WORKSHOP ON QUESTIONS OF ARCTIC ICE SHEET DEVELOPMENT, GROSSWALD'S VISION, AND IMPLICATIONS FOR PALEOCLIMATE INTERPRETATIONS

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ABSTRACT

This workshop followed ICAM Symposium 2A: *Late Cenozoic History of Beringia - New Developments*. Discussion leaders at the workshop were Terence Hughes and Patricia Anderson. Workshop participants included participants in Symposium 2A and other interested scientists.

Grosswald's vision is presented in Figure 1. Grosswald believes that a single Arctic Ice Sheet existed at the last glacial maximum. It consisted of long-recognized continental ice sheets, the Laurentide and Cordilleran Ice Sheets in North America, the Greenland Ice Sheet, and the Scandinavian Ice Sheet, newly investigated marine ice sheets, the Innuitian Ice Sheet over the Queen Elizabeth Islands in Arctic Canada and the Barents Ice Sheet in the Barents Sea, and problematic ice sheets in the Kara, Laptev, East Siberian, and Chukchi Seas of Arctic Siberia. In Grosswald's vision, all of these ice sheets were ice domes of the Arctic Ice Sheet e domes of the Arctic Ice Sheet. Moreover, ice shelves floating over deep basins in the Arctic Ocean, Baffin Bay, and the Labrador, Greenland, and Norwegian Seas connected and drained the ice domes. Therefore, the Arctic Ice Sheet behaved as a single dynamic system, as does the Antarctic Ice Sheet today. The main difference is that ice shelves float around the perimeter of the Antarctic Ice Sheet, not at its center, because a continent lies at the South Pole, whereas an ocean lies at the North Pole.

The circum-arctic continents allow an Arctic Ice Sheet to reach mid latitudes and to impound rivers that now flow into the Arctic. Therefore, large proglacial lakes formed in Siberia. East of Verkhoyansk Mountains, these lakes spilled over into the Sea of Okhotsk. West of the Verkhoyansk Mountains, the lakes spilled over into the Aral, Caspian, and Black Seas, which were linked by other spillways to the Mediterranean Sea. This transformed central Asia into a grassy steppe that was much different from the semi-arid desert that exists today.

It is in postulating marine ice domes that formed on the Arctic continental shelf of Siberia, transgress onto the Siberian Arctic coastal plain, and dammed Siberian rivers now flowing into the Arctic Ocean, thereby creating huge lakes that transformed central Asia from a semi-desert into a grassy steppe, that Grosswald's vision differs from the conventional view of Siberia during the last glacial maximum. In the conventional view, presented in Figure 2, the Arctic continental shelf and coastal plain of Siberia were tundra, glaciation was restricted to ice caps on the larger present-day Arctic islands, the Putorana and Anadyr Plateau, and Taimyr Peninsula of north central Siberia, and mountain glaciers in the highlands of northeastern Siberia. There were no large ice-dammed lakes, and Siberia was generally more arid than it is today.

Most of those holding the conventional view will concede that Grosswald's view of Siberian glaciation is supported by undated glacial geology that is probably of Quaternary age. Much of this glacial geology, in Siberia and elsewhere, lies far south of the limits that Grosswald assigns to the last glacial maximum in Figure 1. Therefore, the basic mystery for these Quaternary scientists is why does Siberian glaciation resemble versions of Figure 1 during some Quaternary glaciations and resemble Figure 2 during other Quaternary glaciations, including the last glacial maximum? Grosswald would reply that a version of Figure 1 exists during every maximum of Quaternary glaciations.

At the workshop, this debate was placed in the larger context of what controls climatic stability on our planet. On the one hand, Earth's climate can be viewed as being in fundamentally stable equilibrium. In this case, primary scientific interest concentrates on the maximum perturbations of climate within a system that is basically stable. These would be times when the slope of a climate versus time curve was zero. During the Quaternary, such times with a period of about 100,000 years were glaciations and interglaciations, whereas stadials and interstadials within glaciation cycles correlate with cycles of tilt and precession of Earth's rotation axis that repeat every 41,000 years and 19,000 to 23,000 years, respectively. This view of Earth's climate was the unstated assumption that drove worldwide field studies undertaken by CLIMAP) (Climate: Long-range Investigation, Mapping, And Prediction), as part of the 1970-1980 International Decade of Ocean Exploration.

The field data were used by CLIMAP scientists as input to computer models that simulated general atmospheric circulation during the last glacial maximum (18 ka BP) and the last interglacial maximum (125 ka BP). The investigations led to maps of global climates at these past times and a belief that future climatic changes could be predicted by computer models that calculated future insolation changes caused by known periodicities of Earth's axial tilt and precession.

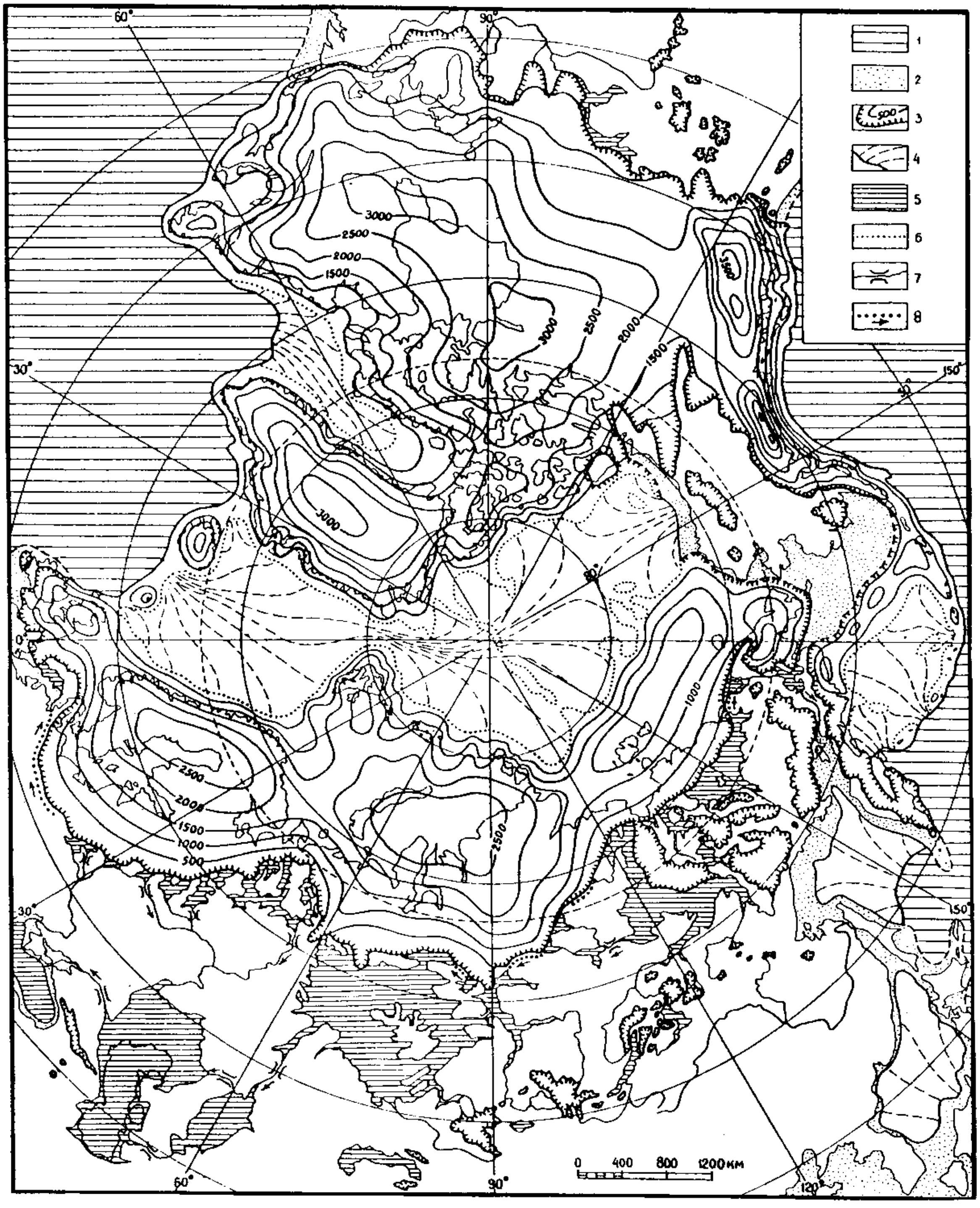

Fig. 1. Grosswald's view of the last glacial maximum in the Northern Hemisphere (Grosswald, 1988).
Polar ice sheets, mountain glaciers complexes and proglacier drainage system in the Northern Hemisphere during the height of the last glaciation, 17 to 21 thousand years ago (Model of 1988)
1 - glacier free ocean, 2 - emerged continental shelves, 3 - ice sheets, glacier complexses, 4 - floating ice shelves, 5 - ice dammed and other melt water lakes, 6 - grounding lines of the ice shelves, 7 - major spillways, 8 - pradolinas (Urstormtäler) and direction of water flow.

On the other hand, and in sharp contrast to the assumption that Earth's climate is fundamentally stable, is the assumption that Earth's climate is fundamentally unstable, always seeking but never finding stable equilibrium. If this view is correct, the parts of a climate versus time curve that are critical are not climatic maxima and minima when the slope of the curve is zero. Instead, it is the times when the slope is greatest; the greatest positive slopes coming out of a major glaciation or out of stadials within a glaciation, and the greatest negative slopes going into a major glaciation or into a stadial within a glaciation. These are times when Earth's climate is changing most rapidly and, therefore, are times when the fundamental instability of Earth's climate is manifested most drastically, and when the forces causing instability are most out-of-control. What is truly frightening about this view of Earth's climate is the possibility of a runaway climate that could transform Earth's environment into ones that exist on our neighboring planets, either the thin atmosphere and frigid surface of Mars or the thick atmosphere and torrid surface of Venus. Both extremes would render Earth uninhabitable. These fears are legitimate. Evidence of former river erosion is widespread on Mars, so once it had an atmosphere and climate more like ours.

In support of the view that Earth's climate is fundamentally unstable, high resolution of climate records from ocean-sediments and ice-sheet cores reveal irregular climatic fluctuations as drastic as major glaciations, but lasting only a few millenia and reversing within perhaps a decade. The timing and magnitude of these fluctuations are not predictable.

It is against this backdrop that Grosswald's view and the conventional view take on global significance. Grosswald's stability. Each cycle of global cooling produces a predictable cycle of Siberian glaciation. The conventional view is a better fit to the model of fundamental instability of Earth's climate. Any given cycle of global cooling, itself unpredictable, may or may not produce extensive glaciation in Arctic Siberia.

During the workshop, Alaskan glaciation was discussed as a possible analog to Siberian glaciation. Stephen Roof and Julie Brigham-Grette noted that Pleistocene glaciation in Alaska was greatest, even reaching present-day sea level in Kotzebue Sound, when the insolation gradient was greatest between the Equator and the North Pole, and the summer cooling rate at high latitudes was greatest. These are conditions of most rapid change, one with latitude and one with time, and they occurred during four of the seven major Pleistocene glaciations, but not during the last glacial maximum. These were expansion of mountain glaciers in Alaska, however, whereas Grosswald proposes glaciations by marine ice sheets that transgress from Arctic continental shelves onto Arctic coastal plains.

Grosswald's marine ice sheets should isostatically depress Arctic coastlines. Coastal erosion presently is rapid along the northwestern Alaskan shoreline, so that marine sequences ranging from 10 m to 60 m high are exposed in coastal cliffs and river banks, with the lowest believed to have formed during the last interglacial and the highest believed to be Pliocene in age. David Carter presented the conventional view that these marine exposures formed when partial or total collapse of present-day ice sheets caused global sea level to rise. Total collapse of the Greenland, West Antarctic, and East Antarctic Ice Sheets could raise sea level by 7, 6, and 60 m, respectively. Marine deposits at elevations in this range are found in New Guinea, New Zealand, on the US Atlantic coast, on Barbados, in England, and elsewhere, as well as along the northern and western coast of Alaska. David Hopkins noted, however, that the Alaskan marine exposures are not "bathtub rings" of uniform height for a given age, as would be required for globally rising sea level along stable coastlines. In addition, the stability of the Antarctic Ice Sheet is in dispute. A major school of thought, presented in Volume 75A of Geografiska Annaler (1993), makes the case that the East Antarctic Ice Sheet has been stable since the Pliocene. The opposing school argues for partial collapse of the East Antarctic Ice Sheet at times during this period. However, none of the Antarctic Quaternary geologists argue for a total collapse of East Antarctic ice that is needed to raise global sea level by 60 m.

This consensus among Antarctic field workers, the lack of a "bathtub ring" chronology along the Alaskan Arctic coastline, and the tectonic stability of this coastline since the Pliocene leave room for the possibility that marine ice sheets formed in the Chukchi Sea, and then advanced eastward onto the Alaskan coastal plain and southward into the Bering Sea, isostatically depressing the coastline such that postglacial isostatic rebound was responsible for at least some of the high marine deposits. Since the marine ice sheet would advance over permafrost in Alaska, little or no glacial geology would be produced and, in fact, none has been reported. Grosswald, however, argues that longitudinal and transverse lineations associated with oriented and beaded lakes on the Arctic coastal plain west of Point Barrow record marine ice-sheet transgressions in Arctic Alaska. He finds these lineations at isolated sites from the Lena River delta in Siberia to the Mackenzie River delta in Canada, and everywhere they are consistent with a marine ice sheet transgressing from the Arctic continental shelf onto the Arctic coastal plain.

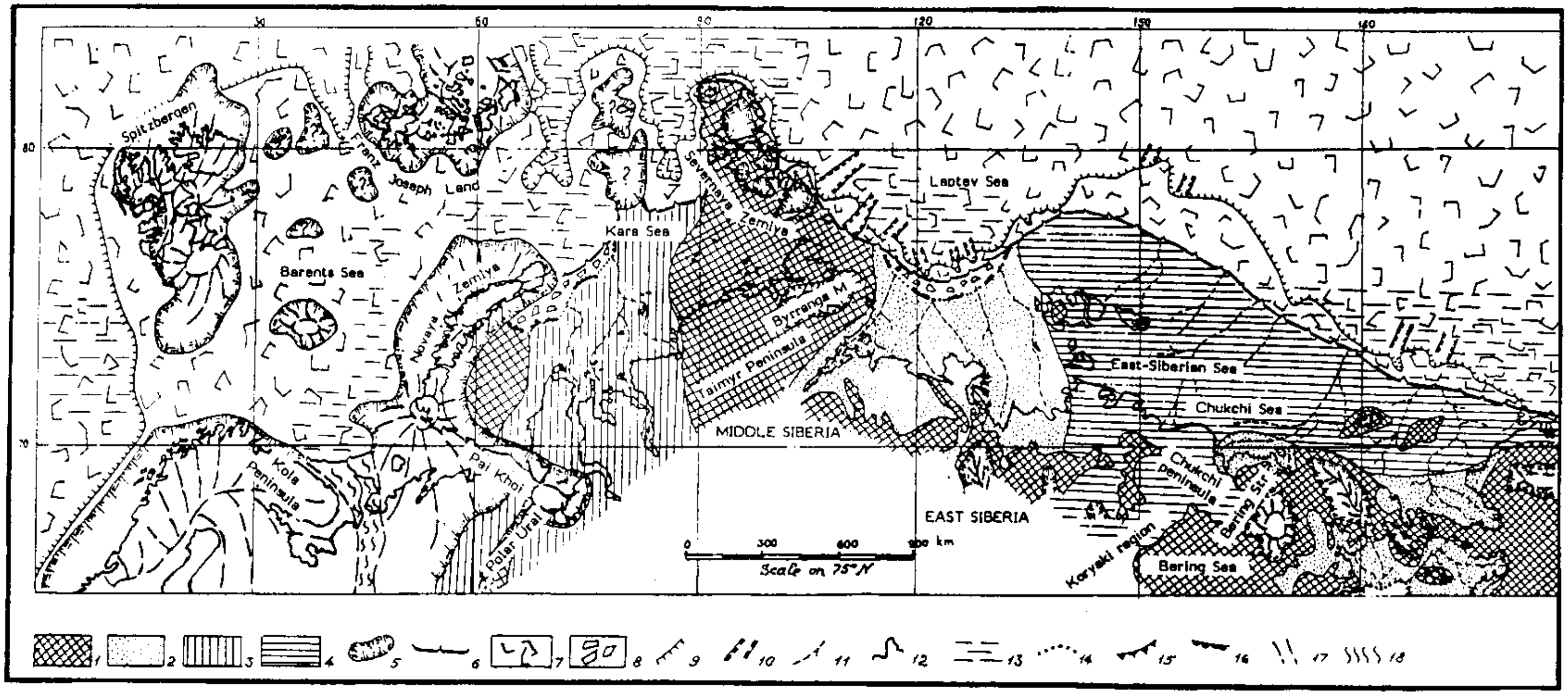

Fig. 2. The standard view of the last glacial maximum in Siberia (Biryukov and others, 1988).

Paleogeographic schematic map of the coast and shelf of North Eurasia during the last glaciation (18,000 yr B.P.)
1 - highlands, denudation plains, 2 - alluvial plains, 3 -alluvial-fluvioglacial-lacustrine plains, 4 - loess-ice plains, 5 -glaciers, 6 - margin of pack-ice, 7 - sea pack-ice, 8 - seasonal ice, 9 - shelf edge, 10 - submarine canyons, 11 - paleorivers, 12 - modern coast line, 13 - regions of intensiveunder-ice clay-sedimentation, 14 - accumulative shores, 15 - abrasion shores, 16 - thermoabrasian shores, 17 - boundary of aggradationof the neighbouring glaciers, 18 - zones of aggradation of glaciers.

Julia Brigham-Grette and Patricia Heiser noted that the snowline in Bering Strait at the last glacial maximum rose from Chukchi Peninsula in Siberia, across Saint Lawrence Island, to Seward Peninsula ion Alaska. This raised doubt that absence of extensive mountain glaciation in Alaska during the last glaciation in northeastern Siberia. This is important, because Grosswald believes that marine ice transgression was much more extensive in Siberia than in Alaska at the last glacial maximum, see Figure 1, and an advancing marine ice sheet should depress the snowline on mountain glaciers in the region.

Among Russian scientists at the workshop, Sergie Zuev pointed out that yedoma on the Siberian lowlands of the Yana, Indigirka, and Kolyma Rivers consists of a general stratigraphic sequence consisting of an upper 5 m of tundra 12,5000 years old at the base, overlying 21 m of yedoma formed from loess 27,400 years old at the base, overlying 21 m of lacustrine yedoma 39,000 years old at the base, overlying more yedoma formed from loess. In situ grass is found in the loess yedoma, along with extensive ice wedges and lenses. This stratigraphy would date Grosswald's ice-dammed lake in these lowlands, shown in Figure 1, at between 39,000 BP and 27,400 BP, about 10,000 years prior to the last glacial maximum. Victor Ivanov noted that he had personally walked along this entire coastline, and had investigated all the arctic islands in the East Siberian and Chukchi Seas. He said that raised marine beaches were common, but they were low, and perennial sea ice impinged on these shorelines throughout the Pleistocene, suppressing the wave action that forms beaches. This opens the possibility that a marine ice sheet could have existed in these seas during the last glacial maximum, it advanced over the Yana, Indigirka, Kolyma lowlands as a frozen-based ice sheet that did not impound large lakes because the environment was too dry, and beaches did not form during subsequent postglacial isostatic rebound because sea ice suppressed beach formation. Subsequent active cryogenic processes in the yedoma would have obscured or destroyed the limited glacial geology that was produced.

Grosswald deals with this paradox of a marine ice sheet that leaves little or no trace by postulating two types of coastal zones. A coastal zone of the Norwegian type, which includes Svalbard, is narrow and lies between the marine ice sheet and the open ocean. The coastal zone is strongly downwarped by the ice sheet, so every step of ice retreat is immediately recorded in marine shorelines in direct contact with the open sea, so contemporary marine fauna are deposited en masse on the shorelines. As a result, high flights of raised beaches are formed and yield clear radiocarbon ages. A coastal zone of the Siberian type, on the other hand, lies between the marine ice sheet and the mainland. The ice margin is minimally depressed, and may even be uplifted as asthenospheric rock is squeezed landward by the ice overburden. The open ocean cannot gain immediate access to the retreating ice margin. Therefore, beach formation is both subdued and delayed. If proglacial lakes exist, their outbursts will be sporadic as the retreating ice exposes different spillways. These constraints create extensive lacustrine terraces containing marine faunas that are recycles with each glaciation cycle, and perhaps during stadials within glaciation cycles. The purely marine terraces would be low and would contain fauna that were contemporary with the advent of seasonal sea ice, instead of the retreating marine ice sheets. Dating the recycled shells would lead to a spurious glacial chronology.

Grosswald's explanation accounts for dates of late glacial age on the Arctic islands and coastal mainland of Siberia, as well as the widespread marine deposits. As the marine ice sheet moved over preglacial marine sediments, they would be eroded, entrained, transported landward, and dumped in proglacial lakes or as glacial outwash, leaving a blanket of old-age fossil-rich sediments having marine geochemistry. These processes would be greatly attenuated if the bed was frozen. Grosswald's explanation also accounts for the high raised beaches, despite the absence of glacial geology, that formed during retreat of the marine Innuitian Ice Sheet over the Queen Elizabeth Islands of Arctic Canada. Being an island archipelago, the coastal zones were of the Norwegian type, so flights of raised beaches formed during deglaciation and had contemporary Holocene radiocarbon ages. Since thick permafrost blankets the Queen Elizabeth Islands today, however, the coastal zone was of the Siberian type in the sense of being a frozen bed which did not permit most of the processes that produce glacial geology.

The workshop began with a group discussion of these problems and concepts, and ended with discussion among individuals that dealt with specific geographic areas or specific processes. From all these discussions, an awareness emerged of the extreme complexity and vulnerability of the Siberian Arctic environment. This was demonstrated most dramatically in the discussion by Anatoly Lozhkin and Patricia Anderson of pollen records cored from diverse lakes in northeast Siberia. These cores revealed that stable early and late Wisconsin glacial environments were highly unstable during the mid Wisconsin, when the Siberian climate seemed to fluctuate wildly between glacial and interglacial extremes.

Many participants moved toward a consensus that the two views of Siberian glaciation, Grosswald's view and the standard view, must be resolved because of the implications each holds regarding the fundamental stability or instability of global climate. Arctic Siberia was seen as a natural laboratory within which Earth's climatic stability could be investigated at its most vulnerable exposure to numerous forcing mechanisms; notably, changes in insolation, snowline elevations, sea level, sea ice, and glaciosoistacy. Moreover, the Siberian history of climatic stability is accessible from the Pliocene through the Quaternary.

The outlines of sustained field research to uncover this history were drawn. Investigations should include (1) a systematic gravity survey to detect evidence for a late-glacial marine ice sheet, in the absence of glacial geology and high marine raised beaches, (2) systematic coring through late Quaternary sediments in the Kara, Laptev, East Siberian, Chukchi, Beaufort, and Bering Seas to map and date any marine, glacial, lacustrine, fluvial, or eolian sequences, (3) systematic dating of landforms by combining AMS ^{14}C dating with surficial dating of cosmogenic nuclides to determine if and when glacial ice may have covered features such as exposed bedrock, glacial deposits, lacustrine terraces and deltas, raised marine beaches, and oriented lakes, and (4) systematic coring of lake sediments to determine pollen records of Quaternary climatic change. These investigations should be planned and conducted under the umbrella of a major new research initiative aimed at determining the fundamental stability or instability of Earth's climate.

ACKNOWLEDGEMENTS

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REFERENCES

Biryukov, V.Y., Faustova, M. A., Kaplin, P.A., Parlidis, Y. A., Romanova, E. A., and Velichko, A. A., 1988. The paleogeography of arctic shelf and coastal zone of Eurasia at the time of the last glaciation (18,000 B.P.). - Palaeogeogr., Palaeoclim., Palaeoecol. 68 (2-4): 117-126.

Grosswald, M.G., 1988. Antarctic-style ice sheet in the Northern Hemisphere: Toward the New global glacial theory. - Polar Geography and Geol. 12: 239-267.