Fram-2020 Final Report

Vision:

Inspired by the drift of “Fram” (1893-1896), our basic premise is to use the drifting sea ice to our advantage for advanced geoscientific exploration of the Arctic Ocean. The ice-locked drifting ship is succeded by a mobile hovercraft platform and Nansen’s pursuit of quality instruments succeded by the latest advances in modern autonomous recording technology. The result is a lean, low cost logistic alternative for polar field operations with drifting sea ice as your team mate and not your adversary.

Fram-2020 objectives

The Fram-2020 expedition was driven by the geological hypothesis that the deep (1500 m depth) northeastern circular (diameter 65 km) tip of Yermak Plateau (700 m depth) is a young volcanic construction and not formed by continental rocks equivalent to the geology of Svalbard. Additional tasks were echosounder recordings for detection of juvenile polar cod in consultation with the Institute of Marine Research, Bergen and deployment of 6 buoys from Met.no to measure attenuation of ocean waves propagating from the ice edge into the sea ice cover. See report for Week 1 for complete list of objectives.

Operation

The Fram-2020 expedition was deployed on 15 July 2020 from the freighter “Norbjørn” at 81° N 15° E in a northern embayment of the ice edge north of Svalbard. The sea ice field in the area turned out to be the remanents of old, thick ice with large irregular fragments of pressure ridges; a landscape impossible to penetrate by hovercraft. We deployed our seismic equipment and drifted westwards along 81° N and later southward while collecting 75 km of seismic data including a small 3-D survey, the first ever carried out from drifting sea ice. The drift trajectory happened to be optimal from a geological perspective.

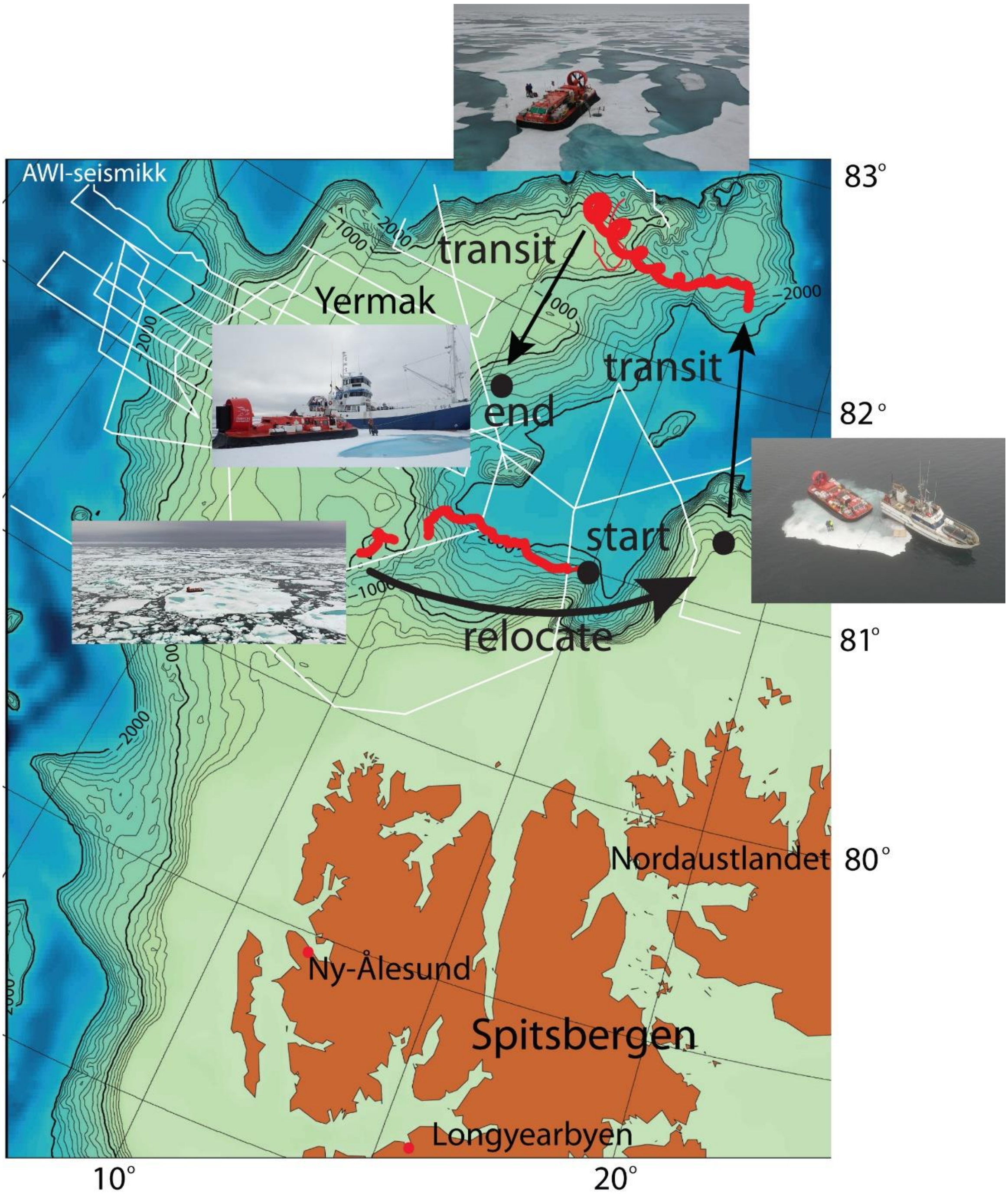

Fig. 1. Summary of the sea ice environment, the main drift segments and the support operations.

On 4 August, the opportunity came to relocate to 80° 30’ N, 18° E, about 155 nautical miles to the northeast. Here, the sea ice field consisted of flat about 1 meter thick floes which presented fair to good driving conditions for the hovercraft. A rendezvous was made at the ice edge (81°23’ N, 17°10’ E) with the vessel “Farm” for resupply of fuel and crew rotation in the early morning of 6 August. Subsequently, the hovercraft headed north towards the target area at 82°30’ N, 17°E.

Clear definition of the surface terrain is essential for safe hovercraft driving in complex sea ice fields. Days of low cloud cover give a diffuse light with “white-out” conditions and no surface contrasts. It took 6 days to cover the 65 nautical mile transit north – only 2 days had sufficient light contrast for safe driving. Observations with a Wide Band Transducer (WBAT) for detection of polar cod juveniles were made for every 5 nautical mile during the transit.

We parked on an ice floe about 600 meter in diameter and 1.2 meter thick at 82°22’ N, 16° 28’ E in the evening of 12 August. We deployed the array of seismic nodes (10) and suspended the Magseis-Fairfield recorder at 700 meter depth. The ice drift was to the north for the first two days and then turned to the west. The drift trajectory was optimal from a geological stand point as it took us up the slope of the deep northeastern tip of Yermak and the westward drift crossed from the tip to the high plateau and continued across it (Fig. 1).

The sea ice motion across Yermak Plateau is strongly modulated by the diurnal ocean tide which gives a cycloidal drift trajectory. On 22 August, we had crossed the high plateau and the cycloids started to overlap. We recovered all instruments and prepared for the return south to the ice edge. Two nodes were lost. During the next two days, we made 5 succesful dredge hauls for rocks from seabed. Every opportunity of suitable light conditions were used to proceed south to rendezvous with the sealer “Havsel” at the ice edge.

The start of the field season had been delayed by 5 weeks and by late August the signs of the fall season were all too obvious. We decided to cancel the last leg of the field operation and prioritize a safe return to Longyearbyen in the company of “Havsel” on 27 August. The return trip became a challenge as a deep atmospheric low pressure (990 hPa) had arrived the Svalbard area. Winds increased to gale force during the 90 mile transit from the ice edge to Spitsbergen and later to strong gale on the leg south from Magdalenafjorden. It was considered too dangerous to continue on another 90 mile transit to Longyearbyen and “Havsel” with the hovercraft under tow called in at Ny-Ålesund for shelter in the late evening of 29 August. ”Havsel” left for Longyearbyen after 24 hours and the hovercraft remained in Ny-Ålesund for 8 days for necessary skirt repair. Additional time was necessary to deal with a loss of propulsion from damaged bearings in the power take-out to the propeller drive belt. The hovercraft was back in Longyearbyen on 14 September.

Platform: Hovercraft “Sabvabaa”

Payload capacity: 2.2 tons Practical hover height: 0.5 meter

Operational endurance: +3 weeks

Total distance operating in sea ice: 262 nautical miles (485 km)

Estimated cost of the field operation: Nok. 700 k. (ex. personnel and new instrumentation).

Crew: Yngve Kristoffersen + Jan Erik Lie (14.07-06.08) and Espen Harris Nilsen (06.08-29.08).

Scientific results

We have accomplished the following:

<u>Geophysics</u>

Two regional seismic profiles, a total of 260 km of seismic reflection data have been acquired (Fig. 2).

The sea ice in the Yermak Plateau area is very dynamic and limits the number of autonomous GTI recording nodes that can be deployed. The seismic data was recorded by a camp hydrophone and 5-11 nodes depending on the size of the ice floe.

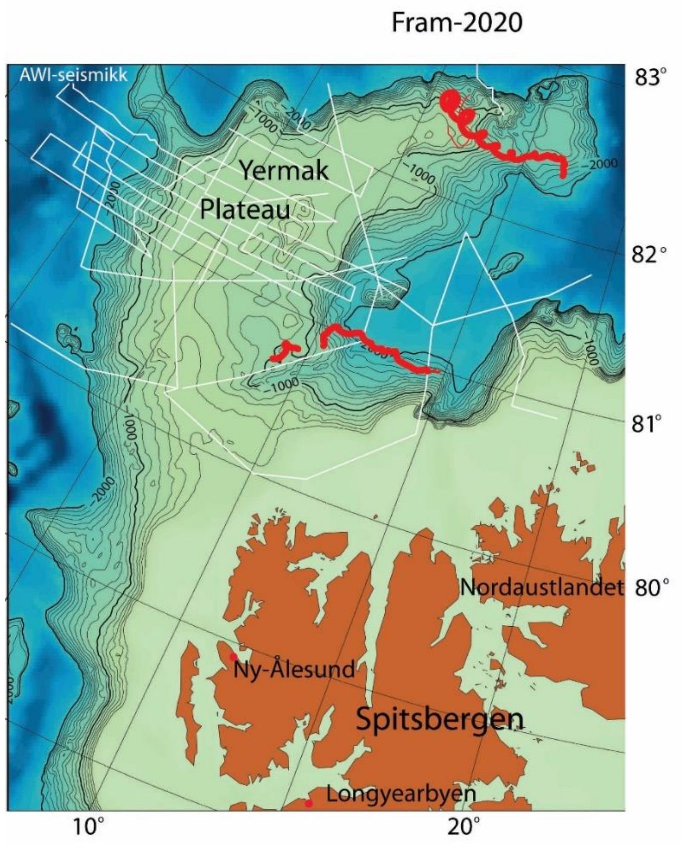

Fig. 2. Seismic reflection data acquired during the drift.

In terms of seismic metodology, the operation included two "firsts" in Arctic Ocean exploration using the benefit of the sea ice cover:

i) a small 3-D seismic survey and
ii) ultra deep underway seismic signature recording to obtain maximum data quality.

3-D seismic mapping from drifting sea ice demonstrates the capability of mapping the seabed and the sediments below in the Arctic Ocean in areas inaccessible to icebreakers. Underway seismic signature recording ensure the highest data quality not practically achievable in seismic surveys in the open ocean.

Geology

We used a small rock dredge tailored to the capacity of a conventional line hauler. The gear successfully recovered 5 dredges with a total or 66 rock samples from the high plateau (Fig. 3). A preliminary examination indicate all samples are either volcanic rocks and related volcanic sediments.

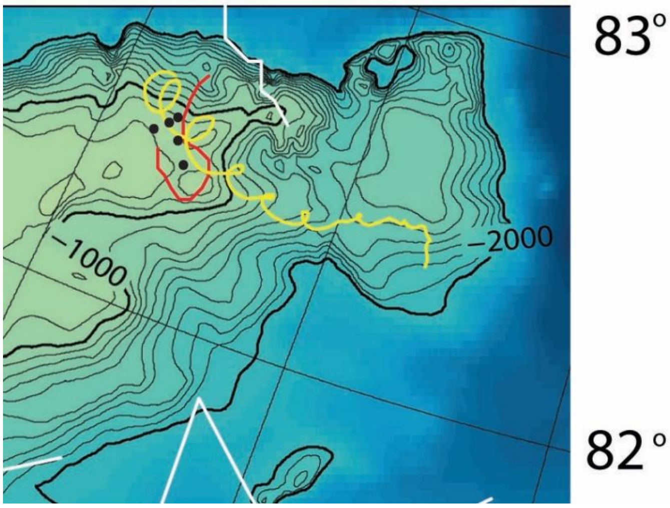

Fig. 3. Location of rock dredges (black dots). The drift track with seismic data indicated

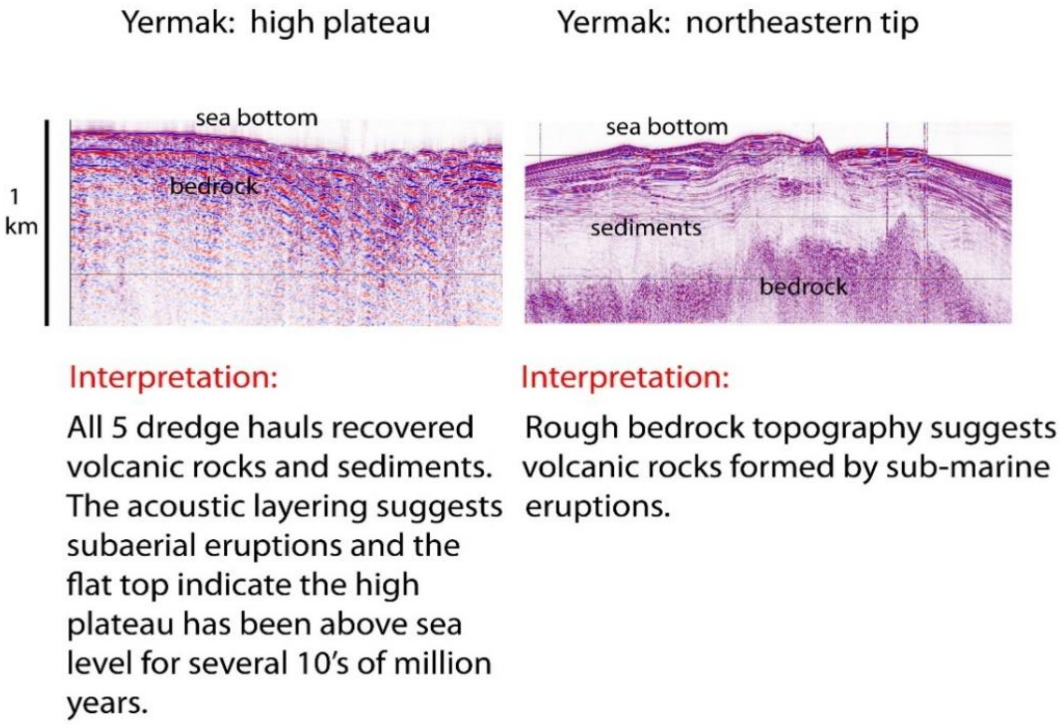

Fig. 4. Our preliminary interpretation of the main seismic and geological results by yellow line.

Preliminary interpretation

The geophysical and geological results suggest the high northern plateau of Yermak may have existed as an island north of Spitsbergen before the time the youngest coal was formed near Longyearbyen about 45 million years ago. The rocks below the seabed on the high plateau are most likely volcanics deposited on land while the basement rocks below the deeper northeastern tip are most likely volcanics from younger submarine eruptions (Fig. 4).

Life in the ocean

A 200 kHz echo sounder transducer is capable of detecting centimeter-sized creatures in the water column, but the detection range is limited to maximum 200 meter. The Wide Band Transducer (WBAT) is an autonomous echosounder that can be lowered to a maximum depth of 1500 meter and in this way it is possible to obtain the resolution of the 200 kHz device anywhere in the 0-1500 meter depth range (Fig. 5).

Fig. 5. The WBAT being deployed

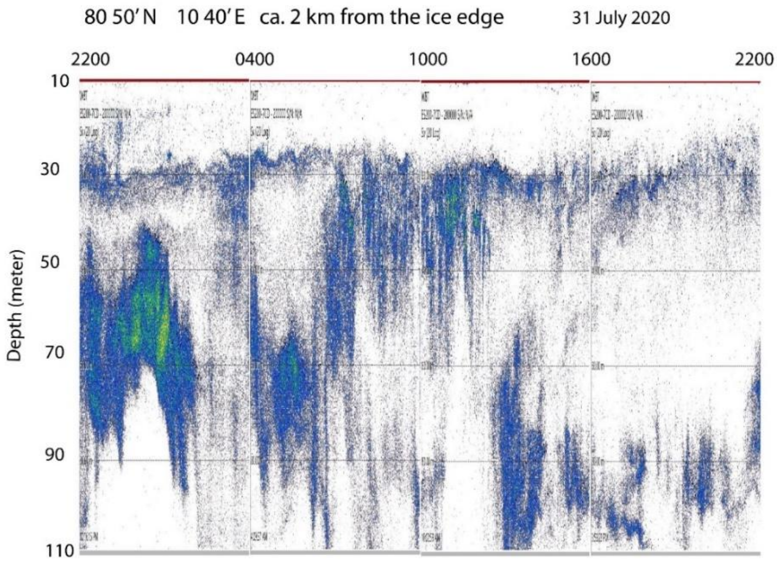

Fig. 6. Echosounder results from 24 hours of monitoring distribution of marine organisms in the upper 100 meter below the sea ice. One ping every 30 seconds at 200 kHz.

In consultation with the Institute of Marine, Bergen, we deployed the WBAT transducer near the underside of the ice in two North-South transects; 10° E and 17° E for acoustic detection of polar cod juveniles (Fig. 7). The southernmost station in each transect segment roughly indicate the position of the ice edge at the time. On four stations, the WBAT was suspended at 300 meter depth for imaging life in the meso-pelagic layer (300-500 meter depth).

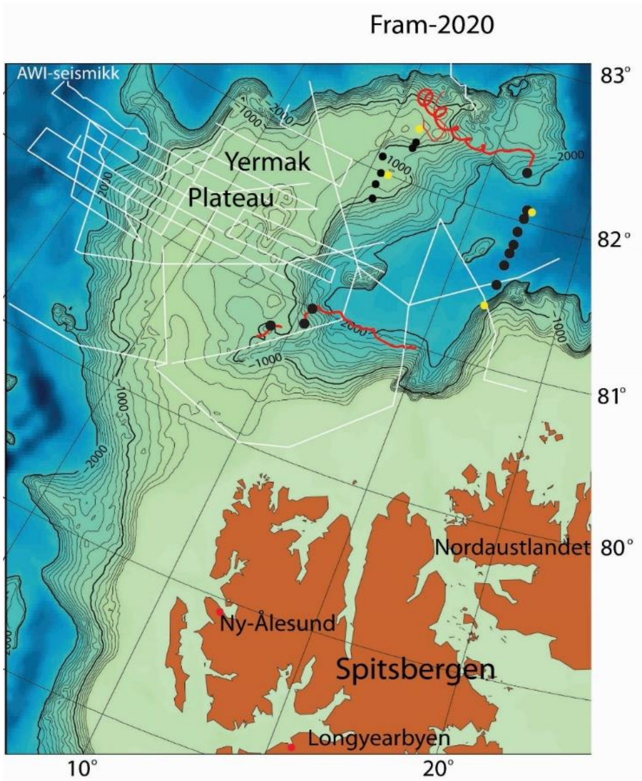

Fig. 7. Map with locations of WBAT echosounder recordings for detection of juvenile polar cod (black dots) and life in the 300-500 meter depth range (meso-pelagic layer) shown by yellow dots.

Sea ice

We deployed 6 autonomous buoys for Met.no for measurement of attenuation of ocean waves by the sea ice cover (Fig. 8 and 9). The buoys continously report the data to shore via Iridium satellite communication. The instrument shown in Fig. 8 was placed on a 30 m x 50 m ice floe with about 1 m free board in an area of scattered ice at 82° 13' N, 11° 30' E about 20 nautical miles from the ice edge.

Fig. 8. Buoy for measuring the decay of ocean waves propagating into the sea ice cover.

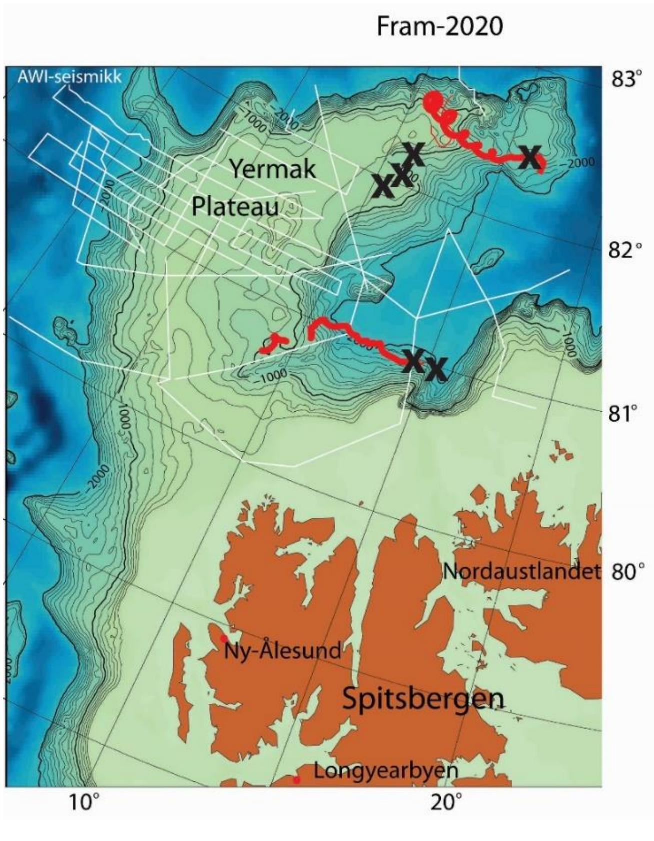

Fig. 9. Location of deployment of autonomous buoys for Met.no

“Firsts” in Arctic Ocean exploration and the significance

3-D seismic mapping

Technological developments always open new doors for science and most often it has to do with our capability to observe natural physical processes with ever greater resolution. Mapping the seabed in the Arctic Ocean with a multi-beam echosounder is one example. An icebreaker equipped with a multi-beam sounder is able to image a two-dimensional swath (2-D) of a width about three times the water depth along the ship track with desimeter resolution of the bottom topography. The mico-topography of the seabed opens up a whole new chapter in studies of the polar paleoenvironment; we see evidence of ice scouring on the bottom on sub-marine ridges and plateaus in water depths exceeding one thousand meter, evidence of sub-marine slides and faulting. An issue such as: Was the Arctic Ocean ever covered by a 1 kilometer thick floating ice shelf, becomes a challenging consept which needs to be clarified.

The sea ice cover in the Arctic Oean can be to our advantage in at least two different ways:

i) areas of tens of square kilometers of the sea ice cover may move as one unit;

ii) the noise level is low in an ocean capped by a sea ice cover.

The first point makes it possible to distribute instruments over kilometer-scale areas and they may maintain their internal geometry while moving with the sea ice. The sea ice cover is more dynamic within the first hundred kilometer from the ice edge and areas with uniform drift may be reduced to less than a kilometer in size. Low ambient noise means we need less energy to get echos from the seabed or the deeper layers.

We have used the advantage of the sea ice cover to implement the first three-dimensional (3-D) seismic survey in the Arctic Ocean. The seismic approach does not only yield the two-dimensional topography of the seabed, but also the topography of the sequence of the sub-bottom acoustic layers down to about 2 km below the seabed. The key tool is a seismic node (data logger) made by Geophysical Technologies Inc. (GTI). The physical size of the node compares with the size of a Coke bottle and a node is capable of unattended recording for weeks (Fig. 10).

Fig. 10. A seismic node (data logger) on the left with hydrophone (right).

The intense ice dynamics over the Yermak Plateau was a disadvantage and the experiment was limited to an ice floe of dimensions about 800 x 800 meter with ten seismic nodes at 50 meter spacing to map out a 225 meter wide corridor on the seabed along our drift track. The principle is illustrated in figure 11.

We were only able to cover about 10 kilometers of track before the ice floe broke up and we had to recover the nodes. Under conditions with a solid ice cover such as experienced during the Fram-

2014/15 ice drift north of Greenland, we would have been able to continue for hundreds of kilometers mapping a +1.5 km wide swath using our full complement of 60 nodes.

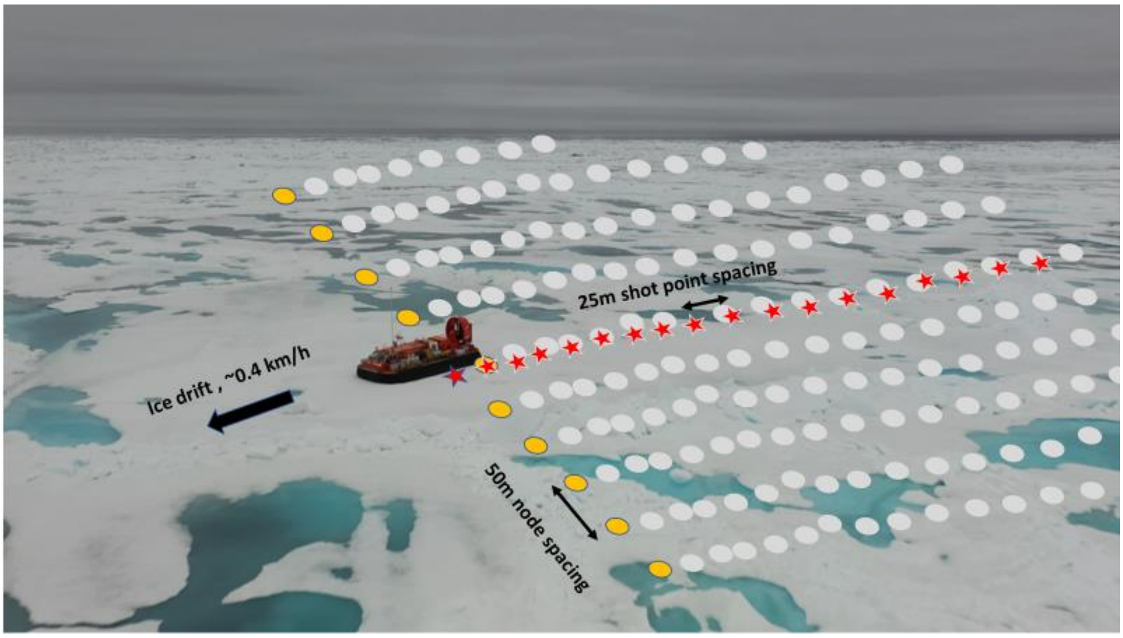

Fig. 11. Figure illustrating the position of the nodes (yellow) and the successive shot points (red) as we drifted along. The nodes recorded reflections from a 225 meter wide swath on the sea bed along the drift track.

Underway ultra-deep far-field seismic signature monitoring

To image the sub-bottom layers as reliable as theoretically possible with the acoustic method, you need to know the excact shape of the signal entering the sea bed as well at the signal returning from the sub-bottom layers. By towing a deep (700 m depth) recorder (Magseis Fairfield), we were directly recording the true signal and there is no need for any assumptions. This is an ideal condition which relate to data quality in seismic acquisition and is not possible to implement in conventional seismic surveys in the open ocean.

Concluding remarks

Fram-2020 is the third ice drift expedition with the hovercraft platform. Fram-2012 (2.5 months) went to the Gakkel Ridge at 85° N and operated in cooperation with the icebreaker “Oden” and retuned with “Polarstern”. Fram-2014/15 (12 months) was the longest continous field operation on drifting sea ice ever made by western scientists. The hovercraft was deployed by “Polarstern” on the Amerasia side of the North Pole. The drift brought new data from the unexplored Canada/Greenland facing section of the Lomonosov Ridge and Morris Jesup Spur and Rise north of Greenland not achievable by icebreaker surveys. Fram-2020 (1.5 month) have probed the unexplored northeastern part of Yermak Plateau using an approach which represents two scientific “firsts” in Arctic Ocean exploration; i) 3-D seismic survey and ii) ultra deep underway seismic signature recording.

The hovercraft “Sabvabaa” (from Inuit; ..*flows swiftly over it*…) has by now covered a distance of more than 4.000 km over sea ice and over 20.000 km in total during 21 trips from Longyearbyen to the ice edge and beyond.

A Norwegian polar exploration effort would benefit from improved understanding of the advantage and cost benefit of integrating complementary logistic resources.

Acknowledgements

We gratefully acknowledge the technical support and systematic approach of senior engineer Ole Meyer, University of Bergen as being the corner stone for making our ambitious seismic data acquisition effort successful. Jan Erik Lie enthusiastically pursued the idea of acquiring the node technology and implemented the field experiment assisted by Espen Harris Nilsen. The fast response with advice on software quirks by Andras Feszthammer of iSeis, Ponca City was very valuable. Ivar Gimse of Magseis Fairfield ASA generously lent us the node for deep source signature recording and Stig Henningsen with “Farm” came north with supplies. In the end, the safe return from the ice edge to Terra firma secured by the advice and tireless effort of Bjørne Kvernmo, skipper and owner of “Havsel”, and the services provided by Kings Bay, Ny-Ålesund are much appreciated.

Blodgett-Hall Polar Presence LLC provided the hovercraft, Lundin-Energy, Norway support for the field operations and the Norwegian Petroleum Directorate and Axxis Geo Solutions support for geophysical equipment. Fram-2020 could not have become a reality without the enthusiasm of Geir Birger Larsen and Halvor Jahre.

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