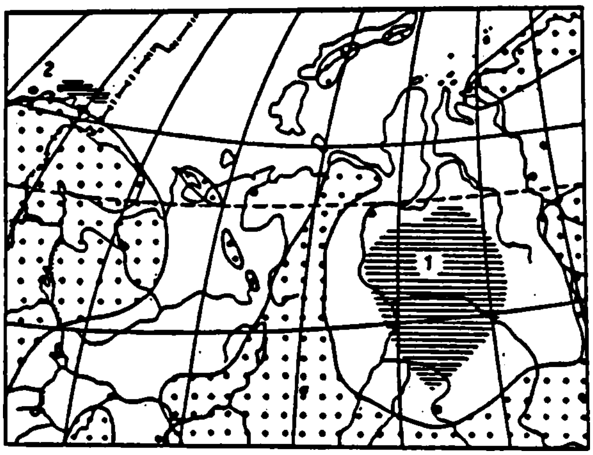

Fig. 1. Paleogeographic scheme of the northern Eurasia at the close of the Jurassic and beginning of the Cretaceous. Shaded are the areas of bazhenovites distribution. 1 - Western Siberia; 2 - Continental shelf in the Norwegian part of the Barents Sea.

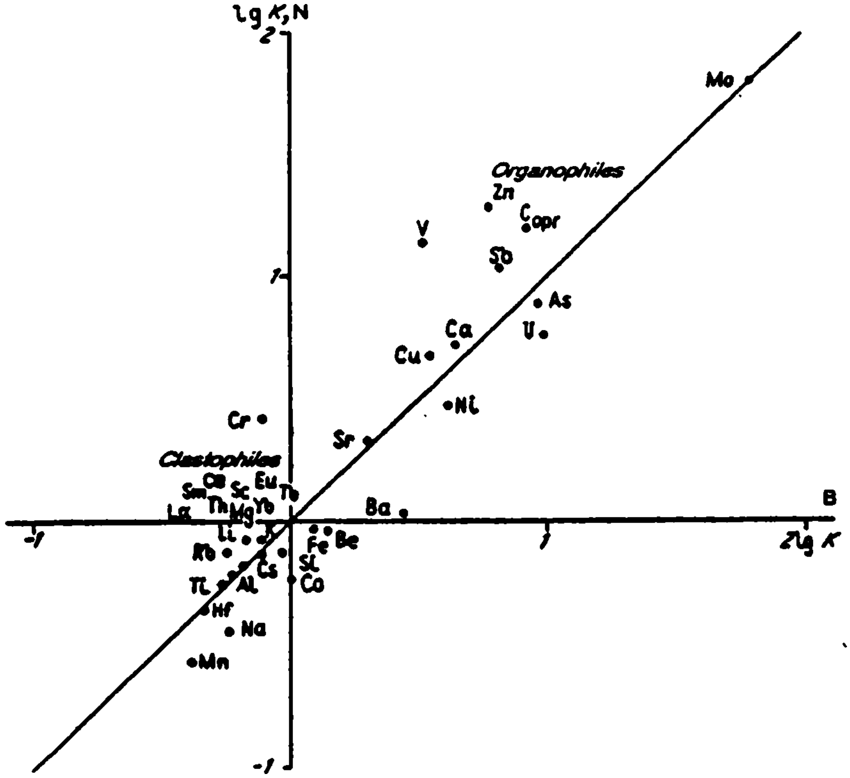

Fig. 2. The ratio of the coefficients of the elements concentration in planktonogene deposits of the Norwegian continental shelf (N) and the Western Siberian plate (B). The elements content are rationed based on the data on the Jurassic aleuropelites and mudstones [5].

evaluated by atomic absorption analysis, thus it has appeared to be possible to evaluate pulse/s in mass percent for the other three samples.

The estimates of chemical elements composition for Jurassic rocks of the Norwegian continental shelf and the Western Siberian plate are given in the table. Their common features are most vividly demonstrated on the graph (Fig. 2). In setting the standard in the content of each element in accord with estimates obtained for common mudstones it appeared that plankton bearing deposits of the Norwegian continental shelf and the Western Siberian plate are enriched by the same chemical elements and all these are the elements of organophilic association almost in the volume that was determined in investigating deep seated deposits of the Black Sea (the Jurassic mudstones of the Western Siberian plate for which earlier there were obtained more reliable estimates than published clarkes have been taken as the basis for setting the standard [5]). Although the rocks of the Norwegian continental shelf contain especially much C_{org}, V, Zn, Sb, Ag, these peculiar distinctions do not bring discord into general tendency.

In terms of the content of the elements from clastophilic association and also the nature of lanthanoids distribution, both plankton bearing deposits of the Norwegian continental shelf and bazhenovites practically do not differ from common mudstones (see Figs. 2, 3). Our data for the Western Siberian plate in comparison to known estimates [20] are distinguished to some extent by lower content of Ce and higher content of Sm (Fig. 4), which may be connected with the specific character of the analytical procedure. The coefficients of variation calculated for the content of clastophilic elements in rocks of the Norwegian continental shelf nowhere exceed 25% (apart from iron and cobalt); on the contrary this figure forms 42% for C_{org} and exceeds 50% and even reaches 95% for the organophilic elements, therefore one may conclude that change of chemical composition of these rocks is controlled by the variation in content of organic matter. With such large figures of variation coefficients and more than modest number of samples, confidence intervals for average content of organophilic elements make no sense, of course.

Table 1

Chemical Elements Composition of Planktonogene Deposits of the Norwegian Continental Shelf and the Western Siberian Plate

Component	1	2	3	4	5	Statistics according to data [1-5]	Statistics from [6]	Method of analysis
Li	39	35	38	27	30	34±6	27±3	AA
Na	0.65	0.55	0.59	0.66	0.60	0.61±0.06	0.95±0.11	NA
K	2.28	2.15	1.73	1.72	2.05	1.99±0.31	1.81±0.21	NA
Rb	110	110	109	73	72	95±25	90±12	AA
Cs	10.5	9.9	9.1	6.5	6.7	8.5±2.3	9.1±1.3	NA
Be	2.7	1.8	2.2	2.0	2.3	2.2±0.4	3.3±1.0	AA
Mg	-	0.95	-	-	0.80	0.88	0.80±0.18	XF
Ca	-	1.24	-	-	2.67	1.96	1.58±0.68	XF
Sr	270	240	240	290	300	268±34	248±37	AA
Ba	775	833	917	732	1203	892±232	2264±969	AA, NA
Al	-	6.88	-	-	5.66	6.27	5.92±0.59	XF
Sc	19.3	18.8	21.3	20.3	27.1	21.4±4.2	16.3±1.2	NA
La	44.7	41.8	40.8	27.1	30.2	36.9±9.6	27.1±3.4	NA
Ce	78.7	82.3	72.3	56.9	62.3	70.5±13.4	53.1±5.6	NA
Nd	37.8	44.7	35.0	33.2	35.6	37.3±5.5	-	-
Sm	8.7	11.3	8.1	8.9	9.4	9.3±1.5	6.3±0.7	NA
Eu	1.9	1.9	1.9	1.77	1.85	1.86±0.07	1.34±0.16	NA
Gd	6.5	7.9	7.2	6.0	7.2	7.0±0.9	-	NA
Tb	1.14	1.29	1.25	1.0	1.3	1.20±0.16	0.89±0.10	NA
Yb	4.12	3.38	4.27	3.83	5.38	4.20±0.92	3.23±0.35	NA
Lu	0.61	0.42	0.63	0.52	0.82	0.60±0.19	-	-
U	6.4	23.8	9.8	22.8	44.5	21.5±18.7	35.7±7.0	NA
Th	12.4	11.4	10.1	11.4	10.9	11.2±1.0	6.3±0.9	NA
Si	-	23.10	-	-	17.75	20.42	25.99*	
Ti	0.41	0.23	0.32	0.29	0.39	0.33±0.09	0.32±0.03	NA
Hf	3.57	3.46	3.65	2.14	2.72	3.11±0.81	3.13±0.42	NA
P	-	0.058	-	-	0.121	0.090	0.113*	-
V	269	1114	1432	2189	4723	1945±2112	461±149	AA
As	20.2	44.9	18.8	59.4	41.7	37.0±21.5	45.0±10.1	NA
Sb	2.4	7.4	2.1	26.3	22.7	12.2±14.3	6.9±2.4	NA
Ta	1.02	0.80	0.80	0.51	0.54	0.73±0.26	0.55±0.19	NA
Cr	207	158	289	228	414	259±122	78±11	AA, NA
Mo	10	90	6	228	270	-	123±27	AA
Mn	125	114	171	125	114	130±29	202±66	AA
Fe	2.87	4.45	2.01	2.61	2.51	2.89±1.16	3.85±0.63	XF,NA
Co	10.5	22.3	14.1	10.7	9.2	13.4±6,6	22.8±2.9	AA, NA
Ni	90	210	126	279	364	214±139	291±51	AA
Cu	100	120	118	265	346	190±136	136±18	AA
Zn	294	1727	545	4273	4090	2186±2364	659±186	AA
Ag	1.4**	2.2	3.5**	6.6	12.6**	5.3±5.7	0.39±0.16	AA
Pb	21	21	25	25	28	24±4	16±4	AA
C_{org}	9.69	11.07	12.02	22.16	23.09	15.61±8.0	7.98±1.26	-
Se	264	619	320	912	1504	-	-	NA

Note: The columns 1-5 present the analytical data for the samples from the Norwegian continental shelf (well 7430/10-U-1), taken at depths of 65,45 m (1), 61.05 m (2), 57.76 m (3), 50.40 m (4), 46.45 m (5); AA - atom-absorption, NA - instrumental neutron activation, XF - X-ray fluorescence. The contents of Na, K, Mg, Ca, Al, Si, P, Fe and C_{org} are given in percentage, other elements in g/t (Se pulse/s).

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* The contents of silicon and phosphorus in rocks of the Bazhenov formation are presented in accord with I.N.Ushatinskii [22].

** The content of silver is evaluated in pulse/s on the basis of two atom-absorption analyses (columns 2 and 4). The reliable intervals correspond to the value of 0.05.

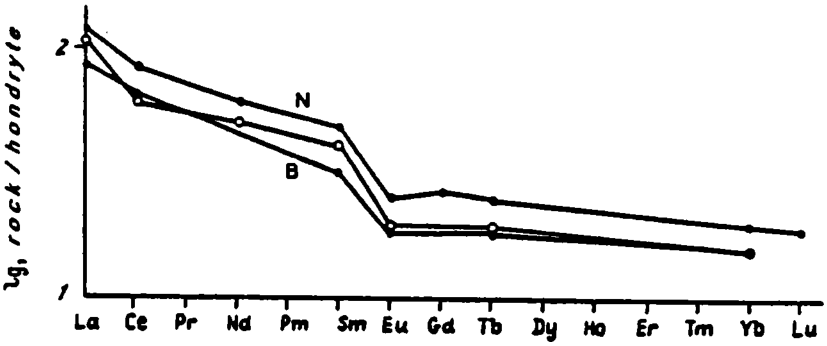

Fig. 3. Distribution of the lanthanoids in planktonogene deposits of the Norwegian continental shelf (N) and the Western Siberian plate (B). The circles show the placement within the Jurassic aleuropelites, mudstones of the Western Siberian plate.

Thus plankton bearing deposits of the Norwegian continental shelf do not differ from bazhenovites indeed in both chemical composition and external indicators. But what is their stratigraphic position?

The time boundaries for the Bazhenov suite are not generally accepted at present. Its old beds are assigned to the Lower Volgian substage (Fig. 5) according to the finds of very rare (only 2 cases!) ammonite genus of Pectinatites. However some reseachers assume younger thin beds which are attributed to the Lower Volgian substage to exist on the territory of Western Siberia though we have no material supporting to this [13].

The problem of the upper boundary for the Bazhenov suite is more complicate since in settled opinion of geologists it "is slipping" through the time from the east westwards within the stratigraphic interval of several ammonite zones. Within the limit of the Ob' meridional flow the Bazhenov suite continues into the Tutleimskaya suite (more shallow-water facies that is closer to the western removal source, i.e., Paleo-Urals) the lower stratigraphic boundary of which apparently coincides with the base of the Bazhenov suite and the upper one is in the middle of the Valanginian [1]. Within the junction of the formations bazhenovites display tongue wedging into the rocks of the Tutleimskaya formation which are characterized by essentialy lower content of bitumen, different values of borehole survey and low radioactivity [1].

Although the stratigraphic range of the Bazhenov formation does not coincide with that of the bazhenovites, their lower boundary on the territory of Western Siberia is everywhere not lower than the base of Pectinatites pectinatus zone (the upper zone of the Lower Volgian substage) and is obviously not higher than the Lower Valanginian (see Fig. 5).

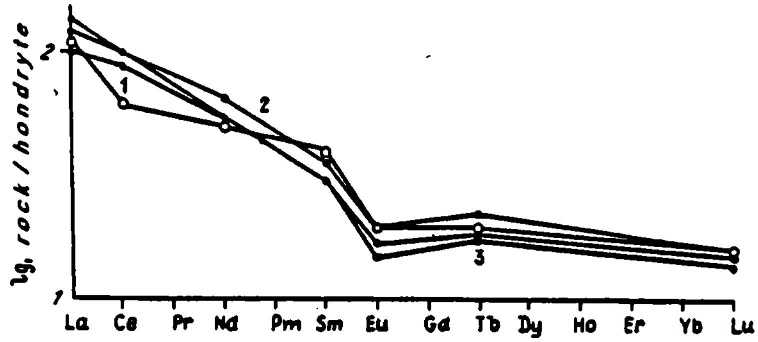

Fig. 4. Distribution of the lanthanoids in the Jurassic aleuropelites, mudstones of the Western Siberian plate (circles) in comparison with the data obtained for "clay shales of the North America" (1), "clay shales of the Europe" (2) and "Post-Archean clay shales of Australia" (3) [20].

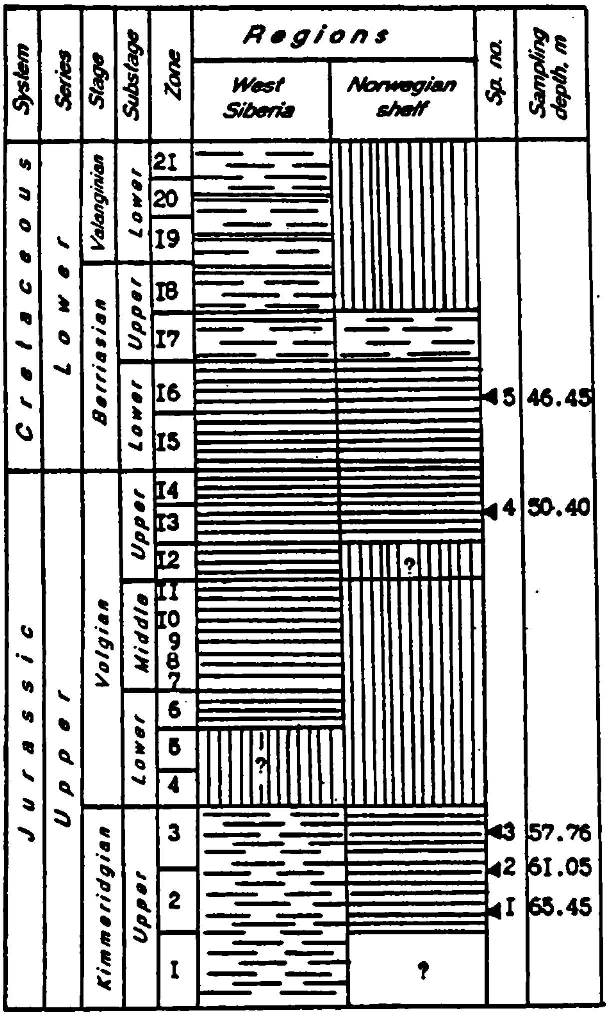

Fig. 5. Stratigraphic position of bazhenovites in Western Siberian and on the Norwegian continental shelf of the Barents Sea. The zones: 1 - mutabilis, 2 - eudoxus, 3 - taimyrensis, 4 - magnum, 5 - subcrassum, 6 - pectinatus, 7 - iatriensis, 8 - ilovaiskii, 9 - maximus, 10 - excentricus, 11 - variabilis, 12 - okensis, 13 - taimyrensis, 14 - chetae, 15 - sibiricus, 16 - kochi, 17 - analogus, 18 - mesezhnikowi, 19 - klimovskiensis, 20 - syzranicus, 21 - michalskii. Continuous horizontal lines show bazhenovites, broken lines - bituminous clays, vertical lines - stratigraphic hiatuses.

Bazhenovites of the south-western (Norwegian) portion of the Barents Sea display somewhat different stratigraphic position. They are included into bituminous member about 25 m thick (the interval in the borehole 7430/10-U-1 = 67.60–43.90 m) that forms the Hekkingen Formation.*

Its lower part (the interval of 67.60–58.00 m) is dated as the Upper Kimmeridgian on ammonites Amoeboceras (Amoebites) elegans (depth 67.25 m) and Streblites (= Oxydiscites) cf. taimyrensis Mesezh. (depth 62 m), Buchia mosquensis (depth 61.05 m and 57.48 m); the upper part of the formation (interval 56.73–43.90 m) is attributed to the Middle Volgian substage on the basis of bad preservation of the shells of the families Craspeditidae (depth 53.65 m), B.terebratuloides (depth 50.23 m); B.unschensis (depth 47.75–47.20 m), B.cf.

* The Hekkingen Formation description is given in accord with the account accomplished by SINTEF group under the guidance of N.Archus. Ammonites were identified by A.Wierzbowski (Warsaw University), buchias were identified by V.A.Zakharov (Inst. Geol. & Geoph., Siberian Branch of the USSR Acad. Sci.).

unschensis and B.cf. volgensis (depth 47.16 m and 44.45 m) and Subcraspedites (Borealites) sp. (depth 44.10 m). Within the limit of the bituminous clay in the Hekkingen Formation there was discovered the indication of only one hiatus (depth ≈ 47.00 m) and 10 m lower the large stratigraphic hiatus is recognized by paleontological evidence that corresponds to the Lower and Middle Volgian substages and to the base of the Upper Volgian substage.

It should be noted that significant stratigraphic hiatuses are often to occur in the Volgian and Berriasian clay deposits in the north of the USSR [13]. The Lower Volgian substage and most of the Middle Volgian substage are missing on the Nordwick (Paxa) peninsula [9], on the territory of Western Siberian as it was mentioned above, the Lower Volgian substage is almost completely omitted in the sequence, we come across such situation in Timan - Ural region; omissions may exist in the Barents Sea plate [2]. In all these regions however bituminous beds form stratigraphically single body. The well 7430/10-U-1 stripped the member of bazhenovites interrupted by a long time gap. The nature of interruption is not clear, though one can assert with a great degree of reliability that the interruption has occurred under submarine conditions.

The distribution of the bazhenovites into the Norwegian continental shelf again draws attention to the global geochemical role of autochthonous plankton-bearing deposits. The Bazhenov formation alone contains V ten times as much, Ni six times as much, Cu and Zn 2-3 times as much as that of all recent ocean; sixty percent of U, Mo, As, Sb of their quantity in the recent ocean. During the Late Jurassic epoch planktonic ooze in the north of Eurasia obviously transferred gigantic masses of the organophilic elements from the world ocean to sediments that decisively affected their global geochemical balance. As E.M.Galimov has noted the deposits of that kind occur at different stratigraphic levels in major oil and gas basins: within the Persian Gulf in the Callovian and Oxfordian, in the North Sea in the Kimmeridgian [7]. Their range in stratisphere have to be apparently evaluated.

CONCLUSIONS

1. Plankton-bearing deposits of the Volgian stage and Berriasian, i.e., bazhenovites widespread in the central part of the Western Siberian plate pinch out northward and eastward, however they occur again across the Novaya Zemlya in the Barents Sea, on the Norwegian continental shelf and possibly east of it.

2. In the Barents Sea the base of bazhenovites is lower in the stratigraphic scale than on the Western Siberian plate, where it is placed in the base of the Upper Kimmeridgian.

3. The bazhenovites of the Barents Sea like those of the Western Siberian plate are essentially enriched relative to common clay rocks by organophilic elements which accompany sapropelic organic matter: Mo, U, V, Cu, Zn, Ni, As, Sb, Se, Ag. This is the association of the chemical elements that came to planktonic sediment directly from marine water. The alternative "clastophilic" geochemical association was involved into the sediments with well homogenized terrigenous clastic material.

4. Against the background of similarity in minor elements composition of bazhenovites in the Western Siberian plate and the Barents Sea there are some differences: planktonic deposits of the Barents Sea contain lots of C_{org}, V, Zn, Sb, Ag.

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Institute of Geology and Geophysics,
Siberian Branch of the AS USSR, Novosibirsk