

G.G. Akhmanov¹, A. Mazzini², O.M. Khlystov³, A.A. Kudaeva¹, and O.N. Vidishcheva¹

¹Faculty of Geology, Lomonosov Moscow State University, Moscow, Russian Federation (akhmanov@geol.msu.ru)

²Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Oslo, Norway (adriano.mazzini@geo.uio.no)

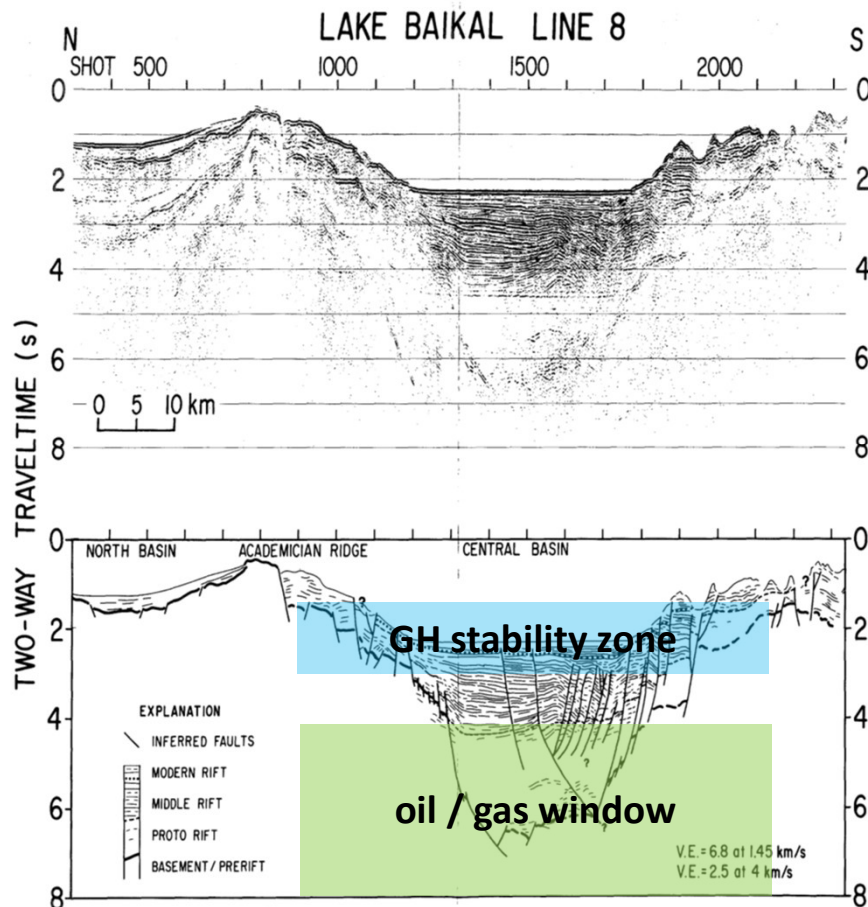
³Limnological Institute, Russian Academy of Sciences, Irkutsk, Russian Federation (oleg@lin.irk.ru)



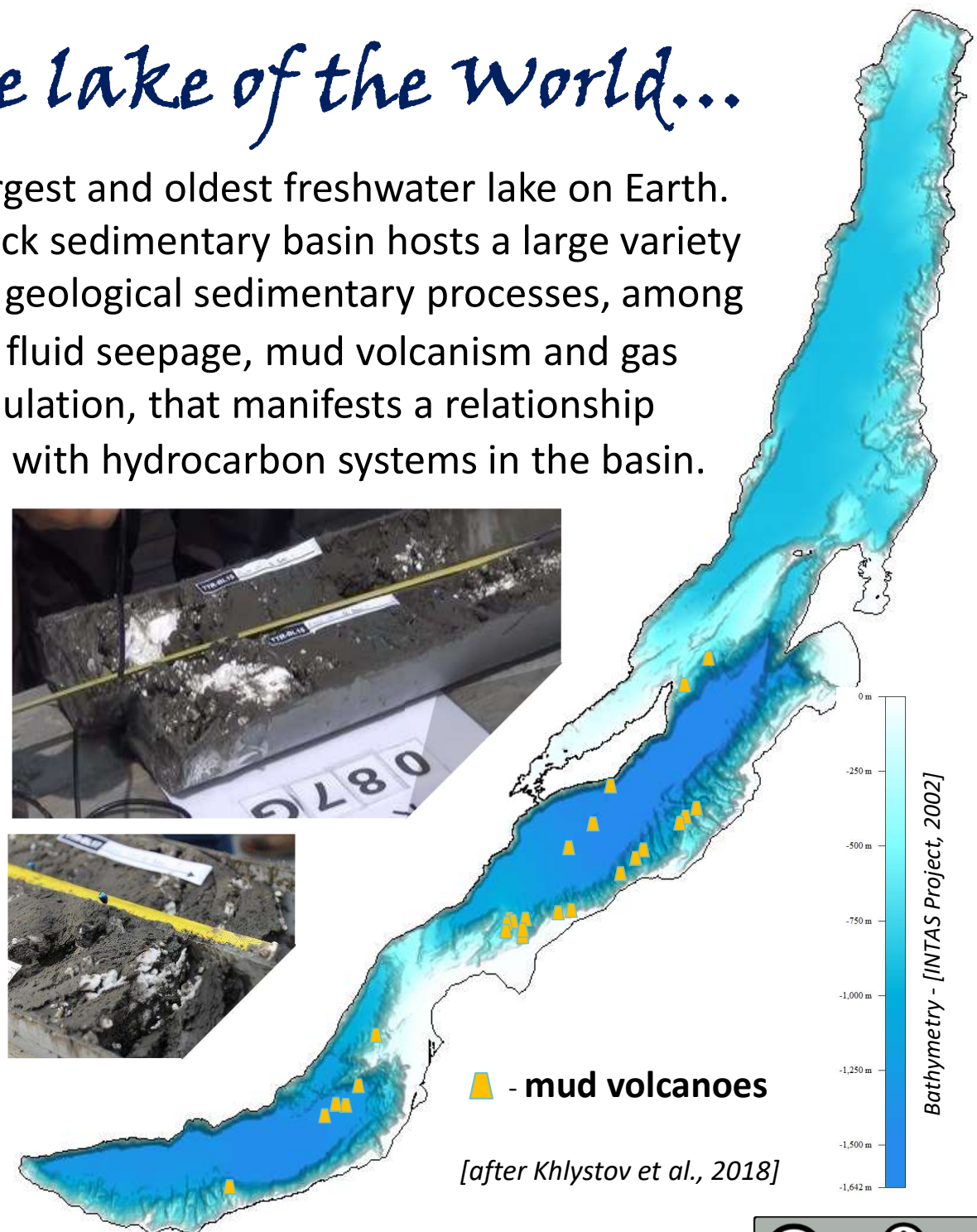


Unique lake of the world...

Baikal is the largest and oldest freshwater lake on Earth. This syn-rift thick sedimentary basin hosts a large variety of present-day geological sedimentary processes, among which focused fluid seepage, mud volcanism and gas hydrate accumulation, that manifests a relationship with hydrocarbon systems in the basin.



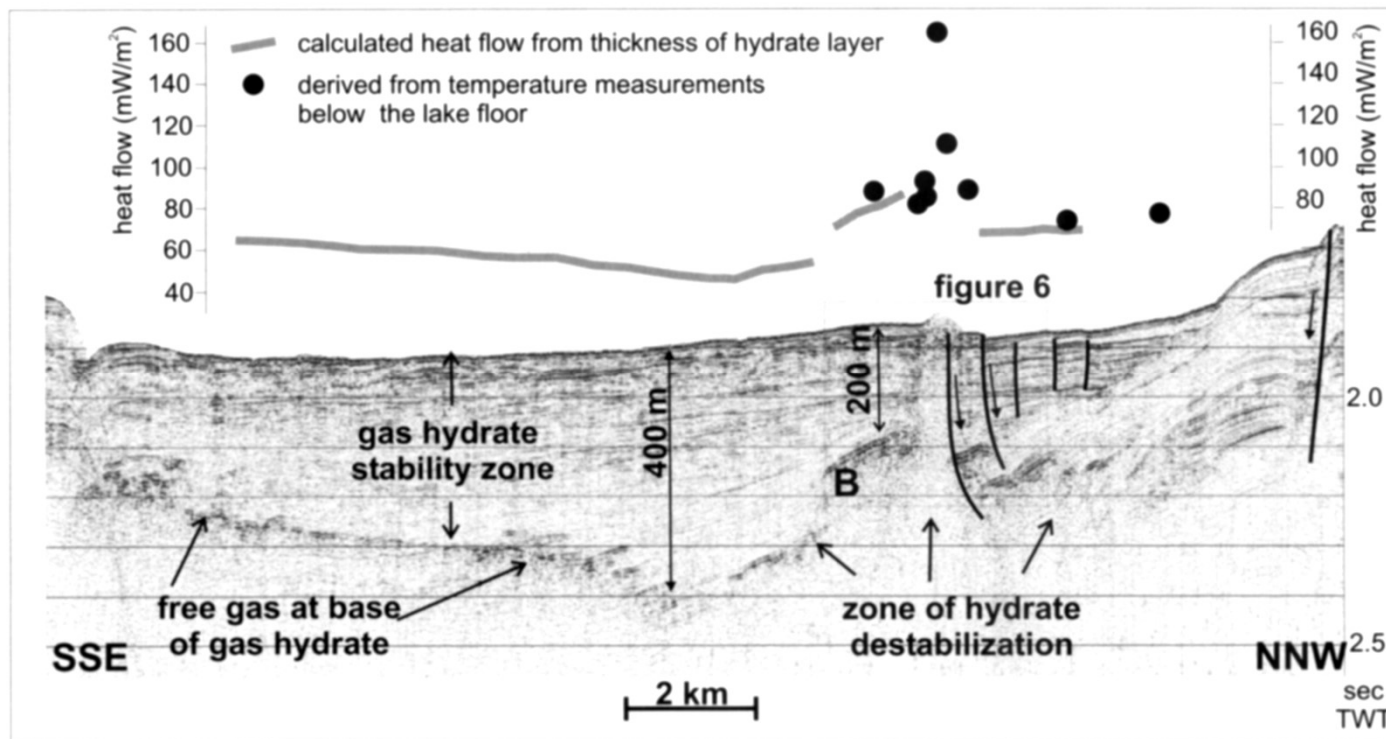
[after Hutchinson et al., 1992]



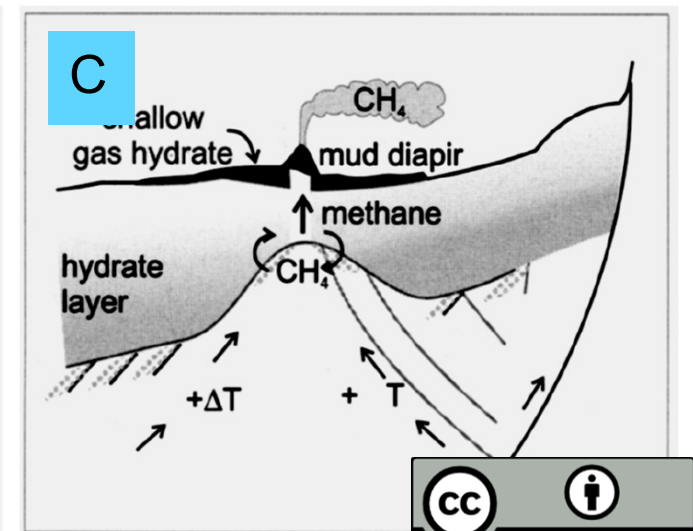
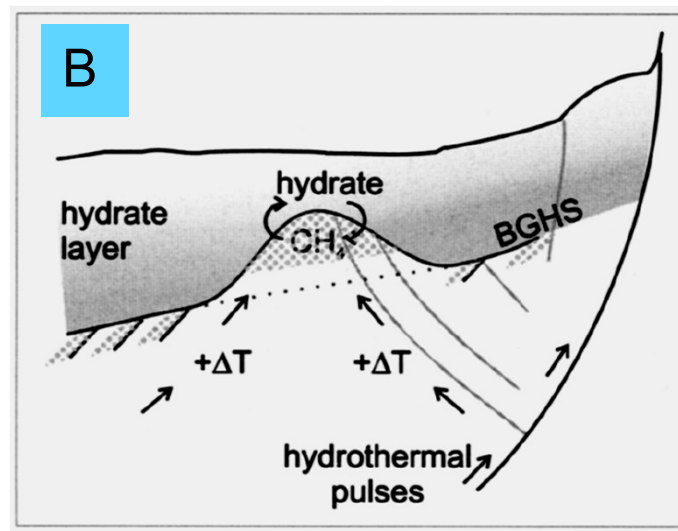
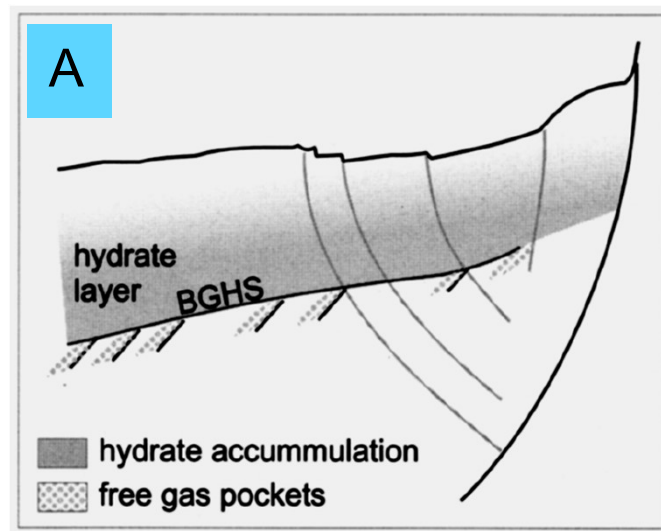
▲ - mud volcanoes

[after Khlystov et al., 2018]

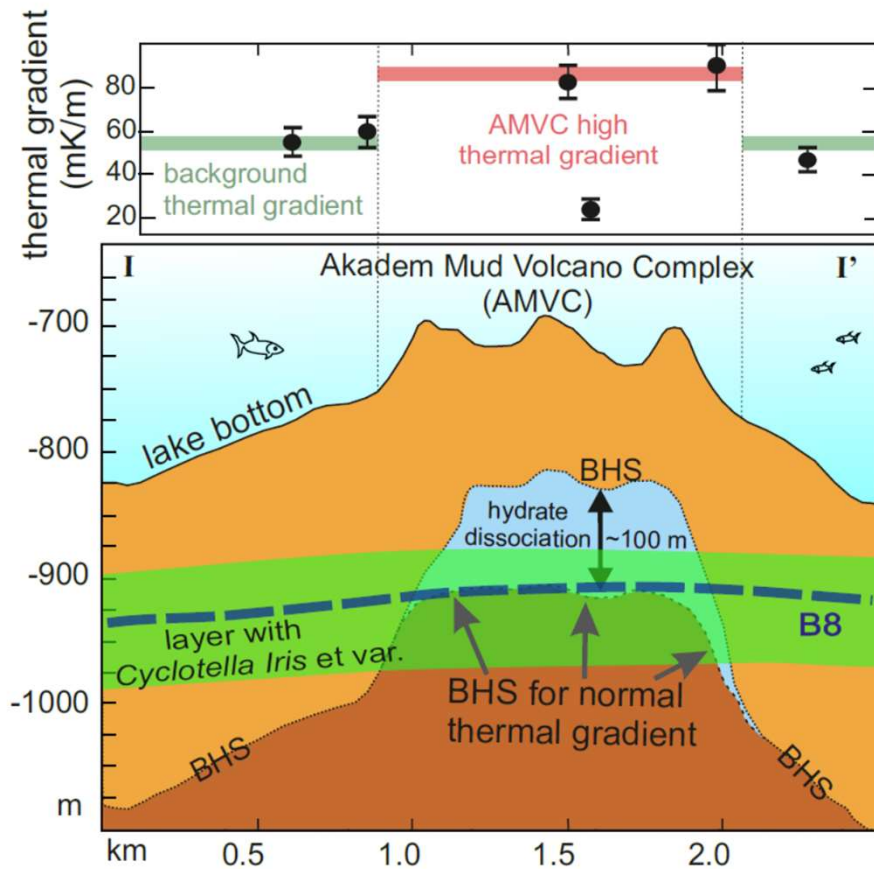
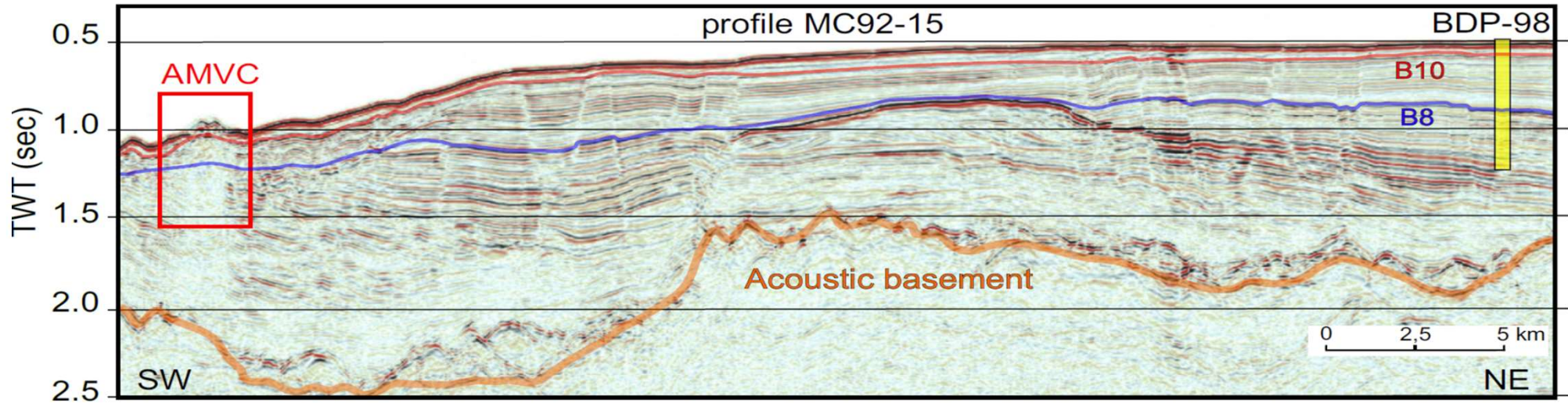
The first hypothesis on Baikalian MVs particular origin...



Van Rensbergen et al. (2003) interpreted the Baikal gas seeps with suggestion that gas hydrate destabilization can create large pore fluid overpressures in the shallow subsurface (<500 m subsurface) and cause mud extrusion at the sediment surface.



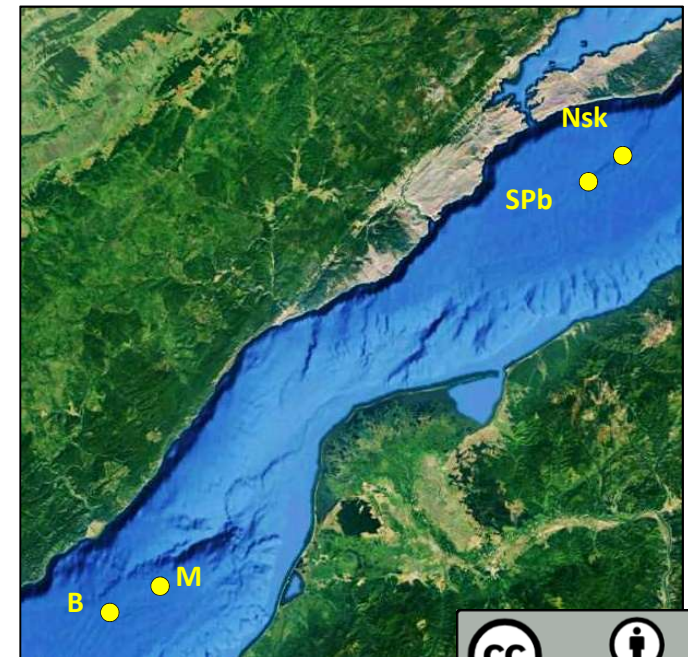
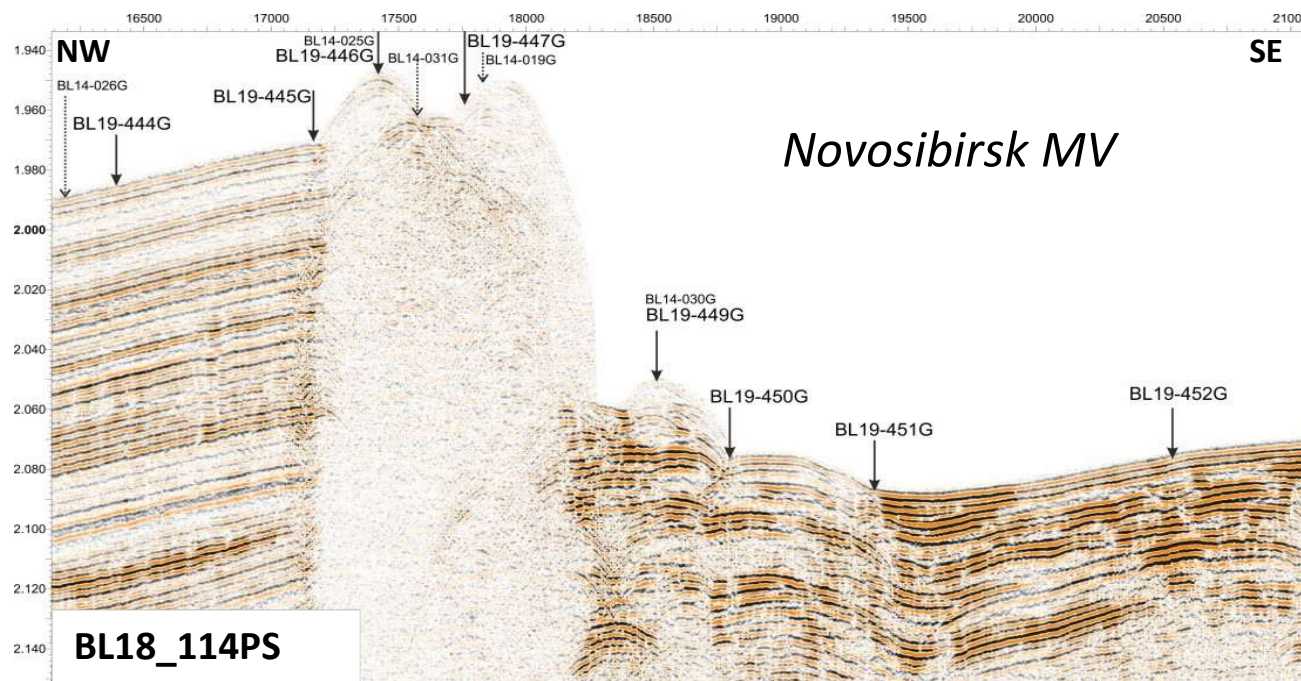
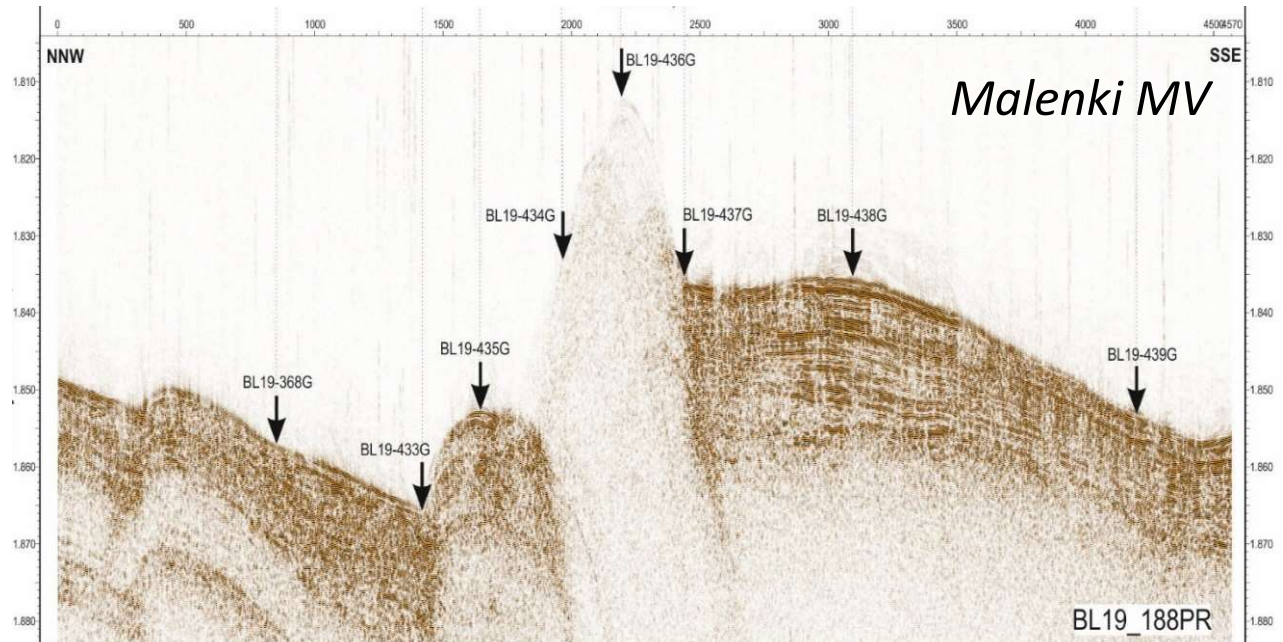
The first proved case of the hypothesis...



Khlystov et al. (2019) reported on the discovery of a new mud volcano field on the Academician Ridge in Lake Baikal where the presence of ancient diatoms in the mud breccia allowed to define a shallow source of the erupted sediments - at depth of 200–300 mblf. Also it was demonstrated that the BHS below the AMVC (originally at ~212 mblf) was shifted upwards of ~100 m and suggested that the vertical migration of deep and warm fluids induced the dissociation of the inferred deep gas hydrates, which liquefied the host sediments and generated overpressure, triggered shallow-rooted mud volcanism.

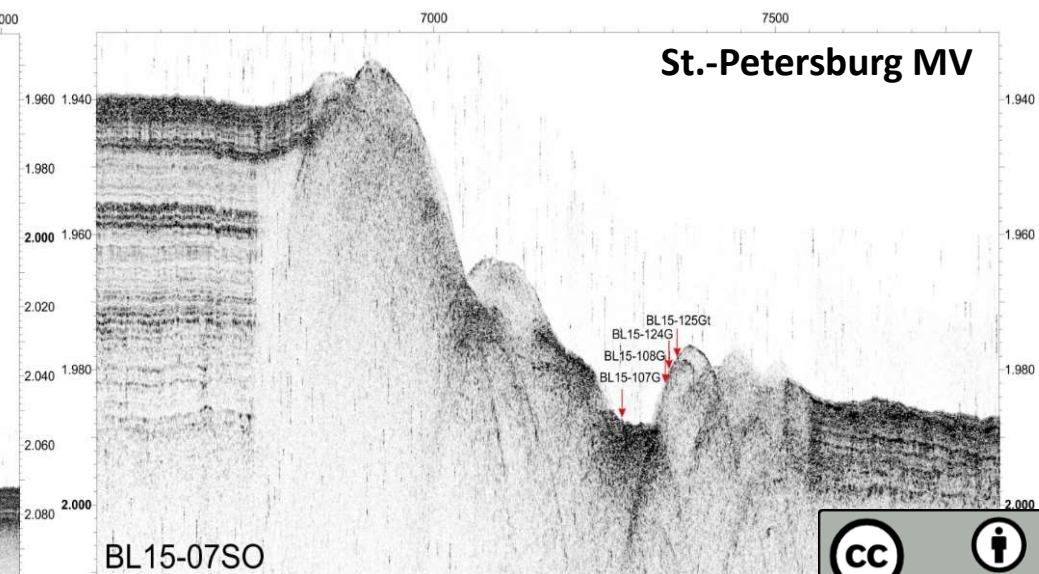
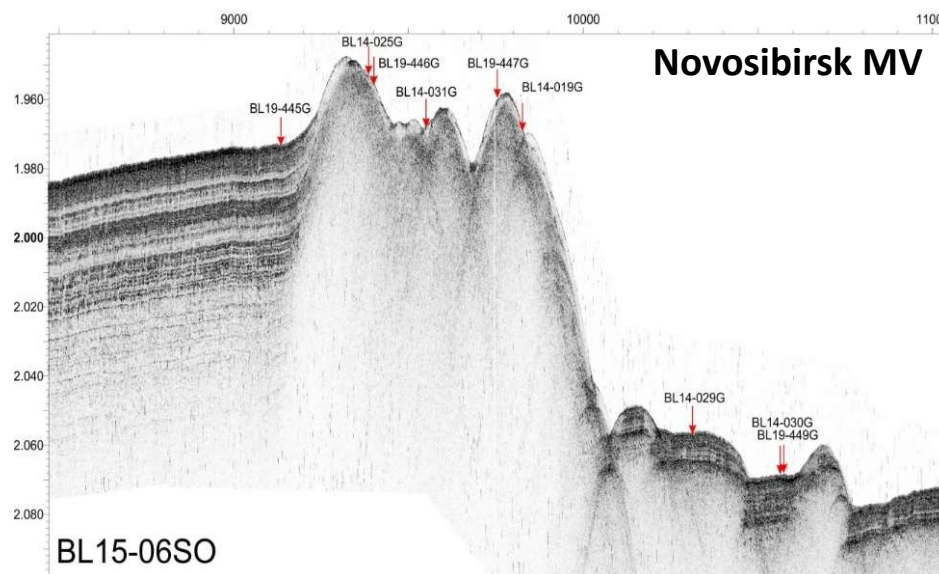
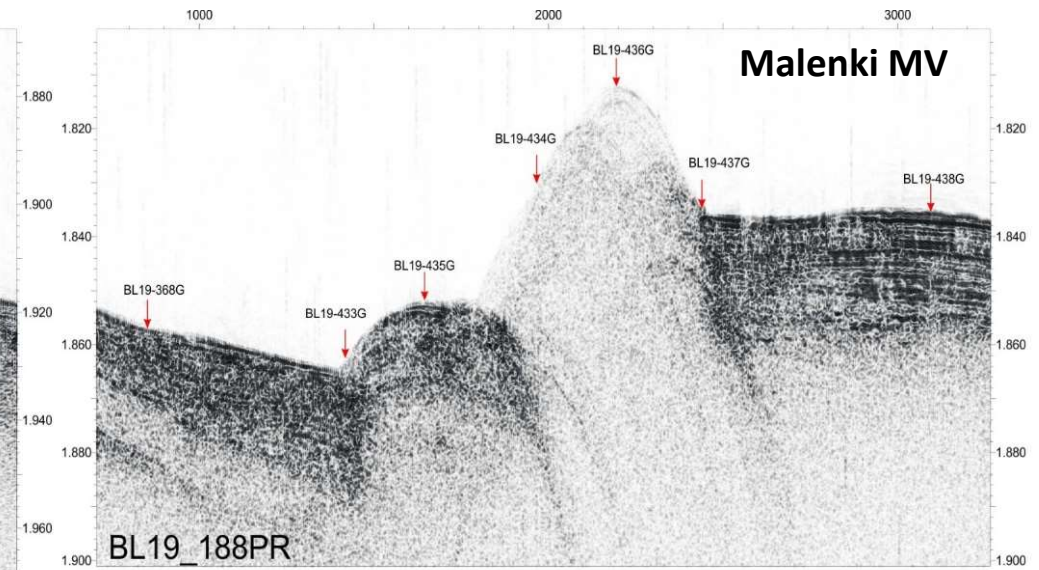
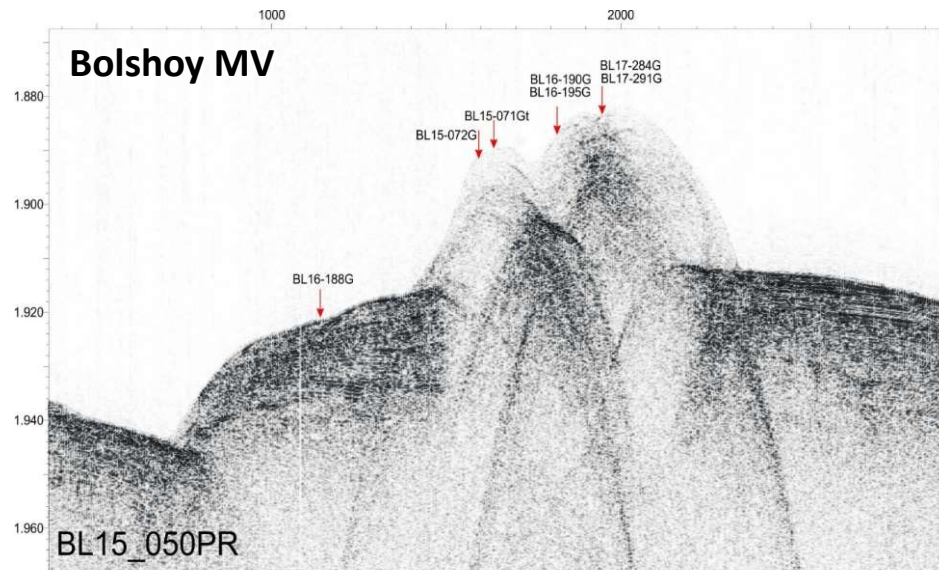
... applicable for other mud volcanoes of Lake Baikal?

Four most prominent MVs of Lake Baikal (Novosibirsk, St.-Petersburg, Bolshoy, and Malenki MVs) were studied in details during some legs of six expeditions of the “Training-through-Research” Class@Baikal Project (www.class-baikal.ru)



... can be applicable for other mud volcanoes of Lake Baikal.

Following seismic and chirp-profiler surveys, a total of 47 gravity core stations allowed collecting sediment (including mud breccia intervals), gas and gas hydrate samples for further studies in in-house laboratories



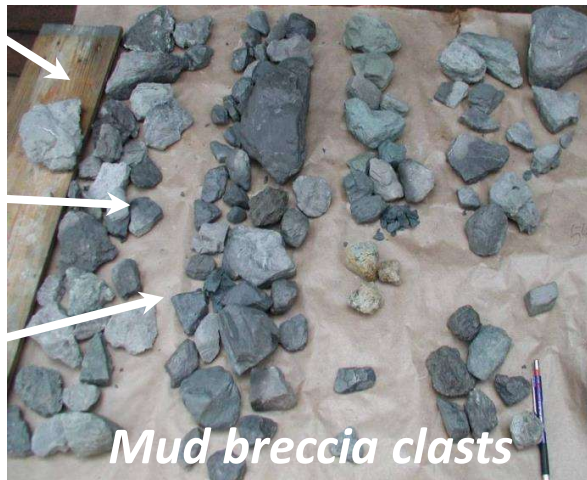
The mud breccia “suggests” shallow roots (for all MVs of Baikal)...

Most mud volcanoes worldwide are characterized by the presence of mud breccia. This mélange of erupted sediments consist of clayey-silty-sandy matrix mixed with clasts of different sizes and lithologies representing mainly well-lithified fragments of the different formations pierced and brecciated through the MV feeder channel. This criteria has been used as an unambiguous evidence to classify new MV structures.

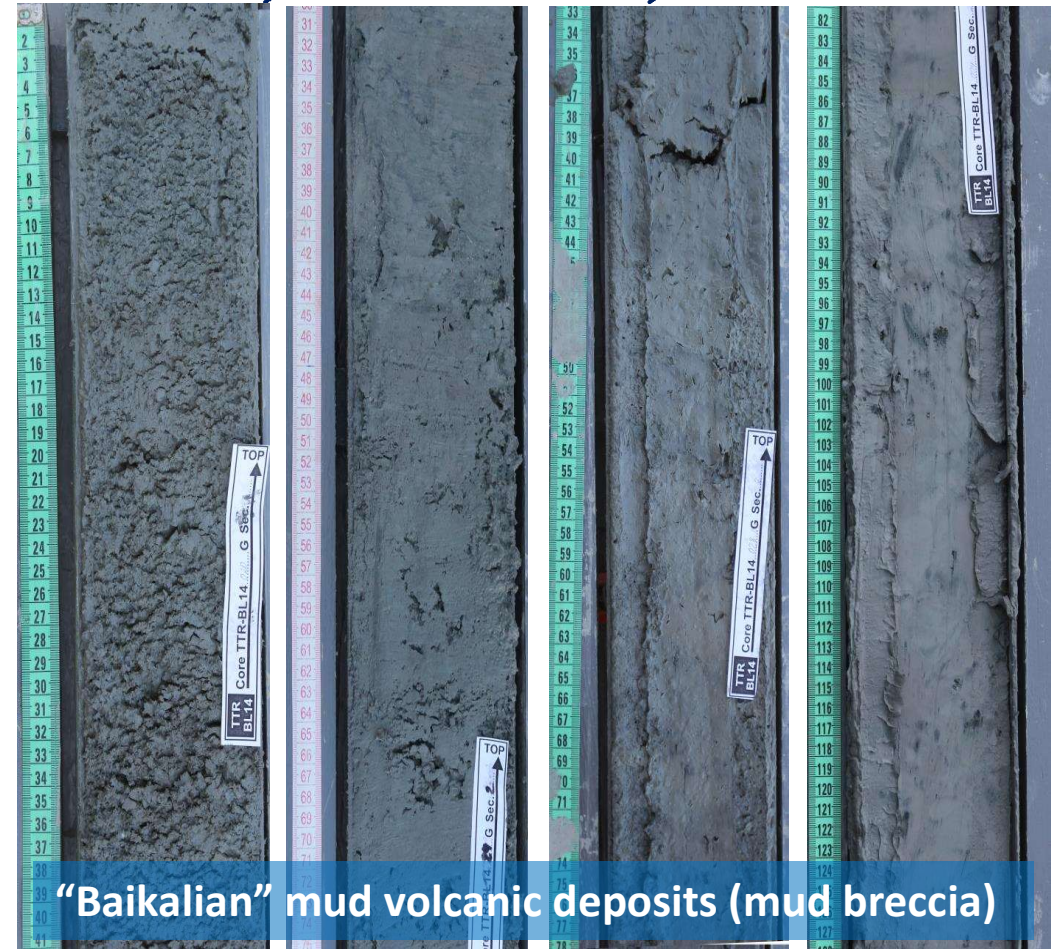


Mud breccia

«Classic»
mud volcanic deposits
(Eastern Mediterranean)



Mud breccia clasts

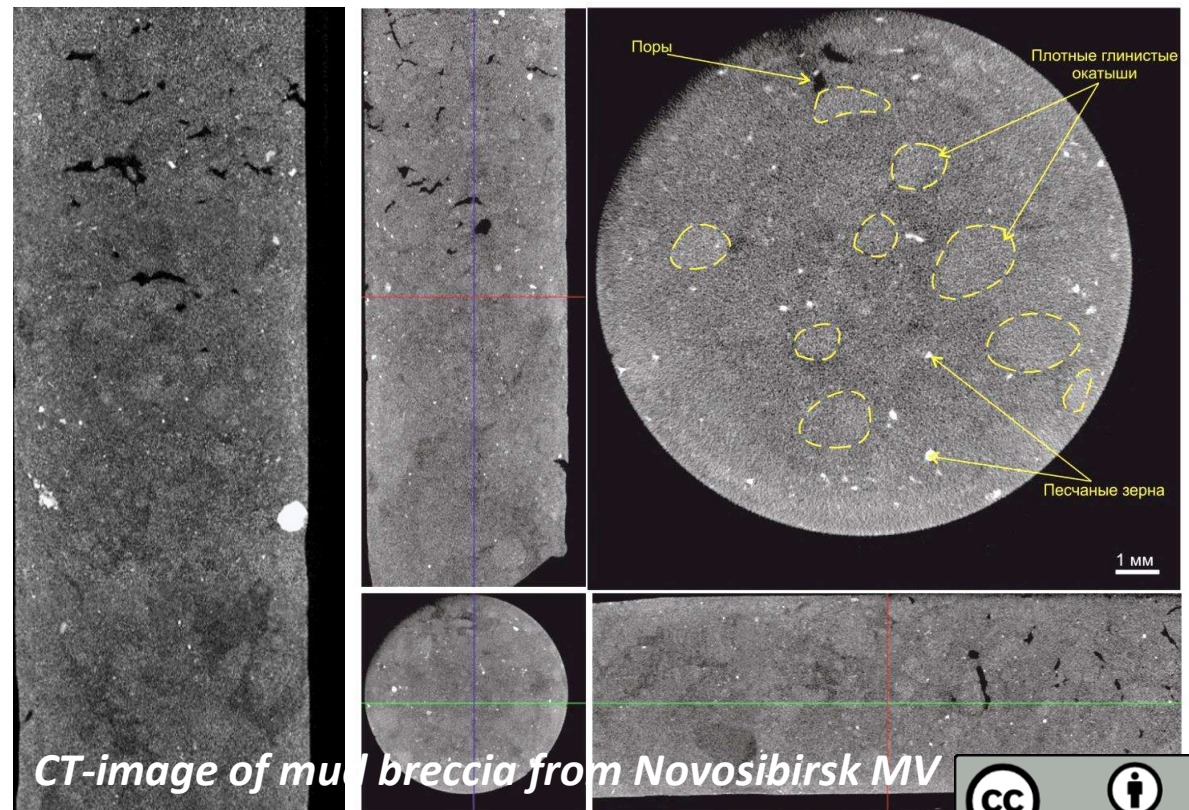


“Baikalian” mud volcanic deposits (mud breccia)

A similar approach is hardly applicable for the investigated structures of Lake Baikal. The recovered sediment cores are barren by the typical presence of mud breccia lithified clasts which are characteristic for “classic” mud volcanic breccia.

...the mud breccia of Lake Baikal is still very distinctive

Sediment core observations revealed the presence of semi-lithified clayey clast broadly distributed in the structureless intervals. Petrography studies of the clasts reveal that they differ in mineralogical composition. The otherwise invisible internal structure of the cored sediments has been studied with CT-scan. Results confirm that the recovered cores contain numerous semi-lithified clasts displaying different X-ray absorption and thus mineralogical content.

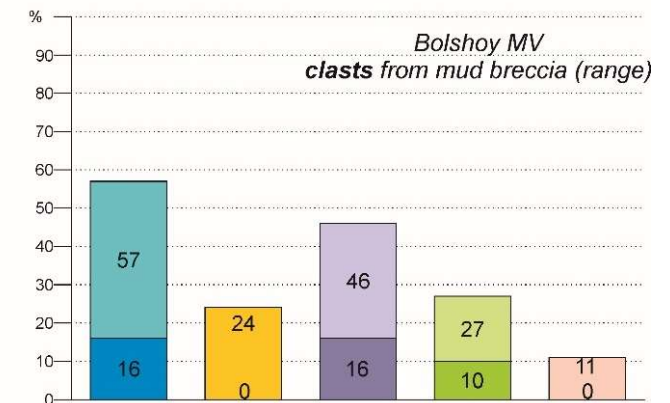
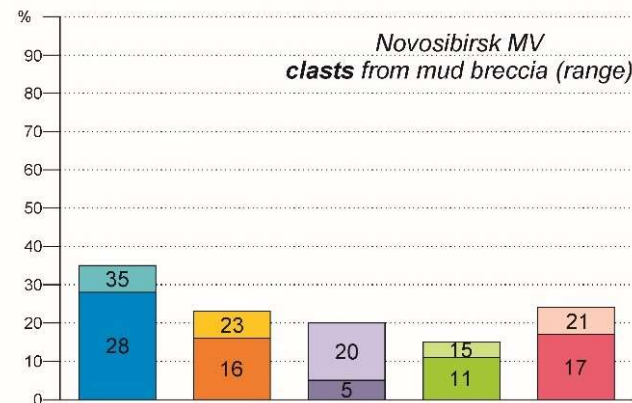
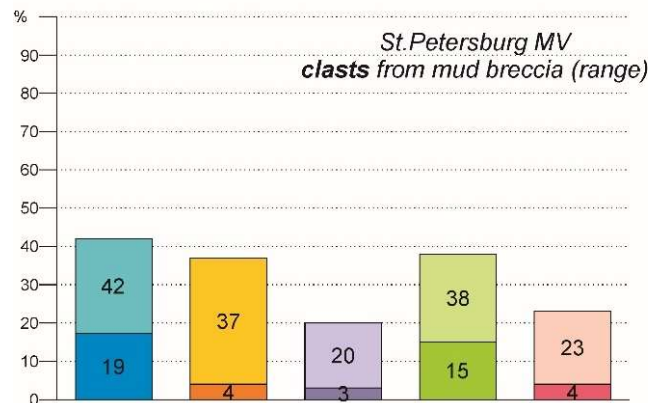
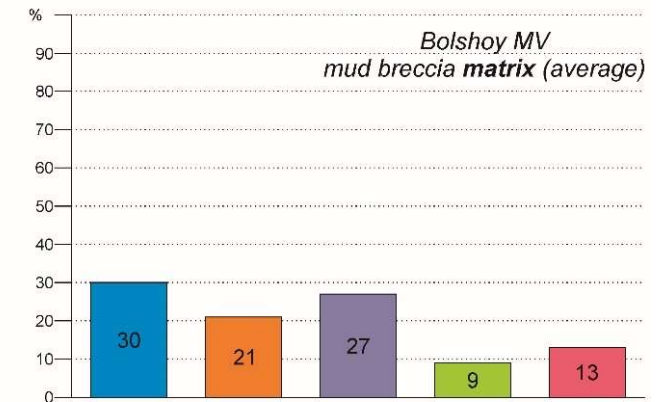
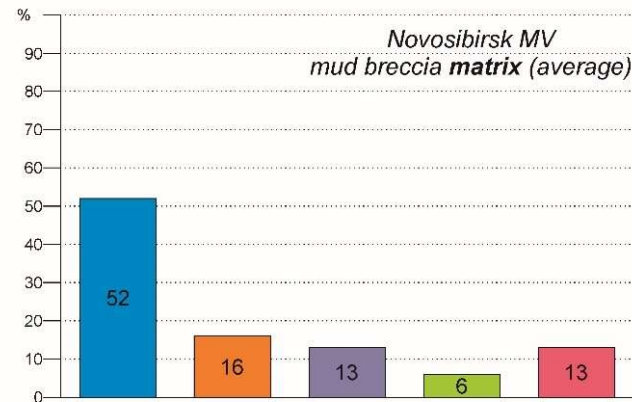
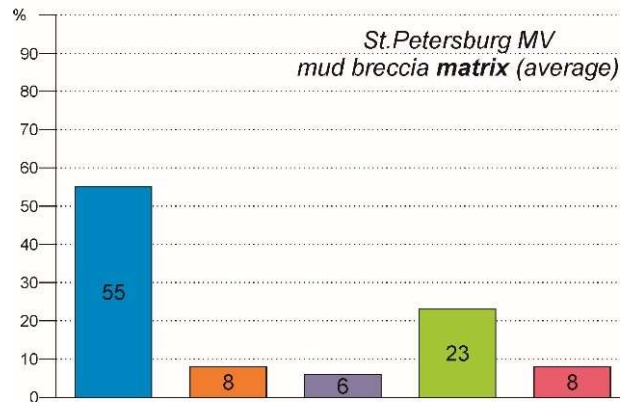
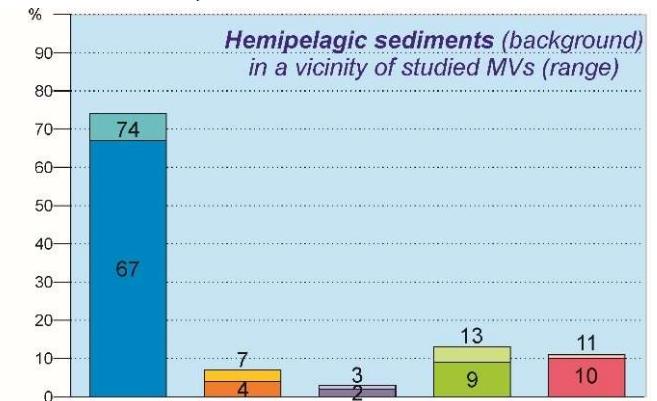


CT-image of mud breccia from Novosibirsk MV

...the Baikal mud breccias differ from hemipelagic sediments

Grains size of erupted mud volcanic material and surrounding hemipelagic sediments is somewhat similar with random variations in silty and pelitic contents.

In contrast, clay mineral composition shows a difference in nature of mud breccia matrix and clasts and hemipelagic sediments

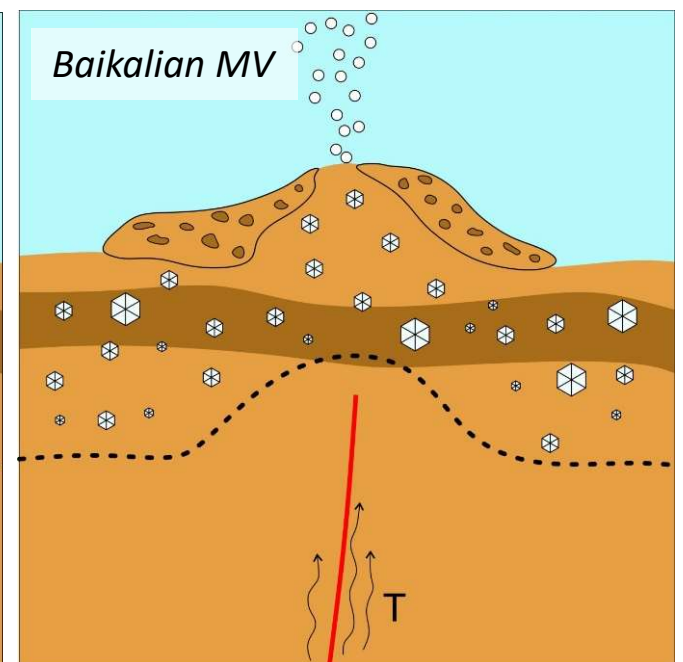
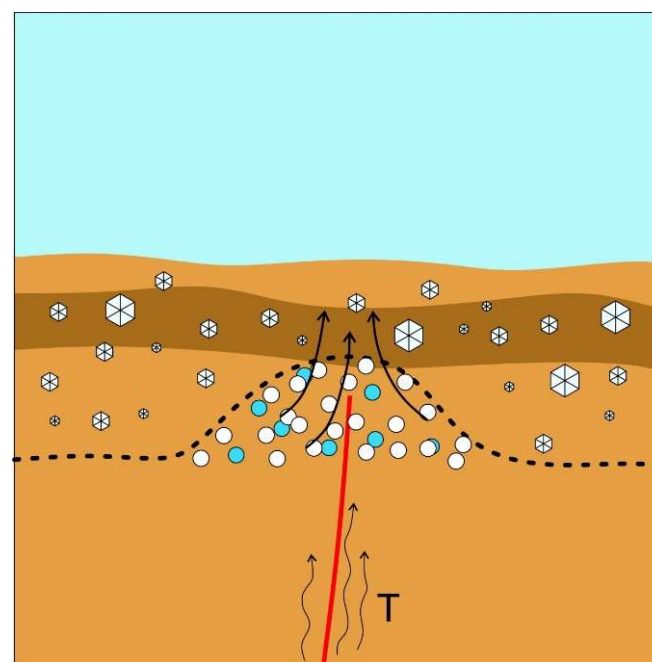
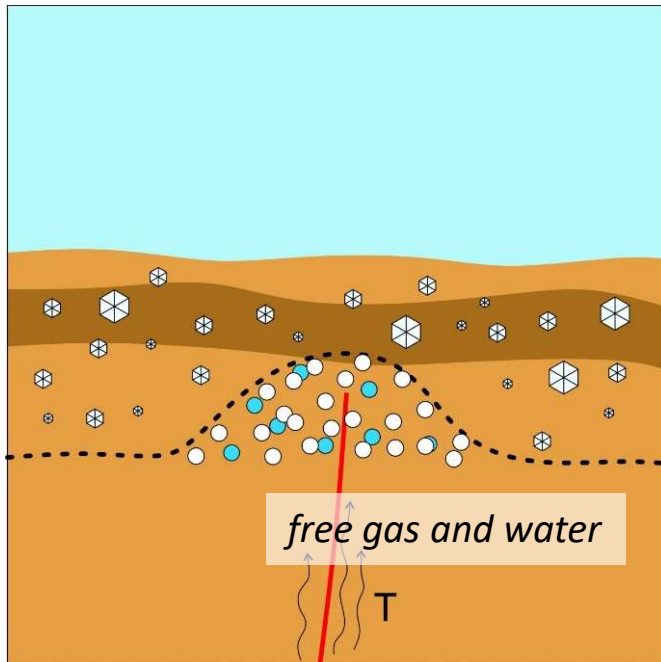
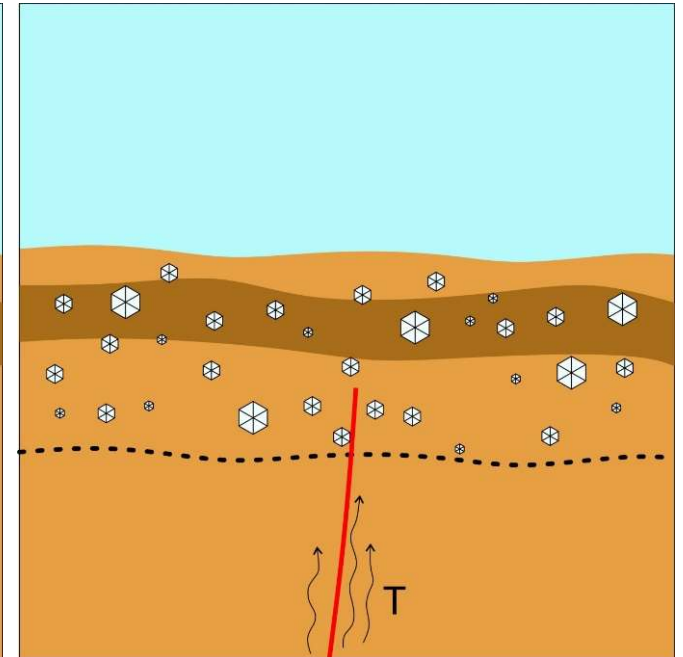
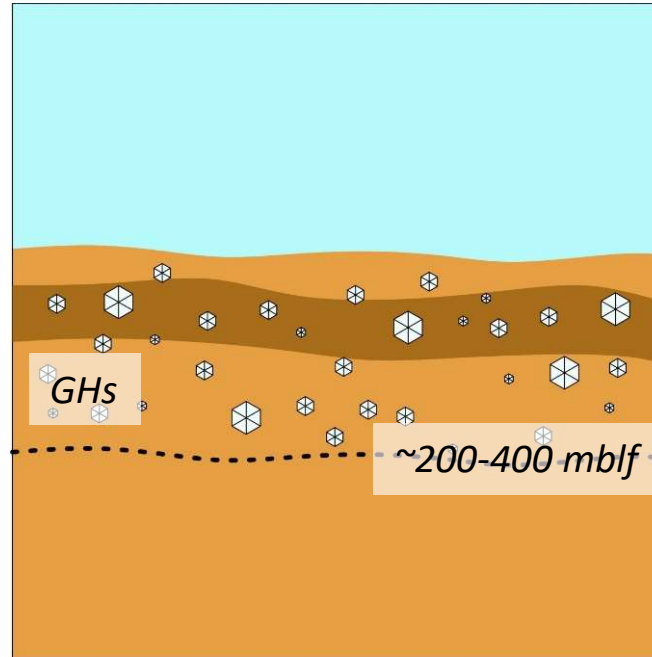


Clay mineral composition (XRD data):

■ - illite ■ - smectite ■ - mixed layered (illite-smectite) ■ - chlorite ■ - kaolinite

...are erupted by shallow rooted mud volcanoes.

Poor lithification indicates that the clasts originate from shallow sedimentary units. The absence of sedimentary structures of the mud breccias and a completely chaotic matrix indicates a vigorous mechanism able to amalgam different lithologies.



(after Van Rensbergen et al., 2003; Khlystov et al., 2019)

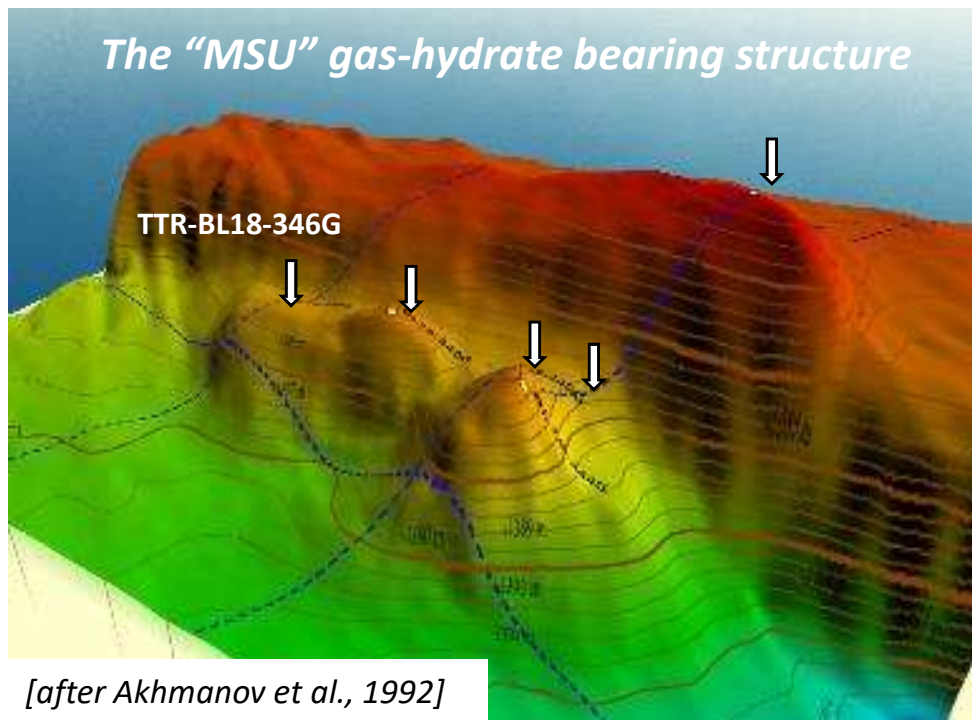
Summary...

- **54** structures containing gas hydrates in subsurface sediments have been discovered since 2000 in Lake Baikal. **26** of them are believed to be mud volcanoes with mud breccia collected from the structures (*Khlystov et al., 2018*).
- Overpressure due to destabilization of shallow gas hydrates as the main reason for MV formation is confirmed for **1** structure (*Khlystov et al., 2019*).
- Visual observations, petrography /mineralogical analyses and CT-scan images show similar mud breccia characteristics for all putative MVs in Lake Baikal. This suggests **the same mechanism for MVs formation**. A chaotic inner structure and the presence of semi-lithified clasts indicate that the emplacement mechanism can only be related to a vigorous upward extrusion of melanged sediments from different strata. Given the poor lithification, these clasts are interpreted as portions of **shallow** sedimentary units brought to surface through the MV conduits.
- Gas hydrates dissociation at the zone of the lower boundary of their stability can be considered as a trigger for **all Baikalian mud volcanoes** which are, in fact, shallow-rooted structures.

... and important post-scriptum

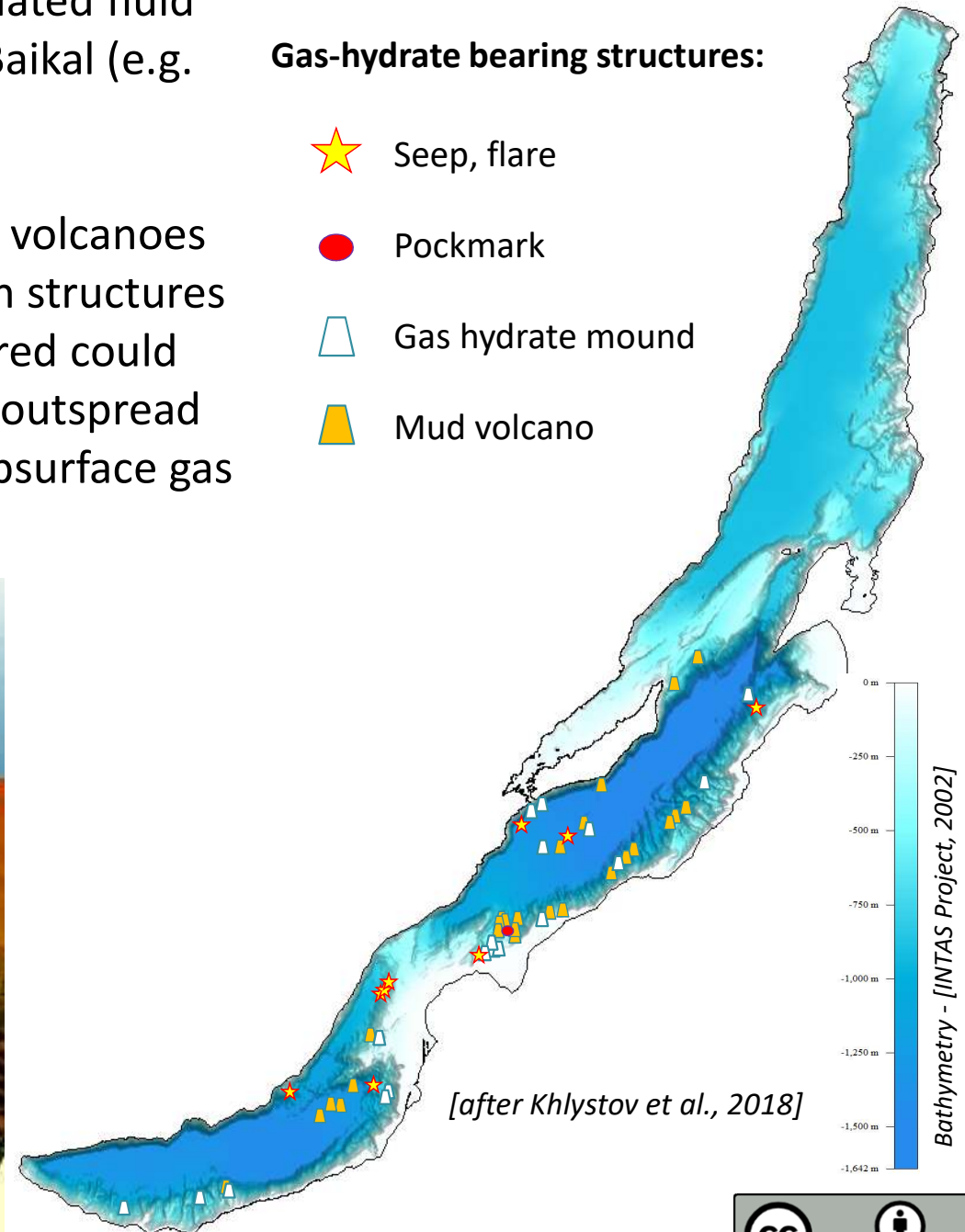
Subsurface gas hydrate accumulations and related fluid seepages are discovered every year on Lake Baikal (e.g. the MSU structure (*Akhmanov et al., 2018*)).

It is possible that all of them are, in fact, mud volcanoes of the special Baikalian type. Sampling of such structures and careful examination of sediments recovered could bring us to a re-estimation of mud volcanism outspread in Lake Baikal and, further, to a revision of subsurface gas hydrate formation mechanism



Gas-hydrate bearing structures:

- ★ Seep, flare
- Pockmark
- △ Gas hydrate mound
- ▲ Mud volcano



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