Ebullition-driven fluxes of methane from shallow hot spots in the East Siberian Arctic Shelf

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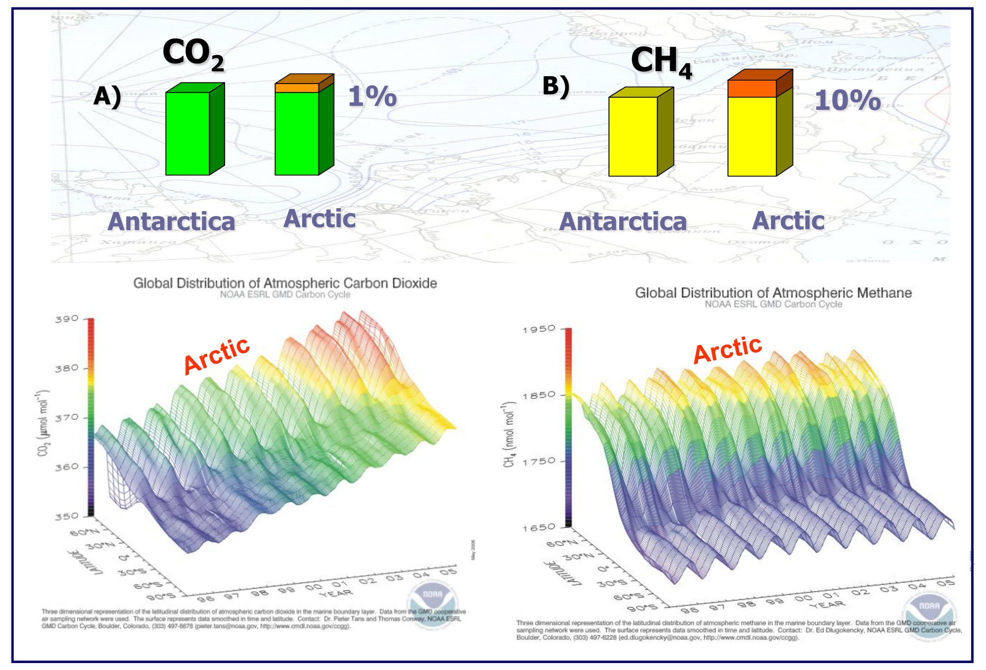
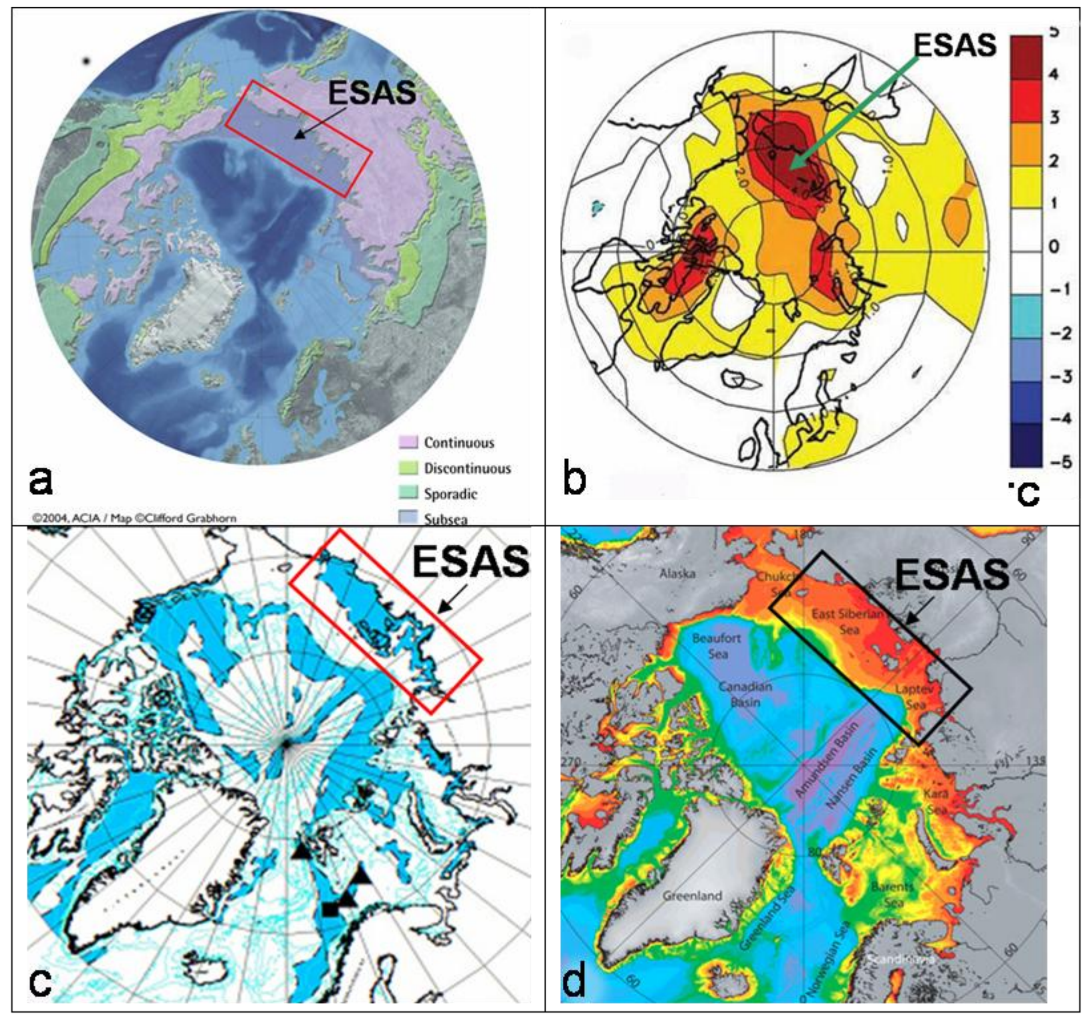
Motivation: Importance of the Arctic for GHGs expansion



- The maximum concentration of atmospheric methane (CH_4) occurs over the Arctic: the value of CH_4 over Greenland exceeds that over Antarctica by 8-10%; an absolute maximum is measured during wintertime (Steel et. al., 1987; Fung et. al., 1991).
- Geologic evidence provides insight into possible climate change effects from a warmer Arctic, suggesting that enhanced Arctic CH4 emissions during warm periods played a key role in past rapid climate change.

The East Siberian shelf – a new focal point for methane studies in Arctic marine environment



- The ESAS is the largest (**2.1×10^6 km^2**) and shallowest (mean depth <50 m) continental shelf among the world oceans; the region has a unique geologic history.
- During cold climate periods, when sea level was more than 100-m lower, the coastline was up to 1000-km northward, exposing the continental shelf and increasing the **Siberian coastal accumulative plain** by a factor of 5;
- Sea level rise associated with the current warm Holocene epoch led to permafrost inundation 8-10 kYr ago, which warmed the upper permafrost **by as much as 12°C**.

Methane emissions from the ESAS provide with different type of methane source to the atmosphere

The ESAS is a **unique area of the World Ocean** for a range of reasons. **1)** The ESAS is the area, where more than 80% of sub-sea permafrost is currently located (*Fig.2a*); **2)** Sub-sea permafrost has been experiencing continuous warming during the last 8-10 thousands years since it was inundated; **3)** The ESAS is significantly affected by global warming - during the first 5 years of 21-st century, mean surface air temperature above the ESAS increased by up to 5˚C (*Fig. 2b*); **4)** The ESAS holds a major reservoir for *shallow Arctic hydrates* and *sub-sea permafrost* (*Fig.2c*); **5)** No comparable region has such an *extensive* continental shelf area (>50% of the ESAS); the ESAS shelf accounts for ~10% of the global continental shelf area; **6)** The ESAS is very shallow (mean depth is less than 50 m), which provides a *short conduit* for seabed CH4 transfer to the atmosphere (*Fig.2d*). **7)** ESAS seabed CH_4 emissions are geologically *controlled*; specifically, failure of subsea permafrost to further restrict methane release from seabed deposits uncorks the huge gas reservoirs, leading to *large-scale releases;* ***8)*** As a marine ecosystem, the ESAS is markedly oligotrophic, which could limit microbial methane consumption (or production);

How methane releases occur in the ESAS

1) Releases in the areas affected by warming effect of river runoff (widespread cold seeps)

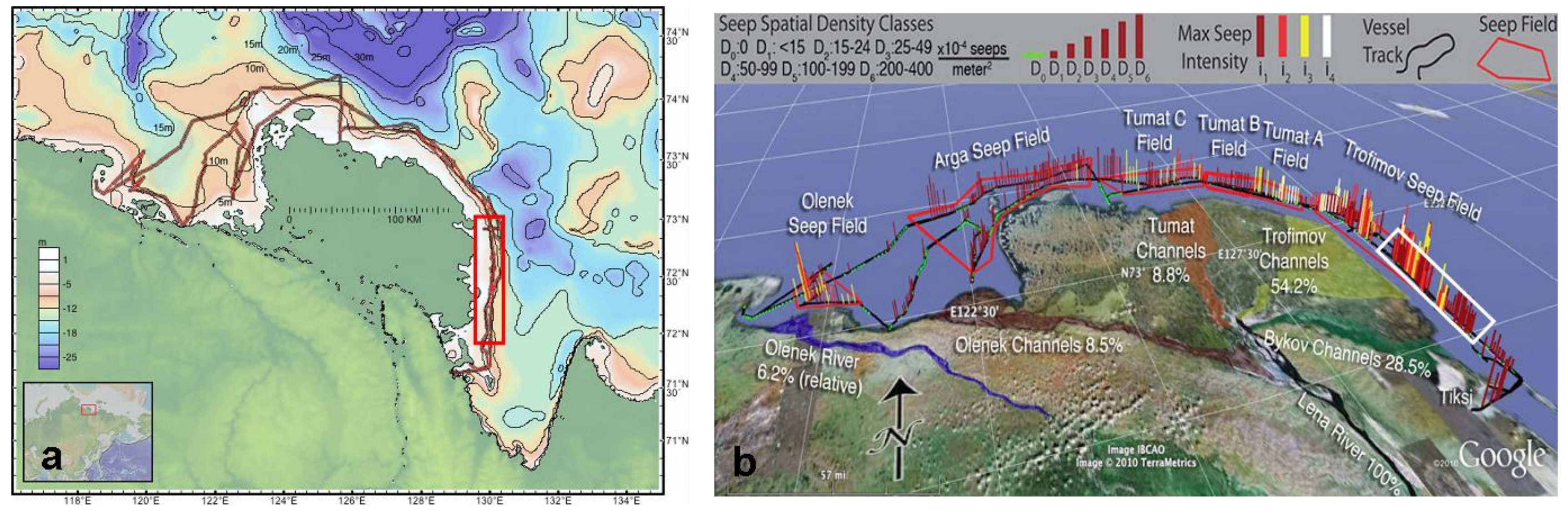


Figure 1. August - September 2009 vessel GPS track around the Lena River Delta in the Laptev Sea. (Vessel track shown as brown line: the study area shown as red rectangle). Topography and bathymetry from the Global Multi-Resolution Topography synthesis (Ryan et al., 2009). 5 m isobath (a) Map of seep spatial density and intensity classes from multibeam sonar data; primary river channels within the Lena Delta and flow proportions from Létolle et al. (1993) and Bareiss et al. (1999 (study area shown as white rectangle) (b).

2) Releases in the areas affected by sub-sea permafrost and permafrost-related hydrates destabilization (torch-like releases reaching the sea surface)

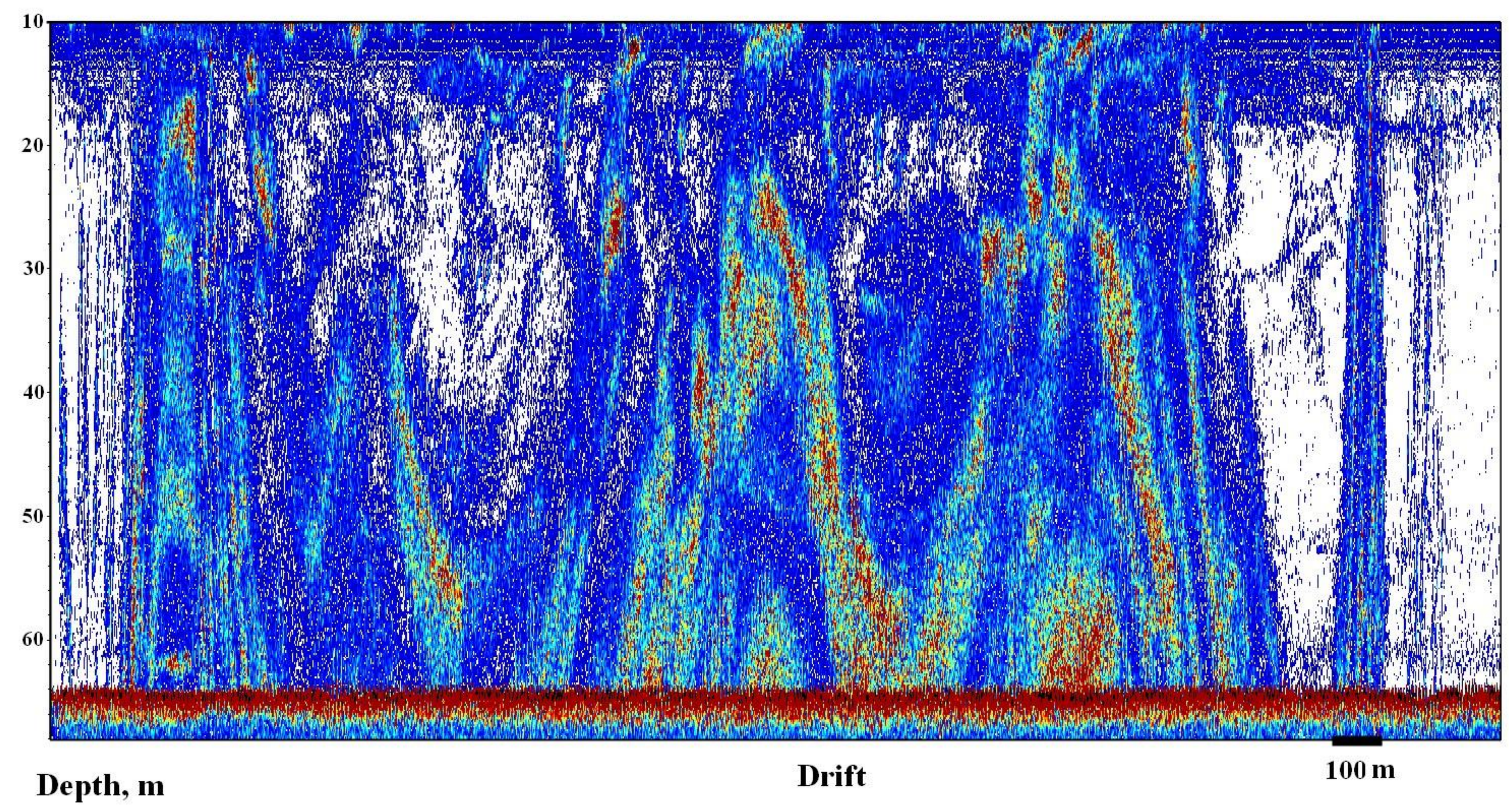


Fig. 2. Example of seismic images, interpreted as strong ebullition stemming from the sea floor all the way to the sea surface. Such torch-like bubble releases was observed over the area of ~20, 000 miles^2. Concentrations of dissolved methane in the water column reached up to 1000 nM and mixing ratio of methane in the atmospheric boundary layer reached 3.5 ppm (wind speed from 10 m/s to 25 m/s).

3) Releases due to the shallow gas front disturbance by ice scour

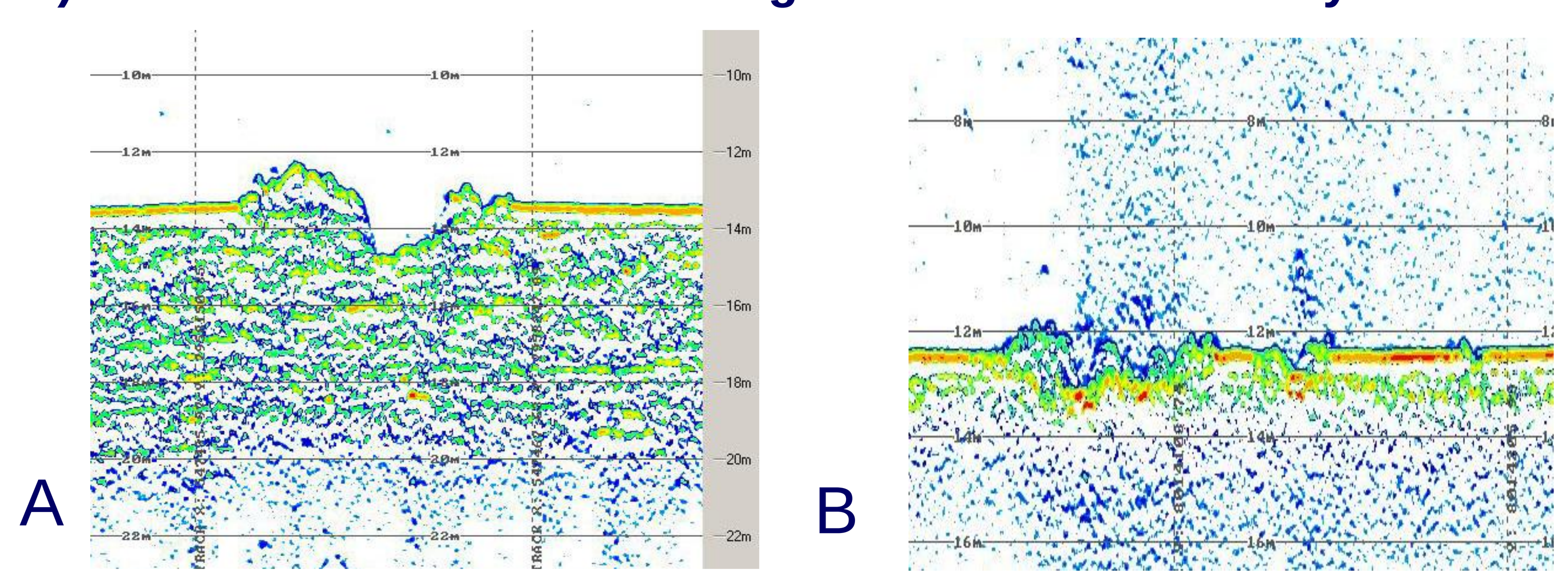


Fig.3. Seismic image of ice scouring in the area where gas front has not been disturbed yet because it sited deeper (A); Seismic image of ice scouring in the area where gas front has been disturbed due to its shallow appearance that led to gas releases as bubbles (B).

Formation of gas migration pathways within the seabed

1). Chimney-like structures

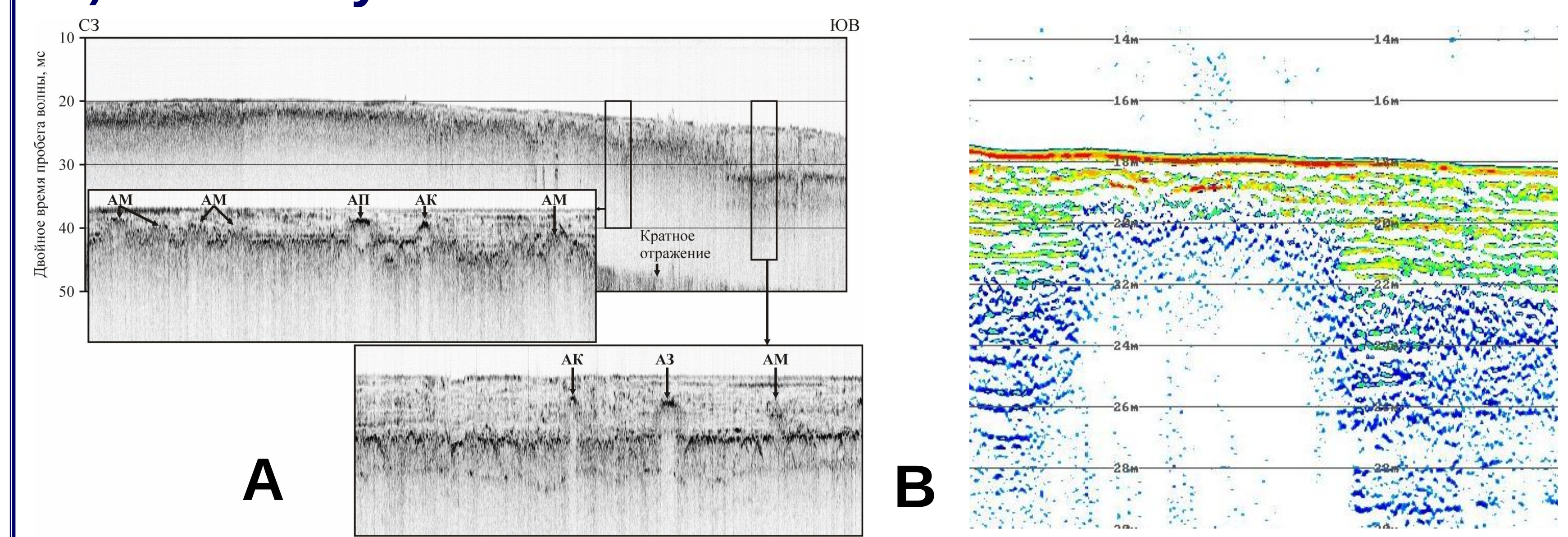


Fig.4. Different stages in formation of gas migration pathways (chimney like structures) within the seabed in the studied area (September 2010, September-October 2011): A) – initial stages when gas front is captured within the sediments; B) – final stage when gas front is approaching the sea floor and gas (methane) starts escaping from the sediments to the water column.

2) Pingo-like fuatures

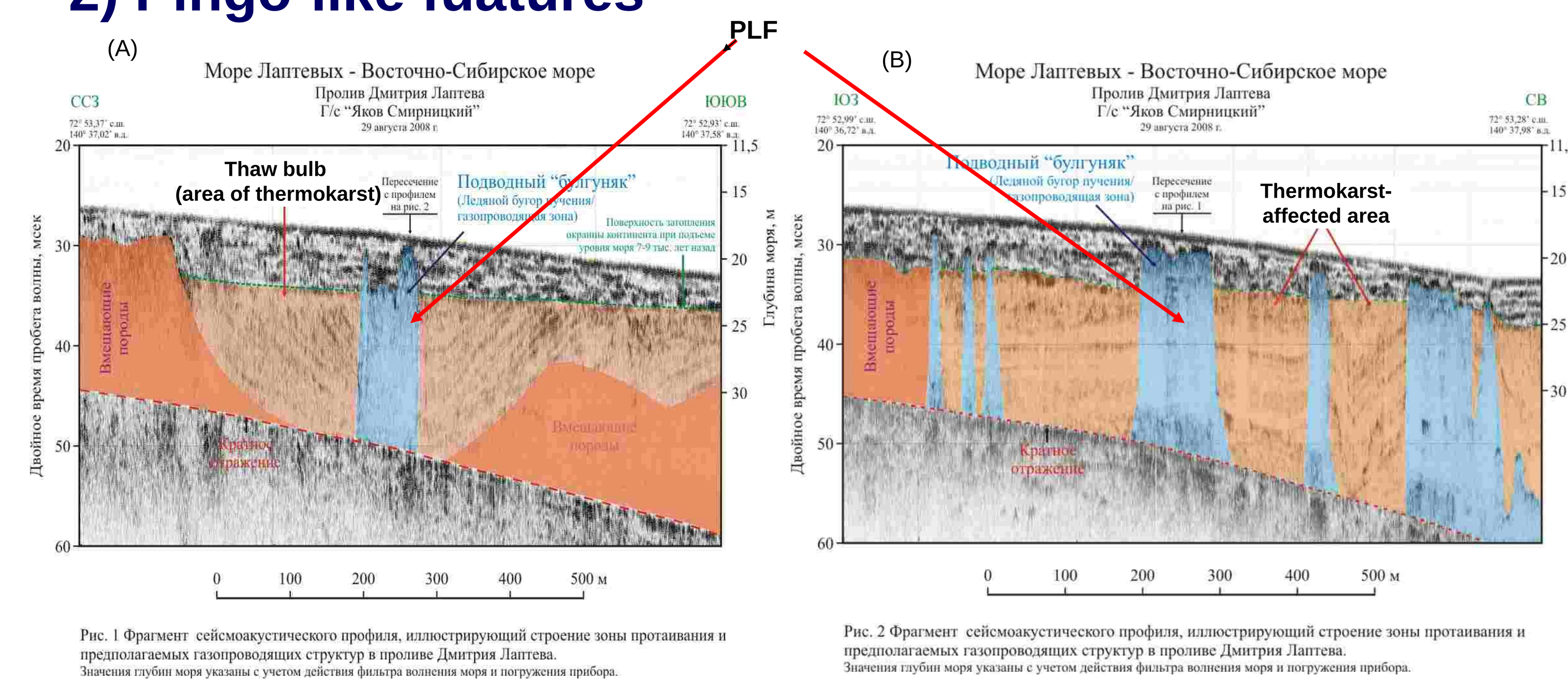


Fig.5. Seismic images showing different stages in development of pingo-like features in the seabed of the Dmitry Laptev Strait in the ESAS

3) Seabed flux measurements using deployed sonar

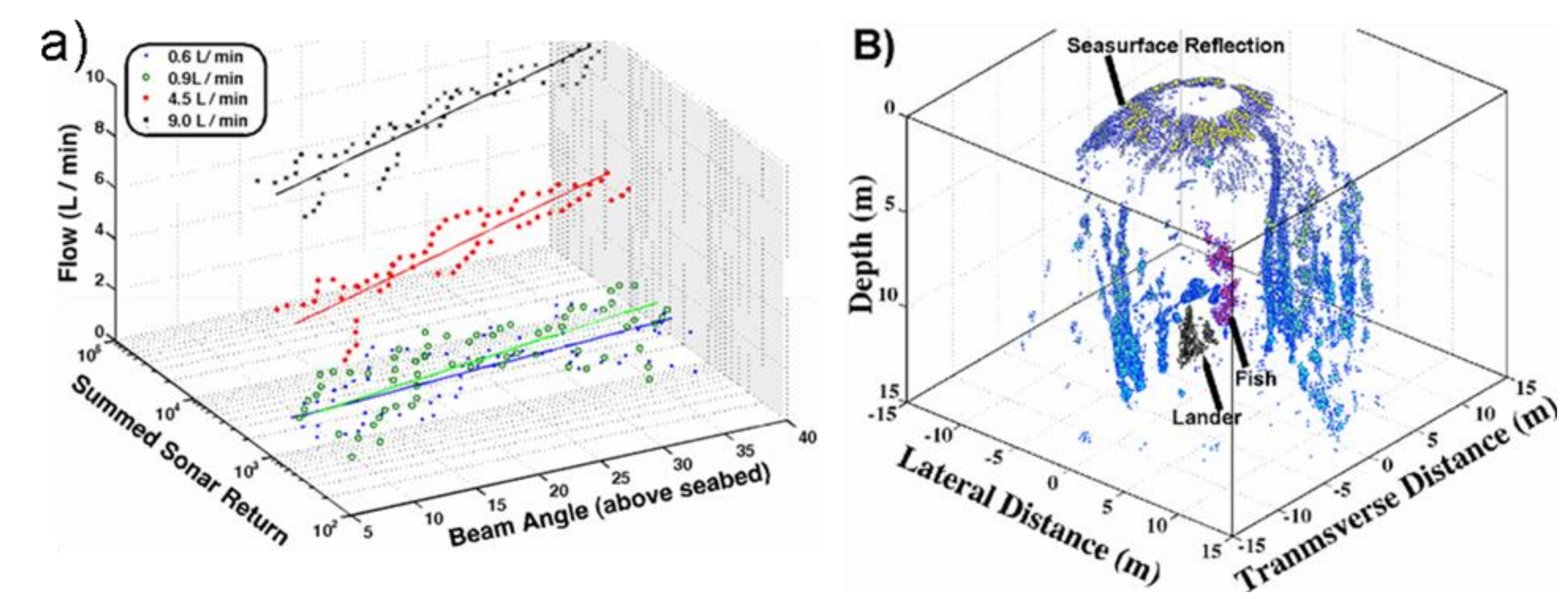


Fig. 8. Calibration curve for vertical fan mode (a) and interpretation of data, obtained in the ESAS in September 2009, from which follows that methane bubbles come out of the seabed all the way up to the sea surface and escape directly to the atmosphere (b).

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