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PERIGLACIAL PROCESSES ON ARCTIC SHELF AND COAST

OFFSHORE PERMAFROST IN THE KARA SEA

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Problems of identifying submarine permafrost in the Kara Sea shelf from seismic-acoustic data are considered. Seismic-acoustic markers indicate the presence of permafrost in the southeastern Kara Sea and in the Yamal shelf to depths of 120 m. Additionally, acoustic permafrost (APF) markers are inferred near the Severnaya Zemlya within local seafloor highs surrounded with 100–120-m isobaths. The existence of permafrost at greater sea depths is most likely an exception and may be due to neotectonic subsidence. The permafrost extent in the Kara Sea has been mapped with GIS tools and the respective database on its setting has been developed. The submarine permafrost table lies at 5–60 m below the sea floor. According to statistical processing of the collected seismic-acoustic data, the subbottom depth to permafrost is most often (47 %) in the range 10–20 m. Gas seeps showing up as noise in seismic-acoustic wavefields are hypothesized to have a genetic relationship with submarine permafrost.

INTRODUCTION

Submarine permafrost is remnant terrestrial permafrost that formed during times of sealevel lowstand of the Last Glacial (20–18 kyr BP) and was flooded during the last transgression (16–5 kyr BP). The flooded permafrost has thawed from above and from below, and partly saline rocks became cooled. Thus submarine permafrost has acquired its present state.

The extent and structure of submarine permafrost at the Kara shelf remain underexplored. The main ideas are based on near-shore engineering-geological drilling data [*Rokos et al., 2001; Rokos and Tarasov, 2007*].

Although there have been several publications on the subject, the limits and depths of submarine permafrost have not been reliably constrained for the lack of explicit geological evidence [*Melnikov and Spesivtsev, 1995*]. For this reason, the permafrost extent has been most often mapped proceeding from expert appraisal while the latter is applicable to small-scale maps only [*Rokos et al., 2001; Rokos, Tarasov, 2007*].

METHODS

High-resolution seismic-acoustic methods are commonly used for crosswell correlation when explicit geological evidence is insufficient. The today's advanced data acquisition and processing techniques allow using seismic records as an independent source of geological information. With the seismic facies analysis, the seismic wavefield can image the ground structure to depths 60–70 m, including permafrost [*Shlezinger, 1998; Rokos et al., 2001; Rokos and Tarasov, 2007*]. A seismic-acoustic section is in the first approximation equivalent to a geologic cross section, the resolvable seismic sequences and subsequences being correlated with geologic (stratigraphic) units, such as strata, suites, horizons, etc. Undisturbed patterns of stratified sediments in a seismic section indicate the absence of submarine permafrost (Fig. 1, *A*).

Among factors that can disturb the seismic image in a given region there are cryogenic and post-cryogenic effects in sediments, as well as structures associated with free gas. Jointly they can produce intricate patterns difficult for interpretation (Fig. 1, *B*).

As it was shown for the shelves of the Pechora and Laptev Seas [*Rekant et al., 2009*], submarine permafrost in a seismic section is detectable from high-amplitude reflections which are seismic-acoustic markers of distinct post-depositional characteristics (Fig. 1, *B*). The permafrost table commonly corresponds to a prominent reflector of normal polarity caused by abrupt acoustic velocity rise in frozen ground.

The presence in the sediments of just little free gas produces seismic interference evident as bright spots or vertical blanking zones (Fig. 1, *B*). These gas structures are called gas seeps (GS) and are hypothesized to have a paragenetic relationship with submarine permafrost [*Rokos et al., 2001; Rokos and Tarasov,*

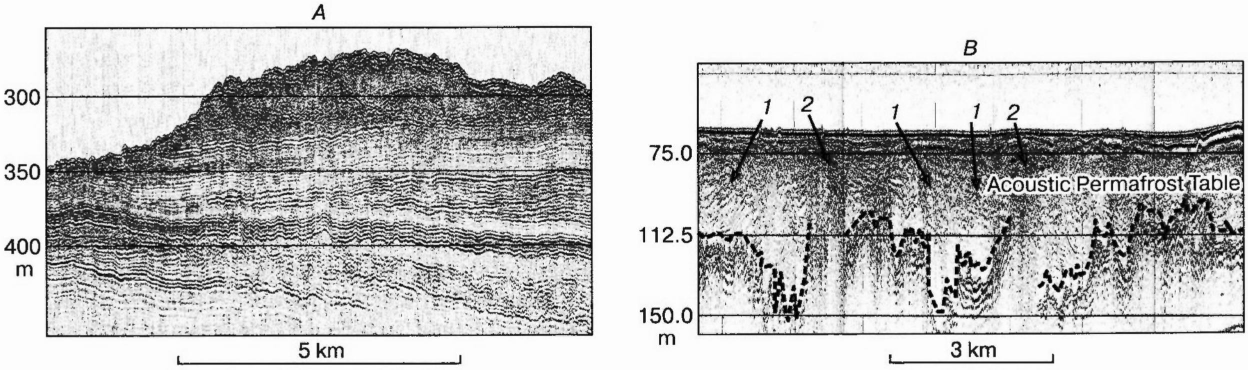

Fig. 1. Fragments of seismic-acoustic profiles in the Kara Sea:

A – a typical seismic image of a section free from submarine permafrost; *B* – a typical seismic image of areas with submarine permafrost. *1* – sites of cryogenic sediment deformation above permafrost; *2* – gas seeps that show up as vertical dead zones.

2007], specifically, to be controlled by taliks [*Rokos et al., 2001; Rekant et al., 2009*].

The seismic-acoustic results agree well with regional drilling data. Most of shoreface and inner shelf logs from the western Yamal (e.g., near Cape Kharasavey) show faster dip of the permafrost table (40 m or more) in a strand between the shoreline and the ~5–7-m sea depth. A similar pattern appears from seismic-acoustic data (Fig. 2).

RESULTS

Processing of more than 100,000 km of seismic-acoustic profiles in total has revealed several zones of prominent markers of acoustically defined permafrost (APF), as well as zones where such markers are poorly pronounced but are inferred (Fig. 3). The APF markers are most reliably detectable within a broad strand in the southern Kara Sea and in the western

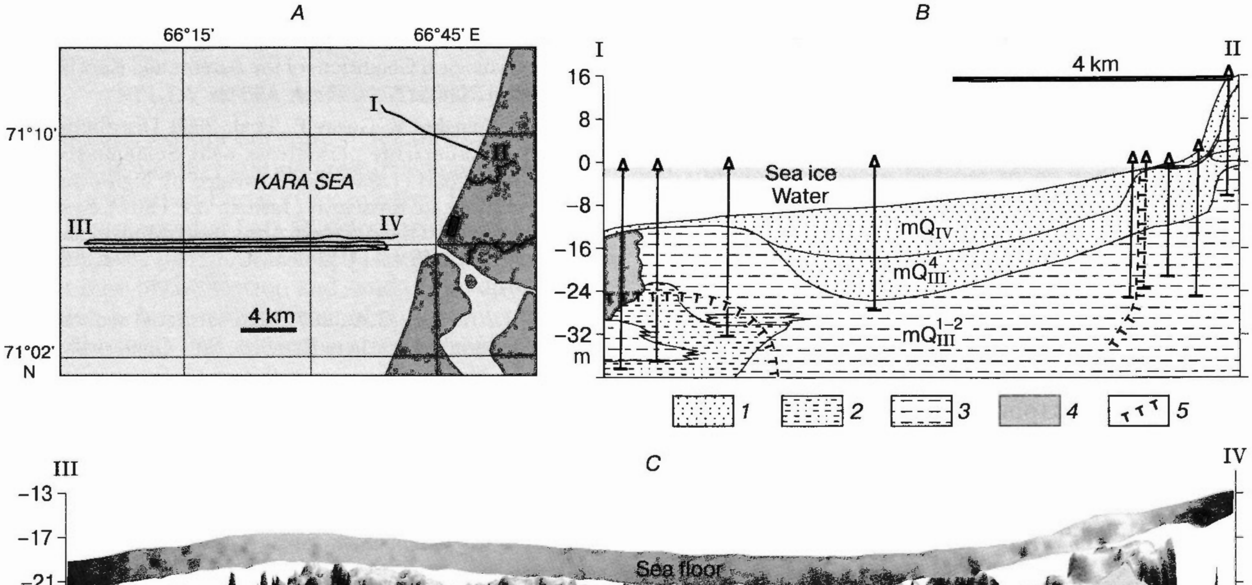

Fig. 2. Processed seismic-acoustic data and drilling results from Cape Kharasavei, compared.

A – location map of seismic-acoustic and drilling profiles; *B* – drilling profile I–II [*Melnikov and Spesivtsev, 1995*]; *1* – sand; *2* – silt; *3* – pelitic silt; *4* – clay; *5* – permafrost table; *C* – position of the submarine permafrost table along profile III–IV: a fragment of a 3D model derived from seismic-acoustic data.

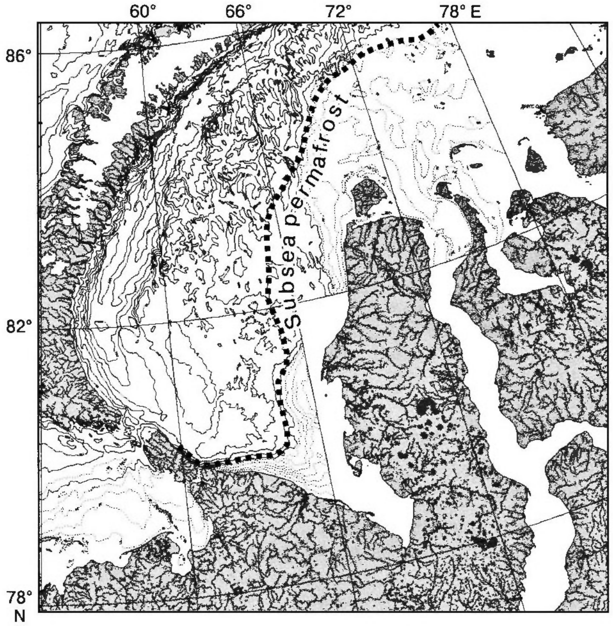

Fig. 3. Map of submarine permafrost in the Kara Sea based on seismic-acoustic data.

Yamal shelf. The extent of submarine permafrost is controlled mainly by the present sea depth. The greatest number of permafrost markers falls within the depth range 100–120 m.

Permafrost is almost absent from sea depths below 120 m, except for a few areas of steady neotectonic subsidence.

Of special interest are zones of gas seeps. As our data show, they occur most often within reliably detected or inferred permafrost zones. This is implicit evidence of their genetic linkage. Gas seeps may originate from zones of a deeply buried permafrost table at the account of gas released during permafrost degradation.

The permafrost table is from 5 to 60 m below the sea floor. According to statistical processing of the data, the subbottom depths to permafrost show a nearly lognormal distribution, at least in the southwestern part of the Kara Sea and in the Yamal shelf, being most often (47 %) in the range 10–20 m. Statistical relationships between the permafrost table and sea depths show direct correlation only when the water is deeper than 40 m. The reason may be in rapid sealevel rise from that depth (40 m) to the present level.

CONCLUSIONS

Acoustic markers of submarine permafrost are reliably detectable in the southeastern Kara Sea and in the Yamal shelf to water depth of 120 m. There are also inferred APF markers near Severnaya Zemlya within local seafloor highs nested in areas of 100–120-m isobaths. The existence of permafrost at greater sea depths is most likely an exception and may be due to neotectonic subsidence.

The permafrost table is from 5 to 60 m below the sea floor. The subbottom depths to permafrost show a lognormal distribution and are most often within 10–20 m.

Statistical relationships between the permafrost table and sea depths show direct correlation only when the water is no shallower than 40 m. The reason may be in rapid sealevel rise from the depth of 40 m to the present level.

The permafrost extent in the Kara Sea has been mapped with GIS tools and the respective database on its conditions has been developed.

There is apparently a paragenetic relationship between gas seeps and submarine permafrost, and the markers of gas seeps may additionally indicate deeply buried submarine permafrost.

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