Polarforschung 68: 215 - 219, 1998 (erschienen 2000)

Gas and Possible Gas Hydrates in the Permafrost of Bovanenkovo Gas Field, Yamal Peninsula, West Siberia

By Evgeny M.Chuvilin[1], Vladimir S.Yakushev[2] and Elena V.Perlova[1]

THEME 12: Gashydrates and Permafrost, Onshore and Offshore

Summary: Large gas content of upper permafrost layers in the Bovanenkovo gas condensate field area (Yamal Peninsula, West Siberia) was determined during field and laboratory studies of gas blowouts in shallow (depth down to 450 m) monitoring wells. Natural gas (methane presumably) was detected in gas releases from shallow permafrost during well drilling and completion. Disseminated hydrates were identified during drill cores study in laboratory. Gas releases were detected in relatively permeable layers of permafrost (sand, silt) and in zones with reduced mineralization of sediment pore water. Possible mechanism of gas and gas hydrate accumulations formation within permafrost is suggested on the base of the study.

INTRODUCTION

Gases and fluids in a given sediment composition within developing or already grown permafrost define a complex multiphase system. The study of such a naturally existing system offers important genetic information. The inclusion of such substances influences the aggradation/degradation of permafrost rocks by inducing specific properties such as texture-morphologic and thermodynamic peculiarities, and under favorable circumstances results in the formation of clathrate compounds of water and gas called gas hydrates.

These phenomena are so far poorly investigated in spite of obvious scientific and practical interest of gas components present in permafrost. For all practical purposes, only scarce data on volume, genesis, formation conditions and forms of gas existence within permafrost are available. At the same time, many researchers working at oil and gas fields in permafrost regions have documented repeated unpredictable gas releasing from within or below permafrost layers. These releases were observed in West Siberia, the Arctic regions of Canada, in Alaska and in some other regions (DALLIMORE & COLLETT 1995, ISTOMIN & YAKUSHEV 1992, YAKUSHEV & COLLETT 1992). Sometimes, gas release rates approached in magnitude industrial production rates. This observation forms the basis for the assumption of the existence of wide-spread and large gas accumulations in permafrost regions.

[1] Department of Geocryology, Faculty of Geology Moscow State University, Moscow, Russia, <chuvilin@geol.msu.ru>

[2] VNIIGAZ (Research Institute of Natural Gases and Gas Technologies), Moscow Region, p. Razvilka, Russia, <yakushev@mosc.msk.ru>

Manuscript received 18 January 1999, accepted 12 October 1999

RESEARCH AREA

A new detailed study of gas accumulations within permafrost has been conducted at the Bovanenkovo gas condensate field (Fig.1) in the northwestern part of Yamal peninsula (West Siberia). Most of the data were received during monitoring of the drilling in the southern part of the field by Scientific-Technical Company (STC) "Krios".

Fig. 1: Map showing locations for permafrost gas release studies

The sedimentary geologic section is a field which typically made by Mesozoic-Cenozoic terrigenous rocks (sandstones, clays, aleurites). The upper horizon consist of about 300 m thick Quaternary deposits of marine origin (silt, loam, clay). According to the drill data of STC "Krios", the deepest monitoring wells (550 m) had penetrated unconsolidated sediments of loam-clay composition presumably (Fig. 2).

The Bovanenkovo gas condensate field is situated in the Northern Geocryologic Zone and characterized by harsh natural conditions (BAULIN et al. 1996). Permafrost is continuous, shallow taliks beneath large rivers and lakes. The thickness of the permafrost layer varies between 200 m in river valleys and 250 m in hilly terrain. The mean annual temperature determined from 10 m depth (depth of zero annual temperature variation) varies between -2 to -7 °C depending on the landscape.

The permafrost layer in the study region is enriched in organic matter. In upper part of the section (20-30 m) organic matter is represented by layers of peat and plant remains (detritus). The lower part of the section contains organic matter such as coal tracks and inclusions. In general, the organic matter content increases with depth and reaches maximum values at the lower boundary of the permafrost layer.

The permafrost layer is characterized by high values of water and ice content decreasing with depth (from 85 % to 25 %). The unfrozen water content increases with depth (from 1 % to 20 %). The organic-rich sediment containing saline fluids have lower freezing points and lower thermal conductivities, when compared with ice-containing sands. The salinity of the permafrost section is irregular although some trend to salinity increase with depth was observed.

GAS RELEASES FROM PERMAFROST

Gas release from the permafrost layer during drilling in the southern part of Bovanenkovo field are frequent in the depth range from 20 to 130 m. Most blowouts are documented for a horizon with frequent gas releases at depth between 60 to 120 m (Fig. 3) in deposits of the sediments mQ1-2 (Fig. 2). The scheme of Figure 4 shows the areal distribution of this horizon and location of exploratory drill wells.

The analysis of the maximum flow rates as function of depth shows an abrupt increase at a depth of approximately 60 m. Flow rates of 100-300 m^3/day occur in layers shallower then 60 m and reach values of 14000 m^3/day (average value is 500 m^3/day) in the interval of 60 m to 120 m.

The chemical composition of the released gases shows a high content of methane (usually more than 99 %). Nitrogen, carbon dioxide and hydrogen occur only in small volumes. Other light hydrocarbons, such as ethane, propane, butanes were not identified. Mass spectroscopic analysis point to microbial origin of methane ($\delta^{13}C$ = -75 to -77 ‰) (SKOROBOGATOV et al. 1998).

Geological index	Depth of layer bottom	Lithology	Short description
a Q_{IV}	5.4		Sandy silt with peat,ICV*50% down to depth 2.2m,lower-<3%
	10		Gray silt, CT** is net-like, ICV is 10-20 %
m Q_{III}^{1}	29		Sandy silt with peat layers, CT is massive
m Q_{I-II}^{1-2}	130		Gray silt with fine-grained sand thin layers of 2-10mm thickness. Down to depth 62m with peat and plant remains inclusions. In depth interval 81-83 m inclusions of small stones, CT is massive. **Gas liberation in intervals: 54-58, 71-76 and 91-94 m**
	165		Gray silt, CT is massive. **Frozen rocks bottom at depth 165m**
	205		Gray clay, with black coal spots and thin layers, peat inclusions at depth 180-183 m. Clay is unfrozen
m P_{1-2}	243		Silt of gray color with sand and gravel
	283		Interbedding of gray silt and fine-grained sand
	314		Gray clay with sand layer at the bottom of the interval (311-314 m)
	507		Dark-gray consolidated clay with stoned macrofauna inclusions and thin layers of sandstone
m K_2	550		Dark-gray aleurolite with clay layers of 10-20 cm thickness and stoned fauna inclusions. Gas production reservoir from depth 600 m

Fig. 2: Geological section of 610-P-3 monitoring well; Alluvium at riverside of Mordy-Yakha river, North- West of Yamal Peninsula. *ICV - visible ice content, **CT - cryogenic texture

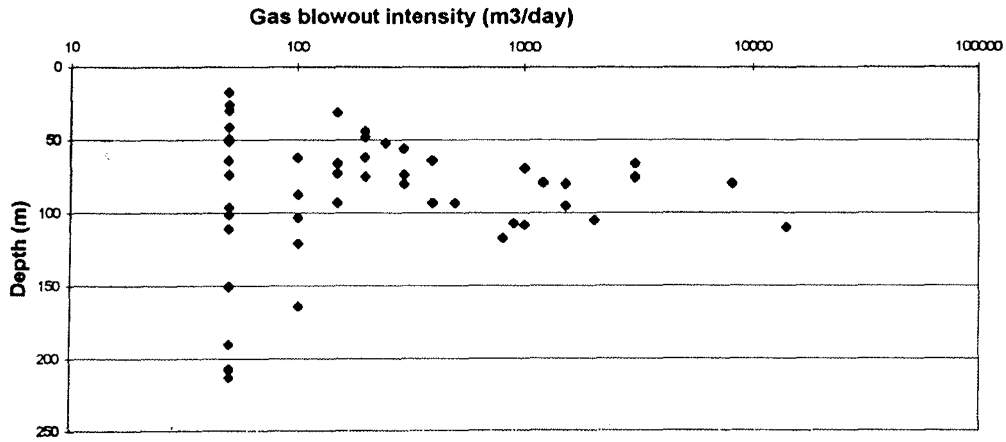

Fig. 3: Distribution of gas blowouts and their intensities with permafrost depth at Bovanenkovo gas field; generalized data from 40 wells.

THE LINK BETWEEN GAS RELEASES AND SEDIMENT COMPOSITION

Practically all the releases are within silty sediments with thin layers of sand enriched by organic matter. From a depth of 130 m onwards, the clay content of sediments increases and sand layers disappear. Strong gas releases from depths below 130 m were not observed.

As mentioned above, the salinity distribution in sediments as function of depth is irregular (Fig. 5). Comparison of the intervals of gas releases with the curve of the salinity variations shows that most gas releasing intervals (about 85 %) are situated in zones of reduced salinity. Immediately below gas releasing intervals, zones with elevated salinity were often registered. For example, in a 610-P-2 monitoring well (Fig. 5a) the average general salinity of rocks is in the order of 0.7 %, but in gas releasing horizons it decreases to 0.4 %. Below the gas releasing intervals, the general salinity increases to 1 %. Besides, the similar tendency is observed for pore solution concentration in the gas releasing horizons. So, in a 610-P-2 monitoring well (Fig. 5b) the pore solution concentration in these intervals decreased to 1.5 %, thus the average is in the order of 2.5 %. Below the gas releasing intervals, the pore solution concentration increased to 3.7 %.

Organic matter content in gas releasing intervals is usually lower than in adjacent rocks (Fig. 5c). Apparently, more intensive decomposition of organic matter in these intervals resulted in larger volumes of gas formed in-situ. Additional volumes of microbial gas could migrate to these intervals from surrounding deposits in the course of cryogenic concentration during geologic section freezing.

POSSIBLE FORMS OF GENERATION AND EXISTENCE OF GAS ACCUMULATIONS IN THE BOVANENKOVO FIELD

Considerable flow rates of gas from shallow permafrost intervals raise the question in what form does gas exist in these geologic section. Rock temperature and pressure condition in the field suggest that the methane hydrate stability zone exists only from depths below about 250 m. However, some of the gas releases increased in volume while heat was applied on surrounding rocks and decreased if this influence was interrupted.

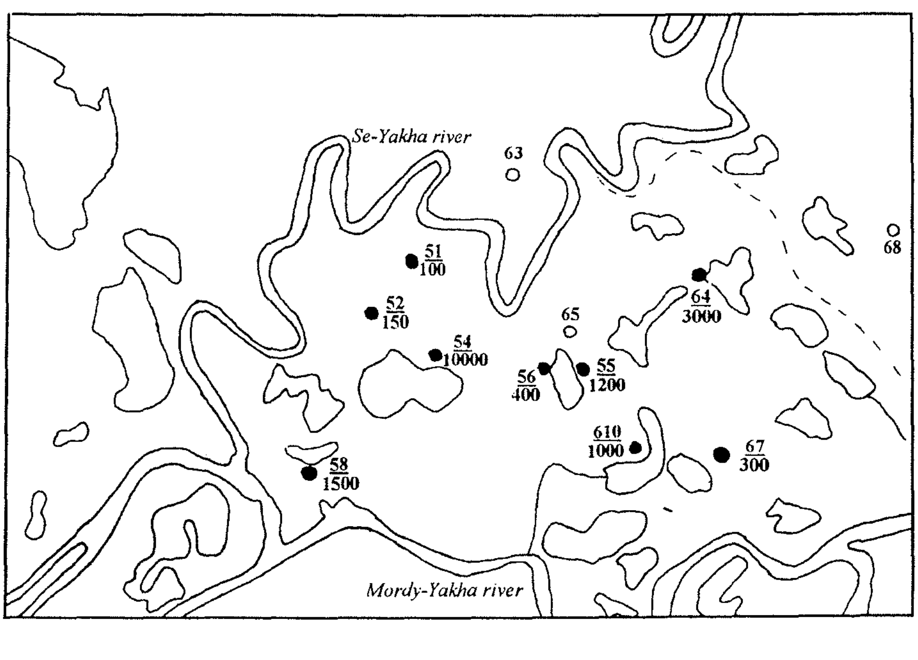

Fig. 4: Map showing locations of monitoring wells. Open circles = well cluster number; filled circles = wells producing from depth intervall 60-120m and maximum gas flow rate (m^3/day).

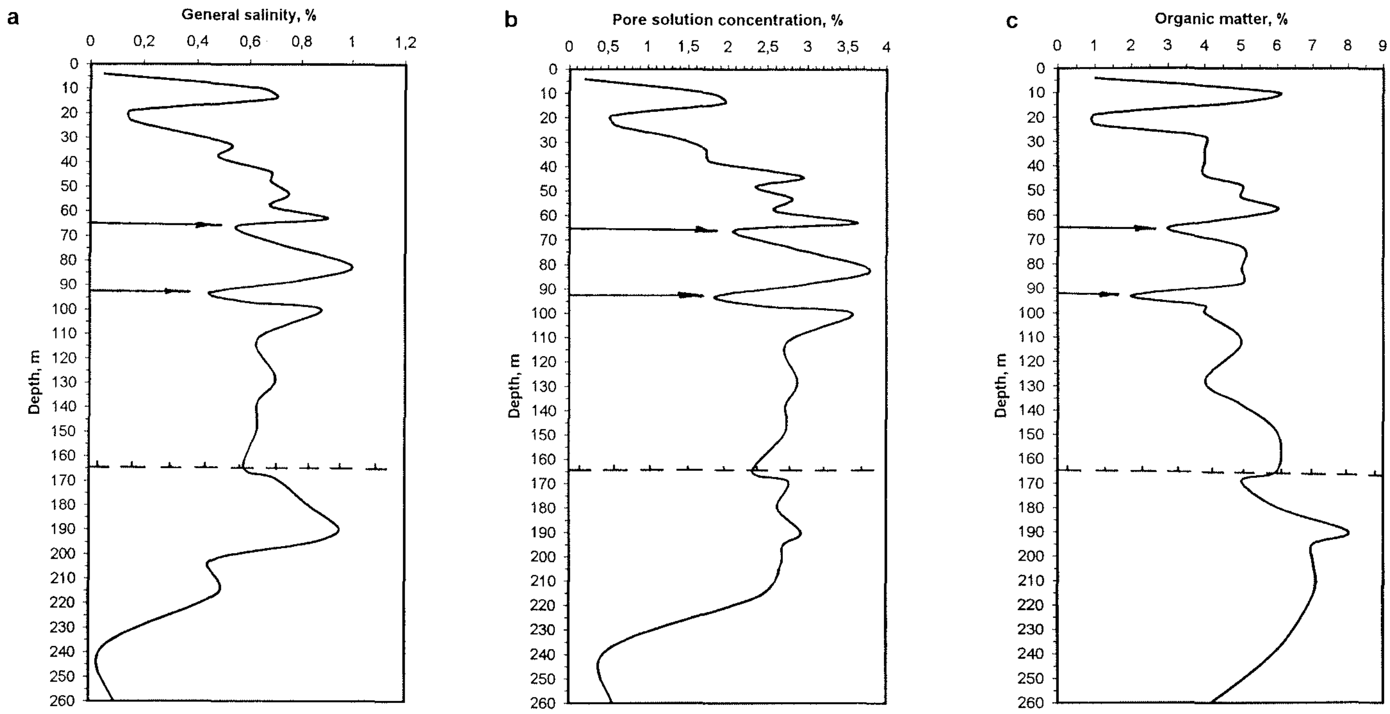

Fig. 5: Gas release in relation to (a) general salinity, (b) pore solution concentration, and (c) organic matter content according to monitoring well 610-P-2 drill cores. Gas releasing intervals at depths of 63-67 m (gas flow rates 500 m^3/day) and 91-95 m (gas flow rates 1000 m^3/day); freezing front at approx. 165 m.

Analyses of undisturbed permafrost drill cores for their gas content showed liberation of large volumes of gas, when core pieces thawed in warm liquid. The specific gas content of some samples reached 0.4 cm^3/g. Taking into account high degree of pore space filling by ice and unfrozen water (more than 98 %), this gas content exceeds several times the possible free gas content of the samples. This phenomenon can be explained only by postulating the presence of gas hydrates in the sample pores. Gas hydrates contain up to 160 m^3 of gas in 1 m^3 of hydrate, so the hydrates once formed can apparently survive in these shallow

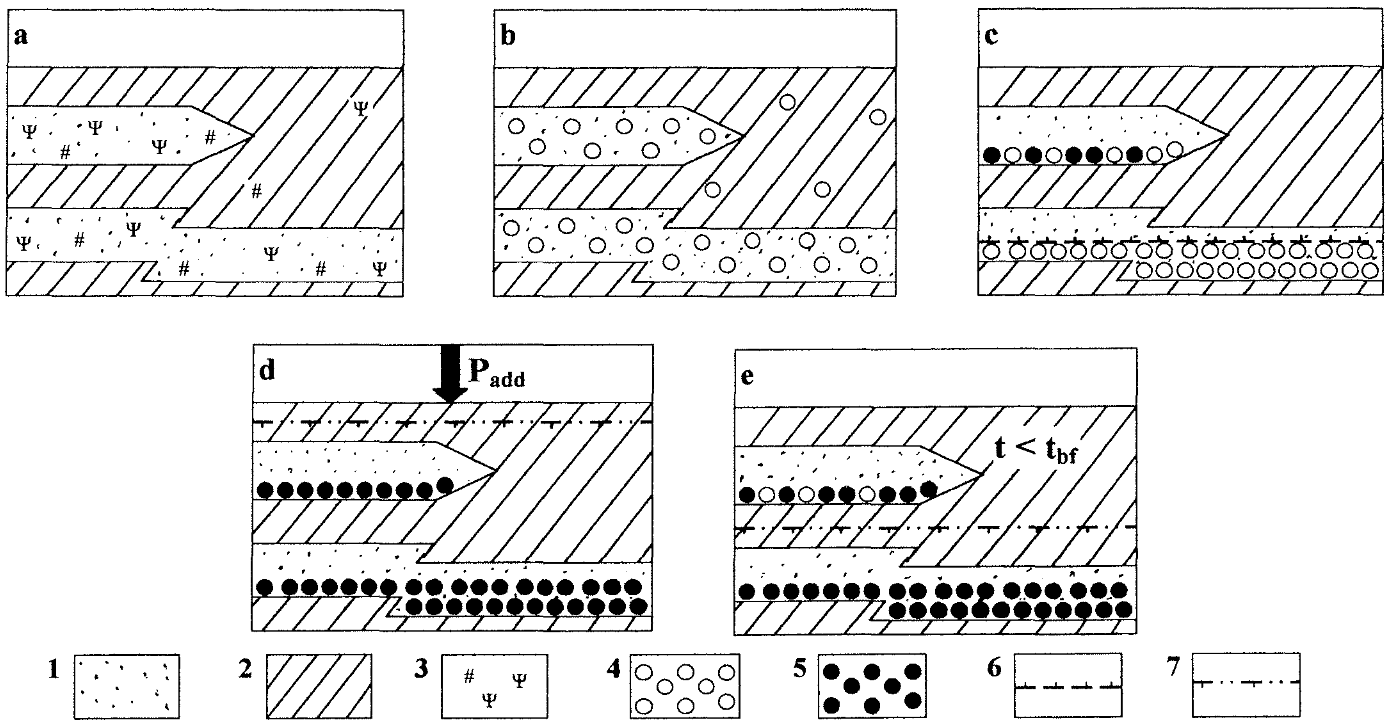

Fig. 6: Scheme of possible gas and gas hydrate formation mechanism in permafrost interval (a) formation of sandy-loam sediments containing organic matter, (b) gas generation during microbial processing of the organic matter, (c) formation of gas and gas hydrate accumulation during permafrost formation, (d) transformation of remains free gas to hydrate within permafrost under additional pressure (Padd), and (e) self-preservation of gas hydrates within permafrost after additional pressure drop. Legend (1) sandy sediments, (2) loam sediments, (3) organic inclusions, (4) gas-containing sediments, (5) gas-hydrate containing sediments, (6) freezing front, and (7) Hydrate Stability Zone (HSZ) top.

permafrost depth due to self-preservation phenomenon (Ershov et al. 1991, Istomin & Yakushev 1992).

These data allows the assumption of a widespread occurrence of disseminated hydrates in permafrost rocks. Probably, the process of gas generation, accumulation and partial hydrate formation in this region occurred in stages (Fig. 6). At the first stage (before freezing), microbial processing of organic matter resulted in micro-accumulations in relatively permeable layers. Then epigenetic freezing of the section resulted to cryogenic concentration of free and formerly water-dissolved gas in sandy layers. During this process in some lithologically isolated permeable layers, gas was compressed by freezing and a part of it formed hydrate.

Hydrates could be formed in these intervals during Arctic sea transgression or regional ice cover formation, when the overburden pressure was elevated. After pressure reduction, hydrates did pass through the self-preservation stage and remained metastable for a long time. It is proper to mention, that harsh climatic conditions are documented in this area for the Pleistocene and Holocene. These conditions caused continuous growth of permafrost thickness without thawing even at the Holocene climatic optimum (about 5000 years ago). These data support the possibility of long-time self-preserved hydrates in permafrost. However, the hydrate formation might have a more complex character, so further study of permafrost rock genesis, composition, properties and paleogeologic simulation is necessary for a detailed understanding of the gas component evolution in this area.

CONCLUSION

The results of this study confirm a wide spreading of natural gas within permafrost, which had been considered earlier as unfavorable medium for natural gas accumulation. Gas hydrate presence in porous space of frozen sediments outside hydrate stability zone depth interval indicates the possibility of hydrate accumulation in permafrost as relic of ancient hydrate formation caused by outer loading (glaciers, marine transgression) or inner temporary pressure elevation during sediment freezing.

Microbial origin of gas within permafrost shows the possibility of natural gas presence in all areas of permafrost spreading independently on oil-gas generation potential of deep strata. This study produced some base for prediction of natural gas accumulation of industrial scale within shallow permafrost in Arctic regions, but special studies are needed to confirm this assumption. Possible contribution of shallow permafrost natural gas accumulations to methane emission into the atmosphere during global warming is also unknown and requires detailed studies.

References

Baulin, V.V., Aksenov, V.I. & Dubikov, G.I. (1996): Engineering-geological monitoring of Yamal oil and gas fields. In two volumes. V.II. Geocryological conditions of Bovanenkovsky gas-field assimilation.- Institute Northern Development Siberian Division Russian Aca. Sci., Tyumen: 240 pp. (in Russian).

Dallimore, S.R. & Collett, T.S. (1998): Gas hydrates associated with deep permafrost in the Mackenzie Delta, N.W.T., Canada: regional overview.- In: Proceedings 7th International Permafrost Conference, Yellowknife, Canada: 201-206.

Ershov, E.D., Lebedenko, Yu.P, Chuvilin, E.M., Istomin, V.A. & Yakushev, V.S. (1991): Peculiarities of gas hydrates existence within permafrost.- Doklady Akademii Nauk SSSR, v.321, No.4: 788-791 (in Russian).

Istomin, V.A. & Yakushev, V.S. (1992): Gas hydrates at natural conditions.- Moscow, Nedra Publish., 236 pp. (in Russian)

Skorobogatov, V.A., Yakushev, V.S. & Chuvilin, E.M. (1998): Sources of natural gas within permafrost in North-West Siberia.- In: Proceedings 7th International Permafrost Conference, Yellowknife, Canada: 1001-1007.

Yakushev, V.S. & Collett, T.S. (1992): Gas Hydrates in Arctic Regions: Risk to Drilling and Production.- Proceedings 2nd International Offshore and Polar Engineering Conference. San Francisco, USA, vol. 1: 669-673.