dipolarization discussed in the above resulted from the current that has a strong eastward component (red arrows), which counters the westward cross-tail current (blue arrows) that grew during the growth phase (10:30-11:30 UT). In fact, the total current direction had an eastward component at 11:40 UT. Such a current can cause a sort of "over dipolarization" that was sometimes observed at the geosynchronous satellites. This shows that the dipolarization is not just reducing or diverting the cross-tail current, which indicates that currents grow against the normal tail current. We hope that such a finding will throw light on a long-standing problem of the so-called "T = 0" issue—the direct triggering process—of substorms.

Another prominent feature of the equatorial currents is the strong radical outward currents associated with the tip of the westward electrojet in the evening sector. These currents must be related to the pair of upward-downward, field-aligned currents at the tip of the westward electrojet. This particular feature is evident in many other cases we examined and will be reported in another article.

Summary

There is no practical way to obtain **J** (r,θ,ϕ,t) everywhere in the magnetosphere as a function of time with a time resolution of 5 minutes or so. However, by taking advantage of the merits of ground- and satellite-based observations and complementing their demerits, and further aided by powerful computer modeling efforts, we have made an important advance in an endeavor that began at the beginning of the 20th century.

With the synthesis of spacecraft observations, ground-based observations, and powerful inversion techniques, we have made considerable strides in understanding the complex system that is the coupled magnetosphere/ionosphere. However, further progress requires the continued maintenance of ground-based observatories, as well as continued deployment of space-borne resources. Such efforts as those described here could be particularly exciting when and if large clusters of spacecraft are launched, providing some of the detailed in situ observations that we can at present only infer.

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Laptev Sea System Discussed at Russian-German Workshop

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The Laptev Sea covers the central part of the vast Arctic shelf seas off northern Eurasia. It receives large volumes of fresh water from the Lena River and other big rivers that drain the central part of Siberia; peak runoff occurs in the early summer. Being tucked away between two groups of islands—Severnaya Zemlya in the west and the New Siberian Islands in the east—and connected to the Kara Sea in the west and the East Siberian Sea in the east only through relatively narrow straits, the Laptev Sea is an important area for sea-ice formation in the Arctic Ocean [*Rigor and Colony*, 1997; *Kassens et al.*, 1999].

Through sea ice formation, the Laptev Sea influences the ice cover of the central Arctic Ocean and its Transpolar Drift, which exports sea ice into the western Norwegian-Greenland Sea. The Laptev Sea is also the central segment of the Northern Sea Route. For this reason, commercial interests wish to gain valuable knowledge about the extremes of its modern environment. past variability, and predictability on time scales of months and years. Both in the Laptev Sea and on the adjacent land regions, large tracts of subterraneous and submarine permafrost have been observed as a consequence of the extreme paleoclimate of the latest geological past.

Investigations of the temporal and spatial variability of northern Siberia and Laptev Sea environments are pursued under the framework of the bilateral Russian-German project "Laptev-Sea System" [*Kassens et al.*, 1998]. The project's fifth workshop in late 1999 drew 130 scientists from Russia and Germany.

After the inaugural session with reports about expeditions that took place in 1999, major sessions with oral and poster presentations were devoted to seasonal and interannual environmental variability, terrestrial/marine interactions in coastal zones, short- and long-term environmental changes in the Siberian Arctic, and onshore and offshore permafrost: modern processes, interactions, and evolution. The workshop, which was funded by the German and Russian ministries for sciences and technology, ended with a discussion session and an excited debate about future research activities.

Seasonal and Interannual Environmental Variability

The system of flaw polynyas on the Russian Arctic shelf is an important component of the climatic system. Continuous southerly winds blowing during the whole winter season are able to keep large open-water areas (polynyas, between 500 m and 10 km wide) off the fast ice edge (Figure 1). Due to extremely low temperatures and high current velocities, this causes intensive ice formation. Thus, the flaw polynya is one of the main sources of ice for Transpolar Drift.

For the first time in the Russian Arctic shelf seas, two oceanographic bottom stations equipped with Acoustic Doppler Current Profilers (ADCP), named YANA (at a depth of 42 m) and LENA (at a depth of 24 m), were deployed in the eastern Laptev Sea (Figure 2) to study the vertical structure of currents, their daily and seasonal variability, and the influence of suspended particulate matter upon transportation. Both stations were working for 15 months from 1998 to 1999, and recorded current velocity and echo intensity every 30 minutes at 2-m intervals from water surface to the sea floor.

The initial data have shown that the water column in the polynya region was stratified during the entire winter season. Echo intensity is a good description of vertical and temporal variations of the main reflectors; namely, suspended particles, zooplankton, frazil ice crystals, lower ice surface, and water (ice)-air interface. Moreover, daily vertical migrations of zooplankton through the water column to the surface for feeding during night hours has been recorded; surprisingly, the migration could also be observed during the "dark" season.

Ice, water, sediment, and under-ice topography are factors that influence sympagic organisms. In the autumn, biomass expressed as pigment concentrations varies considerably in the water column, as well as in the new-ice samples. Near bottom currents and suspension, maxima seem to foster high sediment concentrations and an enrichment of benthic biological material in

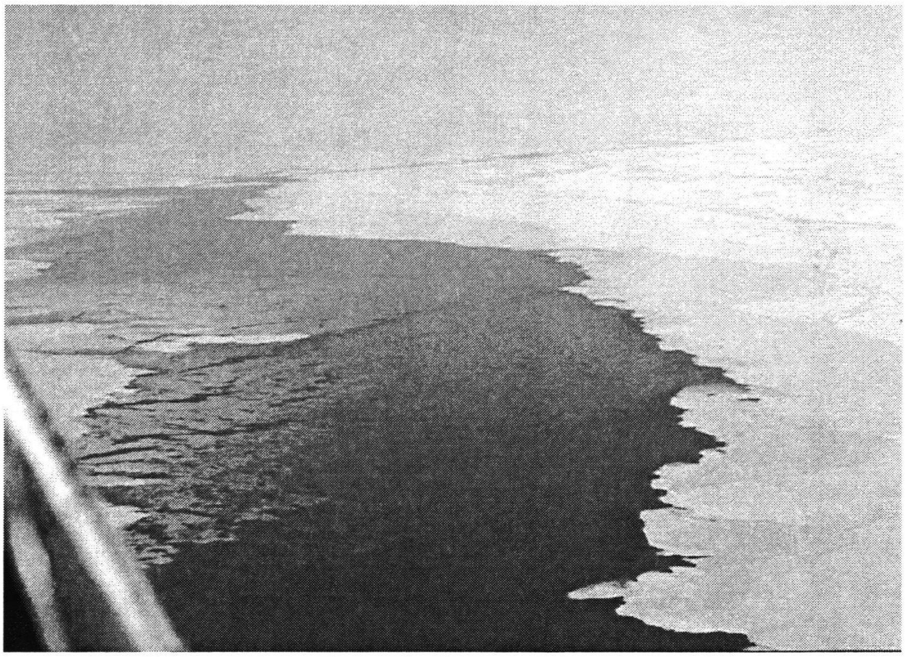

Fig. 1. The Laptev Sea polynya is considered to be an important sea ice production region for the Arctic Ocean. New ice production was directly observed in April 1999 by the research team at the fast-ice edge (left) in the eastern Laptev Sea (Station YANA). While southerly winds are keeping the polynya ice-free, new ice is drifting toward the north (right). (Photo courtesy of H. Kassens). Original color photo appears at the back of this volume.

the ice. Sediment incorporation into the ice is altering the sea ice habitat for organisms.

The river water has a pronounced influence on the distribution, activity, and community structure of the phytoplankton in the whole shelf region. This influence is triggered by the Lena River discharge and varies during the seasons, showing the highest impact in spring and summer, when outflow rates are high. Close to the Lena River outflow, euryhaline (i.e., adaptable to a wide range of salinity) and phytoplankton species of river origin prevailed.

The influence of Arctic haze on radiation and climate in the central Arctic was estimated by monitoring light-absorbing aerosols in the lower and middle troposphere. These aerosols decrease the atmospheric transparency in two ways: directly, by being a radiatively active substance, and indirectly, by functioning as a nucleus for cloud and haze production. The influence of Arctic haze on climate change in polar areas is comparable to that of a doubling of atmospheric carbon dioxide.

These changes in the environment directly influence the biota of the region and are reflected in the patterns of distribution and abundance of various marine organisms. A high seasonal variability in the marine system could be stated for the life cycle and activity of copepods. Monitoring of birds and mammals in the Laptev Sea polynya in the ice-free sea during summer, and in the delta of the Lena, indicates that in addition to seasonal changes, there is high interannual variability. This variability is mainly linked to the availability of food sources and the occurrence of competitors for nutrients.

Terrestrial/Marine Interactions in Coastal Zones

The Siberian rivers Yenisei, Ob, and Lena are some of the biggest on our globe in terms of runoff. Ten percent of all riverine discharge to the world oceans occurs in the Arctic. These rivers flow through large areas of continuous permafrost and thus exhibit an Arctic nival regime, with very low flow rates during the winter, but pronounced flow rates in the spring due to snow melt. In the spring, the flow contains large amounts of suspended particles.

Based on the results of hydrochemical data, several types of water masses were identified in the Laptev Sea. The distribution of pCO_2 shows that Laptev Sea waters, even during or after convection and freeze-up, are mainly a sink of atmospheric CO_2 with an undersaturation of up to 40–60%; supersaturation with CO_2 is reached only in restricted areas near the Lena River delta and in some coastal zones.

Sediment accumulation and erosion play an important role in modern and ancient sediment budgets of the Laptev Sea. Although the modern sediment input of the rivers draining into the Laptev Sea is relatively well quantified, we have a poor understanding of the proportion of the fluvial sediment that does not reach the shelf but is accumulated in the deltas—mainly in the Lena Delta—as well as the environmental history of the Lena delta. Data from 1994–1999 show that the Lena River is a significant source of both minerogenic and organic carbon in the shelf waters. Furthermore, the material input due to the erosion of ice-rich coastlines (so-called "ice complexes;" Figure 3) has not yet been considered when establishing the sediment budget of the Laptev Sea. For the first time, the eolian particle transfer was investigated in and around the Lena delta region, showing average atmospheric concentrations for most of the chemical elements known from other Arctic regions.

Geophysical investigations carried out in the Lena delta, as well as sedimentological analyses and AMS-^{14}C and optically stimulated luminescence dating provide new information on the sedimentation history of the Lena delta. While its eastern part is composed of Holocene delta deposits, with an average age of ~3,500 yr BP, its western part consists of fluvial sediments with an

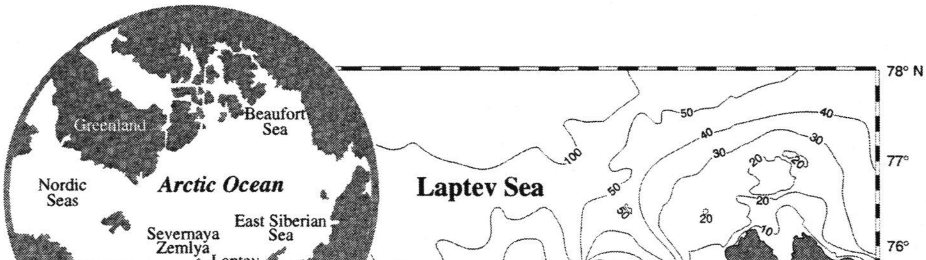

Fig. 2. Map showing the Arctic Ocean (inlet) and the Laptev Sea in the Siberian Arctic. The positions of the oceanographic bottom stations YANA and LENA (deployed in 1998 on board R.V. Polarstern; recovered in 1999 on board R.V. Yakov Smirnitsky), as well as water depths (in meters), are marked.

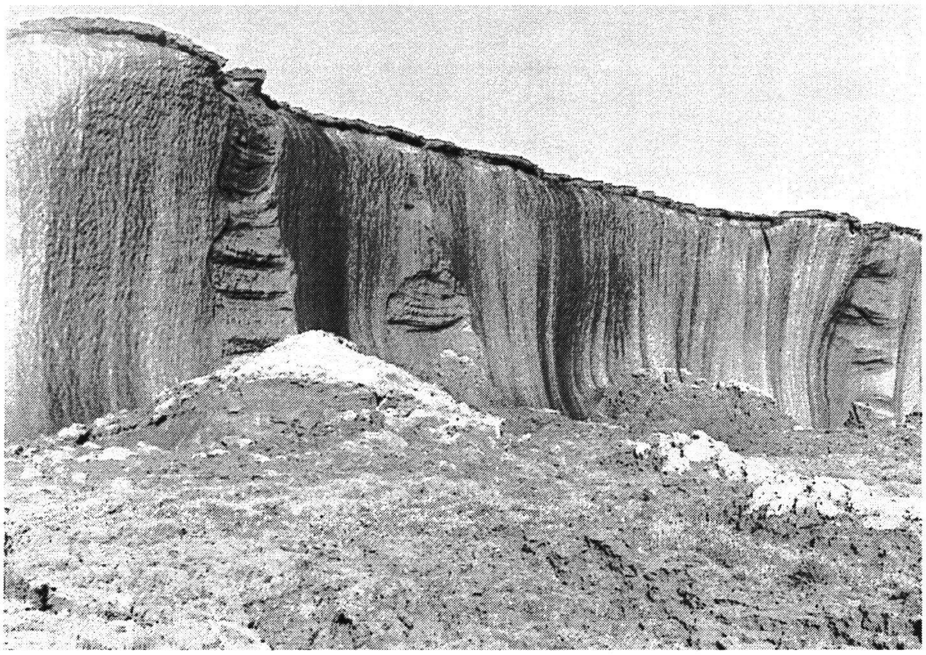

Fig. 3. The shoreline of the Laptev Sea is partly composed of ice complexes up to 40 m high covered by a thin layer of frozen soil, which melts during the short summer. Such an ice complex, named Mammont Khayata in the southeastern Lena delta, was investigated in the summer of 1999. These ice complexes preserve many fossils, such as skeletons of large mammals, that reveal the environmental history of the Siberian Arctic. The coastal zone of the Laptev Sea is regarded as one of the largest mammoth cemeteries in the world. (Photo courtesy of M. Grigoriev) Original color image appears at the back of this volume.

age of ~13,000 yr BP. New data were collected to explain a more detailed history of the western delta sector. Two flood plains and three surfaces above the main flood plain were identified between two channels in the eastern and southern part of the delta area. For each of the levels identified, typical sections of Quaternary sediments were investigated, dated, and a typical complex of cryogenic and bed relief features was identified. In addition, islands formed from the upper Quaternary ice complexes could be located within the Lena delta.

The coastal zone of the Laptev Sea is an ideal area for measuring Arctic shoreline retreat rates and coastal accretion. The continental Laptev Sea shoreline is over 4,900 km long. About one-third of the shoreline (1,600 km) consists of an ice complex; that is, ice-rich deposits containing massive ice bodies that are subject to active marine erosion (Figure 3). Such areas were studied thoroughly. In 1999, field studies were conducted along the shore line of the eastern Laptev Sea that included eroding, stable, and accumulating portions. The average coastal erosion rates are in the range of 1-7 m per year. The input of material from coastal erosion to the sediment balance of the Laptev Sea is at least of the same order as the riverine sediment supply, and probably much larger.

These field data were confirmed by comparison with digitized aerial photographs. To understand coastal dynamics in the Arctic, shore face investigations are necessary. Factual data from different regions demonstrate the diversity and complexity of Arctic shore face morphology. Several shore face profiles of Laptev Sea erosional and accretional shores were obtained during recent expeditions. Preliminary data suggest that: 1) the shore face profiles are concave; this reveals the non-equilibrium state of the coast and allows us to forecast the continuation of intensive coastal erosion into the next decades; 2) the shore face lower boundary of erosional shore is located mainly in the 10-m isobath area; and 3) the shore face of river delta accretional coasts usually has a shallow bench in its upper part up to 20 km wide, with a sharp increase of inclination between the 1- and 2-m isobaths. Biogeochemical and stable isotope data of the Laptev and East Siberian seas have shown that coastal erosion plays an important role in the transport of terrestrial organic particulate matter onto the shelf as well.

Short- and Long-Term Environmental Changes in the Central Siberian Arctic

The Laptev Sea is extremely shallow and comprises an area of active tectonics with a number of horst and graben structures experiencing differential subsidence. The few available sediment cores reflect a complex history, therefore, and modern stratigraphic results are mostly restricted to Holocene sediments. New biostratigraphic studies using a number of microfossil groups and absolute dating established a new interpretation of the evolution of the paleoenvironment after the last glacial maximum. To quantify sediment sources—in particular, those of organic carbon—stable carbon isotopes were studied in marine sediments, and a terrestrial origin was identified for most of the sediment. The reconstruction of the radionuclide pathways helped to unravel the paleoclimatic history of the area where the influx of riverine waters also controls the distribution of stable oxygen isotopes. Source regions were also identified in modern and ancient sediments by means of heavy mineral studies. Accordingly, the Laptev Sea can be subdivided into an eastern and western region with different mineral provenances related to the major river drainage areas.

Many presentations were devoted to the outcropping ice complexes along the shores of the eastern Laptev Sea (Figure 3); these ice complexes are fossiliferous and therefore easily datable. The reconstructed paleoenvironment of the formation of these ice complexes with geocryological and sedimentological studies provided new insight into the environmental history of the region during the late Pleistocene regressive stage, and the resulting dramatic restructuring of fauna, flora, and landscape after the last ice age. More than 900 new mammal bones—about 40% from the woolly mammoth–and the changing composition of the insect faunas helped to describe the change from steppe to tundra environment. Stable isotope studies were also performed in ice wedges and ice-rich permafrost.

Paleogeographic reconstructions, and geomorphological and lake sediment studies identified the limits of the last glaciation [*Thiede et al.*, 1999]. Reconstructions of eustatic and isostatic sea level fluctuations in the Laptev and Kara seas based on marine sediments from the Taymyr Peninsula and Severnaya Zemlya were extraordinarily difficult to understand and are not easily reconciled with data from other coastal areas.

On- and Offshore Permafrost

The features, properties, and evolution of terrestrial and submarine permafrost were a special topic of this workshop. Studies of modern processes focused on investigations of trace gas fluxes (CH_4 and CO_2) on permafrost soils (Gelisols) of the Lena delta. The summer emission rates of methane ranged between 10 and 85 mg CH_4 d^{-1} m^{-2} while the carbon dioxide fluxes reached maximum values of 4400 mg CO_2 d^{-1} m^{-2} from typical wet polygon tundra sites. The main flux-influencing parameters are the soil temperature and soil moisture regimes, which mainly depend on the organic carbon in the soil, the vegetation cover, and the micro relief.

First estimations for the summer periods 1998 and 1999 show that only 1.2-4.5% of soil organic matter is released as methane. Special field experiments on the methane production at near zero temperatures (- 0,6°C to +1.2°C) in the anoxic horizons of wet Gelisols demonstrate distinct methane production during the refreezing time of the year. Nearly 25-30% of the annual fluxes are captured in the upper frozen parts of Gelisols, which are released during thawing periods. Thus, the portion of the CH_4 production at near zero temperature (in autumn and spring time) to the total amount of methane emission has to be considered. These data are necessary for estimating the contribution of permafrost soils to the regional and global methane budget.

Seismic data allowed us to assess the features and evolution of submarine permafrost in the eastern Laptev Sea compared to onshore permafrost conditions. Temperature and heat flow measurements provide evidence for the existence of submarine permafrost over extended areas in the Laptev Sea, down to a water depth of about 120 m. These observations will be tested by drilling into the Laptev sea floor during the summer of 2000. Russian scientists at the workshop also presented a general summary of our knowledge of the evolution of the on- and offshore permafrost during the past 400,000 years, including modeling attempts.

Field investigations focused on different patterned grounds on Samoylov Island, which is representative of the central Lena delta and an ideal site for modern process studies in soils affected by permafrost. A detailed description of the landscape structure and permafrost soils, including vegetation complexes, was established as a basis for measuring and calculating trace gas fluxes from this typical Arctic tundra area. Ground-penetrating radar techniques were applied to gain information about the small-scale textural changes in the active layer and structural differences in selected polygon structures.

Various studies of microbial processes (temperature, water content, nutrients) in relation to trace gas fluxes were carried out for the active layer of permafrost soils. To quantify the decomposition of organic matter under oxic and anoxic conditions (CH_4 and CO_2 fluxes), the distribution and cell numbers of the microbial community were determinated. Methane oxidation—with maximum values of 55 mg CH_4 d^{-1} m^{-2} in the polygon centers—and its dependence on abiotic factors (temperature, soil moisture, substrate) as one major process controlling the methane release from the polygon tundra was investigated. Nearly 50-70% of the methane produced in anoxic layers was oxidized by the methanotrophic bacteria.

Furthermore, the effects of vegetation on methane transportation to the soil near atmosphere were studied by special in situ experiments that showed that in the wet polygon center, about 74% of the emitted methane was released by the sedge Carex concolor. Laboratory tests demonstrate the influence of cryostatic pressures on different soil substrates and soil water contents as well their impact on pore size distribution. Changes in the pore size distribution greatly affect the transportation and release of trace gases from soils affected by permafrost.

Interactions and relationships between on- and offshore permafrost were studied in considerable detail. Permafrost evolution on Arctic shelves and in coastal lowlands of the Laptev Sea region were calculated and modeled on the basis of isotope ratios, sea level oscillations, and the dynamics of ground temperature. The role of thermokarst processes in the post-glacial transgression was probably crucial for the evolution of the morphology of the Laptev sea floor and coasts. These investigations are important for reconstructing and modeling the past and future of the Laptev Sea shelf and its surrounding lowlands.

A new mini-heat probe was developed for measuring the winter temperature regime, especially for short-term temperature variations that are relevant to seasonal and interannual variability. Highest sea floor temperatures (up to - 0.90°C) were obtained on shallow shoals (8-m water depth) in the southern Laptev Sea, while lowest temperatures (- 1.62°C to - 1.40°C) were measured near the polynya. Records were obtained to map and characterize the lateral distribution of subbottom occurrences of permafrost and gas in the sediments, but they were difficult to interpret. Furthermore, a two-dimensional model was applied to investigate the dependence of formation and evolution of permafrost-containing water and the gashydrate stability zones.

Future Research Activities

The Laptev Sea and the adjacent northern Siberian region that contains the Lena delta will be subjects of intense studies about the natural properties and their variability in the past. Lake studies have been performed for some years in several lakes on Taymyr peninsula, establishing beyond a doubt that the Eurasian ice sheet of the last glacial maximum never reached that far east.

Drilling in the Akademik ice cap on the archipelago of Severnaya Zemlya began in 1999 and will be completed in 2001. The ice cap had been drilled by Russian scientists several decades ago and seems to hold a record of the time span from the last glacial maximum to modern times. The collected ice cores will be investigated with the whole suite of modern techniques to generate a data set of comparable qualities of the Greenland ice cores. Drilling into the Laptev sea floor is planned this summer and years afterward to establish the nature of the submarine permafrost occurrences of gas hydrates and to conduct paleoceanographic studies of one of the Arctic shelf seas.

The bilateral Russian-German projects in the Laptev Sea have also led to the establishment of a new research facility in St. Petersburg, the Otto Schmidt Laboratory for Polar and Marine Sciences (inaugurated during this workshop), where modern facilities and modest financial support are provided to promote the scientific evaluation of the valuable data sets from northernmost Siberia and the adjacent shallow shelf seas. Otto Schmidt was the former director of the Arctic and Antarctic Research Institute and a widely known Russian polar researcher in the 1930s. He promoted the establishment of the Northern Sea Route, which passes the Laptev Sea.

The fifth Laptev Sea System Project Workshop was held November 25–29, 1999, at the State Research Center-Arctic and Antarctic Research Institute in St. Petersburg, Russia. The abstracts of the workshop have been published in *Terra Nostra*, Vol. 99 (11) by the Alfred Wegener Foundation, Cologne, Germany.

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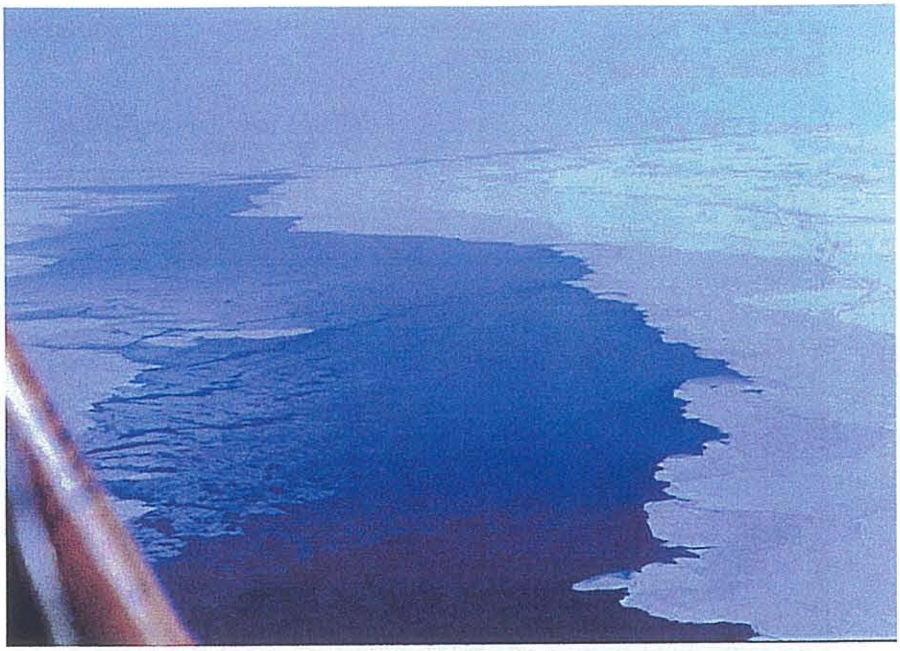

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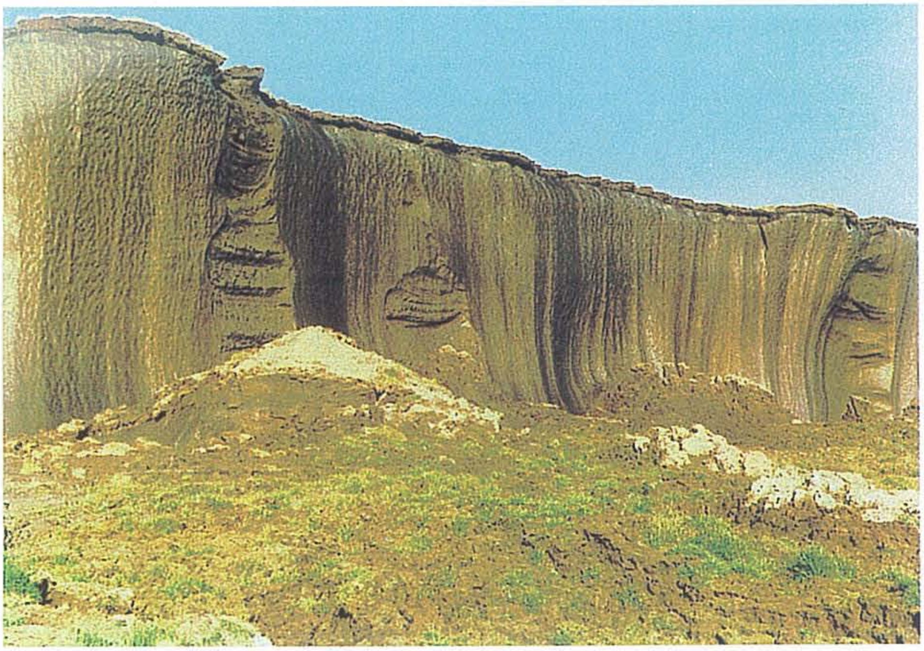

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