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Exploring the Borders of Arctic Shelf...

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14 Arctic climate and fundamental geological research expeditions brought to unexpected result — the boarders of Arctic continental shelf!

The main goals of the marine-geological research program were to study changes in paleoclimate of the Arctic Ocean during Late Quaternary period and track the long-term history of the Cenozoic Arctic Ocean with its environmental evolution from a warm to an ice -covered Polar Ocean.
Exploration Manager of RN Nordic Oil Dr. Natalia Kukina is sharing with us her incredible discoveries.

- Fundamental research
- multi-national projects
- RN Nordic Oil vision today

Biography

Dr. Natalia Kukina was born and raised in Murmansk. In 1989 she graduated from the Kirovsk Mining College (Murmansk region), specializing in geology, prospecting and field exploration. Her career began with a description of the well core drilled in the Barents Sea, late 80s. There was no computer and lithological columns available and all description were hand-written. An example of notes recorded can be seen as

scan copy in the CGG & Robertson Red Books.

The physical and mechanical analysis of the very first wells of Shtokman (Barents Sea) was performed by Natalia in laboratory of Rock Physics in "Arcticmorneftegasrazvedka" company. In 1994, as a student (1991-1996) of the St. Petersburg Mining Institute (Technical University) (now renamed to the National University of the mineral resource "Gorniy"), she began to participate in scientific expeditions of high-latitude regions in the Arctic - *the archipelago of Franz Josef Land, Svalbard, Novaya Zemlya*.

During 12 years Natalia spent in the Murmansk Marine Biological Institute of the Russian Academy of Sciences (MMBI RAS),

she had been in
14 marine Arctic expeditions

(the Barents Sea, Kara Sea, Norwegian-Greenland basin, Fram Strait, in the central part of the Arctic Ocean in areas of the Lomonosov Ridge, Knipovich and Alpha). 10 of them were done on the German ship PFS Polarstern.

The studies were conducted in the framework of fundamental research projects and the memorandum of cooperation between the MMBI RAS and the Alfred Wegener Institute in Germany. The expeditions were a unique opportunity to obtain factual data for the basis of realization next projects:

1)The processes of the contemporary sedimentation and paleo situation in the water areas of the Franz-Josef Land, north-east of the Barents Sea and north-west of the Kara Sea;
2)Flows of the sediment material on the Arctic Seas' shelves under conditions of marine periglacial in the Late Pleistocene;
3)The Pechora Sea - Late Pleistocene Paleogeography, present state of the shelf and coastal zone, and a forecast for the 21th century.
4) *Processes of sedimentation on the glacial shelves and paleoclimate changes in the Arctic.*

While performing geological and geophysical work in the Arctic, research institutes from Norway, Germany, Russia, Canada, France and Denmark had constructed the regional geological, tectonic and other maps. Studies of such international scale allowed to prove that the underwater ridges of the

Central Arctic complex (the Lomonosov, Mendeleev-Alpha Ridge) have continental nature and have components of the continental shelf.

In 2004 Natalia received an invitation from professor A.P.Lisitsyn and the job transfer to the Institute of Oceanology named after Shirshov in Moscow. By that time, she already had obtained a PhD and had 5-years' experience in teaching at Murmansk State Technical University in the Department of Oil and Gas. And, between 2005-2007, she was the editor of the lithology and minerals section in the peer reviewed journal - a main data base of all Russian geo-science abstracts.

In 2006, Natalia worked in the State Reserves Committee, MNR Rosnedra as an expert of Russian hydrocarbon deposits. That was a radical change from the creative scientific activity to management role. And, a year later she decided to go back to science. In 2007, Natalia joined the Halliburton Int. for geological and facial modelling of hydrocarbon fields. Then she carried out exploration work onshore (2007-2011) in a joint venture with ENI in Russia. After that Natalia was responsible for the evaluation of the resource prospects: from strategy, economic, business planning, and risk assessment to the development of proposals for TNK-BP investment portfolio expansion (2012-2013). A further merger of TNK-BP and Rosneft (May 2013) opened possibilities for Natalia to manage projects in Norway. In December 2014 she had moved to Oslo and have been working as Exploration Manager in RN Nordic Oil AS.
Interpretation project "Norway" started in 2013 under the umbrella of RN-Exploration, a subsidiary company of Rosneft. RN-Exploration coordinates the exploration work and supports RN Nordic activities in start-up period.

Natalia is an author of more than 50 scientific publications and one monograph.

PFS Polarstern, German Arctic research ship

Expeditions and Discoveries

14 Arctic expeditions were designed in a frame of 4 big research programs: Kara-Barents basin, Svalbard, Norwegian-Greenland Basin and Central Arctic Ocean. These programs saw collaboration between research institutes of Russia, Germany, Norway, France, Canada. Natalia participated from the Russian research side, where the main purpose for the expedition was to investigate global system of climate changes. This fundamental research program let scientists to define sub-programs, which made valuable inputs to the world's geological studies.

take from the board of Polarstern by hydropneumatic percussion method, and first analyses were performed on them as well. In incredible Arctic condition which were further complicated by water depth (till 3000m), the expedition team successfully managed to lift up core samples with length of 12-17 meters from the Quaternary period. Since Arctic sedimentation rate is slow, at some places they even reached hard layers till Cretaceous.

1997-2004 Expeditions

The main objective of the marine geology group work program was to reconstruct the paleoclimate of the late Quaternary period in the Arctic Ocean and adjacent continental areas by studying of paleoclimate change, paleo oceanographic circulation distribution of that period's sea ice.

On the expeditions in the period, special attention was given to the recovery of paleo oceanographic environment during the Holocene in the area of the Plateau Yermak. Determination of the magnetic properties of glacial and interglacial deposits in the area allowed to perform more detailed stratigraphic correlation.

The transition from the last glacial period to the modern interglacial period had strong and fast fluctuations of the climate system. The sediments of northern latitudes of the Atlantic Ocean are known as distinct cyclical in nature, which is likely reflecting the warm and cold periods (for example, during warm and cold periods Allrod early Dryas, Holocene) which makes controversial opinion on sustainable Holocene interglacial (Bond et.al., 1997; Bianchi & McCave, 1999). To investigate whether or not Holocene climate fluctuations and associated changes in thermohaline overturn left significant traces in high-resolution sediments from the Yermak Plateau was thus one of the major tasks.

The rate of Holocene sedimentation in the Arctic Ocean is too low, which does not allow to determine the short-term climate fluctuations. However, the XIII/2 expedition cut column sample PS2837-5 (water depth 1042 m) on the western slope of the Plateau Yermak (81° 13°N) penetrated a thick Holocene layer. This region is controlled by an Atlantic waters temperature that influence on the position of the ice sea surface boundary in the summer, as well as impact on sediment transfer in a sea.

Why was sedimentation much faster in this region and what was the sources and ways of sediments transfer there, the expedition team tried to find out during the XV/2 expedition trip.

The western slope of the Plateau Yermak is very steep and most likely that it is affected by turbidity currents. The samples of sediment were decided to take along the western and eastern slopes of the Yermak Plateau.

Places of the samples were defined using echo sounding (PARASOUND) acquisition results and sea depth (900-1500m). The expedition team has also access to Atlas PARASOUND including an Atlas Deso 25 printer and PARADIGMA digitizing and post-processing software (Spiess, 1992).

At the upper shoulder of the western Yermak Plateau very hard seismic reflectors were observed. It was chosen for core sample as an evidence for an outcropping salt plume. The core penetrated about 5m structure depth. There was only 47cm of clayey sediment in the core tube. The highest resolution core that had ever been taken from the Yermak Plateau (PS2837-5, Stein and Fahl, 1997) was taken from the western part in a water depth of 1044m.

The shallow *Greenland shelf* was investigated between 79° and 81°75 N. Water depths ranged between 20 and 300m. A seafloor was obviously affected by grounding ice. There were also a few channels, all of them filled with material similar to the adjacent areas, and many places where the influence of gravity flows becomes evident.

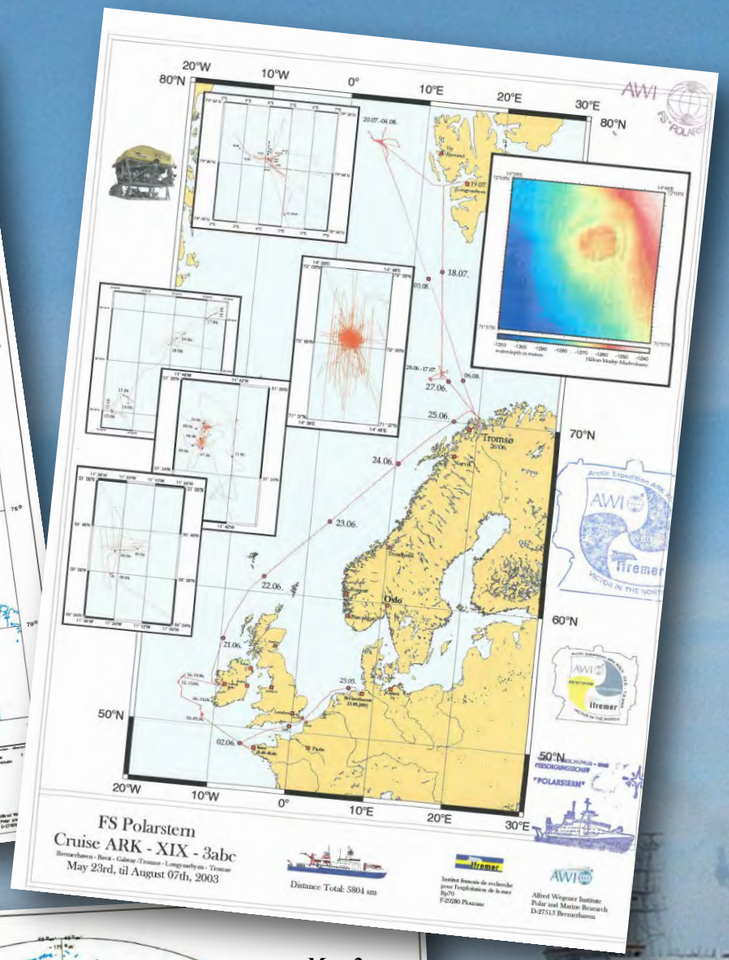
The Svalbard shelf area around 20°E had mostly diffuse reflectors and a very uneven relief. Series of steep more than 80m high ridges may be interpreted as morain ridges.

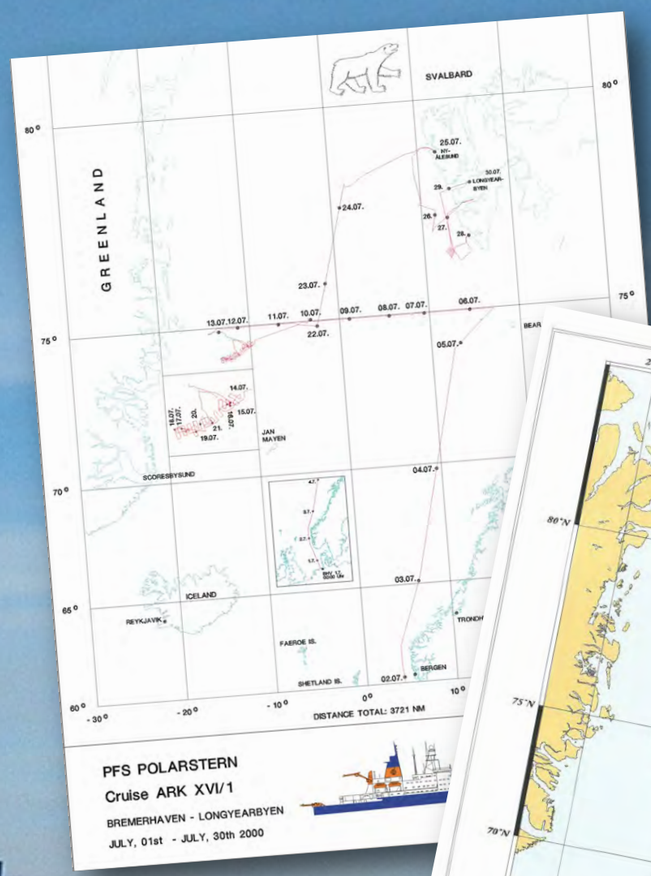
The most of the *Deep Sea* areas (about 2500m) were characterized by influences of turbidities that leave discrete layers of slumping that produce diffuse large sediment bodies with a chaotic internal structure. Sometimes the initial layering was still visible on the deep slope although large parabolic structures indicate sliding sediments at a large scale. These structures were found in the area of the Molloy Deep and north of the Svalbard. However, in some places discrete layering continued down to more then 3000m.

The following coring gear was used during ARK XV/2 expedition: GKG (giant box corer): 60cm long, 50cm x 50cm. - *MUC (multiple corer): 12 tubes, 60cm long, 6cm in diameter. - SL (gravity corer): 5m/8m/10m/13m long, 12cm in diameter. KAL kasten corer): 5.75m/l 1.5m long, 30cm x 30cm.* Onboard investigations included core descriptions, spectrophotometric color scans, smear slide analyses (SL), x-ray analyses, physical property analyses: p-wave velocity, wet bulk density, magnetic susceptibility for all cores, all kasten cores, 1 gravity core.

Natalia performed SL analyses on sediments about 50 long cores. For all period of expeditions over 1000 smear slides were investigated under the light microscope. SL investigations were performed to estimate the mineral compositions and to determine the contents of biogenic and terrigenous components. Based on these analyses the terrigenous particles in the sediments were predominated. The principal minerals include

The First



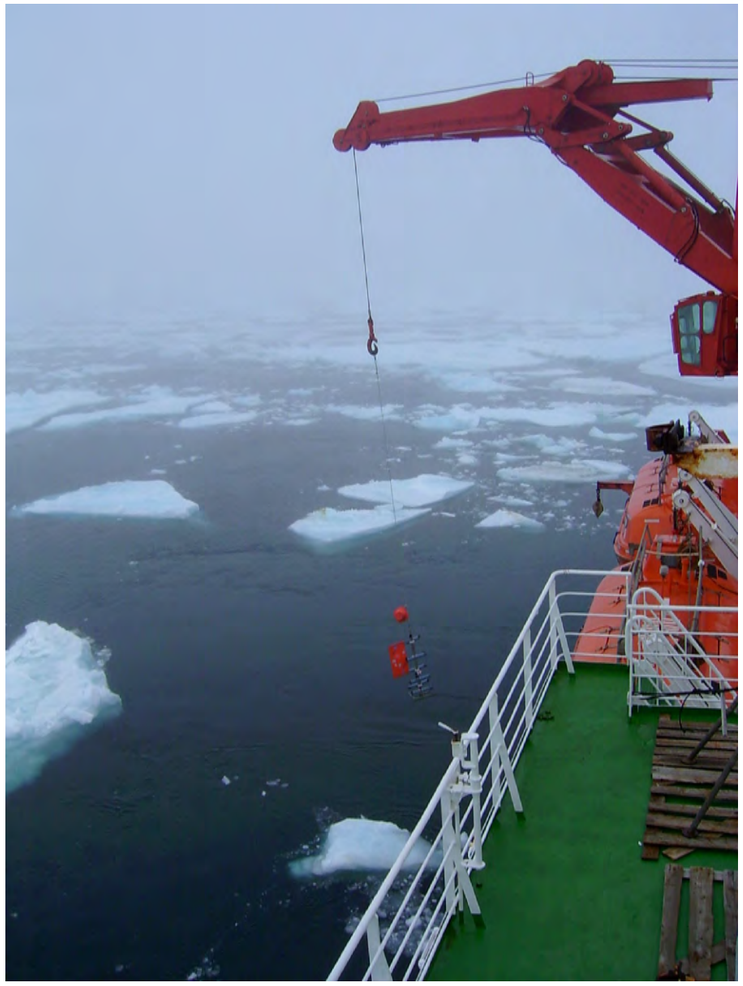


The route maps of international expeditions on the research vessel Polarstern.

Map 1 - *Research cooperation between MMBI and AVI in 1999 (ARK-XV / 2).*
The expedition started and ended in Tromsø (Norway), July 21, 1999 - September 8, 1999.
The aim of the expedition was 1) to study changes in the paleoclimate, paleo-oceanographic circulation distribution of sea ice in the mid Quaternary period; 2)reconstruction of changes in natural conditions of the Arctic Ocean in the Mesozoic and Cenozoic; 3) to study the evolution of sea levels and the dynamics of sediment in the ocean.

Map 2 - *2000-2004 Norwegian-Greenland Basin Research Expedition ARK-VI/1 started on July 1, 2000 from Bremerhafen, Germany. The aim of expedition was to define 1) the age, environment (foraminifera); 2) particle size distribution, geochemical and mineral composition (light and heavy subfraction) sediments; 3) vertical flows of organic carbon (organic geochemistry, kerogenpetrographic); 4) and perform an assessment of the Greenland Sea paleo productivity (biomarkers, bio-opal).*

Other maps are showing routes of sub-expeditions performed in frame of the same project.



quartz, feldspar, terrigenous carbonate and clay minerals. Quartz contents ranged from 15% to 53%. Quartz/feldspar ratios ranged from 0.95 to >3. Feldspar contents were up to 30%. Terrigenous carbonates (i.e. calcite, dolomite) occurred between 0.1% and 10.9%. Opaque minerals tend to increase down core. The highest amounts of Opaques (5.3%) were observed in Core between 270 and 430cm core depth. Biogenic carbonate was between 0.1 and 6.3% with a maximum at 0-140cm in the core. Heavy minerals determined in the various cores include amphiboles, pyroxenes, epidote, biotite, garnets, chlorite, titanite, Fe-Mn-nodules, hydroxides, and iron and black ores. Amphiboles and pyroxenes dominate the spectrum although in intervals of some cores Fe-hydroxides (i.e. limonite and hydrogetite) dominate the association (as example see Figure 1-2). Further investigations at the home laboratory intensified the mineralogical studies.

2000-2002 Svalbard Expedition
Surface sampling
Paleoconstructions of the geological history of Svalbard`s shelf has fundamental scientific challenge. The specific of evolution marine ecosystem in conditions of continuous melting ice sheets, sediment material types, intensive sediment genesis and changing of sea water salinity, are interconnected with anthropogenic influence in the modern period. The aim of the geological investigations was to identify the modern periglacial processes and theirs influence on the geological, geomorphological and sedimentological areas of the archipelago, and to determine the influence of the ice sheets edges on the frontal zones formation in the littoral areas.
Sea-Ice sediments Investigations
Sediments in the Sea-Ice are important factor for erosion and distribution of sediment content of the Arctic Ocean. The main results of the field works there were 1)to track possible ice paths based on sedimentological parameters in surface deposits, and to study sea-ice material in source and melted areas; 2)to define the sample composition, grain size distributions and mineral assemblages between sea-ice sediments in the different areas of the Arctic Ocean.

Expedition to the "Fram Strait" comprised investigation of *terrigenous sediment supply* in the Arctic Ocean controlled by river discharge, oceanic currents, sea-ice and iceberg transport, and down-slope transfers. Most of these mechanisms also influence on biological processes in the water column as well as at the sea floor.
The Project was focused on the quantification and characterization of terrigenous discharge in the Arctic Ocean and its change through Late Quaternary period. This study allowed to obtain the estimates of sedimentary bases, identifications of major move processes and reconstruction of oceanic currents. The biggest interest was in a detailed sedimentological, mineralogical and micro paleontological study of surface sediments and sediment cores.
Benthic foraminifers. The modern distribution of benthic foraminifera and its stable carbon isotope signals were characterized in relation to the modern Arctic environment (bathymetry, water mass properties, sea-ice distribution, etc.). Based on the precise description of that time medias, an actual model was suggested, which then was applied to the fossil records and allowed to reconstruct changes in paleoenvironment (such as water mass properties, surface-water productivity etc.) during late Cenozoic times.

Expedition's Result
The broad analysis of the cores show only small variations which points to similar lithology in the cores. Only one of the southernmost core differs by a larger number of peaks in the density and P-wave velocity curves, which indicates a higher amount of ice rafted debris in this core. Sediment thickness shows increasing sedimentation rate which is also observed in cores from the northeastern Yermak Plateau and in the cores from the slope off Eastern Greenland (Nam, 1997). Taken the preliminary stratigraphic correlations from the core logging data and the macro- and microscopic sediment investigations, then, it turns out that high **sedimentation rates at the shoulder of the western Yermak Plateau are neither a function of water depth (below 1000m) nor a function of latitude.** The reason for the increase in sedimentation rate in the Norwegian—Greenland Sea is **the rapid change of colder arid and warmer humid phases during the last glacial/interglacial cycle**.
In 2000, the oceanographic research work have been carried out on 75° parallel towards coastal areas of Greenland from the

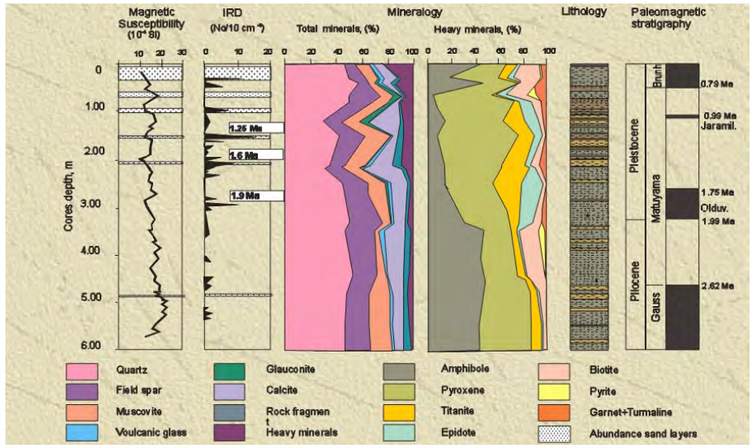


Figure 2. Lithology, Mineralogy and paleomagnitostratigraphy of bottom sediment physical properties and paleomagnetic stratigraphy from Jokat et al., 1999,Stein et al., 1999)

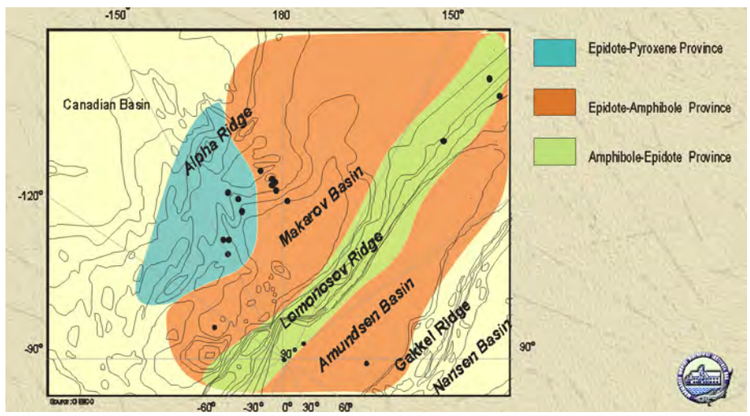


Figure 1. Mineralogical Provinces of the surface layer of bottom sediment Location map of the sediment cores studied. Arrows indicate part of the Cruise route of Polarstern Arctic`91 and ARK-XIV/1a

island Medvezhy. In the southwestern part of the Greenland Sea biological and geological work were conducted, including the study of the distribution and concentration of plankton and benthic organisms, sediment sampling, and determination of geochemical composition of sediments. The main purpose of geological research was to analyze the flow of sediment to the great deeps of the sea (by taking new samples), which will help to create paleoreconstruction of climatic changes in the Quaternary period.
Sediment samples were taken for sedimentological, geochemical and microfossils studies, which allowed to assess the impact of sediment transport slope processes and to distinguish these deposits from glacial and glacial-marine sediments.
That only proved the earlier assumptions about climate phases. The rate of the sedementation in the warm period (interglacial) increased.

The more interesting conclusion of the expedition came unexpectedly. A collection of the cores and analysis of different subprograms, which were dedicated to climate changes, allowed Russia to apply and to prove that Russian shelf continues until Mendeleev-Alpha Ridge.

"The publications which were made by Alfred Wegener Institute and Bedford Institute in Canadian '98 and '12 show geological Arctic map. There is a conference which dedicated to this big study going every 2 years. It is not just a study which founded by all institute, it is a very fundamental research which includes plates tectonic, the Arctic development, sedimentation in different ages, ice influence on the plates move — fundamental geological problems. The expe-