PERMAFROST - Seventh International Conference (Proceedings),
Yellowknife (Canada), Collection Nordicana No 55, 1998

SOURCES OF NATURAL GAS WITHIN PERMAFROST NORTH-WEST SIBERIA

Viktor A. Skorobogatov [1], Vladimir S. Yakushev[2], Evgeny M. Chuvilin[3]

1. 2. VNIIGAZ (All-Russian Research Institute of Natural Gases and Gas Technologies)
142717, Moscow Region, p.Razvilka. RUSSIA.
2. e-mail:yakushev@mosc.msk.ru

3. Moscow State University - 119899, Moscow, Vorobievy Gory, MGU, Geological Faculty, Department of Geocryology.
e-mail: chuvilin@geol.msu.ru

Abstract

Various aspects of sudden natural gas blowouts from within the permafrost sections of deep (greater than 300 m) wells at Yamburg and Bovanenkovo gas fields (northwest Siberia) are presented. Topics covered include: gas geochemistry, blowout intensity (gas flow rate), depth interval and permafrost rock peculiarities in places of these gas releases. The results are compared with similar studies in other polar regions. Although microbial gas is widespread within permafrost, thermogenic gas can also occasionally migrate from deep gas reservoirs along faults or be present locally in areas of gas reservoirs within the permafrost section. Gas can be preserved within permafrost in a free state as well as in hydrate form throughout the permafrost zone.

Introduction

Sudden gas blowouts originating within permafrost intervals have been encountered during well drilling in different parts of the polar region (Yakushev and Collett, 1992; Agalakov and Bakuev, 1992; Yakushev, 1994). Their intensity can reach several tens of thousands of cubic meters of gas per day. Usually drill operators attribute them to leakage from deep production reservoirs beneath permafrost or to gas flows from neighboring defective production wells. Some experimental data have been published concerning possible migration of deep hydrocarbon gases through permafrost and even through the gas hydrate stability zone in North-West Siberia (Starobinets and Murogova, 1985). But studies in Northern Russian gas fields have also shown, that most gas releases do not originate in this way (Melnikov et al., 1989). In natural conditions deep gas can reach surface layers only through permeable tectonic faults accompanying deep taliks. This situation is not very common in permafrost areas because of the plastic properties of permafrost rocks (Medvedskij, 1986), so there is a need to identify another source of natural gas inside permafrost.

One of the main reasons that little is known about the nature of natural gas within permafrost is that under current practice for production drilling, the permafrost interval is passed as quickly as possible, without detailed study. Gas kicks from shallow depths usually are prevented by heavy drill mud. Recent changes in drilling procedure in the Yamal gas fields (planned to be operated by “Gazprom” in near future) have provided an opportunity to study these gas releases in more detail.

Geologic section of permafrost interval in Norh-West Siberia

Studies of gas releases have been undertaken in the Yamburg and Bovanenkovo gas fields situated near the Gulf of Ob in Northwestern Siberia (Figure 1). The thickness of the permafrost in this region reaches 450 m in the Yamburg field and 300 m in the Bovanenkovo field. Average ice-bonded permafrost thickness is approximately 350 m in the Yamburg field and 160 m in the Bovanenkovo field. The top of the upper regional production gas reservoir (Cr2cm) is situated at a depth of 1200 m (Yamburg) and 600 m (Bovanenkovo). In spite of deep drilling and testing, nearly all of the sudden gas blowouts registered occurred in the permafrost interval at both fields. Therefore the permafrost interval should be studied to determine possible mechanisms for gas accumulation (independent of gas origin).

The permafrost interval at both fields is represented by marine deposits of Paleocene, Pleistocene and alluvial deposits of Holocene ages (Figure 2). It consist of silts and clays with thin layers of fine sands. Sand layers commonly are several millimeters thick, and

Figure 1. Map showing sites of permafrost gas release studies.

rarely tens of centimeters in thickness. Organic matter content within the permafrost interval varies from 1 to 5%. The upper 20-30 meters of permafrost at Yamal are usually saturated by ice (sometimes with ice contents of more than 50% by weight). The porosity of sands at both fields is less than 35% with water (ice) content of 30%, so that pore spaces are almost entirely filled by ice.

On the Yamal Peninsula, groundwater can be highly mineralized at depths below 50 m, and taliks within the permafrost section are sometimes saturated with mineralized water.

Gas blowouts from permafrost

Gas blowouts in permafrost zones have been registered in West Siberia since the beginning of oil and gas exploration. Usually, drill operators explained them as resulting from gas migration from deep reservoirs through lithological windows or defective wells. Gas releases in the course of drilling were considered as complications, and operators attempted to stop them as quickly as possible. Practically nothing was learned about the character, distribution, gas composition and origin of these gas releases. Since the late 1980's, some studies have been initiated in response to an increased frequency of blowouts accompanying the intensification of gas exploration in extreme northern regions.

One of the first studies was made in the area around gas treatment unit #2 at the Yamburg gas field (Melnikov et al., 1989; Yakushev and Collett, 1992). Data about gas releases from the permafrost zone were found in the drilling documents of 6 production wells in this area (total area - approximately 50 km^2). Some of the releases resulted in fires at well-heads and damage to equipment. Gas flow rates were not measured, but some of the releases supported flames 3-5 meters in

	Depth of play bottom (m)	Column description
Q	60	Fine sands, weakly consolidated sandstones, silts Cryogenic texture is massive, in upper layers - lense-like. Gas releases in interval 10-60 m
P	Bottom of permafrost 360	In upper 50 m - fine quartz sands with massive cryotexture. Deeper - clays, silts, diatomites and diatomite clays with sand layers. Cryogenic texture - massive. At the bottom of permafrost interval - fine sands with clay layers. Gas releases have been encountered down to depth of 113m.

A

	Depth of play bottom (m)	Column description
Q	180	Clays, silts, rare thin layers of fine quartz sands. Cryogenic textures are net-like, lense-like, layered (in upper 40 m) and massive (disseminated) everywhere along the section. Gas releases have been encountered from depth 15 m (rarely) down to depth 120 (frequently). Several weak gas releases were registered in interval 150-170m.
P	Bottom of permafrost 230	Clays, silts. Cryogenic texture is massive. Some weak gas releases in interval 205-210m.

B

Figure 2. Generalized section of permafrost interval at Yamburg (A) and Bovanenkovo (B) gas fields.

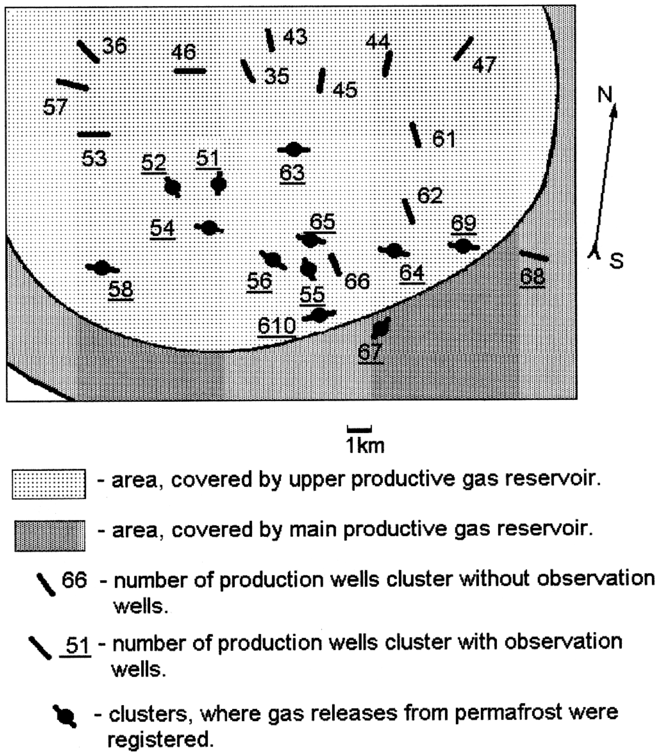

Figure 3. Scheme of gas blowouts spreading in South part of the Bovanenkovo gas field (Yamal peninsula).

migration into the permafrost interval, allowed them to speculate that gas released in blowouts was of local, biochemical origin.

height. The duration of gas leakage varied from several days to 3 months. Sampling of gas released at depths of 50-100 m has been done at two wells.

A special investigation of the gas-production potential of permafrost rocks in this area was undertaken by a group of Siberian scientists led by Prof. P.I. Melnikov (Melnikov et al., 1989). They studied the organic matter component of permafrost cores using of luminescent-bitumen analysis methods and established the possibility of hydrocarbon generation from in situ organic matter. This result, and the lack of means for deep gas migration into the permafrost interval, allowed them to speculate that gas released in blowouts was of local, biochemical origin.

Another study of undisturbed permafrost cores recovered from depths of 70-120 m in this area (gas treatment unit #2) was undertaken by VNIIGAZ. Some cores liberated remarkable volumes of gas when melted in liquid. The total volume of liberated gas was in excess of 10 times the volume of available pore space in the cores. Pore spaces were practically entirely filled by ice with no possibility for gas migration and accumulation in these intervals. Therefore, it was concluded that gas was concentrated in soil pores during freezing and had been transformed into gas hydrate. The pressure drop following the advance of the freezing front caused the hydrates to partially decompose and convert to a self-preserved state (Yakushev, 1989). This result also suggests the possibility of gas generation within the permafrost section in Yamburg area. However, the timing of the gas generation (before or after freezing) is unknown.

The most advanced study of gas blowouts was carried out recently at observation wells drilled in the Bovanenkovo gas field by "Krios" drilling company, under contract to RAO "Gazprom" (Kondakov and Galiavitch, 1995). The Bovanenkovo field is planned for development at the beginning of the next century, so the permafrost section here has not been polluted by deep gas leakage from production reservoirs. More than 30 boreholes in permafrost were drilled at sites of future production well clusters (Figure 3). Only one observation well, drilled at the site of cluster #68, did not encounter gas releases during drilling. From 1 to 3 instances of gas liberation from permafrost were registered for each of the other wells. It is necessary to note, that observation wells were drilled no deeper than 450 m, with no hydraulic connection to the upper

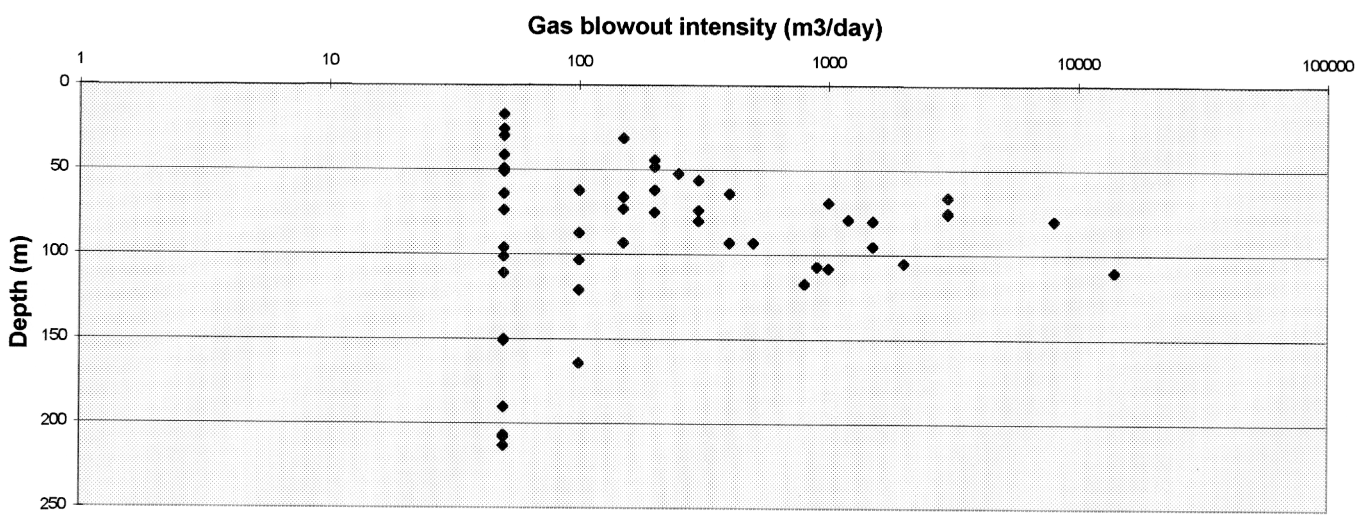

Figure 4. Distribution of gas blowouts and their intensities with permafrost depth at Bovanenkovo gas field (Yamal peninsula).

Table 1. Gas composition in gas releases from permafrost interval (%vol.)

Field name, Well number	Air presence	Interval of gas release (m)	CH_4	N_2	CO_2	O_2	ΣC_2-C_5	CO	H_2	$C_1/\Sigma(C_2$-$C_5)$
Yamburg (data from VNIIGAZ): 1	+	50-100	78.3	18.4	0.3	3.0	-	-	-	∞
1	-	50-100	92.12	7.53	0.35	-	-	-	-	∞
2106	+	50-100	79.3	17.3	0.1	3.3	-	-	-	∞
2106	-	50-100	94.97	4.90	0.13	-	-	-	-	∞
Bovanenkovo (data from «Krios»Ltd.): 51-P-1	+	28-33	95.49	3.51	0.02	0.91	-	-	0.07	∞
51-P-1	-	28-33	99.82	0.09	0.02	-	-	-	0.07	∞
51-P-1	+	59-64	92.8	5.03	0.05	1.15	-	0.83	0.14	∞
51-P-1	-	59-64	98.17	0.75	0.15	-	-	0.88	0.15	∞
51-P-2	+	38-44	74.81	16.02	0.29	3.27	0.07	4.27	1.27	1069
51-P-2	-	38-44	87.66	6.36	0.34	-	0.08	4.06	1.50	1095
51-P-3	-	150-151	97.19	0.09	2.72	-	-	-	-	∞
52-P-1	-	119-123	98.02	1.90	0.08	-	-	-	-	∞
52-P-3	-	89-96	99.79	0.21	-	-	-	-	-	∞

production reservoir (depth - 600 m). Most of the gas releases were encountered in the ice-bonded permafrost section and never below the depth of the 0°C isotherm.

More than 50 gas releases were registered and some of the gas-containing intervals were perforated and tested for gas flow rates. The results of these tests are presented in Figure 4. Gas blowout intensities (flow rates) are shown in accordance with the depth of the gas-containing interval. Gas flow rates varied from 50 to 14000 m^3/day. Most of the gas-containing intervals are concentrated at depths of 50-120 m. This interval represents frozen marine clays and silts of Quaternary age (see Figure 2) with thin layers of fine quartz sand (2-3 cm thick). Gas releases often occurred near these intervals of sands, but in some cases, gas blowouts were registered in weakly permeable frozen silts. This fact allows us to hypothesize the presence of small crack and/or cavern systems in frozen silts (and perhaps even in clays), which can be closed during drilling and sampling of cores. Visible empty caverns with diameters of 0.5-1.0 cm were observed in frozen silt cores from the gas-releasing interval at one well, but it is still unclear whether these caverns are favorable for gas accumulation, or if they are only a feature of the formation.

Gas flow rates decreased with time at all well-heads. Duration of gas flow ranged from several days up to several months (observations were limited by the duration of drill/scientific personnel presence at the well). Studies of gas blowout intensity change with time were conducted on several wells. The most representative was conducted on well 64-P-2 (well cluster #64), where observations were conducted for 6 months. A gas blowout with a flow rate of 3000 m^3/day and gas pressure at the well-head of about 0.7 MPa occurred at depths of 72-80 m (frozen silt with rare layers of fine sand with thickness 1-3 cm). Two days later, the flow rate decreased to 2000 m^3/day and gas pressure reduced to 0.5 MPa. After 10 days, the flow rate was 1200 m^3/day (pressure, 0.4 MPa). Though the intensity of gas release was obviously decreasing, 6 months later the gas flow rate was still about 500 m^3/day and the well-head pressure about 0.15 MPa. Calculations have shown that the total volume of gas liberated from this interval is at least 120,000 m^3. Many wells produced flow rates of 50 to 400 m^3/day during a period 1-6 months.

Gas geochemistry

The first determination of gas composition in permafrost blowouts was done by VNIIGAZ at the Yamburg gas field (production well number 2106 and engineering well number 1). Gas samples were collected directly from gas releases near the wellhead, so the samples contained significant amounts of air. Several wells in the Bovanenkovo fields were sampled too. Results of the gas composition analysis are presented in Table 1.

Gas releases from both fields were composed of 87-99% methane. Gas from one well (51-P-2 at depth 38-44m, shadowed lines in Table 1) had an unusual composition with relatively high concentrations of hydrogen and carbon monoxide. This phenomenon has not been explained at present because no special studies were made and the well is now abandoned. The presence of hydrogen in some wells at the Bovanenkovo field also requires explanation, as the presence of hydrogen gas in permafrost has not been studied in detail.

Table 2. ^{13}C content of methane gas released at Bovanenkovo gas field

Field name, well number	Age of deposits	Gas release depth (m)	$\delta^{13}C$ value (‰) (data G.I.Teplinski, VNIIGAZ)
Bovanenkovo: 51-P-1	Qm_3	28-33	-73.9
51-P-1	Qm_2	59-64	-74.6
51-P-2	Qm_2	38-44	-72.2
51-P-3	Qm_2	62-69	-72.3
52-P-1	Qm_2	63-70	-71.0
52-P-2	Qm_2	114-120	-70.4

Table 3. Geochemical analysis of gas in cores recovered from permafrost interval in 92 GSC Taglu well in Mackenzie Delta, Northwest Territories of Canada
(data S.R. Dallimore and T.S. Collett, 1995)

Field name, well number	Gas sampling depth (m)	Lithology	$\delta^{13}C$ value (‰)	$C_1/(C_2+C_3)$
Taglu: 92GSC	56.9	Interbedded silt and sand	-89.94	22021
	119.4	Sand with occasional silt and gravel	-78.79	6017
	167.5	Sand with occasional silt and gravel	-79.88	4600
	326.9	Silty sand	-77.96	5766
	354.3	Interbedded sand and silt	-79.72	>3800

High concentrations of methane and nitrogen, and the absence of C2-C5 hydrocarbons in the gas samples indicate a biochemical origin for the released gas. High values of hydrocarbon wetness C1/(C2-C5) ratio (greater than 100), also indicate microbial gas. A biochemical origin is confirmed by carbon isotopic ratio determination in methane gas releases from wells of the Bovanenkovo field (Table 2). All $\delta^{13}C$ values were lower than -70 %o.

The data presented in Tables 1 and 2 are in good correspondence with data received earlier by scientists from Canadian and US Geological Surveys during study of permafrost cores recovered at the 92GSC Taglu well drilled in the Mackenzie Delta (Canada) in 1992 (Dallimore and Collett, 1995). Table 3 shows representative results of a chemical analysis of gas liberated from permafrost cores recovered in this well. All the data confirm a biochemical origin for this gas. Large volumes of gas in frozen ice-bearing cores were in a hydrate form.

At the same time, component and isotopic analysis of gas from the hydrate stability zone in the Prudhoe Bay area (Collett, 1993) have indicated the possibility of thermogenic gas within the permafrost section, where good pathways to lower reservoirs exist. According to data presented by T.S. Collett, gas in hydrates below permafrost were of mixed composition: thermogenic (50-70%) and microbial (30-50%). A part of the hydrate-containing massif continues into the permafrost zone without any lithological barrier (except the permafrost base), so it is possible to suppose that gas within the permafrost part of this massif has a similar composition.

Discussion

Practically all known studies of the composition of gas releases from permafrost indicate methane of biochemical origin as the main component of the gas. Although gas sampling has been done in oil and gas field areas, no direct connection between gas within the permafrost zone and deep gas from production reservoirs has been documented (excluding supposed gas composition in hydrate-stability zone at Prudhoe Bay oil field, see above). Some data concerning the presence of thermogenic gas in the permafrost section were recorded in the Yakutian diamond fields (East Siberia) (Porochniak, 1988). The permafrost section in that area consists of Cambrian and Pre-Cambrian deposits containing some heavy hydrocarbons. This fact suggests the possibility of ancient gas and oil reservoirs (or massifs of former hydrocarbon-producing rocks) undergoing freezing with subsequent preservation of thermogenic gas in permafrost. However, such situations are probably not very widespread due to the great time spans between sediment deposition, thermogenic gas formation and genesis of permafrost. Microbial processing of organic matter is likely a much more widespread source of gas within permafrost. Thermogenic gas may be present locally due to spreading along deep faults, around defective wells (no more than 1.2 km from wellhead according to our observations) and as a consequence of the inclusion of gas reservoirs into the permafrost section during freezing.

A biochemical origin of methane in the upper layers of permafrost was confirmed recently by investigations of shallow permafrost cores recovered in various regions of Russia (Rivkina et al., 1996). Measurements of methane concentration in cores recovered from formations with different genesis allowed the establishment of a direct connection between soil cryogenic genesis type and gas generation potential. The study proposed the possibility of the presence of natural gas (methane) in subsurface permafrost in a self-preserved hydrate state, described earlier (Yakushev, 1989). Unfortunately the shallow depth of drilling (down to 50 m) limits generalization of the study. The researchers registered methane only in relatively low concentrations (no more than 22 ml per 1 kg of core) and did not comment on the possibility of free gas accumulation in the permafrost section. It was assumed that all the gas was converted to self-preserved hydrate within the soil pores. Their results for the Yamal peninsula (Bovanenkovo field) indicated decreasing methane concentration with depth (down to 50 m) and they concluded that methane cannot migrate through permafrost. These conclusions are in contradiction with drill data from greater depths (see Figure 4). As it is shown in Figure 4, registered gas releases had maximum frequency and flow rates at depths of 60-120 m.

The mechanism of microbial gas generation and accumulation within permafrost has not been studied in detail. It is probable that some gas is generated from organic matter prior to permafrost development. This gas could be concentrated at certain depths due to gas liberation from water as ice forms during progression of the freezing front. Some of the gas may be converted to hydrate in situations where pore spaces are closed off due to growth of ice, elevating internal pore pressures above the hydrate-formation threshold. The remaining gas should migrate downward within the section due to "squeezing" by the freezing front (taking into account high ice saturation of the front interval and its relative impermeability to gas) (Yakushev, 1989). At depths where water contents decrease, or formation fractures are present, gas accumulation takes place.

We have presented one possible mechanism for gas accumulation associated with permafrost section. Further study could lead to the generation of other models. It is obvious, however, that substantial volumes of methane are trapped in relatively shallow permafrost (down to 150 m). For example, at a depth interval 60-120 m at the Bovanenkovo field, the average gas flow rate was 500 m^3/day. One or two gas releases at these depths were registered at 24 wells drilled in an area 20 km^2. The duration of recorded releases varied from 1 to 6 months (average - 3 months). Thus, the estimated free gas volume at this depth interval should be no less than 1,000,000 m^3, i.e. 50,000 m^3/km^2. This is the minimum value: actual methane content may be an order magnitude greater, taking into account that a single interval at one well released more than 120,000 m^3 during 6 months, and some releases had flow rates up to 14,000 m^3/day (see above and Figure 4).

Conclusion

Permafrost is not impermeable to gas. Natural gas can migrate and accumulate inside permafrost, especially in sand layers. Gas releases from permafrost to the well column can continue for up to 6 months (end of observation) confirming the possibility of long-distance gas migration through permafrost to the well bore.

Natural gas inside permafrost can be biochemical as well as thermogenic in origin. Microbial gas is widespread within permafrost. Thermogenic gas is locally distributed depending on mechanisms for gas migration from deep layers, or the presence of ancient hydrocarbon-producing rocks within the permafrost section. Studies conducted at gas fields in Russia and Canada indicate differences in the composition of gas from within permafrost and gas from deep production reservoirs, although the distance separating the upper productive reservoir from the permafrost gas-releasing interval may be less than 400 m (Bovanenkovo field).

All the studies undertaken confirm that methane is the main component of natural gas in the permafrost section. Typical methane content varies from 87 to 99%. Other components in gas of microbial origin are nitrogen, carbon dioxide and hydrogen.

Gas can accumulate within permafrost as free gas or in hydrate form. Evidence suggests that hydrates can be distributed throughout the permafrost section even without favorable thermodynamic conditions for hydrate stability (self-preserved hydrates).

Most gas releases have been registered in marine deposits enriched by organic matter. Gas was encountered in sand intervals as well as in silt and even clay intervals. This suggests good reservoir properties for silt and clay deposits within permafrost.

Elevated gas content at depth intervals of 50-120 m in the Bovanenkovo field, 50-100 m in the Yamburg field, 60-400 m in the Taglu field, in comparison with other permafrost intervals at these fields, suggests the possibility of regional layers with extremely high methane content, which potentially could liberate huge volumes of methane gas during global warming.

Acknowledgments

The authors are very grateful to Bill Winters and Fred Wright, the reviewers, who have successfully transformed the original Russian English in the manuscript to International English in the paper.

References

Agalakov, S.E. and Bakuev, O.V. (1992). New subjects for hydrocarbon exploration in over-Cenomanian deposits of West Siberia. *Geologiya nefti i gaza (Oil and gas geology)*, **11**, p. 25-28 (In Russian).

Chuvilin, E.M., Kondakov, V.V. and Perlova, E.V. (1996). The peculiarities of gas content of permafrost section at Bovanenkovo gas field. In *Materialy pervoy konferentsii geokriologov Rossii. (Proceedings of 1st Conference of Russian Geocryologists)*. Moscow State University, 3-5 June 1996, **4**, pp. 291-299 (In Russian).

Collett, T.S. (1993). Permafrost-associated gas hydrate accumulations. In *Proceedings of the 1st International Conference on Natural Gas Hydrates*. Annals of the New-York Academy of Sciences, **715**, pp. 247-269.

Dallimore, S.R. and Collett, T.S. (1995). Intrapermafrost gas hydrates from a deep core hole in the Mackenzie Delta, Northwest Territories, Canada. *Geology*, **23**, 527-530.

Kondakov, V.V. and Galiavitch, A.Sh. (1995). *Recovery, description and transport of permafrost cores from observation engineering-geological wells planned for drilling in 1995*. Vorkuta, Krios Ltd., Unpublished technical report, **44**, 13 p. (In Russian).

Medvedskij, R.I. (1986). Mechanism of vertical stream gas and water migration way plugging in regions of permafrost spreading. In *Geochemistry of oil-gas formation and oil-gas accumulation processes in Mesozoic deposits of West Siberia*. Tumen, pp. 140-146 (In Russian).

Melnikov, P.I., Melnikov, V.P., Tsarev, V.P., Degtiarev, B.V., Mizulina, N.B., Popov, A.P., Berezniakov, A.I. and Svetchnikov, A.M. (1989). On hydrocarbon generation in permafrost plays. In *Izvestiya AN SSSR (Proceedings of Soviet Academy of Science), Geological section*, **2**, pp. 118-128 (In Russian).

Porokhniak, A.M. (1988). Gas hydrates in cryolithozone of West Yakutia. Moscow, TsNIITsvetMet Institute, N 1744-88Dep, 30 p. (In Russian).

Rivkina, E.M, Gilitchinskij, D.A., Fedorov-Davydov, D.G., Rivkin, F.M. and Tsherbakova, V.A. (1996). Regularities of greenhouse gases spreading in permafrost plays. In *Materialy pervoy konferentsii geokriologov Rossii. (Proceedings of 1st Conference of Russian Geocryologists)*. Moscow State University, 3-5 June 1996, **4**, pp.157-163 (In Russian).

Starobinets, I.S. and Murogova, R.N.(1985). Screening and carrying role of cryolithozone rocks with respect to migratory hydrocarbons. *Oil and Gas Geology*, **1**, 24-27 (In Russian).

Yakushev, V.S. (1989). Gas hydrates in cryolithozone. *Soviet Geology and Geophysics*, **11**, 100-105 (In Russian edition).

Yakushev, V.S. and Collett, T.S. (1992). Gas hydrates in Arctic regions: risk to drilling and production. In *Proceedings of 2nd International Offshore and Polar Engineering Conference*. San Francisco, California, **1**, pp.669-673.

Yakushev, V.S. (1994). Some environmental problems of gas recovery related to permafrost and natural gas hydrates. In *Proceedings of the 19th World Gas Conference*, Milan, Italy, Paper A5, 13 p.