ORIGINAL RESEARCH ARTICLE

DOI: https://doi.org/10.18599/grs.2019.3.107-124

Coking coals of the Arctic zone of Russia

V.I. Vyalov[1,2,3], A.B. Gurevich[3], G.M. Volkova[3], D.A. Skiba[3], E.P. Shishov[3], A.A. Chernyshev[3]*

[1]*Lomonosov Moscow State University, Moscow, Russian Federation*

[2]*South Federal University, Rostov-on-Don, Russian Federation*

[3]*Karpinsky Russian Geological Research Institute (VSEGEI), St. Petersburg, Russian Federation*

Abstract. Rational and cost-effective development of the richest hydrocarbon resources of the Arctic region of Russia is impossible without the resumption of solid fuel production. On the Arctic coast of Russia there is the largest base of coking coals of valuable ranks, which requires the study and active development in the framework of the overall strategy of development of fuel and energy resources of the Russian North and, in general, the fuel and energy complex of the country. The most valuable in quality and properties deposits and basins of coking coals of the Arctic zone of Russia are considered. Among them are the Taimyr, Tunguska, Zyryanka and Bering basins. The features of coal-bearing, matter-petrographic composition and quality, the basic properties of coal of basins and promising fields, their resource and geological characteristics are given. Recommendations for their further study are given, the prospects of their development and transportation of coal along the Northern Passage are discussed.

Keywords: coal, coal deposits, the Arctic zone of Russia, coking coal, quality of coal, fossil fuels and energy resources, prognostic resources, mineral resources base

Recommended citation: Vyalov V.I., Gurevich A.B., Volkova G.M., Skiba D.A. Shishov E.P., Chernyshev A.A. (2019). Coking coals of the Arctic zone of Russia. *Georesursy = Georesources*, 21(3), pp. 107-124. DOI: https://doi.org/10.18599/grs.2019.3.107-124

To achieve profitability of development of new deposits of hydrocarbon raw materials in complex economic and geographical conditions of the Arctic, along with creation of new main roads and ways of transportation of hydrocarbon raw materials and the corresponding infrastructure, are impossible without development of a new strategy for fuel and energy complex (FEC) of the Russian Federation. This strategy requires mandatory accounting and accompanying development of deposits and basins of coal and oil shale in the Arctic zone of Russia. The Arctic zone is exceptionally rich in coals and oil shales with various quality and age (Dodin et al., 2007). Coals of the Arctic zone are necessary to ensure the infrastructure of the Russian fuel and energy sector in the northern country region. The coals of the Arctic can be used for export to non-CIS countries, since the end of the XX century coal consumption is rapidly growing in the world. In China, over the past 35-40 years, it has increased five times, four times in India, three times in Brazil. According to the forecasts of the International Energy Agency (IEA), coal use continues to grow on average by 1.5 % per year.

Figure 1 presents coal basins and major deposits located in the Arctic zone of Russia. Currently, the development of far coalfields in the Arctic is beginning. Mining and metallurgical company "Norilsk Nickel" made investments in the development of Syradasayskoe coal deposit of the Taimyr coal basin (prognostic resources of category P_2 of the Russian classification of coking and energy coals are more than 5 billion tons). A coal-preparation plant will be built at the deposit with a capacity of 12 million tons of coking coal per year. They plan to sell about 10 million tons of coal to Europe. At the same time, part of the energy coal from Syradasayskoe deposit will supply heat and power station of "Norilsk Nickel". China, the world's largest consumer of coking coal, could become the main direction of sales.

The coal terminal "Chaika" is under construction in 50 km from Dixon[1]. In 2019, the port will be able to overload more than 10 million tons by applying ships with deadweight up to 76 thousand tons with ice class of Arc4. In winter, under difficult hydrometeorological conditions, for further transportation of coal by the Northern Sea Route it is supposed to load two ships – CH-40 (Handymax type bulk carriers) and CH-70 (Panamax type bulk carriers).

[*]*Corresponding author: Evgeny P. Shishov*
E-mail: e-shishov@mail.ro.u

[1]https://www.korabel.ru/news/comments/samyy_severnyy_ugolnyy_terminal_zarabotaet_na_taymyre.html

The development of coking coals of Bering coal basin has also begun. From 2008 to 2015 the "Northern Pacific Coal Company" and "Beringpromugol", parts of Australian "Tigers Realm Coal", discovered four new coal deposits in Amaam (three deposits) and Alkatvaam (one deposit) coal areas[2].

It is obvious, that the main interest for development have deposits and basins of coking coal, if there is possibility to transport energy-technological raw materials from them by the Northern Sea Route. It is not excluded, that the initial delivery of coal can be made by major rivers with access to the Northern Sea Route during the navigation period[3].

Table 1, and Fig. 1 depicture quality of coals of the Arctic zone of Russia in contact of main coal ranks, basins, areas, fields, regions, deposits in conjunction with the characteristics of coal bearing and coal resources.

The West Siberian coal basin

In the Arctic region of the West Siberian petroleum basin, there are mesozoic sediments with hydrocarbon deposits containing a lot of coal seams. Figure 2 shows their total capacity in Jurassic and Cretaceous sediments by isolines (which, in some cases, border the zones of hydrocarbons). The Paleozoic coal-bearing sediments are locally below. Therefore, a number of researchers (Zvonarev, 1982; Golitsyn et al., 1992; Yuzvitsky et al., 2000) identify a huge West Siberian coal basin, geographically coinciding with the West Siberian Plain and entirely corresponding to the West Siberian hydrocarbon basin.

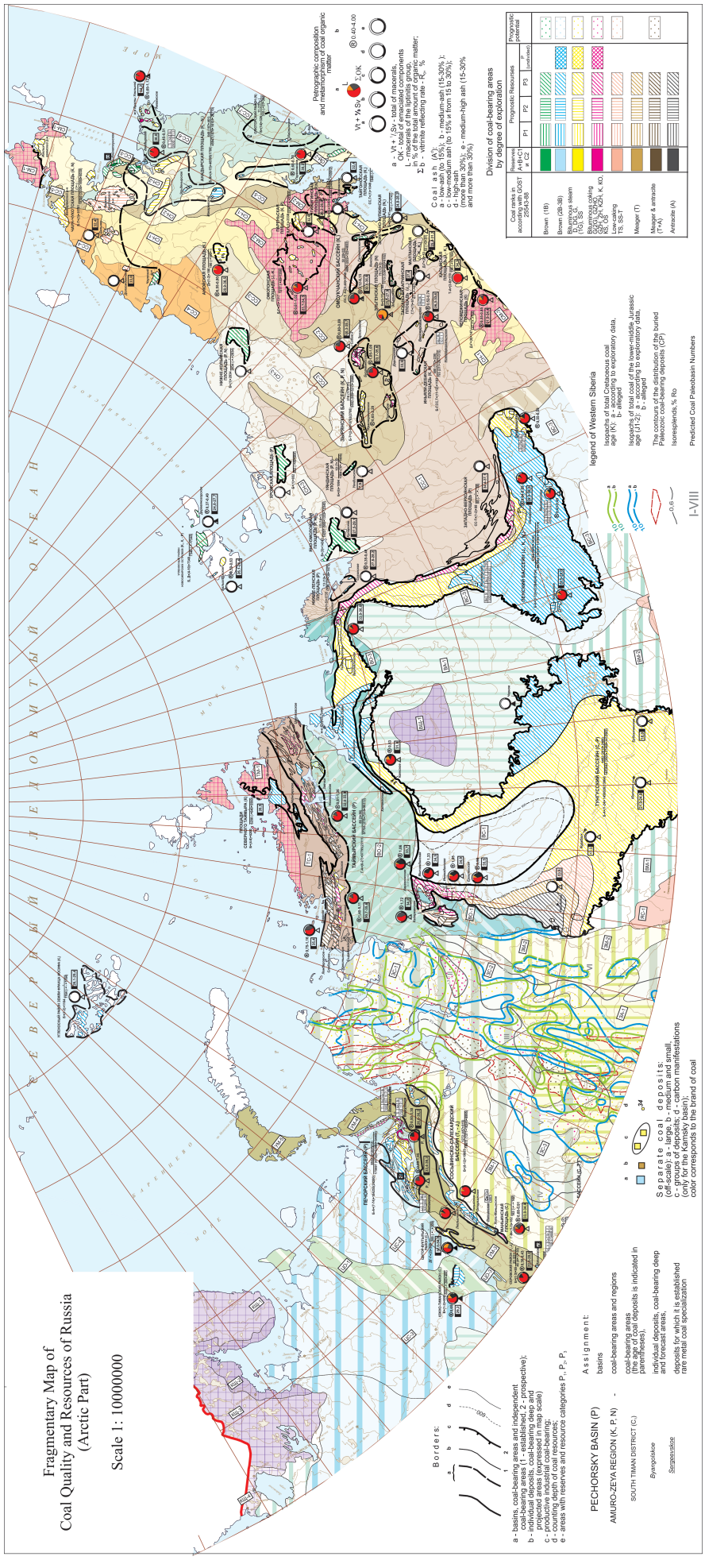

Fig. 1. Fragment of the map of coal-bearing, quality and resources of the Arctic zone of Russia (Petrological Atlas …, 2006, Appendix 1)

[2] http://www.prochukotku.ru/20161126/1774.html

[3] Coking coals of the Pechora basin, located also in the Arctic zone of Russia, developed since 1931, and are not considered in this article

Basin, area, region, deposit	According GOST 25543-2013			Ro,%	ΣFC, %	V^{daf}, %	y, mm/ RI, un	W^a, %	A^d, %	(A_k^d), %	S_t^d, %	Q_i^r, MJ/kg	Q_s^{daf}, MJ/ kg	C_0^{daf}, %	H_0^{daf}, %
	Rank	Group	Code												
The Pechora basin															
Vorgashorskoe	G-ZH	(1-2) G, 1GZHO, 2ZH		0,78-0,88	16-35	32-37	6-20	2,7	20,7	9	0,5-2,2	21-27		81,9	
Yun`yaginskoe	K, KZH	1K		1,2-1,3	17-21	23-26	13-31	1,0	17,1	8	0,8	24		87,6	
Verhnesyr`yaginskoe	KS, OS, T			1,49-2,39	8-25	9,1-20	0-10	1,0	16,5	8-13	0,3-1,3	27-30		90,4	4,2
Nizhnesyr`yaginskoe	ZH, KZH			0,85-1,0	14-33	28-36	18-30	1,4	18,5	8-11	0,6-1,7	26		86,2	
Paemboyskoe	GZH			0,76-1,14	19-33	34-39	23	2,8	19-35	15	0,4	23		82	
Yangareyskoe	OS				20	21	8	0, 9	26-44		0,45		35,3	88,8	
Verhnerogovskoe	B, D	3B, -		0,5	26-44	37									
The Sos`va-Salekhard basin	B	2B, 3B							16		0,3	13			
Tol`inskoe	B	2B							17		-	11,7			
Otor`inskoe	B	3B							21,6		0,36	13,4			
The Taimyr basin															
Slobodskoe	A, T			3,25	32	4-12		2,8	20,2		1,48		34,0	92,2	2,5
Syradasayskoe	G-SS			0,75-1,16	0-69	9,5-44,3	8-35	0,2-9,9	5,8-42,5		0,2-4,1		35,4	79,3-92,6	2,8-5,8
Ozernoe	KS-T			1,11-1,05		8-35	0-13	2,1	14,7		0,5		33,3	78,3	4,2
Pyasinskoe	KS-T, A			1,4-5,1	1,25	5-44,3	0-8	0,5-5,5	7-45		0,65		33,2	85,7-95,8	0,9-5
Tareyskoe	G-GZHO			0,7-1,0	44	37,5	9-15	1,45	11,6		0,17		34,1	82,0	4,6
Seregen	A	3A	5010570	5,9	16	4,1		1,0	12,5		0,09			95,1	1,2
Zayach`e	K-KS					26-31	5-16	2,6	5,6		0,46		33,3	83,0	4,8
Chernoyarskoe	K-OS					21-29	5-16	3,3	7,1		0,37		32,9	82,8	4,6
Tsvetkovskoe	G-OS								16,8		0,56		34,5		
North Taimyr: Tsyganskoe Serdtse	B	3B				47		14,3	10,3		1,3		26,7	73,5	4,3
The Tunguska basin:															
Daldykanskoe	ZH, K														
Kayerkanskoe	KO, KS								20,4		0,66		33,9		
Listvyano-Valkovskoe	KO, SS	2KO,2-3SS													
Norilskoe	-"-								20		1,1	24			
Imangdinskoe	ZH, K, OS	(1-2) ZH				26,9	6-19	1,9	16,1		0,41		33,8	82,7-92,8	
Kayakskoe	D, SS					45,2			7,0		0,43		32,1	75	
Kureyskoe	T, A					5,2-12		6,3	12,1		0,3		32,7	89-96,3	
Mikchandinskoe	D-T					12-39		1,5-5,5	4,8-42,6		-		30,7-35,3	75-89	
Khatangskoe	B	3B							-						

Table 1. Quality of coals of the Arctic zone of Russia in contact of main coal ranks, basins, areas, fields, regions, deposits

Syndaskoe	B	3B													
Yuryung-Tumus	B	2B-3B													
Yuzhny Tigyan	B	2B							3,0		0,5	9,0			
Tiksinsky region															
Buokalaahskoe	D								28,0		0,4				
Taimalyrskoe	D					40		4,9	6,5		0,3		32,0	78,9	
Chai-Tumusskoe	G, ZH					35,7-37,5		1,7-2,8	6,6-10,9		0,42		33,6-35,7	83-85,7	5,6-5,8
The Zyryanka basin:															
Tikhonskoe	G-OS								14,1		0,46		31,3		
Sibik-2	GZHO		08_3610	0,8-0,89		32-39	8-12	1,7-3,0	12,2		0,25	27,2	33,7	82,3-85,5	5,3-6,2
Erosionnoe	ZH-K		1023023	1,0-1,1	10-34	28,6-32	17-28	1,2	14,5		0,27	26,2	35,0	85,8	5,6
Buor-Kemyusskoe	GZHO		0813012	0,87	16-20	30,7-31,5	11-13		12-14		0,3-0,4	24,5	35,4	75,8-85,5	5,3
Anyuiskaya	D														
Yablonskoe	T	1T, 3SS							15,4		0,77		35,5		
Eldenyrskoe	D				5-43				17,0		0,6	16,0			
Rarytkinskoe	B, D					44		5,9	22,3		1,0		30,5	74,7	5,7
Anadyrskoe	B, D	3B,-	0302010(B)	0,35-0,49	0-2	47		5,5	6-21,3		0,6	19,8		74,5-77,6	5,6
Koinatkhunskoe	B	1B				54,8-55,6			10,8-20		2,0	7,8		62,3-63,2	4,3-5,6
Bukhta Ugolnaya	G	1G-2G		0,66-0,95	2-22	43,3	10-18	1,8	8,2		1,86		32,7-35,6	81,0	5,9
Amaamskoe	ZH-T					31		2,9	17,9		0,76		31,1	81,0-79,5	5,2
Dolgozhdannoe	T, SS					7-29		0,5-	7,2		0,68		32,3	75,7-90,1	2,7-3,0
Dal`nee	SS, T,A					4-29		1,1-4,4	7,2		0,76		31,2	81,7-93,6	1,3-3,7
Zaliva Kresta	D														
Verhne-Amguensky	D														

Continue Table 1. Quality of coals of the Arctic zone of Russia in contact of main coal ranks, basins, areas, fields, regions, deposits

Mainly, there are low-metamorphized bituminous coals, but presence of sintering characteristics in them is not excluded. Figure 2 shows the paragenetic relationships of coals and hydrocarbons (Petrological Atlas..., 2006).

A number of coking coal deposits has been identified in the upper Paleozoic sediments of Taimyr and Tunguska basins in the Krasnoyarsk Krai (Fig. 3). The prognostic resources of coking coal, mainly of high-value ranks, amount to 37 billion tons here (Table 2).

The Taimyr coal basin belonging to the area of distribution of Permian coal-bearing strata is in the form of a sub-latitude strip with a length of 1000-1100 km and a width of 100-150 km, crossing the entire Taimyr Peninsula from the Yenisei Bay in the West to the sea coast of Laptev Sea in the East.

From the North, according to the fault system, it is limited by the field of development of the lower and middle Paleozoic formations. Its southern border conventionally draws a line within the Northern side of the imposed Yenisei-Khatanga deflection, where the Upper Paleozoic and Lower Triassic sediments are buried under the sediments of the Meso-Cenozoic.

The area of Taimyr coal basin is about 80 thousand km^2. Structurally, it belongs to the Taimyr Fold System. Tareysky lifted block divides the basin into two separate areas: Western and Eastern Taimyr coal-bearing areas localized in the eponymous tectonic depressions.

Coking coals predominate in Syradasaiskaya coal-bearing area and Tareyskoe deposit in the West-Taimyr region, as well as in Chernoyarskoe and Zayach`ya River deposits, Uglenosnaya River and Tsvetkov Cape coal-shows in East-Taimyr region. Besides, bituminous coals with medium and low volatile ("KC" and "TC" coal ranks according to GOST 25543-2013) present in Pyasinskoe and Ozernoe deposits (West Taimyr), among the predominant of low-caking coals and semi-anthracites.

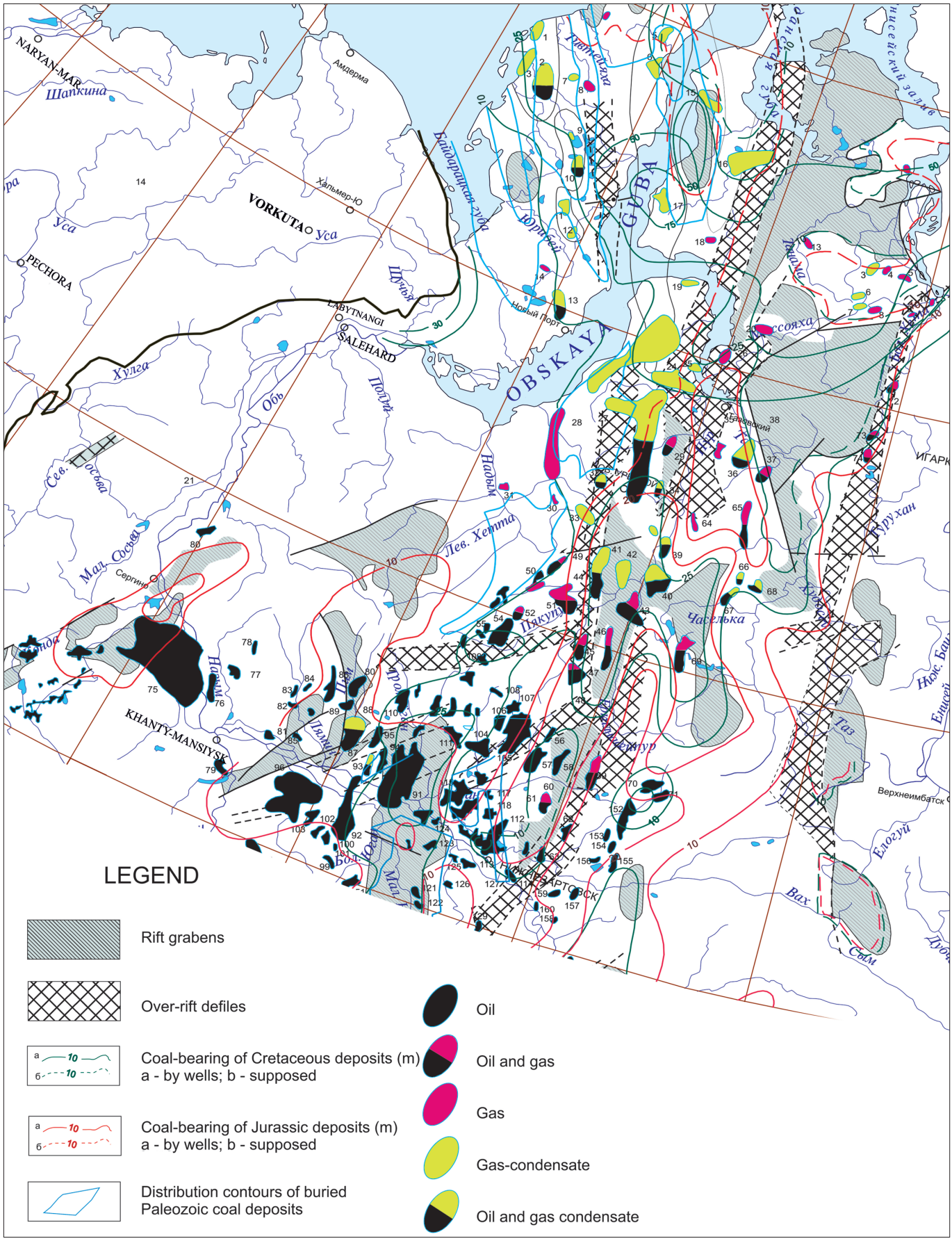

Fig. 2. The relationship of hydrocarbons and coal objects (in the contours of the total thickness of the Cretaceous, Jurassic coal seams + deeply buried Paleozoic coal-bearing strata) in the north of the West Siberian petroleum province

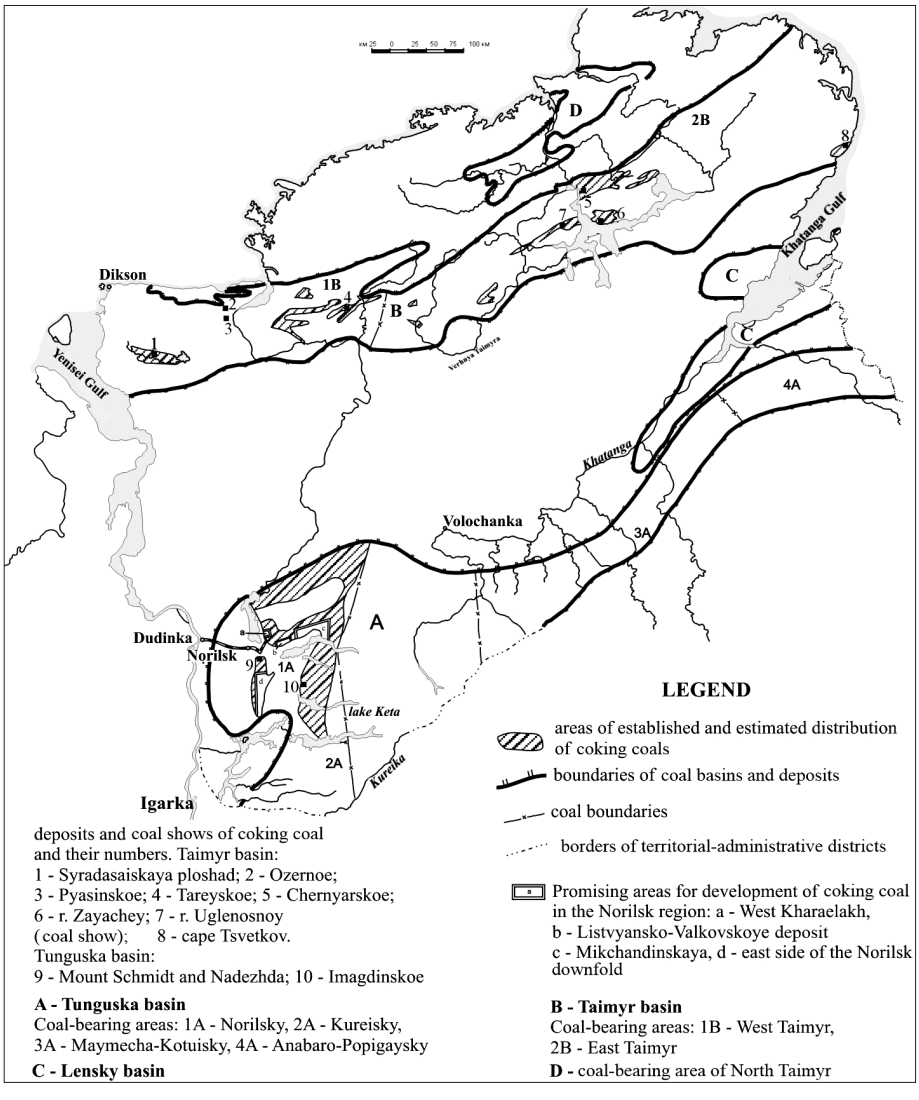

Fig. 3. Distribution scheme of coking-coal deposits in the northern part of the Krasnoyarsky Krai

Basin, region	Estimate depth	Coal rank	Common Resourses	Balance Reserves			Prognostic Resourses			
				Total	By Category		Total	By Category		
					A+B+C_1	C_2		P_1	P_2	P_3
	0-600	G	1299	-	-	-	1299	-	230	1069
Taimyr basin	0-600	GZHO, GZH, ZH, KZH, K,	10347	-	-	-	10347	-	2833	7514
	0-600	KO, KS, OS, (TS)	11465	-	-	-	11465	56	2227	9182
Total: coking coals	0-600	G-TS	23111	-	-	-	23111	56	5290	17765
Tunguska basin	0-600	GZHO, ZH	7444	244	151	93	7200	-	3200	4000
Norilsk region	0-600	K, KO, KS	6520	-	-	-	6520	120	5700	700
Total: coking coals	0-600	GZHO-KS	13964	244	151	93	13720	120	8900	4700
Total:	0-600	G	1299	-	-	-	1299	-	230	1069
Taimyr	0-600	GZHO-KZH	17791	244	151	93	17547	-	6033	11514
District	0-600	K-TS	17985	-	-	-	17985	176	7927	9882
Total: coking coals	0-600	G-TS	37075	244	151	93	36831	176	14190	22465

Table 2. The prognostic resources of coking coal of the Taimyr District of Krasnoyarsk Krai (million tons)

All of these coal objects are studied insufficiently, there are no proven deposits with balance (economic) reserves, permanent population and roads on this territory are absent.

The Syradasayskoe deposit contains valuable coking coals. It is located in the West part of the Taimyr Peninsula, approximately 60 km from the Yenisei Bay and 110-120 km from the urban-type settlement

of Dikson. There is presence of coal beds in the sequence of Efremovskaya, Uboyninskaya, Krestyanskaya and Makarevich-Brazhnikovskaya formations. The Efremovskaya formation is a lower coal-saturated part of the coal-bearing assemblage. In the central part of Syradasayskaya area the most complete views of the coal-bearing formation is represented. It is studied by full sections of wells 1, 3, 4 and 5. The character of coal bearing in the East is obtained by well 8. The upper, most coal-saturated part of the formation has been opened by wells 16, 17 and 18 in the West. The well 14 highlights the lower, less coal-bearing part. The height of coal seams of the formation varies from 0.2 to 5.3 m. Uboyninskaya formation includes 10 coal beds with simple and complex structures. Its height varies from 0.2-0.4 m up to 12.1 m (in terms of coal). Coal-bearing of Krestyanskaya formation is low (6 beds – from 0.3 to 1-1.6 m). Table 3 presents metamorphism and rank composition of coals of Syradasayskoe deposit.

Metamorphism of coals of Syradasaiskoe deposit is determined not only by the stratigraphic depth of the strata position, but also increases in the East-West direction. Table 4-5 shows quality indicators of coals of different stages of metamorphism and ranks.

Composition of coals ash: SiO_2 – 49-62 % и Al_2O_3 – 14 23 %. Iron oxides are from 3,5 to 6,8 %, TiO_2 – 0,7-1,2 %, CaO – from 6,7 to 16,7 % with the mass values about 10-12 %; MgO – 2,1-5,0 %; SO_4 – 4,3-8,2 % with means about 4-6 and anomalous value to 15 %; P_2O_5 – 0,1-1,7, often less than 1 %; K_2O ~ 0,6-1,3 with anomalous contents 2,4 %; Na_2O – 0,2-3,0 %.

Index of coal seams	Districts					
	"Zapadny"		"Tsentralny"		"Vostochny"	
	Stage of Meta-morphism	Coal Rank, Coal Group	Stage of Meta-morphism	Coal Rank, Coal Group	Stage of Meta-morphism	Coal Rank, Coal Group
m_1	III	1ZH	II-III	-	II	G
k^2_4		ZH		-		-
k^1_4		1ZH		-		-
k_3		ZH		-		2G
k_2		1 ZH		-		2G
k_1		-		-		2G
u_{10}		KZH		2ZHV		2G-GZH
u_9		-		2ZHV		-
u_8	III-IV	-		GZH		2G
u_7		-		GZH		-
u_6		-		GZH		-
u_5		-		GZH		-
u_4		KZH	III	ZH		2G
u_3		KZH, KF		KZH		-
u_2	IV	1KB	III-IV	-	III,III-IV	-
u_1		-	IV	-		-
e_{11}		-		K		-
e_{10}		-		KZH-KO	IV	KSN
e_9		1SS, KSF		K-KSN		.
e_8		1KV		1K-2KCH		-
e_7		KS		KO		-
e_6	IV-VI	SS		K-KO		-
e_5		K	IV-VI	1SS		-
e_4		T		T-SS		-

Table 3. Stages of metamorphism and rank composition (according to GOST 25543-2013) of coals in the districts of Syradasayskoe deposit

Coal resources. Estimation of prognostic resources of coal is implemented according categories P_2 and P_3 (Russian classification) in different sites of the area up to depth of 600 m, depending on the degree of their study.

Coal seams with coals of low-caking ranks (according to GOST 25543-2013), with a width of 0.7 m and above and with an ash content below 25 % are accepted as qualified for coking and coal seams with a capacity of 0.8 m and above and ash content up to 40 % are usable for energy purposes, by analogy with the Pechora basin both.

For calculating the prognostic resources, the correction factors of 0.6-0.8 on erosion and attenuation of coal seams, influence of intrusions of traps and the position of coal seams to a depth of 600 m were taken.

Total prognostic resources of the Syradasayskoe deposit are 5,678 billion tons, of which qualified coking coals – 5,298 billion tons, including the categories P_2 – 3,898 billion tons and P_3 –1,400 billion tons.

The Tunguska coal basin is located in the Krasnoyarsk Krai (90 %), partly in the Sakha Republic (Yakutia) and in the Irkutsk Oblast. The area of basin is more than 1 million km^2. The basin is located in remote areas and therefore poorly studied. Exploration work has been carried out on disunited areas. Balance reserves (A+B+C_1 categories of Russian classification) are about 2015 million tons, balance estimated reserves (C_2 category of Russian classification) – 2466 million tons. The basic proved fields in the Norilsk district are Kaierkanskoe, Daldykanskoe, the Norilsk-I and Imangdinskoe deposits, in the North-East part of basin there is Kayakskoe deposit.

Coals were discovered in the sediments of middle and upper Carbon, Permian, Jurassic and Paleogene.

The main coal bearing is associated with continental sediments of Perm and Carbon with a capacity of 350-1460 m. They compose large flat structures in the sedimentary cover of the Siberian platform. The sediments are overlain by tuff and lava strata with thickness up to 1500-2000 m of and broken by intrusions of igneous rocks.

All coking coal resources of the Tunguska basin are localized in the Norilsk industrial district. It is known that in the 40-60-ies of the last century, these coals were used for the production of conditioned metallurgical coke, which was used for smelting of non-ferrous metals at the Norilsk mining and metallurgical plant. The coke was burned from the coal seam "The First" of the Cayercan formation, and was mined in the "West-coke" mine of Schmidt and Nadezhda mountains. With the thickness of the plastic layer of the initial coals of 7-9 mm, the drum sample was 250-270 (kg), with the

Stage of metamorphism, coal ranks	R_o	V^{daf}	C^{daf}	H^{daf}	N^{daf}	Q_s^{daf}, MJ/kg
	%		%			
II (G)	0,74-0,86	37,1-44,3	79,4-83,2	5,4-5,6	1,64-2,53	33,07-35,12
II-III (GZH)	0,8-0,96	30,6-36,1	83,5-86,2	5,2-5,5	1,6-2,06	35,02-35,63
III (ZH)	0,89-1,11	30,0-35,9	79,3-86,6	5,1-5,5	1,7-2,4	33,76-35,35
III-IV (KZH)	0,88-1,14	26,5-31,7	86,6-87,2	5,0-5,5	1,7-2,3	35,09-35,55
IV (K)	1,10-1,23	22,1-28,5	80,9-89,5	4,3-5,0	1,8-3,0	34,46-35,56
III-V (SO)	1,06-1,54	18,2-26,1	85,1-88,9	4,0-4,9	1,2-1,9	34,39-35,31
VI (T)	1,92-2,21	7,9-18,2	89,1-93,2	1,4-4,1	0,6-2,3	30,35-35,07
VII (A)*	2,52-5,51	5,6-18,3	85,1-94,5	1,4-2,5	0,9-1,4	32,15-33,87

*Table 4. Coal quality indicators of different stages of metamorphism and ranks. * Anthracites are only in the zones of thermal influence of intrusions.*

Formations	Districts		
	"Zapadny"	"Tsentralny"	"Vostochny"
Krestyanskaya	16,5-38,3	-	18,3-21,4
Uboininskaya	14,8-25,5	12,6-20,7	12,6-24,3
Efremovskaya	10,2-33,8	10,0-28,9	9,9-30,4

Table 5. Ash content (%) of coals in the coal-bearing formations and districts of the Syradasayskoe deposit

thickness of 11-14 mm the drum sample was 310 (kg). Pilot scale testing of coals of Listvyanka-Valkovskoe and Imangdinskoe deposits gave positive results for coking.

However, due to the occurence of the thermal contact metamorphism, which worsens the sintering properties of coal, there was a misconception about the unsuitability of coal of the Tunguska basin for the production of conditioned metallurgical coke. Thermal metamorphism, widely occurred in the Norilsk region, caused the formation of coking coals. Coking coals of the Witbank basin (South Africa), the nearest analogue of Tunguska basin (by geological structure and saturation by dolerite intrusions), is exported to EU countries in large volumes. Petrographic types of coal of Norilsk region shown in Fig. 4.

General evaluation of the perspectives of the Norilsk region on coals of coking brands. The coking coals of Norilsk district belong to the following ranks: High Volatile B Bituminous, High Volatile A Bituminous, Medium Volatile Bituminous, Low Volatile Bituminous ("GZhO", "Zh", "K", "KO", "KS" according to GOST 25543-88). Their marking according to GOST 25543-88 was performed in the Department of Fossil Fuels of FSBI "VSEGEI".

The areas of the established and expected distribution of coals of various ranks are confined to the sides of Kharaelakh and Norilsk downfolds, as well as to the northwestern wing of the Tunguska syneclise. High volatile B bituminous and high volatile A bituminous coals ("GZhO", "Zh") predominate on the East wing of the Norilsk downfold, on the north of the Kharaelakh downfold and on the East outskirts of the district (Tunguska syneclise). Medium volatile bituminous and low volatile bituminous coals ("K", "KO", "KS") predominate on the southern outskirts of the Kharaelakh downfold and on the northern closure of the Norilsk downfold (Fig. 5).

Imangdinskoe deposit is located 85-90 miles east of Norilsk, is separated from it by full off-road and by a wide valley of the Rybnaya river. It is unlikely to be of industrial interest in the nearest future. A similar conclusion follows in relation to remote and hard-to-reach areas in the North and East of the district.

The objects close to the transport infrastructure of the West part of the Norilsk industrial region are promising for the creation of the raw material base of coking coal. The order of the development is dictated, in addition, by the degree of their study. It includes the following objects.

Listvyansko-Valkovskoe deposit is located about 25-35 km northeast of Norilsk and about 10 km of Talnakh. Along the extention of the upper Paleozoic coal-bearing sediments, its length is 22 km, width 500-1500 m, its area is about 20 km^2. Coal-bearing mass with an average width of 210 m reaches the daily surface on the southern slope of the Haraelah Plateaus. It concludes 5-6 working seams grouped into two productive horizons: the lower, in Daldykanskaya formation (P_1) with 2 layers, mainly of medium width, and the upper, in Kaierkanskaya formation (P_2) with three layers, which width is about 1.5-8.2 m and an average total capacity of 11.7 m.

Ditches, pits, galleries and holes drilled from the surface and from the mine workings, opened all target coal seams.

Coking coals, which are localized mainly in Kaerkanskaya formation of the East (Valkovskaya) part of deposit are mid-ash (15-20 %), low-sulfur (0.5 %), with a calorific value of 35-36 MJ/kg and a thickness of plastic layer about 7-15 mm, belongs to the medium volatile bituminous rank ("KO" – coking lean coal). Their resources on area of 11 km^2 are estimated at 100 million tons out of a total of 235 million tons by category P_1. Potentially recoverable resources, counting negative impact of dolerite intrusions on sintering properties of

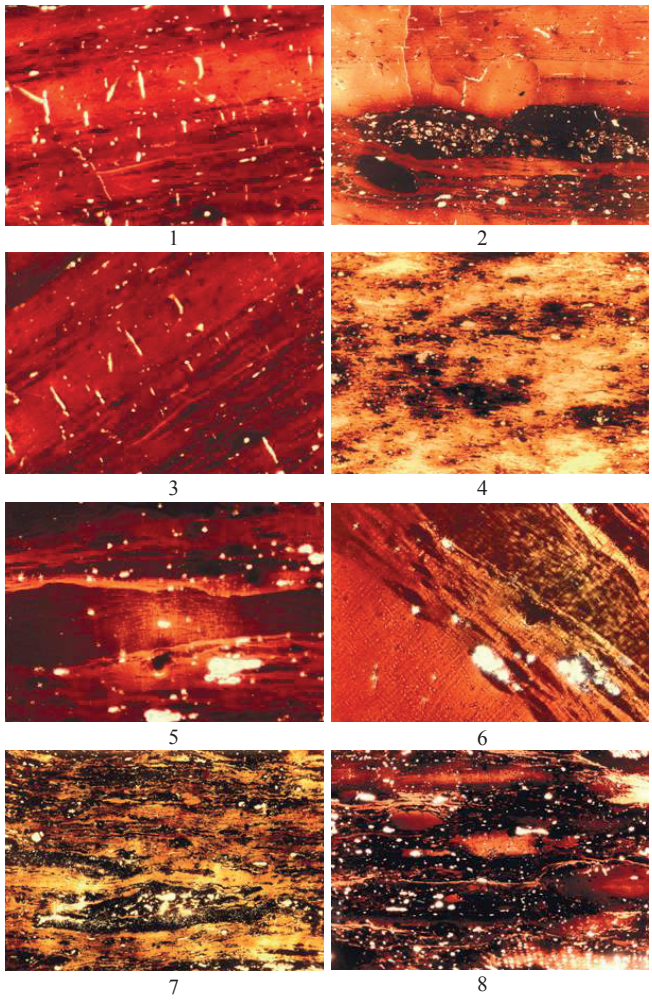

Fig. 4. Types of coal in the northern part of the Tunguska basin (Norilsk region): 1) Fusinite-gelitite attrito-fragmentary. x150. Schmidt Mountain deposit, K (P_2); 2) The same object, nicol +; 3) Fusinite-gelitite attrito-fragmentary. x90. Seam I, Listvyansko-Valkovskoe deposit, K (P_2); 4) Fusinite-gelitite attritic. x150. Seam VI, Nadezhda Mountain deposit, OS (P_1); 5) Fusinite-gelitite desmito-fragmentary. x200. Band IX, Kayerkanskoe deposit, T (P_1); 6) The same object, nicol +; 7) Gelito-fusitite attrito-fragmentary. x90. Band VII, Imangdinskoe deposit, ZH-rank (P_1).

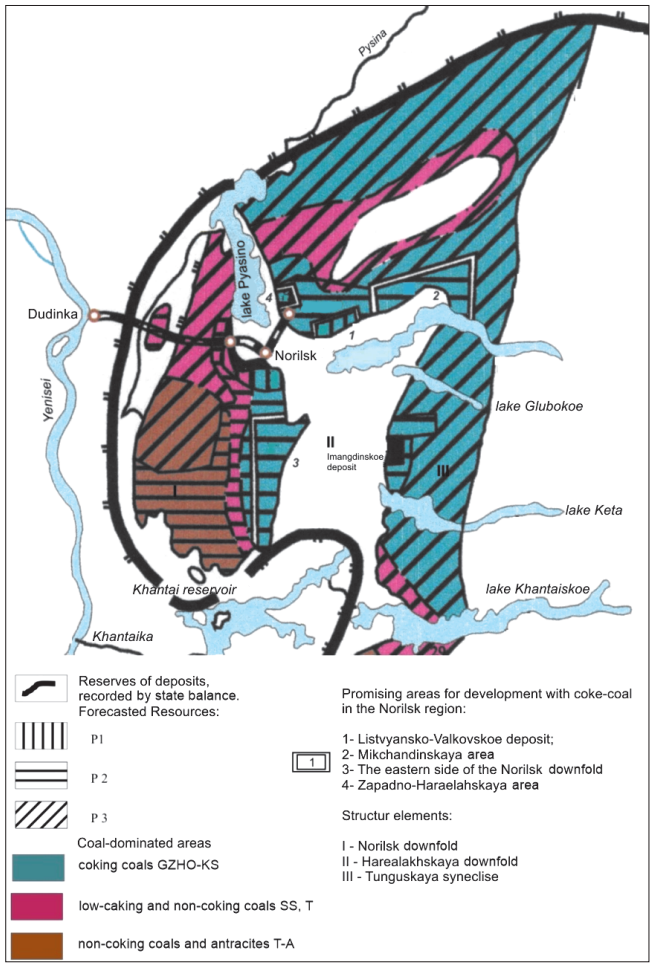

Fig. 5. Schematic map of the distribution of coal resources in the Norilsk region

coal, number 60 million tons. There is a possibility of their growth due to the areas adjacent to the North and East. Low-angle bedding (5-15°) and dissected relief allowed an adit-cut mining with the estimated capacity of the mining enterprise about 1 million tons per year. The West side of the field is located just in a few kilometers from the highway and railway on the territory of Talnakh deposit of copper-nickel ores. The deposit was explored in 1958-1969 in order to replace the reserves of coking coal of the mine of Schmidt and Nadezhda mountains. Technological testing confirmed the identity of the characteristics of the obtained coke of both deposits. In the late 60s of XX century all specialized work on coal in local geological organizations was finished. For this reason, the definition of vitrinite reflectance, the universal indicator of the degree of metamorphism of coals, and the maceral composition of the organic matter, necessary to codification and marking of coals according to GOST 25543-88 (currently GOST 25543-2013), were not carried out.

Geological exploration may be recommended at this field.

Mikchandinskaya area is located in the cutoff part of the Southeastern wing of the Kharaelakh downfold, from the watershed of Ayakly River in the West to the valley of Mikchandy River in the East. The length of the area on the coarse direction is about 40 km, on the fall direction of coal-bearing fill is from 6-8 to 16 km, the area is about 350 km^2. The tectonic structure and modern relief are close to such of Listvyansko-Valkovskoe deposit, from which the Eastern border of the object in question is removed 20-25 km. Coal-bearing thickness is from 150 to 300 m and contains from 2 to 7 working seams (6 average), with mainly medium and large width and relatively simple structure. They are opening in natural outcrops on the steep slopes of the Kharaelakh plateau, as well as in structural mapping and ore-prospecting wells during geological survey works of scale 1:50000. About 2-4 layers of the Kayerkanskaya formation with the thickness of 0.7 to 9.5 m and with an average total thickness of 13.8 m are of interest. Coals belong to the medium volatile bituminous rank ("KS", group "1KS"

according GOST 25543-88); coals are low-and mid-ash (10-15 %), low-sulfur (0.4-0.5 %), with a calorific value of 34-35 MJ/kg; the thickness of the plastic layer is 8-9 mm. The geological knowledge of this area is significantly lower than Listvyansko-Valkovskaya field. In the contour of a rare network of ore wells the prognostic resources of coking low-melting coals up to a depth of 600 m are rated with category P_2 in the amount of 1.5 billion tons, potentially extractable – 900 million tons. The depth of bedding of coal seams not exceed 500 m, their flat monocline occurrence (5-15°) and dismembered relief allow providing an adit-cut mining. Transport conditions are somewhat more complicated than in the area of Listvyansko-Valkovskaya field. The area is removed 40 km from rail and roads connecting the Norilsk and Talnakh mines. Permanent ways of communication are absent. The square (80 km^2) with prognostic resources of P_2 category allocates in the West part of the field and numbers 630 million tons. The potential recoverable resources number 380 million tons taking into account the influence of the intrusive factor. FSBI "VSEGEI" and Moscow State University offer to make additional studies of the area, and then produce a specialized prospecting work on the coal of the second stage (after Listvyansko-Valkovskaya field.)

East side of the Norilsk downfold. This promising coal-bearing area forms a submeridional band with length up to 50 and width up to 10-15 km. Its northern border is 30 km South of Norilsk. The coal-bearing sediments with a capacity of 90-150 m reach the daily surface along the Eastern edge of the Norilsk plateau. In the rest of the territory, a layer of Permian-Triassic welded tuff covers the coal-bearing sediments. They are revealed by structural-mapping and ore-prospecting wells done with geologic surveying of 1:50 000. The Kaerkanskaya formation is the only well-conditioned productive level. It encloses from 2 to 3 working layers with a unit thickness of 0.95 to 8.9 m and total thickness about 6.3-8.9 m. They sink gently to the west at angles of 5-25°. The rank of coals is hvBb. There are low- and mid-ash coals (6-20 %), with low sulfur content (0.2 to 0.5 %). Its heat of combustion is 34-35 MJ/kg and the thickness of the plastic layer is 10-11 mm. On the estimated area of 200 km^2, the prognostic resources (P_2 category of Russian Classification) to 600 m depth amounted about 1100 million tons. Potentially recoverable resources (taking into account the intrusive factor) are about 650 million tons. There is a road with a hard surface to the extent of the northern border of the square, within its limits – only temporary soil road. The specialized coal search of the third stage can be recommended here (after Listvyansko-Valkovskoe deposit and Mikchandinskaya area).

The West-Kharaelakh area is located in the southwestern closure of The Kharaelakh downfold. Its size is 6×16 km^2. In the East, it is directly adjacent to the territory of the Talnakh ore field. The coal-bearing sediments with a thickness of 180-270 m are slightly sloping (5-15°) and immersed in the northeast direction. It concludes up to six working layers. About 2-4 layers of the Kaerkanskaya formation are taken for estimation. Its average total thickness is 11.5 m on the area of 40 km^2. According to the few analyses of core samples, there are low-ash and low-sulfur coals. It can be conditionally related to mvb coals. The prognostic resources of coal of P_3 category are 300 million tons. The area is removed 12-20 km from the mine "October" with a railway and highway. The re-description and revision testing of coal seams on the core samples of previously drilled wells, with a complex studying of the physical and petrographic composition, of vitrinite reflectance and chemical-technological characteristics of coal are necessary to determine the rationality of specialized search works on this area. In general, the prognostic resources of promising areas are 3 billion tons, mainly by category P_2. Potentially recoverable resources are 1600-1700 million tons. In the further study of coking coals of the Norilsk region, it may provide a real opportunity for creation the reserve of raw material base for coke chemical industries. The perspective areas of Norilsk region have a number of competitive advantages in comparison with Syradasayskoe deposit, purchased by Nornickel:

- These areas are located on the territory of the developed mining-district with developed industrial, transport and social infrastructure. The distance from railways and highways do not exceed a few tens of kilometers;
- The adaptability of the Norilsk coals for metallurgical coke production is proved;
- The facilities can be connected with the existing power grids;
- An adit-cut mining, the traditional method of development of the area is possible to use. The method has a bit negative effect on the environment;
- There is local workforce;
- There are relatively more favorable climatic conditions.

The coal occurrences of the Norilsk region of the Tunguska basin can be submitted to the licensing, similar to Syradasayskoe deposit of the Taimyr basin, if they will be studied. An additional research of resource potential of coking coals of the Norilsk region for the purpose of substantiation of reserve of raw material base of coke-chemical industry will allow its development in the nearest future, with incomparably smaller investments than at the Syradasayskoe deposit. As a result, production volumes of complex of minerals (ore, coal), employment of the able-bodied population, the workload of transshipment terminals of the Dudinka port on the Yenisei River and sea transportation on the

Dudinka – Murmansk lane of the Northern Sea Route will be stabilized for a long time. Supply of coking coal can be oriented to the European part of Russia and for export to the world European and Asian markets. In addition, the creation of a stand-by raw material base of coking coals in the Norilsk region will allow partially compensate the reduction of coking coal resources of traditional mining areas (the Pechora and the Kuznetsk Basins etc.) Expected production may be several million tons per year.

The Zyryanka coal basin is located in the northeastern part of Yakutia, in the middle reaches of Indigirka and Kolyma rivers. The length of the basin is up to 500 km in the northwestern direction, the width is up to 170 km, the total area is about 7.5 thousand km^2. Thye Lower Cretaceous coal-bearing sediments (3 formation) fill five isolated superimposed depressions. The basin consists of separated coal regions: Zyryano-Silyapsky (with Erosionnoe, Buor-Kemusskoe, Harangskoe deposits), Myatissky (Krasnorechenskoe deposit), Indigirsko-Selennyahsky and Momsky (Tikhonskoe).

Coal-bearing sediments of Zyryanskaya depositional sequence of lower Cretaceous age compose a large flat brachysynclines. Coal bearing formations with a total thickness of more than 5000 m contain up to 80 coal seams and interlayers with thickness of more than 0.6 m. The main indicators of coal quality are: total moisture (W_t^r) – 9 %, ash-content (A^d) – 14 %, average sulfur mass content (S_t^d) – 0.4 %, higher calorific value (Q_s^{daf}) – 31.4 MJ/kg, lower calorific value in terms of a working fuel (Q_i^r) – 23.26 MJ/kg.

The degree of geologic certainty of the basin is low. Proven coal reserves are 160.8 million tons in category $A+B+C_1$ (according Russian Classification), C_2 – 53.1 million tons. The prognostic resources are estimated at 8.6 billion tons. Total balance reserves of coal, suitable for open development in the basin, is about 130 million tons. The coal deposits of the central part of Zyryano-Silyapsky coal region are the most studied in the basin. The Khatangskoe deposit is located upon the territory of distribution of sediments of the Silyapskaya formation. The Erosionnoe, Buor-Kemyusskoe, Sibik-2 and Nadezhdinskoe deposits as well as some promising areas (Fig. 6) are located upon the territory of distribution of the Buorkemyusskaya formation.

Silyapskaya formation has 56 layers and interlayers of coal with thickness from 0.1 to 13.6 m. Of these, a group of very thin includes 12 layers, thin – 23 layers, medium thickness (1.3-3.5 m) – 12, and thick (3.5-15 m) – 9 layers. The structure of the coal seams most often are simple, rarely are relatively complex. The coal seams are continuous, rarely are relatively continuous. The coefficient of total coal bearing of coal formation is 7.2 %.

Buorkemyusskaya formation consists about 90 layers of coal. Their thickness is about 0,1-14,2 m.

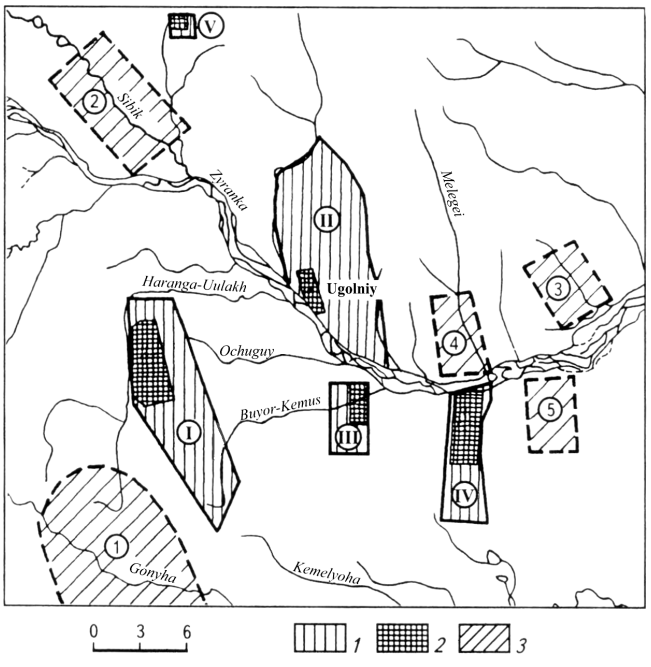

Fig. 6. The scheme of deposits and sections of the Zyryano-Silyapsky coal region. 1 – deposits: I – Kharangskoe, II – Erosionnoe, III – Buorkemyusskoe, IV – Nadezhdinskoe, V – Sibik-2; 2 – explored area of deposits; 3 – promising areas for setting up exploratory works: 1 – Gonyukhinsky, 2 – Sibik, 3 – Komariny, 4 – Melegey, 5 – Nadezhdinsky-Vostochny.

The coefficient of total coal bearing is 8.2 %. According to the thickness of the layers, they are distributed as follows: very thin – 21, thin – 28, medium – 32 and thick – 10. The structure of the seams is complex, rarely is simple.

The thick and medium coal seams of Silyapskaya and Buorkemyusskaya formations are interesting for development if their occurrence is shallow and they have the suitability for open-pit mining.

Table 6 shows the quality of the coal of the region. Coals are medium-rich, concentration ratio is 70 % with a specific gravity of 1.4 g/cm^3, with an ash content of 6 %. Semi-coking resin output on dry coal is an average of 9.5 %. As the plastometric parameters indicates, the ability of coal to sinter and give strong metallurgical coke mixed with lean additives. All coking coals of the formation are placed in the Zyryano-Silyapsky coal region. Fig. 7 shows the petrographic types of coals. The prognostic resources of coals of Zyryano-Silyapsky coal region by P_1 category are about 4.0 billion tons. The prognostic resources calculated to the depth of 300 m on coal seams with thickness about 1 m and more. Of these, coking coal accounts for 2.6 billion tons. Coal resources suitable for open-pit mining in permafrost are about 0.8 billion tons. Of these, coking coal accounts about half.

The Erosionnoe deposit is located on the left shore of the Haranga-Uulakh creek (a left inflow of the Zyryanka River), in 2 km from the Ugolniy townsite, which it is separated from deposit by Zyryanka river. The deposit was developed by underground mining method, and

Formation	Coal rank	W^r_t	A^d	V^{daf}	Q_s^{daf}	Q_i^r	S^d_t,%	C^{daf}	H^{daf}	R_o
		%			MJ/kg			%		
Buorkemyusskaya	ZH, G, GZHO, K	7,6-9,4	6,7-45,0	28,8-45,6	29,7-34,5	19,7-33,5	0,1-0,5	72,6-92,0	4,4-6,4	0,95-1,12
Silyapskaya	T, TS	11,2-14,2	2,2-24,5	10,7-23,0	31,2-37,0	18,2-32,0	0,1-0,5	78,1-93,2	3,0-4,5	1,47-1,86
Ozhoginskaya	T, A	12,7	8,6-45,0	10,5-12,4	32,9-33,8	17,1-27,9	0,4-1,9	83,7-92,3	3,0-3,7	5,54

Table 6. Main indicators of coal quality in Zyryano-Silyapsky coal region

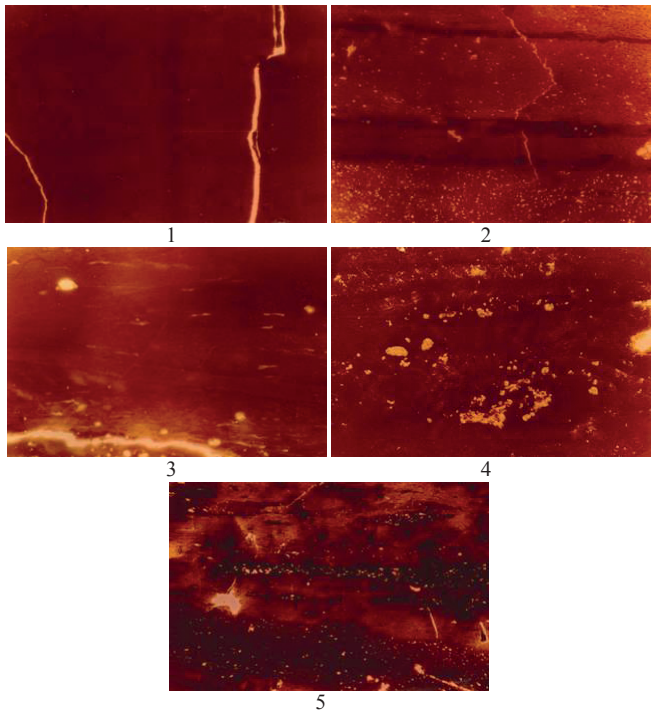

Fig. 7. Types of coal of the Zyryanka basin (rank ZH) (Petrological Atlas..., 2006). 1 – Ultragelite, consisting of: parenchinite and parencho-attrite. x150. Seam "Tolstiy"; 2 – Ultragelite, consisting of: xylinite, β- and Δ-vitrinite. x80. Seam "Moshchniy"; 3 – Lipoid-gelite. x250. Seam "Tolstiy"; 4 – Lipoid-gelite. x80. Seam "Gryazniy"; 5 – Fusinito-gelite. x80. Seam "Moshchniy".

then by open method. The fall of the coal seams are monoclonal on west, within the boundaries of the Zyryansky Opencast.

The coal-bearing capacity of the deposit is confined to the lower part of Buorkemyusskaya formation. The field has five main coal seams with working capacity. They are compared with the indexation adopted for the whole coal-bearing region (from bottom to top): the Velikan (No. 13); the Moschny (18), the Tolsty (22) and the Gryazny (32). The most powerful is the Tolsty seam (from 7.5 to 10.7 m). The Velikan, the Moschny and the Gryazny seams, reaching 6-8 m in some areas, on average have a thickness of 4.5-4.7 m. The structure of the Tolsty and the Gryazny seams is complex. The other seams are simple. They are most often continuous by the area of distribution. Most of the coals are semibright indistinctly-striated, indistinctly-banded and semi-dull. An average maceral composition of coals (in %) is: vitrinite – 65-80, inertinite – 35-20, liptinite – less than 1. The most common minerals are siliceous and carbonate minerals, less often – clay substance.

The coals of the Erosionnoe Deposit are low- and mid-ash (A^d = 11-16 %), low-sulfur (0.23-0.33 %), with lower heat value about 25.8-27.2 MJ/kg, with higher heat value about 34.6-35.5 MJ/kg. The yield of volatile matter varies from 27.3 to 33.7 %, naturally decreasing with depth. The elemental composition coal (%) is: C^{daf} – 82.2-85.5; H^{daf} – 4.8-5.3; N^{daf} – 9.2-12.5 (on average of layers). These coals are sintering. The thickness of the plastic layer in the average of layers varies from 17 to 22 mm. The zone of oxidized coals is untill 30-50 m from surfaces. The main components of coal ash (%): SiO_2 – 43.5-54.6, Al_2O_3 – 19.2-21.8, CaO – 4-7.3, MgO – 1.1-2.3, Fe_2O_3 – 3.3-13.1, Na_2O – 0.6-1.78, K_2O – 0.39-0.77. Phosphorus content in the coals of the main layers is 0.01-0.09 %. Ash-fusion temperature (°C) is: t_1 – 1247, t_2 – 1274, t_3 – 1297.

According to genetic and technological parameters, the coal of the Moschny (18), Tolsty (22) and Gryazny (32) seams are high volatile A and medium volatile bituminous (according to GOST 25543-2013 the coals correspond to the rank "Zh", group "2Zh"). The coals of the Velikan (13) seam are medium volatile bituminous (they are assigned to mark "K", group "1K", subgroup "1KB" according to GOST 25543-2013).

The Nadezhdinskoe Deposit is located on the right shore of the Zyryanka River, in 12 km from the Ugolniy Townsite. The deposit is located in the northeast wing of Gonyukho-Silyapsky Downwarping, in the hanging wing of the Visyachy Overthrust. The tectonics of the deposit is simple. The monocline has a fall of rocks in the northern part at north-west at angles of 5-10°, and in the southern part at west at angles 25-30°. The northern half is the most disturbed area of the deposit. It adjacent to the Vostochny Overthrust. Five uplifts installed with an amplitude of 5 to 30 m. The coal-bearing capacity of the deposit is confined to the lower part of Buorkemyusskaya formation. The average thickness of the layers 13, 18 and 22 is about 1.0-6.6 m. The thickness of the above layer 32 is about 4.0-12.8 m. The seam is complex; it is continuous by the area of distribution. All coal seams are feathering out in the south of the deposit.

The coals of the deposit are humic. Most of the coals are bright, semibright and common-banded (60-70 % of coal thickness). The semi-dull coals fills about 20-30 %. An average maceral composition of coals (in %) is: vitrinite – 66-74, semi vitrinite – 2-4, inertinite – 20-26, liptinite – 1-3. In the composition of mineral matter, the clay substance played a major role (12-15 %, in the extreme values up to 33) and carbonates (up to 8). Quartz and sulfides are rare. Table 7 lists the main parameters of the coal quality of the described coals.

The coals of the Nadezhdinskoe Deposit are mid-ash (A^d = 11-14 %). The chemical ash composition (%) is: SiO_2 – 46.3-58.0; Al_2O_3 – 18-23; CaO – 5.5-12.0; MgO – 2.5-3.5; Fe_2O_3 – 10.1-12.1; Na_2O – 0.9-1.1; K_2O – 1.1-1,6; TiO_2 – 0.7-1.1; SO_3 – 3,0-4,0; P_2O_5 – 0.4. The t_1 value on average varies from 12.75 to 1330°C, t_2 – from 1300 to 1390, t_3 – from 1320 to 1390.

The coals are bituminous (mvb, hvAb). Their rank according to GOST 25543-2013 is "Zh"; the group is "1Zh".

In the coal-bearing thickness there are numerous of free gas deposits. The main component in the depth range of 90-220 m is methane (from 40 to 90 %). The residual methane content of coal in this range varies from 0.5 to 1.9 m^3/t of dry ashless mass (the zone of gas weathering). In the zone of methane gases, this range varies from 4.8 to 10.2 m^3/t of dry ashless mass.

The coal reserves of the deposit, suitable for open development on Nadezhdinsky strip mine constitutes 5608 thousand tons of B category, 14343 thousand tons of C_1 category and 23607 thousand tons of C_2 category.

The low ash content of most working layers, the practical absence of sulfur, the high sintering ability and the high heat of combustion makes coals of the Zyryanka basin a potentially valuable raw material for the metallurgical industry and energy. The Zyryanka basin has a significant thickness of coal seams (up to 11.5 m). Their bedding is gently sloping in most parts of basin. It is slightly disturbed by disjunctive tectonics. The large reserves for open-pit, large forecast resources and unique quality of coals makes the basin the most promising for development on North-East Russia. Coal of the Zyryanka basin, along with coal of the Yuzhno-Yakutsky basin, are the most valuable in the Far Eastern Federal District of the Russian Federation.

However, the geological exploration and development of basin is restrained by his location in hard to reach and undeveloped area. The basin is remoteness from possible consumers. There are lack of reliable transport infrastructure. The transportation of coals of Zyryano-Silyapsky coal region is possible by the Kolyma River to the Arctic coasts of Russia and further to the ports of Russia. The quality characteristics of these coals are answer the call of countries of the Asia-Pacific region. The development of the Nadezhdinskoe deposit in the Verkhnekolymsky district of the Sakha Republic (Yakutia) (about 200 thousand tons/year) is important for the Northern group of districts of Republic of Sakha (Yakutia) and for the nearest northern regions (Chukotka Autonomous Okrug, Magadan Oblast, Krasnoyarsk Krai) development. The product is a high and medium volatile bituminous coal. The coal mining can be implemented by the open way. Land and water vehicles can carry out the transportation of coal to consumers, during the navigation period on the river Kolyma. Coals can be used as an energy fuel in industrial boilers and domestic stoves.

Further development of the Zyryanka coal basin of the Republic of Sakha (Yakutia) and the development of its transport and port infrastructures should be seen as a promising direction, that contributes to the intensification of transport along the Northern Sea Route and the development of arctic territories, the creation of raw material potential for guaranteed provision of boiler fuel and coal concentrate in region needs.

To increase the supply of coal to other northern regions of the Republic of Sakha (Yakutia), to other northern regions of Russia and to export to countries of Europe and the Asia-Pacific region, it is necessary to create favorable transport conditions to significantly increase the capacity and volume of coal transportation of Zyryansky coal mine on the Kolyma river, with output to the Northern sea route.

The production volumes can be increased to 2-4 million tons per year. Coal mining company "Kolmar" made a list of necessary investments for development of transport infrastructure of the Kolyma region (http://www.nrbf2012.com/files/Transport/Transport-Berlin-Kolmar-project.pdf).

The Bering Coal Basin is located in the southeastern part of the Bering Peninsula in the Anadyr region of the Chukotka Autonomous Region. The basin

Coal seam	W^{af}_{max}	W^a	A^d	V^{daf}	Q_s^{daf}	Q_i^r	S^d_t	C^{daf}	H^{daf}	y, *mm*	R_o	ΣFC
					MJ/kg							
32	7,0	0,5	11,9	34,0	34,57	27,27	0,15	84,6	5,2	16	0,95	21,8
22	6,6	0,5	13,5	33,2	34,2	26,58	0,20	85,2	5,2	16	0,96	32,2
18	6,5	0,6	13,2	31,5	34,0	26,08	0,20	85,4	5,3	15	0,95	20,8
13	5,5	0,4	14,6	30,8	34,72	28,11	0,20	86,4	5,5	15	0,98	28,2

Table 7. Coal quality (in %) of the Nadezhdinskoe deposit

consists of coal-bearing areas such as Bukhta Ugolnaya, Verhne-Alkatvaam (Amaam North) and Amaam; coal shows Laguna Arinai, Laguna Zabytaya, Guba Gavriila and Peschanaya river (Fig. 8).

Structurally, the Bering basin is associated with the same deflection of about 100 × 100 km (the Cenozoic Koryak fold system). Basement sediments is a wide complex (9-15 km) of the Mesozoic and Cenozoic terrigenous and volcanogenic marine, lagoon and continental formations from the Late Jurassic to the Eocene (Fandyushkin, 2016). The coal-bearing areas (coalfields) are mainly associated with the brachinclinal structures filled with Upper Cretaceous (Barykovskaya, Koryak and Gangutskaya formations) and Palaeogene (Chukchi formation) sediments. Most of the structures are located in the coastal part of the Bering Sea.

There are four settlements on the territory of the Bering basin: the urban-type settlement Beringovsky, which has an airport, a seaport, the closed Nagornaya mine, different administrative institutions; three national villages (Khatyrka, Meynypylgino and Alkatvaam). The open-pit mining of the "Fandyushkinskoe Pole" coalfield is near the Alkatvaam. The projected production capacity of the field is 750 thousand tons per year, $A + B + C_1 + C_2$ reserves (Russian classification) – 10390 thousand tons for open pit mining to a depth of 300 m.

Coals of the "Zh" coal rank are mainly distributed in the area of Bukhta Ugolnaya coalfield. In the Alkatvaam and Amaam districts – "GZh" and "Zh" coal ranks. The total coal resource potential of the Bering basin (reserves and prognostic resources) is estimated at 1.7 billion tons to a depth of 600 m.

The coal-bearing region of Bukhta Ugolnaya contains coal seams of Barykovskaya, Koryak and Chukchi formations.

The coals of the Barykovskaya formation are concentrated in two piles, including up to 7-10 seams with a thickness from 0.4 to 0.5 m, only one seam reaches a thickness of 1.1 m. The coals of the Koryak formation are mainly represented by the Podsopochny seam with a thickness of 1.5-3.0 m. The most carbonated Chukchi Formation of the Paleogene consists of three subformation (lower, middle and upper). The Lower Chukchi includes one seam of the complex structure "Rechnoi" with a thickness of 1.3 to 3.5 m. The Middle Chukchi includes three coal seams: "Moshchniy", "Dvoinoy", "Karierniy". The "Moshchniy" seam is predominantly of a simple structure with a thickness of 0.1 to 3.73 m. The "Dvoinoy" seam of a complex structure is unstable. Its thickness ranges from 0.05 to 3.65 m. The "Karierniy" seam of a complex structure is unstable. The thickness varies between 0.1-4.0 m. The "Dvoinoy" and "Karierniy" seams are characterized by the presence of nodules of predominantly carbonate composition. The coal-bearing ratio of the Middle

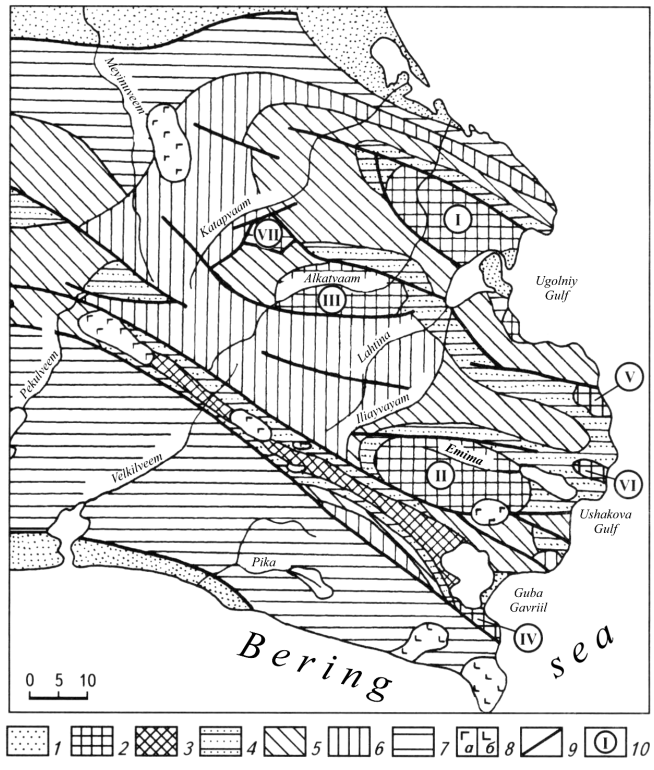

Fig. 8. Schematic geological map of the Bering basin. 1 – Quaternary sediments; 2 – Paleocene-Eocene coal-bearing sediments of the Chukchi formation; 3 – Upper Cretaceous sediments of the Gangutskaya formation; 4 – Upper Cretaceous sediments of the low-carboniferous Koryakskaya formation; 5 – Upper Cretaceous sediments of the Barykovskaya formation; 6 – Lower Upper Cretaceous sediments of the Ginterovskaya formation; 7 – Lower Cretaceous sediments undivided; 8 – covers of basalts: Paleogene (a), Quaternary (b); 9 – main faults; 10 – the main deposits: I – Bukhta Ugolnaya, II – Amaam, III – Alkatvaam, IV – Guby Gavriila, V – Laguna Zabytaya, VI – Laguna Arinai, VII – Peschanoe.

subformation is 3.7 %. The Upper subformation has low coal-bearing capacity (0.3 % coefficient), consists of three seams: the "Noviy", the "Somnitelniy" with a thickness of up to 0.5 m and the "Koryaksky" with a thickness of 1-2 m.

Black coals, mostly bright, homogeneous and semi-bright, lenticular-thin-striped. With prismatic or tiled separateness, angular-stepped fracture. The maceral composition of coals (Table 8) is consistent, with a vitrinite content of up to 95 %, alginite can be found singly. Of the mineral impurities, clay and carbonates prevail, less often pyrite and quartz.

Coals are moderately sulfur and moist, with medium ash, with high calorific value, increased volatile matter and hydrogen. Coal plastometric index varies from 12 to 14 mm. The chemical composition of the ash – refractory components of 60 %, low-melting – 20.9 %. Ash is characterized by lower melting values. Coals are light and medium enriched. The main quality indicators are in the Table. 9.

Deposit	Petrographic composition of pure coal, %					Mineral components, %
	Vitrinite		Semivitrinite	Inertinite	Liptinite	
	Collinite	Telinite				
Bukhta Ugol`naya	84	10	2	2	2	4
Alkatvaam	86	9	1	4	0	11
Amaam	91	6	1	1	1	7
Peschanoe	62	32	2	1	3	4
Average value	81	14	1,5	2	1,5	6

Table 8. Average maceral composition of coals of Bering basin

Indicator	Mine "Nagornaya"	District "Zasbrosovy"	District "Alkatvaamsky"
W_t^r	2,0-20,6 (5,1)	1,3-13,0 (4,4)	1,7-11,2 (4,3)
A^d	2,9-29,2 (11,5)	4,0-30,0 (11,7)	4,0-28,4 (12,4)
$A^d_{г.м.}$	10,4-30,0 (16,5)	10,0-30,0 (17,0)	4,6-30,0 (18,5)
V^{daf}	33,6-56,0 (44,1)	35,8-58,5 (43,4)	34,4-57,5 (43,7)
S_t^d	0,80-9,02 (1,70)	0,26-8,05 (1,51)	0,12-8,24 (1,54)
C^{daf}	69,7-89,4 (81,5)	73,3-85,8 (81,6)	78,1-85,4 (81,9)
H^{daf}	4,9-8,4 (6,1)	5,2-6,7 (6,1)	5,5-7,4 (6,2)
Q_s^{daf} MJ/kg	30,2-38,2 (34,4)	27,6-36,8 (34,2)	29,4-37,0 (34,2)
Q_i^r MJ/kg	28,9-36,4 (32,8)	27,7-34,7 (32,7)	29,72-35,87 (31,9)
Y, mm	3-25 (12)	6-18 (12)	7-21 (13)
RJ, un.	18-80 (42)	-	2-91 (62)
R_O	0,66-0,73 (0,68)	0,68-0,69 (0,68)	0,69-0,72 (0,69)
∑FC	8	4	9
Technological group (GOST 25543-2013)	1G	1G	2G

Table 9. Quality indicators (in %) of coal of Bukhta Ugolnaya deposit

Coal reserves in the region of Bukhta Ugolnaya come to 121 million tons for A + B + C_1 types and 500 million tons for C_2 type. The prognostic coal reserves of P_1 type of the deposit come to 314 million tons.

Soldering coal deposits of the Alkatvaam coal-bearing region are located 40 km south-west of the Beringovsky deposit and even further south, in the area of Ushakov Bay are located the deposits of the Amaam coal-bearing region (Fig. 9).

The Alkatvaam coal-bearing region. The coal-bearing capacity of the region is confined to sediments of the Upper Koryak and Middle Chukchi formations. On the territory of the district, there is a "Zh"-type "Fandyushkinskoe pole" coalmine, developed since December 2016 (Fig. 10) confined to the Koryak Formation.

A thick "Odinokiy" coal seam of complex structure was revealed here. The number of partings in the coal seam varies from 1-2 to 10-12. The thickness of the partings is variable and varies from the first centimeters to 10-15 meters. The seam consists of two working seams group – the lower ("Nijniy") and upper ("Verkhniy"). The thickness of the lower seams plies is 7.5-10 m, it is characterized by the presence of many partings and lens out in the southwest direction until the working thickness is lost. The upper seams are characterized by a more consistent structure, quality and thickness of 3-6 meters, with the presence of thin partings (up to 0.5 m). In the upper and lower seams, frequent small-amplitude splits observed to a depth of 20-30 meters. In the outermost southwestern part of

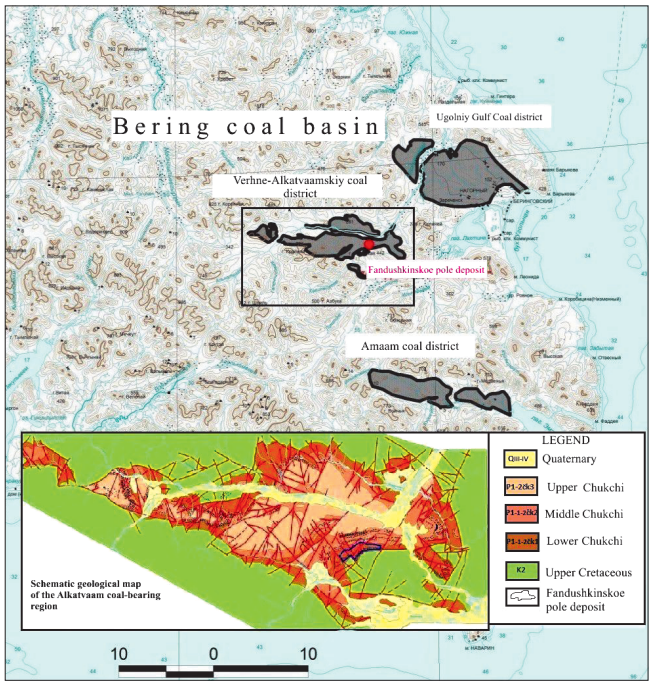

Fig. 9. The main coal-bearing areas of the Bering coal basin. Schematic geological map of the Alkatvaam coal-bearing region.

the field of the "Odinokiy" seam lens out and loses its working thickness. The priority reserves approved by the Russian State Reserves Committee come to 10.4 million tons, of which type B shares 8 %, C_1 – 50 % and C_2 – 42 % (Russian classification). The mine development project provides for annual producing of 750 thousand tons of coal. In addition to this deposit and its flanks,

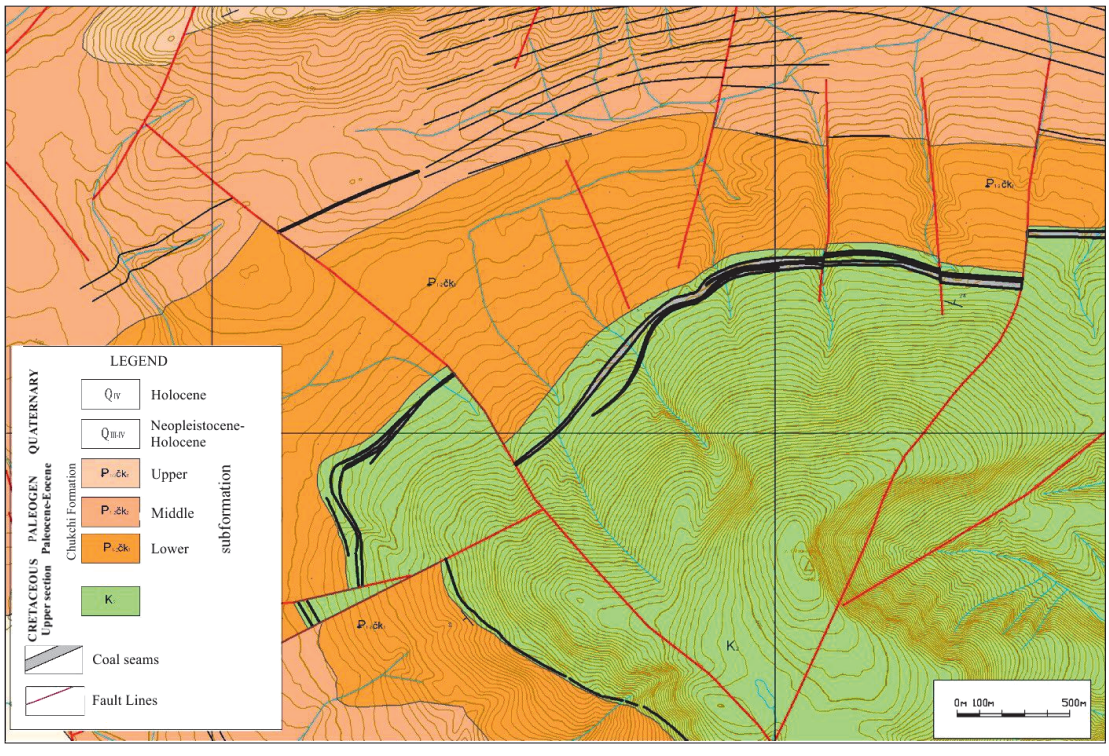

Fig. 10. Schematic geological map of the "Fandyushkinskoe Pole" deposit and its flanks

the coal-bearing capacity of the Koryak Formation in the Alkatvaam region was not identified. It will become the object of a search after the coal-bearing capacity of this formation will be confirmed.

The Middle Chukotka is the main coal-bearing subformation of the Alkatvaam coal-bearing region. Coal seams with industrial (economic) characteristics are found throughout the distribution subformation. Coals are characterized by high sulfur contents and are suitable mainly for burning. The maximum coal-bearing capacity of the section is 13 coal seams ("Povorotniy" deposit), on average – 5 coal seams with a thickness of 0.5 to 5 meters. The coal seams in the section (geological record) of the Middle Chukchi sub-formation lie down after 10-50 meters. Macroscopically, the coals of the Alkatvaam region are black, mostly bright and semi-bright with dull bands, have an indistinctly streaky structure, prismatic jointing. Coals of the Koryak Formation are "Zh", Middle Chukotka Formation – "GZh" coal rank. The coal of the Middle Chukchi is characterized by a high content of macerals of the vitrinite group (92-96 %) and, accordingly, insignificant inertinite (2-4 %). For coals of the Koryak Formation, the content of vitrinite is 50-60 %, and inertinite is up to 30 %. The main qualitative characteristics are given in Table 10.

Coal resources to a depth of 300 m (for open-pit coal mining) of the Alkatvaam coalfield come to 870 million tons (P_1 – 90, P_2 – 180 and P_3 – 600 million tons by Russian classification Resources), including for open pit mining with favorable subsurface conditions – 140 million tons (P_1 – 90, P_2 – 50 million tons by Russian classification).

Indicators	Sectional position	
	Middle Chukchi subformation	Upper Koryak subformation
W^a,%	1,2	1,0
Wmax,%	1,8	1,8
A^d,%	12,5	21,1
V^{daf},%	39,6	30,0
Qs^{daf} MJ/kg	35,45	34,9
Qir, MJ/kg	27,16	28,5
St^d, %	2,7	0,39
P^d,%	0,06	0,06
x, mm	37	29
y, mm	25	14
Ro, %	0,76	1,02
Coal rank	GZH	ZH
Vitrinite, Vt%	92,0	55,5
Semivitrinite, Sv%	2,0	16,0
Inertinite, I%	4,8	28,1
Liptinite, L%	1,2	0,34
Mineral components, MI%	7,5	5,3
C^{daf}, %	86,5	86,6
H^{daf}, %	5,4	5,2
N^{daf}, %	0,96	0,9
O^{daf}, %	6,8	7.0
$S_{org}{}^{daf}$, %	0,42	0,42

Table 10. Coal quality of the Alkatvaam coal-bearing region of the Bering coal basin

The Amaam coal-bearing region. The coal-bearing capacity of the Amaam is confined to the Koryak Formation of the Upper Cretaceous and the Chukchi Formation of Paleogene (Fig. 11).

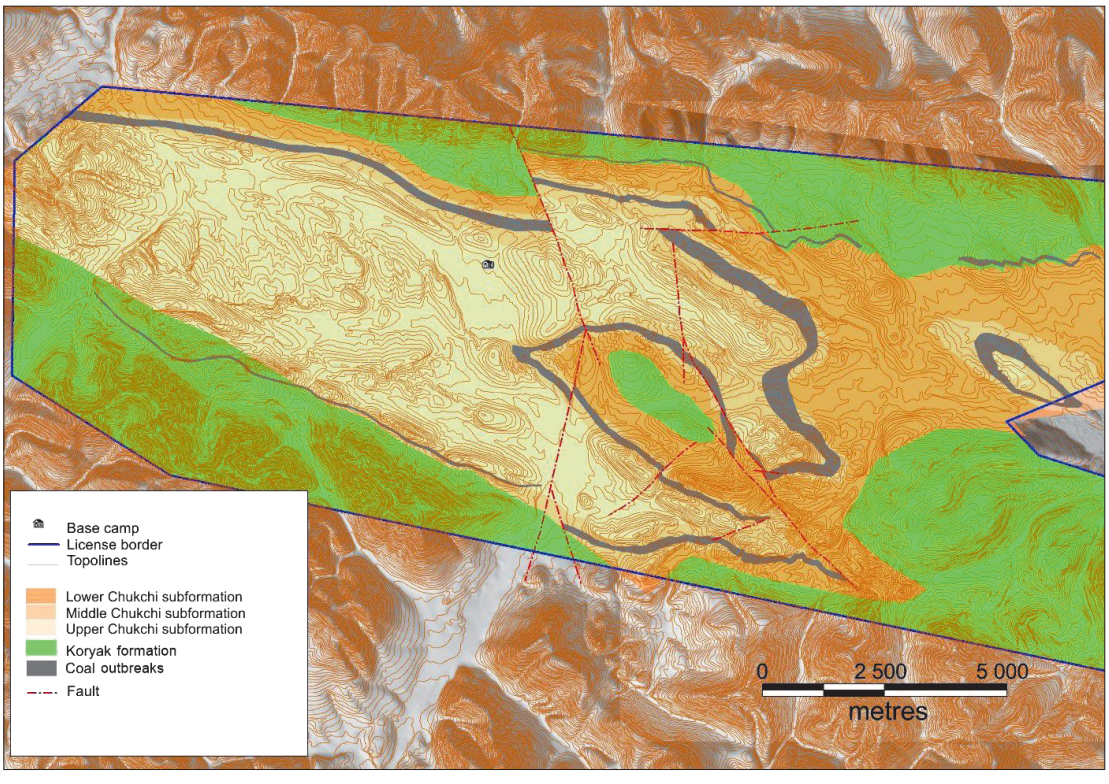

Fig. 11. Schematic geological map of the Amaam coal-bearing region

The Koryak formation contains the "Podgravelitovy" horizon, in which there are two coal seams – "Sputnik" (0.5-0.6 m) and "Podgravelitovy" (up to 1.5 m) lie down. The seam "Podgravelitoviy" is located 30-32 m above the seam "Sputnik". The Chukchi Formation is coal-bearing in the Lower and Middle subformation. Coal seams of Middle Chukchi are of industrial interest. The coal-bearing section contains 9-12 seams and plies of coal from a simple to complex structure.

In the region, the coal seams are consistent and relatively consistent.

The most significant for the region is the Seam with "I" index, located at the floor of the section. The share in the resource potential of the Seam "I" is estimated at 50-52 %. The average thickness of coal seams is 1-1.5 m, for Seam "I"– 1.5-2 m, the thickness of interbed (partings) – from 5 to 40 meters. The average coal-bearing ratio is 8-10 %. The main quality characteristics are given in Table 11.

Coals are ultraclaren. The Seam "I" is characterized by the smallest ash, the largest – Seam "II". The main components of ash are silica (45.5-55.2 %) and alumina (25.8-31.3 %). In the ratio $SiO_2 / Al_2O_3 \approx 1.8$ (1.16-2.50) coal ash is alumina. $K_2O / Na_2O \approx 1.5$ (0.58-4.04). Coal ash are medium and high fusing. All coal seams of the Amaam coal-bearing region are well sintering: values of sintering index (G) – 93-100. According to GOST 10100-89, the coals are hardly enriched.

At the achieved stage of geological exploration of prospective areas, there are estimated coal reserves of categories $C_1 + C_2$ in the amount of 29.56 million tons,

Indicators	From	To
W^a,%	0,55	0,66
V^{daf},%	31	33
Qs^{daf} MJ/kg	36,02	36,2
$Q^i r$, MJ/kg	25	26
St^d, %	0,52	0,94
P^d,%	0,12	0,23
x, mm	19,4	24,2
y, mm	19	22
Ro, %	0,98	1,07
Coal rank	ZH	
C^{daf}, %	85,3	87,1
H^{daf}, %	5,57	5,87
N^{daf}+ O^{daf}, %	5,8	7,3
$S_{org}{}^{daf}$, %	0,57	1,7

Table 11. Coal quality of the Amaam coal-bearing region of the Bering coal basin

resources of category P_1 – 105.62; $P_2 + P_3$ – 83.64 million tons by Russian classification. Without calculation of decreasing coefficient, the coal resources are estimated in quantity by categories: P_1 – 137; P_2 – 75; P_3 – 60 million tons. In total $P_1 + P_2 + P_3$ – 270 million tons by Russian classification.

The "Peschanoe", "Guba Gavriila", "Laguna Arinay", and "Laguna Zabitaya" coal shows of are poorly studied. The coal-bearing capacity of the "Peschanoe" coal show are according to the Middle Chukotka sub-formation. Coals contain ash of 3-5 %, a higher calorific value of 29.2-30.0 MJ/kg, rank is "D".

"Guba Gavriila" deposit is located on the coastal slopes of Greig Bay and in the Vyrugna river basin, which flows into the Oreanda lagoon in the far southeastern part of the coal basin and directly adjoins the seashore. Coal-bearing capacity is confined to the Middle Chukchi subformation. Two coal seams are known: the lower one with a thickness of 0.5-0.6 and the upper one with a thickness of 1.5-2 m. The ash content of coal from individual samples is 13.9 %, volatile-matter content 33-34, sulfur up to 0.6, phosphorus – up to 0.003, carbon – 78-80, hydrogen – 5.1 %. Coal type, presumably, "KZh".

"Laguna Arinai" deposit is located on the north from "Guba Gavriila" deposit, near the sea coast. Coal-bearing capacity is confined to the Middle Chukchi subformation. Three coal seams with a thickness of 0.4–2 m of a complex structure were detected. The coalfield of the "Laguna Zabytaya" is located near Cape Otvesniy. In the Middle Chukchi subformation, one coal seam of complex structure is known. Intense faulting and complex structure characterize all coalfield. Complex transport accessibility makes these sites not very promising for study.

Coals of the Bering coal basin have a large resource potential of about 2 billion tons. They differ favorably in quality, have low – rarely, medium ash (ash content of 8-12 % coal mined at the "Fandyushkinskoe Pole" open pit), low sulfur content. They are mostly easily or moderately enriched, have good sintering properties (average values of coal plastometric index "y" of the "Bukhta Ugolnaya" deposit are 12-14 mm, up to 24 mm in the Amaam), the content of bitumen in coal reaches 6.3-20.2 % (Coal Base ..., 1999).

All this indicates the possibility of intensive industrial development of the coal basin, taking into account their location, and, accordingly, the need for further geological exploration for poorly explored deposits to assess their resources and prepare for licensing. Coals can go to energy-deficient areas of the Far Eastern Federal District and exported by cheap sea transport (according to the type of export from Australia). Note that the coals of the Bering basin can be used as raw materials for the production of liquid fuels, phenols and other chemical products (Coal Base ..., 1999).

Thus, in the Arctic region of Russia there is the largest base of coking coal of valuable types, requiring further study and more active development, as part of the general strategy for the development of fuel and energy resources of the subsurface of Russian North.

References

Coal Base of Russia. (1999). Vol.V. Book 2. Moscow: Geoinformmark, 638 p. (In Russ.)

Dodin D.A., Evdokimov A.N., Kaminsky V.D. et al. (2007). Mineralno-syrevye resursy Rossiiskoi Arktiki (sostoyanie, perspektivy, napravleniya issledovanii) [Mineral resources of the Russian Arctic (state, prospects, directions of research)]. St.Petersburg: Nauka, 767 p. (In Russ.)

Fandyushkin G.A. (2016). Beringovsky basin coals metamorphism. *Izvestiya Vysshikh Uchebnykh Zavedeniy. Geologiya i Razvedka* [Proceedings of Higher Schools. Geology and Exploration], 4, pp. 37-41. (In Russ.)

Golitsyn M.V., Golitsyn A.M., Androsov B.N., Shnyrev L.N., Soloviev D.G. (1992). Coal of Western Siberia. *Izvestiya Vysshikh Uchebnykh Zavedeniy. Geologiya i Razvedka* [Proceedings of Higher Schools. Geology and Exploration], 2, pp. 75-83. (In Russ.)

Vyalov V.I., Volkova I.B., Volkova G.M. et al. (2006). Petrologicheskii atlas iskopaemogo organicheskogo veshchestva Rossii [Petrological atlas of fossil organic matter of Russia]. St.Petersburg: VSEGEI Publ., 604 p. (In Russ.)

Yuzvitsky A.Z., Fomichev A.S., Bostrikov O.I. (2000). West Siberian coal basin. *Otechestvennaya geologiya*, pp. 25-33. (In Russ.)

Zvonarev I.N. (1982). Ob-Yenisei coal-bearing area. *Geology of the USSR. Western Siberia*. *Minerals*. Vol. XIV. Book 1. Moscow: Nedra, pp. 82-89. (In Russ.)

About the Authors

Vladimir I. Vyalov – DSc (Geology and Mineralogy), Chief Researcher, Karpinsky Russian Geological Research Institute (VSEGEI); Professor, Lomonosov Moscow State University & South Federal University

74, Sredny ave., 199106, St. Petersburg, Russian Federation

Alexandr B. Gurevich – PhD, Chief Researcher, Karpinsky Russian Geological Research Institute (VSEGEI)

74, Sredny ave., 199106, St. Petersburg, Russian Federation

Galina M. Volkova – Head of Laboratory, Karpinsky Russian Geological Research Institute (VSEGEI)

74, Sredny ave., 199106, St. Petersburg, Russian Federation

Darya A. Skiba – Graduate Student, Karpinsky Russian Geological Research Institute (VSEGEI)

74, Sredny ave., 199106, St. Petersburg, Russian Federation

Evgeny P. Shishov – Senior Researcher, Karpinsky Russian Geological Research Institute (VSEGEI)

74, Sredny ave., 199106, St. Petersburg, Russian Federation

E-mail: Evgeny_Shishov@vsegei.ru

Artem A. Chernyshev – Researcher, Karpinsky Russian Geological Research Institute (VSEGEI)

74, Sredny ave., 199106, St. Petersburg, Russian Federation

Manuscript received 18 April 2019;
Accepted 06 August 2019; Published 1 September 2019