FINAL REPORT

of the

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

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POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

(Convened at the USGS National Center on 12-13 November 1991)

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Rapporteurs: *Thomas A. Ager, ORG (BPS), Polar Environmental History*
Alan K. Cooper, OEMG (PMG), Polar Marine and Continental Geology and Geophysics
Bruce F. Molnia, OIG, Polar Geologic Processes, Hazards, and Environmental Indicators
Thomas S. Ahlbrandt, OEMG (BPG), Polar Energy and Mineral Resources

Division Participation: *Geologic*
National Mapping
Water Resources

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INTRODUCTION

In mid-August 1991, Gary W. Hill, Chief, Office of Energy and Marine Geology (OEMG), Geologic Division (GD), U.S. Geological Survey (USGS), suggested that a Polar Research Program Strategies (PRPS) Workshop be convened under OEMG auspices by mid-November 1991. The principal objective of the PRPS Workshop was to evaluate (1) extant OEMG programs and projects in the Arctic and Antarctic, (2) related and/or cooperative polar programs with other GD offices, USGS divisions, Department of the Interior (DOI) bureaus, other federal agencies, and outside institutions [United States (U.S.) and foreign], and (3) make a prioritized list of recommendations for an integrated bipolar regions research program as the basis for FY 1994 and future budget initiatives.

On 12-13 November 1991, 26 scientists (from an initial list of 46 invitees met at the USGS National Center, Reston, Virginia, to achieve a consensus on recommendations for an integrated bipolar regions research program. As the basis for the discussions, all invitees (attendees and non-attendees) were key scientific program/project, ongoing or proposed, within four primary topical areas: Polar Environmental History; Polar Geologic Processes, Hazards and Environmental Indicators; Polar Marine and Continental Geology and Geophysics; and Polar Energy and Mineral Resources. Each abstract included four criteria for evaluation by Workshop participants: 1. Scientific importance, 2. Program relevancy, 3. Societal benefits, and 4. National policy goals. Thirty-five abstracts are included in this Workshop report.

Five principal recommendations for action resulted from the Workshop and are presented in the following section. Also included in the report are synopses of Workshop topics, the four working group topical summaries and recommendations, a list of invitees and attendees, a selected bibliography, 35 abstracts, an "Integrated Bipolar Regions Research Program" document, and a draft Memorandum of Understanding between the U.S. Geological Survey and the National Science Foundation.

WORKSHOP RECOMMENDATIONS

The top recommendations, ranked in order of priority, represent a consensus achieved during a meeting of the Workshop Coordinator and the four topical rapporteurs (Environmental History; Geologic Processes, Hazards, and Environmental Indicators; Marine and Continental Geology and Geophysics; and Energy and Mineral Resources) at the conclusion of the Polar Research Program Strategies Workshop. The five Workshop leaders carefully evaluated each of the priorities recommended by each of the four topical working groups to arrive at the following five recommendations for action:

1. Geological and Geophysical Transects of Key Areas -

Geological and geophysical mapping along key transects of onshore and offshore areas in the Arctic and Antarctic are needed as the initial step to achieving a better understanding of the geological framework and paleoenvironment of the two polar regions. It is also imperative that a long-term program be developed for systematic regional geological, geophysical, and glaciological mapping of the Antarctic continent; such an effort would involve cooperation between all countries carrying out such work, but the USGS would provide the lead role. To map the coastal regions inland to the most southerly nunataks would require about 30 1:1,000,000-scale, 120 1:500,000-scale, or 500 1:250,000-scale maps. Data from technological advances such as Geological Long Range Inclined Asdic (GLORIA) sea-floor imaging, satellite and airborne remote sensing, and airborne radio-echo-sounding tied to the Global Positioning System will be used to prepare topographic, planimetric, various types of thematic, and satellite image maps. In the Arctic, the emphasis is on undiscovered petroleum and mineral resources. In the Antarctic, the emphasis is on geoscience research, with a special focus on paleoenvironmental and global environmental change and structure and evolution of the Antarctic lithosphere. Geological and geophysical research in the polar regions by USGS scientists will benefit significantly by international cooperation with other nations carrying out research in these regions. Bilateral and multilateral Memorandum of Understanding (MOU) should be prepared, whenever significant cooperative research is undertaken.

2. Onshore and Offshore Drilling to Provide Cores -

Implementation of deep, intermediate, and shallow ice-core drilling programs and the expedited development of a comprehensive sediment-drilling program in the continental margin (onshore and offshore) and polar ocean basins of the Arctic and Antarctic will provide the data needed to improve our knowledge of the geological and paleoenvironmental history and the fundamental geologic framework of the polar regions. Achieving a better understanding of the paleoenvironmental history of the Arctic Ocean and environs holds the key to global-environmental change during the past 40 million years.

3. Increase in Studies of the Cryosphere -

In cooperation with other DOI bureaus, federal agencies, and outside institutions (U.S. and foreign), systematically expand studies of volume, areal extent, and mass-balance investigations of representative glaciers in the Arctic; increase monitoring of ice sheets, ice caps, and ice fields in the Arctic and Antarctic; expand the permafrost-research effort, including paleothermometry, permafrost engineering, and areal distribution; hire an engineering geologist (permafrost); in association with National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center, establish a lake-ice/lake-level monitoring program in the Arctic; and expand research on methane concentrations in permafrost and on methane hydrates in the Arctic in cooperation with foreign institutions, a necessary series of actions to carrying out an effective program of scientific research in the cryosphere.

4. Full Implementation of Unique USGS Capabilities in the Analysis and Management of Large Geoscience datasets in Polar Regions -

The USGS should establish itself as the lead federal agency for the acquisition, analysis, archiving, and distribution of geoscience information in the polar regions by building on an-already-existing foundation [e.g., Antarctic rock-sample library, Scientific Committee on Antarctic Research (SCAR) Library, National (Glacier) Ice-Core Curatorial Facility, satellite image archive [Earth Resources Observation System (EROS) Data Center (EDC)], National Energy Research Seismic Library (NERSL) datasets (including an Antarctic CD-ROM, seismic data from the National Petroleum Reserve (NPRA) of Alaska on a CD-ROM, etc.), Seismic Data Library System (Antarctic), Arctic Environmental Data Directory, etc.].

5. Bi-Lateral MOU Between the USGS, the National Science Foundation, and other Agencies and Institutions (U.S. and Foreign) -

A Memorandum of Understanding (MOU) between the USGS and National Science Foundation (NSF) to facilitate cooperative studies in polar regions has the highest priority and should be agreed upon as soon as possible. Wherever possible, programs carried out in polar regions by the USGS should be done in cooperation/collaboration between other USGS divisions; DOI bureaus; federal, state, and local agencies; universities, industry, and domestic and foreign institutions.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP TOPICS

1. POLAR ENVIRONMENTAL HISTORY - Emphasis is on paleoclimatic studies in descending order of relevancy and priority (historic, Holocene, Quaternary, pre-Quaternary); includes "retrieval, analysis, and interpretation about terrestrial environments of the polar regions and the impact of the polar environment on global geosystems" (NSF, 1990); history as preserved in polar marine sediments, and "retrieval, analysis, and interpretation of the paleoenvironmental record preserved in ice cores from ice sheets, ice caps, ice fields, and smaller glaciers in polar regions" (NSF, 1990). RAPPORTEUR: Thomas A. Ager (ORG/BPS)

2. GEOLOGIC PROCESSES, HAZARDS, AND ENVIRONMENTAL INDICATORS - This eclectic topic includes studies of gas hydrates and offshore permafrost; analysis of temperature measurements in permafrost to detect past climates; areal distribution and thickness of land and subsea permafrost; studies of coastal and near-shore processes, including erosion, ice gouging, sediment transport by sea and glacier ice, and changes in ice-fronts and ice walls; seasonal and interannual changes in area and concentration of sea ice; explosive and effusive volcanic activity in polar regions (including emissions into the atmosphere of gases, aerosols, and particulates that can produce changes in climate and/or the ozone layer); geologic hazards, such as slope failure, glacier-outburst floods (jökulhlaups), volcanic eruptions, melting of permafrost, flooding resulting from breakup of ice dams, earthquakes, etc.; and response of glaciers to climate change, including the use of satellite (imaging and altimetric sensors) and airborne (radio-echosounding and altimetry) remote sensing techniques. RAPPORTEUR: Bruce F. Molnia (OIG)

3. MARINE AND CONTINENTAL GEOLOGY AND GEOPHYSICS - Research is directed at processes of glacial and marine sediment deposition on the continental shelf, slope, and deeper sea floor environment; characteristics of the seabed revealed through sidescan sonar imaging, high-resolution bathymetric mapping, and direct sampling; and the acquisition and analysis of geophysical data from the polar continental margins and adjacent sea floor to determine tectonic history and the effects of ice-sheet loading. This topic also includes determination of polar continental structure, evolution of the lithosphere, and tectonic history, including exploration and earthquake seismology, and magnetic and gravity data to locate plate boundaries to better understand their geodynamic importance, and the fundamental geologic framework of the polar regions. RAPPORTEUR: Alan K. Cooper (OEMG/PMG)

4. ENERGY AND MINERAL RESOURCES - The polar regions contain enormous potential and proven energy and mineral resources. The North Slope of Alaska is the source of nearly one-quarter of the Nation's daily oil production and is the area where an estimated one-quarter of the Nation's undiscovered oil resources and one-seventh of its undiscovered gas resources remain to be found. More than one-half of the region is federal land and it is critical for the USGS, which has more than a century of experience and research in polar regions, and the Department of Interior to understand the resources of these regions. Similarly, for mineral resources, world-class occurrences are found in both the Brooks Range in the Arctic as well as the unique complex of the Dufek Intrusion in the Antarctic which is on a scale comparable to South Africa's prolific Bushveld Complex. The single largest low sulfur and high BTU coal resource in the United States occurs on the North Slope of Alaska. For these reasons alone, energy and mineral resources are critical elements of any resource

strategy that the Nation might undertake, including unconventional resource such as gas hydrates which occur in abundance on the North Slope. Much research and assessment activity related to identification of these resources will be needed by the Nation.

TOPICAL SUMMARIES

POLAR ENVIRONMENTAL HISTORY WORKING GROUP:

Rapporteur: Thomas A. Ager (ORG/BPS), Working Group Members: L. David Carter (OMR/BAG), Elisabeth M. Brouwers (ORG/BPS), Joan J. Fitzpatrick (OEMG/BSP), and Raymond D. Watts (NMD/R-RGCR)

The polar regions characterized by environments that are highly sensitive to disturbance by natural events and human activities, including climate change. Yet many aspects of modern environmental conditions and how such environments respond to changes in polar regions are poorly understood. The USGS is actively involved in several international research efforts in the Arctic to improve our understanding of climate-environmental interactions on time scale of decades to millions of years. In 1992, a very important international research effort, the Nansen Arctic Drilling (NAD) Program, produced an initial science plan: "The Arctic Ocean Record: Key to Global Change." These efforts include studies aimed at reconstructing paleoclimates and paleoenvironments in onshore and offshore areas of Alaska during the Neogene and at glacier-ice-core investigations aimed at short-term, high-resolution climate records spanning several centuries or millennia. To achieve a better understanding of present-day polar climates, research emphasis is placed on studies of the historic, Holocene, Pleistocene, and pre-Quaternary record of environmental change in descending order of priority. Though greatest emphasis in on understanding environmental change in the Arctic during the late Cenozoic, studies are also needed of environmental change in Antarctica since the onset of glacierization.

With the recent establishment of the National Ice-Core Curatorial Facility (NICCF) at the Denver Federal Center, under joint management by the Geologic Division and the Institute for Arctic and Alpine Research (INSTAAR) at the University of Colorado, there is an unprecedented opportunity for scientific growth in ice-core research. At the present time, the Geologic Division of USGS has strong research capabilities in the analysis of physical properties, entrained gases, stable isotopes, and trace metals in glacier ice. Additional analytical capabilities which mostly remain unexploited include tephrochronology, downhole-logging techniques, and particulate analysis. The USGS could make major contributions in these topics with minor redirection and upgrade of existing in-house technological capabilities. Researchers within the USGS have been asked by the academic community to participate in active drilling programs such as the [second] Greenland Ice Sheet Project-II (GISP-II) and to become involved in future drilling programs in Antarctica on the McMurdo Dome and the West Antarctic Ice Sheet. Under NICCF, broad spectrum of scientists from the national and international community will be interacting soon with USGS scientists on a daily basis. Inquiries from the academic community about the possibility of sabbaticals, extended visits and cooperative research have already begun. The ability of USGS scientists to participate in these types of highly topical programs depends, to a large extent, on their ability to find a programmatic home within the Geologic Division.

RECOMMENDATIONS:

1. *An environmental/paleoenvironmental component to offshore and adjacent onshore drilling-and-coring efforts is needed. The component should be aimed at improving marine-terrestrial correlation by means of biostratigraphy, geochronology, stratigraphy, and sedimentology. These investigations will contribute to a better understanding of the Cenozoic history of climate change (including extended intervals of time when the Earth was warmer or colder than the present time), sea-level change,*

ecological change, and may contribute to the understanding of the chronology of some major tectonic events. Development of a detailed Cenozoic biostratigraphy will contribute to improved regional correlations and mapping of deposits onshore and offshore in and adjacent to Alaska, other Arctic areas, and Antarctica.

2. The USGS also needs to expand its research and analytical capabilities for glacier-ice-core studies in polar and sub-polar regions including Alaska, Antarctica, and Greenland), that have the following objectives: improved understanding of atmospheric compositional changes over time (including greenhouse gases, such as CO_2 and CH_4, volcanic tephra and aerosols, desert dust, etc.); reconstructing shifts in the tracks of low-pressure systems and in the position of the high-latitude jet stream that affects global climate (e.g., the Aleutian Low in the Bering Sea area), and changes in temperature and precipitation patterns in Alaska, Antarctica, and Greenland. These glacier-ice-core investigations will include expansion of USGS analytical capabilities in particulate analysis (including volcanic tephra), downhole-logging methods, and ice geophysics (e.g., ice-penetrating radar, other ground-based geophysical techniques, etc.). The Geologic Division and the Office of Energy and Marine Geology must take a leadership role in establishing a solid programmatic home for glacier-ice-core research.

These two recommendations are well suited to interdisciplinary cooperative research with other branches, offices, and divisions of the USGS, other DOI bureaus, other federal agencies, academic institutions, and foreign scientific institutions. DOI bureaus that are most likely to cooperate include Bureau of Land Management, Minerals Management Service, National Park Service, and perhaps U.S. Fish and Wildlife Service.

<u>POLAR GEOLOGIC PROCESSES, HAZARDS, AND ENVIRONMENTAL INDICATORS WORKING GROUP</u>: Rapporteur: Bruce F. Molnia (OIG). Working Group members: L. David Carter (OMR/BAG), Gary D. Clow (ORG/ASTRO), Jane G. Ferrigno (OEMG/AMG), Andrew G. Fountain (WRD/BRR), Baerbel K. Lucchitta (ORG/ASTRO), and Richard S. Williams, Jr. (OEMG/AMG)/

- The polar regions contain more that 99.7 percent of Earth's glacier ice, most of its permafrost, and all of its sea ice.

- At least 5 percent of all methane hydrate resides in the Arctic, with much of it underlying the Arctic ocean and its margins.

- Melting of the Antarctic ice sheet could raise sea level by more than 73 m; melting of the Greenland ice sheet could raise sea level by more than 6 m.

One of the most important outcomes of the research accomplished during the International Geophysical Year (1956-1957) was the realization of the absolute necessity for cooperation by many organizations to successfully carry out investigations in polar regions. The, USGS, other DOI bureaus, other Federal agencies, private enterprise academic, and other institutions, domestic and foreign, involved in polar-region research must work together.

The Working Group on Geological Processes, Hazards, and Environmental Indicators considered ongoing and proposed USGS activities in coastal processes, glaciers, hydrates, lake ice, permafrost and greenhouse gases, sea ice, river ice, and volcanic and tectonic processes, potential components for a cryosphere - surface processes component of an Integrated Bipolar Regions Research Program. The result of the Working Group's assessment is a ranked outline of research topics.

I. Cryosphere and Polar Processes
   A. Glaciers
      1. Monitoring of Alaskan and other North American glaciers
         a. Implement a strategy to monitor volume, area, and mass-balance of selected glaciers
         b. Correlate changes in area and volume of polar glaciers to variations in global sea level
      2. Monitoring of Antarctic and Greenland ice sheets
      3. Ice-sheet thermometry studies
      4. Division-wide consolidation and expansion of the USGS's Geologic Division glacial geology capability
      5. Hazards
         a. Glacier-outburst floods
         b. Icebergs
   B. Permafrost
      1. Paleothermometry
      2. Distribution (area and depth)
      3. Changes in areal distribution
      4. Engineering characteristics
   C. Lake ice
      1. Lake level changes
      2. Seasonal timing of the freeze-thaw cycle
   D. Sea ice
      1. Distribution and areal extent of sea ice and leads
      2. Climatic implications
   E. River ice
      1. Ice jams
      2. Seasonal duration
II. Methane and hydrate and other greenhouse gases
   A. Hydrates
   B. Active layer permafrost gases
   C. "Fossil" organic gases and materials
   D. Permafrost as a reservoir of methane and other greenhouse gases
III. Coastal Processes
   A. Sediment dispersal
   B. Mechanical erosion
   C. Thermal erosion
   D. Impacts on communities and archeological sites
IV. Volcanic and tectonic processes
   A. Volcanic effects
      1. Ease of lofting volcanic ejecta and emissions into the stratosphere because of lower tropopause in Arctic
      2. Albedo modification of snow, sea ice, and glaciers
      3. Depletion of ozone layer
      4. Volcanism beneath the West Antarctic ice sheet
   B. Tectonic effects
      1. Earthquake hazards
      2. Coastal uplift and downwarp
      3. Debris avalanches
      4. Giant landslide
      5. Active rifting beneath the West Antarctic ice sheet

RECOMMENDATIONS:

The U.S. Geological Survey needs to strengthen its existing cryosphere and polar processes research activities by:

1. Expanding its studies of glacier geometry (changes in volume and areal extent), glacier hydrology (mass-balance investigations) and monitoring of ice sheets, ice caps, ice field, and associated outlet glaciers.

2. Expanding its permafrost research effort, including paleothermometry, permafrost engineering and areal distribution, and the hiring of an engineering-oriented permafrost geologist. Increased permafrost research is also important, because permafrost may contain significant volumes of methane and other greenhouse gases, the release of which would contribute to global climate warming.

3. Developing a lake-ice/lake-level monitoring program.

4. Improving its capability to carry out onshore and offshore studies of methane hydrates.

There is considerable opportunity within the scope of these four recommendations to strengthen existing or initiate new cooperative programs with other USGS divisions, other DOI bureaus, other Federal agencies, and outside institutions (U.S. and foreign), especially with inter-agency funding through the U.S. Global Change Research Program. The USGS Water Resources Division and National Mapping Division, U.S. National Park Service, Bureau of Land Management, NASA, NSF, National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corp of Engineers, and many U.S. and foreign governmental and academic institutions have existing activities that are relevant to the recommendations.

POLAR MARINE AND CONTINENTAL GEOLOGY AND GEOPHYSICS WORKING GROUPS:

Rapporteur: Alan K. Cooper (OEMG/PMG). Working Group Members: John C. Behrendt (OEMG/AMG), Stephen L. Eittrem (OEMG/PMG), Jerry L. Mullins (NMD/PO-IA), and Uri tenBrink (OEMG/AMG)

The USGS currently conducts a wide range of geologic and geophysical investigations in the onshore and offshore areas of the Antarctic and Arctic. USGS polar research seeks to understand the geologic framework and evolution of the continents, continental margins and ocean basins and their interactions with the cryosphere (especially glaciers and sea ice). Much of this work is done cooperatively with government (principally NSF in the Antarctic and many agencies in the Arctic), academic, and foreign research groups because of the difficult and costly logistics of operating in polar regions. Cooperation at all levels is an essential to polar research because the different geopolitical regimes (e.g., Antarctic Treaty, national Exclusive Economic Zones (EEZ's), etc.) affect how, where, and what research can be done.

The review of current and needed (*) research, based on the panel's experiences and several national (NRC, NSF, etc.) and international (SCAR, IGBP, etc.) documents, indicated that some items relate to both polar regions but others are site-specific. The order of items listed below is arbitrary.

Both Polar Regions: research needed in both polar regions includes:

* -- Systematic regional geophysical surveys (including GLORIA swath mapping of the polar oceans) and syntheses;
* -- Shallow drilling of onshore and offshore areas

Antarctica: Current and needed research in the Antarctic include:

-- Geophysical surveys and geologic mapping (*) along transects in the West Antarctic Rift [Corridor Aerogeophysics Southeast Ross Transect Zone (CASERTZ), Antarctic Lithosphere (ANTALITH), Lithospheric Investigations of the Ross Sea Area (LIRA), German Antarctic Northern Victoria Land Expedition (GANOVEX), etc.];
-- Marine geophysical surveys and sea-floor coring of the Antarctic continental margin under Antarctic Offshore Acoustic Stratigraphy (ANTOSTRAT);
-- Seismic data library system (SDLS) for cooperative research;

-- NMD mapping, geodesy, and digital cartography (*) in support of geologic mapping and special NSF requirements;
* - Systematic geologic mapping and map compilations for Antarctic; including completion of 13 1:250,000-scale geologic maps of the southern part of the Antarctic Peninsula. Field mapping was completed during 1969 to 1977; 1:250,000-scale base maps can be compiled from Landsat TM images, so that the geologic maps can be completed as was done with USGS Map I-1763, for example.
-- Satellite remote sensing of glaciological changes, image-map production, etc.
-- Operation and maintenance (*) of Antarctic seismometers;
* - Systematic radio-echosounding, aeromagnetic, and aerogravity surveys and mapping of Antarctica;
* - Research on Antarctica's minerals and hydrocarbons, in accordance with the guidelines of the 1991 Antarctic Environmental Protocol.

Arctic: The 1991 Arctic National Research Council (NRC) report (Art Grantz, Chairman) gives a current assessment of the research needs in the Arctic. This report and the workshop abstracts were the principal sources used to identify the following site-specific research:

-- Geologic sampling and geophysical transects of the U.S. Arctic continental margin and Amerasia Basin;
* - Geologic compilations and mapping of the circum-Arctic region;
* - Geologic mapping and geophysical survey of the Aleutian Arc, Beringian margin, and abyssal basins of the Bering Sea;
* - Systematic aerogeophysical mapping of the Arctic Ocean;
-- Sediment dispersal studies (i.e., by ice and water)

RECOMMENDATIONS:

1. *In Antarctica, marine and over-ice geophysical investigations (e.g., seismic, aerogeophysics, heat flow) combined with geologic studies of the West Antarctic Rift and continental margins are essential to achieving a better understanding of the dynamic links between Antarctic tectonism (including active volcanism and rifting) and glacial processes acting during the past 40 Ma and their global effects (e.g., sea-level changes and paleoclimate). This research is important for global environmental change research.*

2. *In both polar regions, shallow drilling (tens to hundreds of meters) and coring are essential to better understand the evolution and paleoenvironments of the polar continents and adjacent ocean areas. The technology to do this drilling exists for many applications and locations; logistic and financial support are needed to obtain rock cores for a variety of scientific studies. The USGS should take a lead role with NSF in supporting polar shallow drilling.*

3. *In both polar regions, systematic GLORIA side-scan, "Sea-Beam"-type bathymetric, and geophysical mapping of the polar oceans is needed to understand the evolution and geomorphology of these basins and their effects on local hazards (e.g., landslides, volcanism, etc.) and global ocean circulation processes (e.g., origin and distribution of bottom and intermediate waters) that effect global ocean temperatures, climate, and the ocean biota. Such surveys should be done as soon as technologically feasible.*

4. *Regional geologic mapping and other thematic-map compilations and geophysical surveys of the polar regions are needed to better understand the evolution, structural framework, glacial history, and, for the Arctic, the economic resources of the land and continental margin areas. This research should be supported as a long-term continuing inter-*

divisional, inter-bureau, inter-agency, and outside organizations (domestic and foreign) cooperative effort. In Antarctica, a major effort should be made to prepare, as soon as possible, 1:250,000-scale Landsat TM image base maps to complete 13 quadrangles for which field mapping was completed 15 years ago at the base of the Antarctic Peninsula. Funding should be made available for the base maps and for salaries of the field geologists to do the compilation.

5. For polar research, the USGS is the agency best suited to handle data repository and synthesis studies for polar activities (e.g., seismic data library, ice-core facility (NICCP), NMD-proposed G.I.S. for Antarctic maps, proposed rock-sample and core library, SCAR library, including aerial photographs, geodetic control, satellite images, maps etc.), and to provide long-term continuity of technical expertise on systems such as over-ice seismic exploration polar shallow drilling, satellite remote sensing, aero-geophysical and marine surveys, and NMD digital cartography. The USGS should design its polar programs to capitalize on this long-standing expertise.

6. For all polar activities, an effort should be made to formalize interagency and intergovernmental agreements to solicit greater fiscal and logistical support for cooperative research studies. Because NSF-DPP is the principal support group for U.S. Antarctic activities, high priority should be given to preparing a cooperative agreement (Memorandum of Understanding) that addresses logistic and science support for tasks that are best handled by the USGS.

POLAR ENERGY AND MINERAL RESOURCES WORKING GROUP:

Rapporteur: Thomas S. Ahlbrandt (OEMG/BPG). Working Group Members: Arthur B. Ford (OMR/BAG), James N. McNeal (OMR), and Charles D. Masters (OEMG/BPG).

The Arctic regions represent perhaps the most important present and future domestic and international opportunities for discovery of new mineral-and-energy resources of critical national need. Three divisions of the USGS will integrate scientific studies of geology, geochemistry, hydrology, geophysics, and digital-mapping techniques to assess resource potential using state-of-the-art methods for statistical analysis and deposit modeling.

Results of the investigations will provide information required for environmental, resource, and land-management issues pertinent to many Federal agencies (DOE, BLM, MMS, USGS, USNPS, USFWS), the State of Alaska, and the Alaskan Native corporations. Realistic assessment of the potential impact of any economic and environmental changes related to resource development requires prior determination of physical, chemical, geological, and biologic environments (for example, gas hydrates are an important area of investigation for both global environmental change and resource analyses). The results of the studies will help establish priorities to support administrative and congressional mandates related to land use and land disposition in Alaska, including international boundary issues and trade negotiations.

USGS studies will involve international cooperation with other Arctic nations, such as in the work now underway (Branch of Alaska Geology) comparing Siberian and Alaskan metallogenic terranes. Industry involvement will be encouraged for data contributions. The U.S. Geological Survey's Branch of Petroleum Geology has a number of cooperative research efforts underway with the Russian Ministry of Geology (VNIGNI), including investigations on 10 energy-related topics ranging from estimating conventional hydrocarbon reserves to evaluating gas-hydrate production potential.

RECOMMENDATIONS:

The dominance of proven and undiscovered mineral and energy resources in polar regions combined with much of their occurrence on federal or Native lands make these valuable assets of utmost importance for research at the Department of Interior. Recognition of their significance is reflected in the Workshop giving highest priority to a series of transects as discussed on Page 4; "Recommendations of the Workshop". The impending Congressional legislation relative to Arctic National Wildlife Refuge (ANWR), the National Petroleum Reserve of Alaska, the high priority given to development of ANWR petroleum resources in President Bush's National Energy Strategy and the significance of mineral resources in both polar regions necessitates careful review of the potential and consequences of resource identification and environmental impact of their development (particularly for the Arctic). While many areas of research deserve investigation, based on resource potential and scientific uncertainty associated with some of these frontier topics, the highest priority studies are listed below.

Because of international treaty obligations relating to environmental considerations in the Antarctic, scientific studies of potential energy and mineral resources of the Antarctic were not directly addressed. If the USGS and DOI decide to carry out scientific research on Antarctic resources, that is clearly permitted by the 1991 Antarctic Environmental Protocol, a major policy decision will need to be made by both organizations. Scientific studies of unique geological features, such as the Dufek Massif (west of the Forrestal Range in the northern part of the Pensacola Mountains), the largest known layered intrusive on Earth, and potential source of platinum-group metals, chromium, copper, cobalt, and nickel, should not be precluded, however.

1. *Construction of a series of geologic and geophysical transects [similar to Trans-Alaska Crustal Transect (TACT)] across the Brooks Range and extending north as far as possible into the little known, ice-covered Arctic Basin, to establish the regional structural and stratigraphic framework. In cooperation with other nations, this transect approach should be extended to other Arctic regions as outlined in Element 2 of the Arctic National Wildlife Refuge (ANWR) Central Arctic Management Area (CAMA) initiative.*

2. *Petroleum resource assessment related to distribution, quality, and quantity of Triassic source rocks, in particular, for the Arctic Basin.*

3. *Refinement of deposit models for such ore bodies as the newly producing Red Dog zinc mine and Greens Creek properties, to aid in assessing the potential of similar deposits elsewhere.*

The studies of Arctic resources can largely be accomplished through increased funding of present line-item programs such as National Mineral Resources Assessment Program (NAMRAP), Development of Assessment Techniques (DAT), onshore oil and gas, world energy, coal, and Evolution of Sedimentary Basins (ESB), though other funds may be needed for the international phases of the research. Cooperative data sharing with industry and universities would be useful and funding or logistical support by other Federal agencies should actively be sought.

Oil, gas, coal, and a wide variety of other minerals are abundant in both polar regions of the Earth, and the exploration for and development of these resources have increased steadily during the past several decades. Industrial development will depend increasingly upon national need rather than market competitiveness, which leads to increased dependence on scientific knowledge. The USGS should play a key role in the development of the U.S. Arctic Research Policy.

LIST OF POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP PARTICIPANTS:
(**BOLD: ATTENDEES**; NON-BOLD: NON-ATTENDEES; *Rapporteurs; ** Observers):

Thomas A. Ager*	**GD/ORG/Paleontology and Stratigraphy - Lakewood, CO**
Thomas S. Ahlbrandt*	**GD/OEMG/Chief, Branch of Petroleum Geology - Lakewood, CO**
Peter W. Barnes	GD/OEMG/Pacific Marine Geology - Palo Alto, CA
John C. Behrendt	**GD/OEMG/Atlantic Marine Geology - Golden, CO**
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POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

U.S. Geological Survey National Center

Reston, Virginia

12-13 November 1991

ABSTRACTS

TOPICS:

Polar Environmental History

Polar Geologic Processes, Hazards, and Environmental Indicators

Polar Marine and Continental Geology and Geophysics

Polar Energy and Mineral Resources

POLAR ENVIRONMENTAL HISTORY

Cenozoic Terrestrial-Marine Paleoclimates of the Bering Sea-Chukchi Sea Region

Late Cenozoic Climate History of Alaska and Yukon

Late Pleistocene and Holocene Climates, Beaufort Sea

Late Cenozoic Arctic Climatic Change

Polar Shallow-Drilling Geologic-Research Program

Recent Climate History of Southeastern Alaska from High-Resolution Ice-Core Records

The Last Interglaciation in Alaska

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental History and Global Change

Title: **(Proposed) Cenozoic terrestrial-marine paleoclimates of the Bering Sea-Chukchi Sea Region**

Principal Investigators: (proposed by Thomas Ager, USGS, MS 919, Box 25046, Federal Center, Denver, Colorado 80225).

SCIENTIFIC IMPORTANCE: Understanding high latitude history of climate and oceanography is a key element needed to understand the dynamics of the modern global climate system. Climate changes tend to have the most dramatic effects on high latitude regions, and therefore the evidence for past changes in climates are most likely to be discernable in those regions. Yet our current understanding of late Cenozoic climate history and its effects on marine and terrestrial ecosystems and oceanography remains fragmentary. Much of the existing evidence from onshore sites in the arctic and subarctic are poorly dated, and therefore difficult to interpret in the context of climate change. The proposed project will seek to obtain by drilling and piston-coring long sediment cores from the Bering Sea and Chukchi Sea regions in areas where terrestrial and marine sediments are likely to be interfingered through millions of years of deposition. Analysis of such cores will permit the scientific community to improve dating of terrestrial deposits and permit improved integration of the terrestrial and marine records of paleoclimates, paleoceanography, and paleoecology. This will involve the participation of marine geologists and geophysicists, biostratigraphers, sedimentologists, and paleoclimatologists from government and academic institutions, and the project has excellent potential for international cooperation with scientists from the USSR, Japan, Canada, and perhaps other countries rimming the North Pacific. Potential drilling sites: Norton Sound, Kotzebue Sound.

PROGRAM RELEVANCY: Proposed project will contribute to the Earth Systems History, Paleoclimates component of the U. S. Global Change Program as outlined in recent publications by the Committee on Earth and Environmental Sciences. This project will contribute to the reconstruction of a long marine and terrestrial climate history of the North Pacific, Bering Sea, Chukchi Sea, and adjacent parts of the Arctic Ocean.

SOCIETAL BENEFITS: It is now widely recognized that there is an urgent need to understand the dynamics of the global climate system that sustains life on Earth. Understanding the history of climate change and its consequences in high latitudes is of particular importance because these regions contain large areas of sea ice, permafrost, large volumes of glacier ice, and highly sensitive ecosystems.

NATIONAL POLICY GOALS: Proposed project would contribute directly to the objectives of the Earth Systems History, Paleoclimates component of the U. S. Global Change Program.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental History and Global Change

Title: **Late Cenozoic climate history of Alaska and Yukon**

Principal Investigator(s): Thomas A. Ager, USGS (ORG/PAS), Mail Stop 919, Box 25046 Federal Center, Denver, CO 80225

SCIENTIFIC IMPORTANCE: Current concerns about possible global warming due to increases in "greenhouse" gases in the atmosphere are based in large part upon computer models (General Circulation Models, or GCM's) of global climate. The GCM's indicate that global warming will be most dramatic at high latitudes. The high latitude regions of our planet contain vast areas of sea ice, glacier ice, permafrost, and highly sensitive marine and terrestrial ecosystems. What are the likely consequences of significant climate warming at high latitudes on glaciers, permafrost, and sensitive arctic and subarctic ecosystems? Should we rely entirely on models to predict the consequences of anticipated warming in high latitude regions? The alternative is to examine the geologic record for evidence of past climate changes, especially past warming events, and examine the environmental consequences of those events. In comparison with temperate regions of the world, the history of climate change and its effects are poorly known in high latitude regions, so there is a geat need for such research. This project seeks to fill part of that need by carrying out an interdisciplinary cooperative research program aimed at examining evidence of climate change in Alaska and Yukon during the past ca. 16 million years.

PROGRAM RELEVANCY: The project "Late Cenozoic climates of Alaska and Yukon" is a cooperative project between the U. S. Geological Survey, the Geological Survey of Canada, and several other government agencies and academic institutions. At present, 21 scientists are involved in this research effort. The project contributes directly to the stated goals of the Federal Global Change Research Program of the U.S. and its counterpart program in Canada. The project contributes to the Earth Systems History component of the U.S. program, specifically addressing the need for late Cenozoic paleoclimate reconstructions. The project closely follows the objectives and priority recommendations of the National Academy of Sciences for the U. S. Global Change program.

SOCIETAL BENEFITS: Understanding the probable consequences of climate change on high latitudes contributes to societal issues of maintaining environmental quality, preservation of fragile ecosystems, provides guidance for policy makers responsible for management of Federal and State lands at high latitudes, and may contribute to understanding the dynamics of permafrost, glaciers, and ecosystems under unstable climatic conditions.

NATIONAL POLICY GOALS: Project contributes to national policy goals of the U.S. Global Change Research Program.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental History and Global Change

Proposed study: Late Pleistocene and Holocene climates, Beaufort Sea

Proposed by: Elisabeth Brouwers

SCIENTIFIC IMPORTANCE: The Arctic has been identified in global circulation models to potentially undergo the greatest temperature increase under a global warming scenario. Not well studied in the Arctic is a detailed history of late Pleistocene and Holocene climates, particularly the past 120 ka. Such a study could provide information not only on warming of the marine and terrestrial systems, but adds the important parameter of sea ice, which profoundly affects temperature, circulation, and insolation. Some offshore cores exist, which have not been taken in a systematic manner, and limited outcrop sections are available. The scattered cores analyzed from Prudhoe Bay and from the Beaufort continental slope suggest a complicated sedimentologic and oceanographic history. To date, interpretations are based on seismic records for the late Quaternary of the Beaufort shelf. Additional cores should be taken offshore, in the middle-outer shelf and upper slope, as weather and ship conditions permit, and these records should be integrated with information available from the Geological Survey of Canada, the USSR, the USGS program in the Chukchi offshore, and onshore studies of terrestrial systems being conducted by the a number of academic institutions.

PROGRAM RELEVANCY: Understanding paleoclimatic conditions of the Arctic from the onset of a significant warming period and back into a glacial cycle is important to modeling of climate systems in high latitude regions.

SOCIETAL BENEFITS: The ability to evaluate the effects of warming in terms of ice retreat, migration of animals, and changes in shallow water oceanographic conditions is important both to residents of high latitudes and to subsequent effects at lower latitudes. The Holocene record will additionally provide a biologic component to the baseline data of the continental margin, which would be useful in the pursuit of future energy programs, especially in ANWR.

NATIONAL POLICY GOALS: The proposed program would contribute to the Paleoclimate component of the Global Change Program.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental History and Global Change

Title: **Late Cenozoic Arctic Climatic Change**

Principal Investigator: L. David Carter, USGS (OMR/BAG), 4200 University Drive, Anchorage, Alaska 99508-4667

SCIENTIFIC IMPORTANCE: This research will define the details of climatic change in the Alaskan Arctic during the last interglacial-glacial-interglacial cycle (the last 125 ka), and determine the response of sea ice, permafrost, and the landscape to these changes. Prior to 80 ka the geologic record is discontinuous and consists of marine sediments formed during eustatic high sea-levels that occurred when caloric summer insolation at high northern latitudes was greater than it is during modern summers. Research on these sediments is aimed at determining summer sea-ice conditions relative to those of the present, as possible analogs for sea ice conditions during future climatic warming, because sea ice is a key element in Arctic and global climate. For the period 80 ka to the present, the sedimentary record is nearly continuous and consists of loess, eolian sand, lacustrine deposits, and paleosols that are sensitive indicators of climatic change and its effects on permafrost and the landscape. Particular research emphasis is placed on the warm period that peaked about 10 ka as a possible analog for conditions that might occur during future climatic warming. Caloric summer insolation at this time at high northern latitudes was also greater than at present, and this warm period has a well-preserved geomorphic, cryogenic, sedimentological, paleontological, and geochemical record.

PROGRAM RELEVANCY: This ongoing project of the USGS Global Change and Climate History (GCCH) Program will link climatic change to physical processes at the Earth's surface in the climatically sensitive Arctic, which are goals of the Paleoclimate research element of the GCCH Program, and the Earth System History and Solid Earth Processes Elements of the National Global Change Research Plan (NGRCP). This research also will contribute to both elements of the Past Global Changes (PAGES) core project of the International Geosphere-Biosphere Program (IGBP). Studies of last-interglacial marine deposits on the Arctic Slope will contribute to the synoptic view of the last interglaciation in Alaska being developed by the GCCH Program project "The Last Interglaciation in Alaska" (T.D. Hamilton, OMR/BAG, Project Chief), and will thereby benefit Project CELIA (Climate and Environment of the Last Interglaciation in Arctic and Subarctic North America), a joint Canadian/U.S. investigation.

SOCIETAL BENEFITS: The effects of climatic change on sea ice, permafrost, and the landscape are important for national and international commerce, Arctic resource development, wildlife habitat, and the lifestyles of indigenous peoples. The ability to predict the magnitude of these effects would have significant economic benefit.

NATIONAL POLICY GOALS: This research addresses several goals and objectives of the United States Arctic Research Plan of the Interagency Arctic Research Policy Committee, and it is part of the U.S. Global Change Program, which is a Presidential Initiative.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental History and Global Change AND
Marine and Continental Geology and Geophysics

Title: Polar shallow-drilling geologic-research program (PROPOSED)

Principal Investigators: Alan Cooper, David Scholl, Art Grantz

SCIENTIFIC IMPORTANCE: Drilling data are perhaps the most highly sought research data from the Polar regions because, in conjunction with acoustic reflection records, they hold the detailed record of the Earth's paleoclimates, sea levels, glacial and ocean history, sedimentary processes, paleomagnetism, and many other critical factors for resolving the evolution of paleo-environments and major earth structures. Polar regions are of particular interest because the paleo-fluctuations of the cryosphere (which greatly affect global climate and ocean circulation processes) are recorded by the sediments and microfossils buried directly beneath present and past ice-covered areas. Shallow research-drilling (less than 500m), based on existing acoustic data from carefully selected areas, could reach both young and old Cenozoic strata that record Arctic (since 2.5 Ma) and Antarctic (since 40 Ma) glacial histories. Such records could a) establish the predicted linkages between polar northern and southern glaciations, and the likely reasons for these linkages and b) resolve the current debate about paleoclimates, ice-sheet sizes, and sea levels during Pliocene time in the Antarctic and Arctic. Drilling would further provide data on regional geologic problems.

Systematic geologic shallow-drilling (offshore and onshore) is proposed because a) it is critically needed by all disciplines; b) it is (or soon will be) technically feasible in many areas; c) it can be done from ship, remote sea-floor device, and from portable rigs onshore; d) it is environmentally and politically acceptable; e) it can be done at reasonable cost; and f) sufficient geophysical data exist to begin the program immediately.

PROGRAM RELEVANCY: The USGS should establish itself as the lead national agency for a polar geology shallow-drilling project. Such a program would interface with nearly all other national and international polar geoscience research programs because drilling is recognized by NRC and NSF reports as the only means to get in-situ "ground-truth" data to verify geoscience models and support predictions. Research drilling is also relevant to mineral resource assessments in the Arctic as noted in OTA report O-270 (1985).

SOCIETAL BENEFITS: Such systematic polar shallow-drilling would provide both short-term and long-term paleoenvironmental records to link circum-Arctic and circum-Antarctic ice-sheet histories with those of sea-level fluctuations, and global climatic changes, thereby conferring greater accuracy and public credibility to future climate and sea-level predictions and possible economic impacts.

NATIONAL POLICY GOALS: The U.S. Global Change program, which this project would benefit, is one of several Presidential Initiatives. The program is in accord with a) HR 2826, the Antarctic Protection Act and b) recommendations of the Antarctic Treaty for baseline studies.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental History and Global Change

Title: Recent Climate History of Southeastern Alaska from High-Resolution Ice Core Records

Principal Investigators: Joan Fitzpatrick / BSP / OEMG
Gary Landis / CMR / OMR
Todd Hinkley / IGP / OEVE
Robert Rye / BIG / ORG

SCIENTIFIC IMPORTANCE: Weather patterns propagating across Canada and the conterminous U.S. are dominated by the position and severity of the Aleutian Low. Current climate models and recent observational evidence indicate that the position and severity of the Aleutian Low may be strongly teleconnected with the status of the Southern Oscillation phenomenon, most especially during the northern hemisphere winter. This project seeks to recover a high-resolution, near-term climate record from polar glacier ice in southeastern Alaska for comparison with the SOI / ENSO record from the Quelccaya ice core in Peru, and to estimate the degree of correlation between these records and dendrochronologic, lake-varve, and instrumental records from southern Alaska, the western Yukon and the lower, conterminous U.S. In addition to the elucidation of the coherence between statistically significant weather phenomenon in North America and the state of the Southern Oscillation, the high-resolution record recovered from this core will extend the Northern Hemisphere geographic coverage of simultaneous climate events. Recovery of a climate record in southeastern Alaska covering the spans of time during which unusual or exceptional weather / climate phenomena are known to have ocurred throughout the Northern Atlantic and Europe (e.g. the anomalous period between 1310-1319 A.D. and the Little Ice Age) will help determine the extent and hemispheric significance of these events and provide constraints on Global Circulation Models.

PROGRAM RELEVANCY: This research is closely aligned with the objectives of the Earth Systems History, Paleoclimate component of the U. S. Global Change Program as outlined in recent publications the the Committee on Earth and Environmental Sciences and with the high-resolution paleoclimate reconstruction objectives of the USGS Global Change Program.

SOCIETAL BENEFITS: An understanding of the linkage between the Southern Oscillation and prevailing weather patterns over most of the conterminous U.S. is a highly desirable goal when the record of the consequences of past ENSO winters is examined. The El Ñino winter of 1982-1983 produced unprecedented devastation from unanticipated flooding in the southeastern U.S.. If such phenomenon can be anticipated from the observation of sea surface temperatures in the pacific equatorial region, and the mechanisms for teleconnection understood, such losses may be avoidable in the future.

NATIONAL POLICY GOAL: The proposed project contributes directly to the objectives of the Earth Systems History, Paleoclimate component of the U.S. Global Change Program.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Environmental history and Global Change

Title: **The last interglaciation in Alaska**

Principal Investigator: Thomas D. Hamilton, USGS, 4200 University Dr., Anchorage, AK 99508 (907)786-7451

SCIENTIFIC IMPORTANCE: This project attempts to provide a synoptic view of the climate, biota, and physical environment of the last interglacial maximum (marine oxygen-isotope substage 5e) in Alaska. This interval was the latest episode in earth history when global sea level and worldwide temperature were significantly higher than present; it can serve as an important predictive model for future effects of global warming.

The transition to isotope stage 5 from the preceding glaciation (marine oxygen-isotope stage 6) also is of extreme paleoclimatic interest because it was a major shift from extreme glacial climate to one of the warmest interglacial maxima known in the Pleistocene record.

High-latitude regions such as Alaska are of particular significance because of complex feedback effects involving snow, ice and permafrost. For example: (1) albedo changes resulting from decreasing surface areas of snow and ice could intensify global warming; (2) thaw of permafrost could have severe physical effects such as intensified retreat of coastlines; and (3) release of methane from thawing permafrost and desiccating peatlands could contribute to atmospheric loading of greenhouse gases.

PROGRAM RELEVANCY: This ongoing study is relevant to the USGS Global Change and Climate History Component 1.1, which emphasizes "climatic extremes and transition periods" and "intervals of rapid....environmental changes in response to climate change". It also is providing information that is of value to the Earth System History element of the U.S. Global Change Research Program, particularly question 1 (Natural ranges and rates of change) and question 2 (impact on ecosystems).

SOCIETAL BENEFITS: The last interglaciation can serve as a model for climatic and environmental effects of future global warming, and as such is of importance to land managers, economists, and other planners. Alaska is of particular significance because (1) global warming may occur earliest and be intensified in high-latitude regions and (2) thaw of permafrost could cause severe disruption to roads, pipelines, and other facilities.

NATIONAL POLICY GOALS: The Alaskan interglacial study is part of the U.S. Global Change Research Program, which is a major Presidential Initiative.

POLAR GEOLOGIC PROCESSES, HAZARDS, AND ENVIRONMENTAL INDICATORS

Arctic Coastal Erosion and the Interaction of Sea Ice, Permafrost, and Hydrates

Geologic and Climatologic Implications of Ice-Rafted Sediment in the Arctic

Influences of Active-Layer Boundary Conditions in the Correlation of Permafrost Temperatures with Air Temperatures

Arctic and Antarctic Sea-Ice Studies

Permafrost Temperatures and the Changing Climate

Relation Between Permafrost-Associated Gas Hydrates and Global Climate

GLORIA Side-Scan Surveys of Polar Basins

Permafrost Map of Alaska

West Antarctic Ice Sheet Studies

Permafrost and Gas Hydrates as Possible Sources of Methane

Antarctica: Glacier Velocity Measurements and Coastal Changes

Alaska Volcano Observatory (Alaskan Volcanic Hazards)

Inventory of North American Glaciers

Neotectonics and Earthquake Risk in Southern Alaska

Satellite Image Atlas of Glaciers of the World

Antarctic Coastal Changes and Glaciological Maps

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards and Environmental Indicators

Title: **Arctic Coastal erosion and the interaction of sea ice, permafrost and hydrates**

Principal Investigators: Peter W. Barnes, Keith Kvenvolden, Erk Reimnitz, USGS (OEMG/PMG), MS 999, 345 Middlefield Rd. Menlo Park, CA 94025-3591; David Carter, USGS (OMR,AG), Anchorage, AK

SCIENTIFIC IMPORTANCE: Climate models predict the greatest changes will occur in the Arctic. Manifestations of those changes will be amplified and perhaps accelerated at environmental boundaries like the coast. The extensive arctic coastline of low relief, with vast wetlands and deltas with permafrost and associated hydrates both on- and off-shore exposes fragile and sensitve physical and biological ecosystems to environmental change. Ecologically unique coastal tundra and pond environments may be inundated by the sea when narrow coastal barriers are overwashed. The geologic environments are ripe to record small changes in climatic signals of ice flux, temperature, fluvial discharge, and permafrost. Increased quantities of methane may be released by coastal transgression adding to the gas load in the atmosphere. Erosion along the Arctic Coast of Alaska is high (1-10m/yr) and waves and currents are insufficient to remove the eroded materials. The rates become extraordinary when we consider the coast is frozen for 8-10 months per year. Modeling experiments and atmosphere indicate that the warming in the polar regions will probably be three to five times greater than the global average. Such changes in the thermal and sea-ice regime are expected to impact the low lying coasts. Coastal monitoring and re-mapping reveals that several areas appear to be out of equilibrium with the present sediment transport regime. A map of coastal change in the Arctic National Wildlife Refuge (ANWR) is about to be released.

PROGRAM RELEVANCY: The National Coastal Program of the USGS calls for arctic coastal studies of erosion. The USGS Element of the US Global Change Program on Cold Region Research emphasizes studies observing, understanding and predicting changes in the crysosphere as a sensitive component to global warming. Coastal studies of sediment, permafrost and hydrate stability directly address these goals. A joint USGS/Canadian GS workshop held at the behest of the Chief Geologists recommended similar goals. The program also has relavancy to concerns of coastal archeologic site preservation and the National Park Service's International Beringia Peace Park.

SOCIETAL BENEFITS: Preservation of pristine habitats and archeological sites is a recognized societal goal. In light of existing and planned coastal petroleum activities in the Arctic the vulnerability and stability of coastal environments needs to be determined. In addition, permafrost degradation and methane release from hydrates are known factors influencing the interpretation and prediction of climate change.

NATIONAL POLICY GOALS: The U.S. Global Change Research Program is addressed by coastal change studies and observations of permafrost and hydrate stability. The President's policy of Protecting America's Wetlands is aided by our understanding of the processes leading to wetland loss in the coastal arctic. National Energy Plans is aided by our understanding of coastal stability and coastal processes in ANWR.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards and Environmental Indicators

Title: **Geologic and Climatologic Implications of Ice Rafted Sediment in the Arctic**

Principal Investigators: Peter W. Barnes, Erk Reimnitz, USGS (OEMG/PMG), MS 999, 345 Middlefield Rd. Menlo Park, CA 94025-3591

SCIENTIFIC IMPORTANCE: According to global models, the effect of global climate warming will be magnified in the Arctic. The signal carried in the sediments of the Arctic ice canopy, and found at the seabed of the Arctic Basin has the potential to help understand ice canopy melting and to record recent changes in the ice canopy environment. Understanding the modern character and rate of ice rafting is critical to unraveling this record in cores and in determining which sediments indicate an "ice-free" or "ice-covered" arctic. Sediment entrainment events on the shallow shelves around the margins of the basin introduce pulses of ice rafted sediment into the polar pack. Sediment budget considerations of arctic Alaska's inner shelf and coast calls on the action of ice to effect cross-shelf transport, although no data exist to confirm this. Mineralogy, chemistry, and biota of ice rafted sediments has the potential to indicate source areas, trajectories, and ages of ice floes in which they are rafted. In addition, the nature of ice rafted material is a reflection of the rate at which shelves process and release organic and inorganic particulate matter. While sediment laden ice is in transit the radiation balance of the ice canopy is effected by dark sediment accumulations on and in the ice which alters the light transmittance and albedo of sediment rich ice floes.

PROGRAM RELEVANCY: Ice rafted sediments have traditionally served as key high latitude data indicating changes in the physical environment and the response of the biosphere. These are goals of the Global Change Program. However, data on the present interglacia, ice rafted contribution to the sedimentary record is almost nil and understanding of the geologic record is compromised. In addition data obtained on ice born sediment provides information on ice sources and circulation which relates to ice canopy radiation balance, light transmission, and nutrient transfer from the shelves. Increased quantities of ice rafted sediment would reflect changing nearshore sea ice conditions and, in turn, lead to negative feedback processes for pack ice stability in the Arctic Basin be decreasing albedo. Project involves teaming with Eastern and Western European colleagues as well as with scientists in Geochemistry and Paleontology in the USGS and at U.S. Universities.

SOCIETAL BENEFITS: The linkage between variations in arctic sea ice cover and climate are strongly related to variation in albedo which is dependent on sediment content. Precursor changes in the arctic ice cover may be seen by deciphering the modern and Holocene ice rafted signal.

NATIONAL POLICY GOALS: The U.S. Global Change Research Program, NSF's Arctic System Science program would benefit from this program.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards and Environmental Indicators

Title: **Influences of active layer boundary conditions in the correlation of permafrost temperatures with air temperatures** (Proposed)

Principal Investigator: Max C. Brewer, US Geological Survey (OMR/BAG), 4200 University Drive, Anchorage, AK 99508-4667

SCIENTIFIC IMPORTANCE: Theory suggests that changes in the climate in Arctic areas could provide an early indication of global climatic change, particularly since the changes are postulated to be more pronounced at the high latitudes. Additionally, the permafrost found there provides an ideal medium for preservation of the historical record of climatic change because the transfer of heat within the permafrost is almost entirely by conduction. From measurements obtained in Arctic Alaska, Lachenbruch and Brewer in 1959 and 1962, and more recently Lachenbruch and Marshall (1986), and Lachenbruch and others (1987) have noted an increase in temperatures of as much as 2 to 4^{o}C within the upper 100 m of permafrost during the past century. Some researchers have assumed that those data have tended to validate the proposition that the average annual air temperatures in the Arctic also have increased, without recognizing that the temperatures quoted applied only from the surface of the permafrost downward. The relevant discussions also carefully avoided the regulatory buffering effect of the overlying active layer that annually freezes and thaws. The average annual heat conducted through that active layer to the permafrost is affected by changes in other climatic parameters such as rainfall, evaporative cooling, snow cover, and soil moisture content and by changes in the ground surface cover at any given location.

PROGRAM RELEVANCY: This research is designed to meet the goals set forth in Element 2 (Cold Regions Research), Component 2.2 (Permafrost temperature monitoring and research) of the USGS Global Change and Climate History (GCCH) Program. The use of approximately one-quarter million temperature measurements, obtained to depths of up to 30 m at approximately 100 locations through the active layer and into the underlying "cold" (colder than -5^{o}C) permafrost in Arctic Alaska, should provide evidence concerning the relative impacts of changes in climatic parameters, other than air, on the permafrost temperatures. The measurements were obtained on a year-round schedule between 1949 and 1961. The evidence also could be of importance in better explaining the non-correlation between the increasing average annual carbon dioxide measurements and the absence of any increase in the average annual air temperatures at Barrow, Alaska (71^{o} 18'N). The carbon dioxide measurements there increased approximately 16 percent (302 to 350 ppm) from 1920 to 1990, yet there is no evidence of a corresponding general trend of air temperature warming, rather that there has been on average a cooling of about 0.3^{o}C during the past 30 years.

SOCIETAL BENEFITS: A number of the proposals to curb the production of greenhouse gases, particularly that of carbon dioxide because of a postulated direct connection with increasing air temperature, would result in major changes in existing lifestyles in the United States as well as cost many billions of dollars. Thus, the importance of determining if parameters other than increasing air temperatures could be responsible for the warming noted within the upper 100 m of the cold permafrost in Arctic Alaska during the past century.

NATIONAL POLICY: The U.S. Global change Research Program is one of several Presidential Initiatives.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: Arctic and Antarctic Sea Ice Studies

Principal Investigators: William J. Campbell and Edward G. Josberger, USGS, Ice and Climate Project (ICP), University of Puget Sound, Tacoma WA 98416

SCIENTIFIC IMPORTANCE: Sea Ice is a extremely dynamic and fundamental component of the climate system, it controls the exchange of heat, water vapor and momentum between the polar oceans and atmospheres. Variations in sea ice extent and concentration strongly affect the water resources of the United States and the world through the complex interactions that take place between the sea ice, atmosphere, and the ocean at time scales that range from days to decades and longer. Microwave satellite observations of sea ice provide the only way to obtain the polar-wide, synoptic observations necessary to understand this key climate component. The most dynamic sea ice region is the seasonal sea ice zone where the polar ice, water, and air masses collide and interact with the sub-polar air and water masses. In this region ICP is collaborating with the Nansen Environmental Research Center (NERSC) and the French Space Agency (CNES) in the Seasonal Ice Zone Experiment (SIZEX). This research program has been chosen by the European Space Agency (ESA) as part of the Geophysical Calibration and Validation Program for European Research Satellite-1 (ERS-1), the only ice/ocean experiment so honored. The primary goal of SIZEX is to understand the complicated atmosphere-ice-ocean interactions that take place in the Barents and Greenland Seas. A very successful SIZEX-89 expedition took place in February-March 1989, as an ERS-1 pre-launch experiment, in which ICP scientists played a key role in obtaining aircraft synthetic aperture radar (SAR) sea ice images and concurrent snow and sea ice characterizations . Once fully processed, the high-resolution (~5m), digital SAR ice images will be used to determine sea ice drift, ice type, and open water fraction to be used as input to and verification of regional coupled ice-ocean-atmosphere models. These aircraft SAR observations will provide the basis for the sea ice algorithm to be applied to the SAR on ERS-1. ICP scientists are also involved in the new French-American radar altimetry satellite, TOPEX, to be launched in 1992; observations from this satellite will provide surface winds and ocean wave conditions in the open ocean portion of the SIZ, two of the primary forcing functions in the SIZ. This information will be evaluated and then incorporated into SIZ models and Climate models. ICP, in close collaboration with NASA continues to analyze the decade-long satellite passive microwave record, identifying a significant decreasing trend in the extent of the Arctic sea ice that is not found in the Antarctic. In the central Arctic ocean, large regions of low ice concentrations, polynyas, have been observed. These regions will be further studied using the SAR on ERS-1.

PROGRAM RELEVANCY: The long-term satellite passive microwave observations of the global sea ice distributions have shown significant changes in one decade, and the continuing observation sea ice distributions will have greater importance as the record becomes longer. The additon of high-resolution SAR observations to these studies will allow more detailed

studies of the complex processes that take place in the Arctic and especially the SIZ. These studies involve a team of 25 university and government scientists from 6 nations.

SOCIETAL BENEFITS: A complete understanding of the processes that affect sea ice distributions will allow for the effects of sea ice to be accurately accounted for in global climate models, which will improve modelling efforts. Also, accurate synoptic sea ice observations can be used to verify GCM's and detect global environmental change.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Permafrost Temperatures and the Changing Climate**

Principal Investigator(s): Gary D. Clow (G-ORG/AST) and Arthur H. Lachenbruch (G-EVE/TTP), USGS, 345 Middlefield Road, Menlo Park, CA 94041

Scientific Importance: Atmospheric concentrations of important greenhouse gases (CO_2 and CH_4) began to increase significantly during the middle of the last century due to industrial activities and accelerated landuse changes. Analysis of the available meteorological records indicate that the average global surface temperature has indeed increased ~0.5℃ since 1870 A.D. However, it is currently unknown what fraction of the observed global warming is due to the anthropogenic greenhouse effect and how much is simply a "natural" recovery from previous cooler temperatures. In order to resolve this issue, the history of surface temperature changes in "key" climatic regions must be documented for the last several hundred years.

One of the most robust predictions of the global circulation models is that the anthropogenic greenhouse effect will be appreciably magnified in the polar regions. For a 2x-CO_2 scenario, the predicted mean-annual warming for the Arctic is ~4℃ and is ~7℃ for the Antarctic. If temperatures in the Arctic do increase 4-5℃ above current levels, the Arctic Ocean is predicted to become completely ice-free during the summer, affecting the meridional temperature gradients that drive weather systems in the northern hemisphere. In addition, the degradation of permafrost is expected to have profound effects on the regional hydrologic cycle, established ecosystems, and engineering structures (roads, buildings, pipelines, etc.). Both the reduction in regional snowcover and sea ice, and the release of methane from permafrost, can have global implications due to positive climate feedback mechanisms. Hence, the Arctic (and the Antarctic) are among the "key" regions whose recent climatic history must be documented in order to provide a context for the current global warming.

Unfortunately, meteorological records from the polar regions remained extremely sparse well into this century. Aggravating the problem, the limited meteorological data that do exist tend to be collected at sites that are dominated by local processes. However, information regarding changes in polar surface temperatures during the past several hundred years is still effectively stored at depth within permafrost and ice sheets in the form of subsurface temperature transients. Paleosurface temperatures reconstructed from precise measurement of these transients at regionally representative sites can: a) help provide data crucial to the interpretation of the current warming trend, and b) provide the baseline data needed to discern future effects of climatic change in the critical polar regions. In addition, paleotemperatures reconstructed directly from the subsurface temperature transients can be used to help calibrate paleotemperatures inferred from other methods, e.g. tree-rings and isotopic methods.

Program Relevancy: Reconstruction of surface temperature changes for the past several hundred years in areas of permafrost, and the continued monitoring of these changes, addresses one of the existing components of the USGS Global Change and Climate History (GCCH) Program and the Solid Earth Processes element of the National Global Change Research Plan (NGRCP).

Societal Benefits: If temperatures in the Arctic warm an additional 4-5℃, as predicted by the GCMs for a 2x-CO_2 scenario, the effects on the regional hydrologic cycle, wildlife habits, engineering structures, shipping, and the lifestyles of indigenous peoples, will be profound. In addition, the Arctic has the potential to affect global climate through snow/albedo feedback and the release of methane from degrading permafrost. The ability to discern the onset and magnitude of climatic changes in the polar regions is required to assess the consequences of certain industrial and landuse activities and what may be required to mitigate their effects. The combined effects of climatic change in the Arctic will potentially have a significant economic impact.

National Policy Goals: This research is part of the U.S. Global Change Research Program, which is a Presidential Initiative.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Relation Between Permafrost-Associated Gas Hydrates and Global Climate**

Principal Investigator(s): Timothy S. Collett, USGS (OEMG/BPG), Denver, CO 80225, and Keith A. Kvenvolden, USGS (OEMG/PMG), Menlo Park, CA 94025

SCIENTIFIC IMPORTANCE: Atmospheric methane, a potential greenhouse gas, is increasing at such a rate that the current concentrations (≈1.7 ppm) will probably double in the next 50 years. Analysis of gases trapped in ice cores indicates that the contemporary atmospheric methane concentrations and their rate of increase are unprecedented over the last 160,000 years. Numerous researchers have suggested that destabilized gas hydrates may be contributing to this build-up in atmospheric methane. Little is known about the geologic or geochemical nature of gas hydrates, even though they are known to occur in numerous arctic sedimentary basins. The Arctic is well endowed with gas hydrates because conditions for their occurrence are met in three distinct regions: 1) offshore in sediment of the outer continental margin; 2) onshore in areas of continuous permafrost; and 3) on the nearshore continental shelf, where relict permafrost has persisted since times of lower sea level when the present shelf was exposed to cold sub-aerial temperatures. Because gas hydrates occur close to the earth's surface in these three regions, they are affected by surficial changes in pressure and temperature; thus, destabilized gas hydrates may be sources of atmospheric methane. Under the present climate regime, the gas hydrates of the nearshore continental shelf may be the most vulnerable to change. Because of the abundance of available geologic data, our research has focused on assessing the distribution of gas hydrates within the onshore regions of northern Alaska. Our onshore gas hydrate studies are being used to develop geologic analogs for potential gas hydrate occurrences within unexplored areas, with a particular emphasis on the thermally unstable nearshore continental shelf.

PROGRAM RELEVANCY: Within the U.S. Global Change Research Program (USGCRP) planning document--*Our Changing Planet*, the Committee on Earth and Environmental Science (CEES) has identified gas hydrates as a potential source of greenhouse gas. The CEES included the Terrestrial and marine methane gas hydrate research program under the Solid Earth Processes science element in the FY-91 research plan. Our project has been designed around the FY-92 USGSGCRP science elements which dictates that the USGS will assess the importance of the Arctic as a source of greenhouse gases.

SOCIETAL BENEFITS: Gas hydrates have been recognized as an important high-latitude methane source. The process of permafrost warming and release of methane from destabilized hydrates may already be in progress. The amount of methane that may be released from destabilized hydrates is unknown. Knowledge pertaining to the distribution and stability of Arctic gas hydrates are necessary to assess the impact of destabilized methane hydrates on global climate change.

NATIONAL POLICY GOALS: As part of the U.S. Global Change Research Program this project is identified as an important contribution within several National Policy Initiatives.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators AND Marine and Continental Geology and Geophysics

Title: GLORIA side-scan surveys of polar basins (PROPOSED PROJECT)

Principal Investigators: Alan Cooper, Steve Eittreim, Mike Marlow, Dave Scholl, Art Grantz

SCIENTIFIC IMPORTANCE: GLORIA side scan sonar is a proven tool for areal mapping of sea-floor physiography and acoustic reflectance of the continental slopes, rises and abyssal basins. The geophysical data (i.e. gravity, magnetic, and seismic) collected during GLORIA mapping operations provide information on sub-surface structures to depths of many kilometers. Such mapping of the entire U.S. EEZ (except the Arctic Ocean) has provided detailed information on the geologic structure and potential hazards of the continental margin. GLORIA surveys of polar continental margins of the Arctic and Antarctic are needed to determine the effects of the cryosphere (ice-bergs, sea ice, grounded ice sheets, etc.) on the sedimentary and oceanograpic processes affecting the construction and destruction of the margins during glacial and interglacial times. Bathymetric features affect the distribution of cold and intermediate waters that control temperatures and geochemistry of the world's oceans. GLORIA surveys would further provide detailed information on geologic evolution of the polar basins and separation of adjacent land masses such as Gondwana. A GLORIA survey of the Antarctic Peninsula has verified that these surveys can safely be conducted in polar regions and will give detailed resolution of glacial and non-glacial features. The survey also demonstrated that short- and long-term effects of ice-related processes on the continental slope and abyssal basin can be seen in GLORIA data.

PROGRAM RELEVANCY: Relevance is with U.S. EEZ program to map the geology and hazards of U.S. continental margins and adjacent ocean basins and with ongoing USGS mapping of Antarctic offshore areas. Research is relevant to scientific goals of Scientific Committee on Antarctic Research, International Commission on Arctic Research, and the International Geosphere and Biosphere Program.

SOCIETAL BENEFITS: The linkage of the dynamic cryosphere to the development of physiographic features on the sea floor is needed to better assess hazards due to submarine slides, ice-erosion, etc. Bathymetric features that control ocean upwelling along the biologically productive polar margins would be mapped by GLORIA giving more accurate assessments of major ocean food-sources, especially in Antarctica. Protection of such food sources is of great concern to U.S. and International environmental groups.

NATIONAL POLICY GOALS: GLORIA surveys would be part of U.S. EEZ program. They would also fall under a) U.S. Antarctic Treaty participation to assist with baseline studies for protection of the Antarctic environment; b) Convention on Antarctic Living Resources; and c) U.S. participation in International Commission on Arctic Research and in Scientific Committee on Antarctic Research.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Permafrost Map of Alaska** (Proposed)

Principal Investigator: Oscar J. Ferrians, Jr., USGS (OMR/BAG), 4200 University Drive, Anchorage, Alaska 99508-4667.

SCIENTIFIC IMPORTANCE: The proposed permafrost map of Alaska, to be published at a scale of 1:2,500,000, will provide baseline data on the general distribution, thickness, and character of permafrost, and the distribution of permafrost-related landforms that are necessary to evaluate changes in the distribution and character of permafrost that would be caused by future changes in climate. Climate is the major factor that controls the regional (and global) distribution of permafrost. The climatic control is also reflected by the thickness of permafrost, which ranges from more than 630 m at Prudhoe Bay, in northern Alaska, to lenses less than a meter thick in the southernmost part of the permafrost region.

PROGRAM RELEVANCY: This research is designed to meet the goal of "Better documentation of the geographic extent and variation of permafrost areas" that is set forth in Element 2 (Cold Regions Research), Component 2.2 (Permafrost temperature monitoring and research) of the USGS Global Change and Climate Hisory (GCCH) Program.

SOCIETAL BENEFITS: Baseline data on the distribution, thickness, and character of permafrost is of enormous economic value because its presence or absence heavily impacts many human activities: the engineering and construction of facilities, surface transportation, the development of water supplies, sewage and solid waste disposal, the interpretation of seismic data, the production and transportation of oil and gas, and environmental disruption associated with any of these. Evaluating possible changes in the distribution and character of permafrost that would result from climatic change is equally significant. For example, the thawing of foundation materials in ice-rich permafrost due to climatic warming can cause roadways to become impassable, airstrips to become unusable, buildings to settle differentially and become unusable, buried hot oil pipelines to settle differentially with the risk of rupture, and buried cold natural gas lines to differentially heave, especially in areas of discontinuous permafrost. Furthermore, the presence of permafrost often controls the erosion that shapes sea coasts, influences the capture of streams, exacerbates the danger of flooding during heavy runoff, and causes the drainage of lakes that often provide the only water supplies avaliable.

NATIONAL POLICY GOALS: This research would address several goals and objectives of the United States Arctic Research Plan of the Interagency Arctic Research Policy Committee, and it would be a part of the U.S. Global Change Program, which is a Presidential Initiative.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards and Environmental Indicators

Title: West Antarctic Ice Sheet Studies

Principal Investigators: Steven M. Hodge, USGS, Ice and Climate Project (ICP), University of Puget Sound, Tacoma WA 98416

SCIENTIFIC IMPORTANCE: The West Antarctic Ice Sheet is considered to be marginally stable and should predictions of global climate warming be true, the ice sheet may catastrophically collapse. Should such a collapse occur sea level will rise dramatically. To understand the stability of the ice sheet requires detailed mapping of not only the ice elevation but also its bed topography. ICP, in collaboration with scientists from USGS-GD, Lamont-Doherty Geological Observatory, Ohio State University, and the Naval Research Laboratory, through a joint NSF-funded program will carry out an airborne mapping program of the West Antarctic Ice Sheet beginning in 1991 and continuing for at least 6 years. Using the Global Positioning System for navigation, a small aircraft will carry out penetrating ice radar observations, magnetometer and gravity meter measurements across the divide of the West Antarctic Ice Sheet, an area that may be tectonically active. The ice radar measurements combined with the precision navigation will give ice thickness and bed topography fundamental data for determining ice sheet stability as well as providing a baseline for thinning or thickening measurements.

PROGRAM RELEVANCY: Accurate measurements of ice thickness and bed topography are essential to understanding the stability of the West Antarctic Ice Sheet, even a small collapse would significantly impact sea level. In addition, these measurements will provide a baseline for ice sheet thinning or thickening determinations.

SOCIETAL BENEFITS: The stability and potential for a collapse of the West Antarctic Ice Sheet will greatly change sea level and have a profound impact on low lying coastal areas.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Permafrost and Gas Hydrate as Possible Sources of Methane**

Principal Investigator: Keith A. Kvenvolden, USGS (OEMG/PMG), MS 999, Menlo Park, CA 94025

SCIENTIFIC IMPORTANCE: Methane is the most abundant organic compound and one of the most important trace gases in the Earth's atmosphere. Methane exerts a strong influence on the chemistry of the troposphere and stratosphere; through its infrared absorption properties, methane is an important greenhouse gas affecting global climate. At present, atmospheric methane concentrations are increasing at an unprecedented rate of almost 1% each year, and the contemporary atmospheric concentration of about 1.7 ppmv exceeds any values observed during the past 160 ka of geologic time. Sources of this methane are still incompletely known, but permafrost and gas hydrates have been identified as possible high-latitude sources of methane. Permafrost and gas hydrates occur in two distinct, but related, high-latitude settings: (1) on shore, where permafrost is continuous and the zone of gas hydrate stability ranges in subsurface depth from about 180 to 1200 m, and (2) on the nearshore continental shelf, where relict permafrost and gas hydrates are associated. The nearshore continental shelf provides a test for the consequences of global warming on permafrost and gas hydrates because this shelf has undergone about a 10°C increase in temperature due to the transgression of the Arctic Ocean during the Holocene. Our studies attempt to quantitate the amount of methane in occurrences of permafrost and gas hydrates in Alaska in order to evaluate these substances as possible sources of atmospheric methane.

PROGRAM RELEVANCY: The Committee on Earth and Environmental Sciences of the Office of Science and Technology Policy has identified permafrost and gas hydrates as possible sources of atmospheric methane in the US Global Change Research Program planning report "Our Changing Planet". This report indicates needed research on methane in permafrost and/or gas hydrates under three interdisciplinary science elements--Solid Earth Processes, Climate and Hydrologic Systems, and Biogeochemical Dynamics. Also the United Nations Intergovernmental Panel on Climate Change has identified permafrost and gas hydrates as important high-latitude methane sources. Likewise, the National Research Council in "Opportunities and Priorities in Arctic Geosciences" lists gas hydrates and permafrost as high priority issues for research.

SOCIETAL BENEFITS: Planning by society for the consequences of future global climate changes requires a knowledge of the elements contributing to those changes. Although methane, because of its greenhouse-gas properties, has been identified as a possible contributor to global climate change, the sources of methane are still incompletely known. This project seeks to quantify methane in permafrost and gas hydrates in order to determine the role that these substances may play under future climate change scenarios.

NATIONAL POLICY GOALS: As part of the US Global Change Research Program, this project has been identified as an important National Policy issue.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: Antarctica: Glacier Velocity Measurements and Coastal Changes

Principal Investigators(s): Baerbel K. Lucchitta (ORG, Astrogeology) USGS, Flagstaff, AZ 86001; Jane G. Ferrigno, and R.S. Williams, Jr. (OEMG/AMG) USGS, Reston, VA 22092.

SCIENTIFIC IMPORTANCE: Antarctica plays a major role in the Earth's climate: the extent of the ice sheets and shelves affects the Earth's radiation budget and ocean circulation. In addition, global-climate models have shown that the effects of global-climate changes, including those of possible greenhouse warming, are amplified in the polar regions. The recent calving of gigantic icebergs off the Ross and Filchner-Ronne ice shelves, as well as the rapid disappearance of the Wordie Ice Shelf on the Antarctic Peninsula, may indicate that ice shelves are disintegrating rapidly. Melting of the marine West Antarctic ice sheet alone would cause a sea-level rise of as much as 3 to 5 m, a rise that would severely impact the densely populated coastal regions of the Earth. Theoretically, the West Antarctic ice sheet could disintegrate within the next 100 years.

In spite of the possible grave consequences of such ice-sheet disintegration, the mass balance (the net gain or loss) of the Anatarctic ice sheets is poorly known . Indeed, we are not yet certain whether the ice sheets are growing or shrinking. Because of the difficult logistic problems in Antarctica, field research has focused on only a few major ice streams and outlet glaciers. Yet, to fully understand the ice-sheet dynamics, we must carefully document all the coastal changes associated with the advance and retreat of ice shelves and outlet glaciers. Our study attempts such documentation.

An integral part of ice sheets is the velocity field, which allows the determination of discharge rates. Remote sensing, using moderate-resolution satellite images such as Landsat and ERS-1 SAR, offers a unique opportunity to measure the velocity of all floating ice quickly and inexpensively by tracing crevasse patterns on shelves and ice tongues. In such a method, time-lapse measurements are made on sequential images covering the same scene. Laser altimeters, to be deployed on the Earth Observing System (EOS) platforms of NASA, will eventually yield the third dimension needed to calculate discharge volumes and an accurate mass balance. However, our present research already permits us to monitor coastline changes and thus contribute to an understanding of global climate change and its consequences for man and the natural environment.

PROGRAM RELEVANCY: The monitoring of coastal changes and velocity fields of the Antarctic ice sheets and outlet glaciers is essential to an understanding of the mass balance of the ice sheets and the interaction between the cryosphere, the atmosphere, and the oceans. Without such monitoring and the resulting input of pertinent data into global-climate models, predictions will be at best incomplete. Such predictions concern atmospheric and oceanic circulation, greenhouse warming, and sea-level changes. Therefore, the behavior of the

Antarctic ice sheets, particularly of the ice-edge zone, was given a high research priority in several published recommendations by the Polar Research Board of the National Academy of Sciences (1983, 1985, 1986, 1989). The study of ocean-atmosphere-cryosphere interactions also has a high priority in the report "A U.S. Strategy for Global-Change Research" by the Committee on Earth Sciences of the White House Office of Science Technology Policy (OSTP) for the budgets of fiscal years 1990 through 1992. "Glacier Monitoring" was also given a high score for programmatic relevance by a science advisory committee to the USGS Global Change Research Program (FY 1992). "The Antarctic Sea Ice Zone" and the "Mass Balance of the Antarctic Ice Sheet and Sea Level" are also core programs in "The Role of Antarctica and Global Change," an implementation strategy currently being drafted for the International Geosphere-Biosphere Programme (IGBP). The study of ice-sheet dynamics and the use of remote sensing were highlighted in a report on "Antarctic Climate Research" by the Scientific Committee on Antarctic Research (SCAR), a division of the International Council of Scientific Unions (1983). An international consortium of SCAR nations is currently pooling their resources to acquire new Landsat images over the coastal regions of Antarctica that were first imaged in the early to middle 1970's. A Soviet-USA agreement is in place to exchange Soyuzkarta and Landsat data to facilitate remote-sensing research of Antarctica. The European Space Agency (ESA) has agreed to Furnish ERS-1 SAR images over Antarctic coastal areas for research that focuses on coastal-change measurements. All these national and international agencies realize the importance of Antarctic coastal-change monitoring for global change assessment. The present research is done in cooperation with NMD and ISD of the USGS.

SOCIETAL BENEFITS: The causes of sea-level changes are poorly understood, yet it is known that during past glaciations sea level has varied by as much as 100 m. The current documented warming of the atmosphere, most likely due to emissions of anthropogenic CO_2 and other gasses, may eventually lead to the melting of the fragile marine West Antarctic ice sheet. We know that such melting would result in a sea-level rise that would profoundly impact the densely populated coastal regions of the world. Severe economic and societal stress and a potentially great loss of life would be the result. Therefore, a better understanding of the linkage between the ice sheets and sea-level change is of utmost importance.

NATIONAL POLICY GOALS: The Antarctic Research Program and the Global Change Program, of which the present study is a part, have been the subject of several Presidential initiatives and memoranda.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: Alaska Volcano Observatory (Alaskan Volcanic Hazards)

Principal Investigator(s): Thomas P. Miller, Scientist-In-Charge, Alaska Volcano Observatory, 4200 University Drive, Anchorage, AK 99508

SCIENTIFIC IMPORTANCE: The Aleutian arc-trench system extends over 3,000 km across the North Pacific and includes 65 Quaternary volcanic centers, 60 of which have been active in the Holocene and 42 of which have historic (within the past 200 years) activity. The volcanic centers, about equally divided between an oceanic island arc and a continental margin arc, average 1-2 eruptions per year and constitute one of the the world's most active subduction zone volcanic provinces. The high level of activity, the change from island arc to continental margin volcanism, the intersection of the Aleutian arc-trench system with the Kurile arc-trench system to the west and with the Queen Charlotte-Fairweather transform system to the east, and the high frequency of catastrophic caldera-forming eruptions (about 1/400 years through the Holocene) combine to present a wealth of scientific research opportunities in magmatic petrology, processes, and dynamics.
The Quaternary volcanic centers in the Wrangell Mountains represent additional scientific challenges recording sporadic Holocene activity along a seismically passive subduction zone.

PROGRAM RELEVANCY: I always have trouble associating Aleutian arc volcanism with Polar (i.e., Arctic) programs in spite of the arbitrary decision made to include the Aleutians in "the Arctic". Many Aleutian volcanoes are at the same latitude as Berlin and London (not usually thought of as Arctic) and even the northernmost Aleutian volcanoes are at the same latitude as Oslo and Stockholm. The Wrangell volcanoes might be thought of as sub-Arctic (in my opinion) but only the Late Quaternary extension-related basaltic volcanism of the Seward Peninsula and Interior are above or near the Arctic Circle.
If, in spite of the above, the definition of Polar in Alaska includes the Aleutians, then the program relevancy seems obvious.

SOCIETAL BENEFITS: The hazards presented by the above volcanoes are numerous, varied, and both regional and local. The recent 1989-90 eruption of Redoubt volcano caused an estimated $175,000,000 economic loss through damage to aircraft on trans-continental flights, disruption of

domestic and international air traffic and commerce, and oil production and shipment facilities. The KLM 747 that lost all four engines after encountering airborne ash was within one minute of impact when two engines were restarted. The maze of domestic and international flight routes that go over, around, and near the Aleutian volcanic arc and the distance airborne ash travels in a short time constitute a major hazard to life and property.

NATIONAL POLICY GOALS: The monitoring and research done by AVO on Alaskan volcanism are conducted within the Volcanic Hazards Progam of the U.S.G.S. with the goal of identifying, predicting, and mitigating hazards associated with active volcanism.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

TOPIC: Geologic Processes, Hazards, and Environmental Indicators

TITLE: INVENTORY OF NORTH AMERICAN GLACIERS

PRINCIPAL INVESTIGATOR: Bruce F. Molnia USGS (OIG),917 National Center, Reston, VA 22092

SCIENTIFIC IMPORTANCE: "Glaciers advance and retreat in response to subtle, persistent changes in climate. Thus, glaciers are indicators - perhaps the most sensitive in nature - of climate change" (Meier, 1986). The objective of this project is to systematically assess changes in the volume and aerial extent of 30 carefully selected glaciers, representing a north-south transect of North America, in order to determine whether North American glaciers show any discernible evidence of being influenced by changing climate or global change. Additionally, other factors, such as increases in iceberg production, outburst flood history and potential, and changes in seasonal discharge will also be observed. Glaciers to be studied occur in numerous climatic zones, ranging from sub-polar Arctic to temperate. These individual climatic zones range from coastal-maritime to interior desert. Studies are currently underway at Bering, Malaspina, and Mendenhall Glaciers. Iceberg production at the retreating Bering Glacier is being monitored to evaluate its potential impact on Alaskan petroleum tanker traffic.

PROGRAM RELEVANCY: The primary product of this study will be long-term assessments of changes in the aerial extent and volume of the glaciers of North America. This is critical information for a global change baseline. Specifically, studies of glaciers like the Bering, provide information on the potential for iceberg production, flood hazard, paleoclimate, and Neoglacial history.

SOCIETAL BENEFITS: Preventing oil spills, predicting glacial outburst floods, predicting long term impacts on water availability, and understanding how sea level change will affect coastal areas are important societal benefits.

NATIONAL POLICY GOALS: Results of this project are relevant to: environmental protection coupled with energy production (i.e. Bering Glacier), IDNDR, and the USGCRP Presidential Initiative.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Neotectonics and Earthquake Risk in Southern Alaska** (Proposed)

Principal Investigator: George Plafker, USGS (OMR/BAG), 345 Middlefield Road, Menlo Park, California 94025

SCIENTIFIC IMPORTANCE: The scientific objectives of this proposed project are to determine the relation of active faults and land-surface elevation changes to the tectonic framework of southern Alaska, and to integrate geologic, seismic, and ground-response observations and interpretations into a computer-based model designed to assess the seismic risk that exists at specific geologic environments in southern Alaska. These observations and interpretations include displacement history, recurrence interval, slip geometry, and slip-event displacement length of active faults; history, distribution of hypocenters, magnitude and energy release estimates, and seismic source characteristics of earthquakes; attenuation of seismic energy with distance from hypocenter for earthquakes at various depths in the crustal environment of southern Alaska; and ground response of various typical or critical substrates such as till, swamp, Bootlegger Cove Clay, slopes susceptible to landsliding, and snow cornices. With site-specific input, such a model would permit an improved estimate of risk at specific sites.

PROGRAM RELEVANCY: This project is designed to contribute to the Regional Earthquake Hazards Assessments element and the Current Tectonics and Earthquake Potential Studies element of the National Earthquake Hazards Reduction Program (NEHRP), which is authorized under the Earthquake Hazards Reduction Act of 1977. The USGS participates in this program with the National Science Foundation (NSF), the National Institute of Science and Technology (NIST), and the Federal Emergency Management Agency (FEMA), which has the lead role to plan and coordinate the national effort. The goal of NEHRP is to mitigate earthquake losses that can occur in many parts of the Nation by providing earth science data and assessments essential for warning of imminent damaging earthquakes.

SOCIETAL BENEFITS: Southern Alaska is a region with significant earthquake hazard and risk. Numerous active faults cut the surface, including the Castle Mountain, Denali, Totschunda, and Fairweather fault systems, and the region is underlain by the Aleutian subduction zone. The most severe historic earthquake in North America occurred in southern Alaska in 1964, and a great earthquake is expected in the "Yakataga seismic gap" sometime in the next 20 to 30 years. This region contains more than half the population of Alaska, concentrated mostly in the Anchorage area. It also contains a significant part of the Trans Alaska Pipeline System, which transports 20% of the U.S. domestic petroleum production, as well as shipping and storage facilities at the terminus of the pipeline.

NATIONAL POLICY GOALS: As part of the NEHRP, this project would contribute to achieving the national policy objective of providing earth science data and assessments essential for warning of imminent damaging earthquakes.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Satellite Image Atlas of Glaciers of the World**

Principal Investigator(s): Richard S. Williams, Jr., and Jane G. Ferrigno, USGS (OEMG/AMG), 914 National Center, Reston, VA 22092

SCIENTIFIC IMPORTANCE: Of all the expected impacts of the predicted global warming on the geosphere and biosphere, the one with the greatest potential economic disruption of human population is accelerated melting of glacier ice (net los of global glacier volume) and a concomitant rise in sea level. The cryosphere (glacier ice, floating (sea, river, and lake) ice, snow cover, and ground ice) is the most sensitive component of the geosphere to seasonal and longer term changes in global surface temperature. According to global circulation models, the effect of global climate warming will be magnified in the Arctic. During the past two decades satellite sensors have recorded interannual and long-term changes in the areal extent of sea ice, snow cover, and glaciers. Satellite sensing technology is the only practical way of continuing such regional and global measurement of area and other remotely derived changes in the cryosphere. The realization that one element of the Earth's cryosphere, its glaciers, was amenable to global inventorying and areal-change monitoring with Landsat images led to the decision, in 1978, to prepare an 11-volume (A-K) U.S. Geological Survey Professional Paper 1386, Satellite Image Atlas of Glaciers of the World, in which Landsat 1, 2, and 3 multispectral scanner (MSS) and Landsat 2 and 3 return beam vidicon (RBV) images are used to inventory the areal occurrence of glacier ice on our planet within the spacecraft's coverage (between about 82^0 north and south latitudes). Of the nine geographic area volumes, five are directed at glaciers in polar regions.

PROGRAM RELEVANCY: The establishment of a global baseline of the areal extent of glaciers is important for comparative analysis of changes that are occurring in glacierized regions (in response to climate warming. The research is an existing component of the nine-Federal agency U.S. Global Change Research Program that is coordinated by the Office of Science and Technology Policy through the Committee on Earth and Environmental Sciences. It is also relevant to the objectives of the International Geosphere-Biosphere Programme. The glacier atlas project involves a team of 54 scientists from 25 nations representing 42 institutions.

SOCIETAL BENEFITS: The linkage of variations in global glacier are (and volume) to changes in sea level could lead to a predictive method for calculating future changes in sea level. Changes in sea level can have a large economic impact on low-lying coastal areas and islands.

NATIONAL POLICY GOALS: The U.S. Global Change Research Program, of which the glacier atlas project is but a small part, is one of several Presidential Initiatives.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Geologic Processes, Hazards, and Environmental Indicators

Title: **Antarctic Coastal Changes and Glaciological Maps**

Principal Investigator(s): Richard S. Williams, Jr., and Jane G. Ferrigno, USGS (OEMG/AMG), 914 National Center, Reston, VA 22092; Charles Swithinbank, Cambridge, England, U.K.; and Baerbel K. Lucchitta, USGS (ORG/ASTRO), Flagstaff, AZ 86001

SCIENTIFIC IMPORTANCE: Of all the expected impacts of the predicted global warming on the geosphere and biosphere, the one with the greatest potential economic disruption of human population is accelerated melting of glacier ice (net loss of global glacier volume) and a concomitant rise in sea level. The cryosphere (glacier ice, floating (sea, river, and lake) ice, snow cover, and ground ice) is the most sensitive component of the geosphere to seasonal and longer term changes in global surface temperature. Antarctica contains the largest area (85.9 %) and volume (91.4 %) of glacier ice on Earth. During the past two decades satellite sensors have recorded interannual and long-term changes in the areal extent of sea ice, snow cover, and glaciers. Satellite sensing technology is the only practical way of continuing such regional and global measurement of area and other remotely derived changes in the cryosphere. Publication of Chapter B, Antarctica, of the Satellite Image Atlas of Glaciers of the World (USGS Professional Paper 1386-B) in 1986 provided the source material of Landsat 1, 2, and 3 multispectral scanner (MSS) and Landsat 2 and 3 return beam vidicon (RBV) images to compile a baseline inventory of the areal occurrence of glacier ice in Antarctica within the spacecraft's coverage (from the coast to about 82^0 south latitude). The continued acquisition of Landsat MSS and thematic mapper (TM) images of Antarctica has provided additional source material to monitor changes which have occurred in the coastal regions of Antarctica and compute velocity vectors on outlet glaciers and ice streams. The master set of Landsat images of Antarctica (1972-present) is being used to compile a set of 1:1,000,000-scale maps of the coastal areas to show: (1) changes in ice fronts (outlet glaciers, ice shelves, etc.) and (2) velocities of outlet glaciers.

PROGRAM RELEVANCY: A precise baseline of the areal extent of the Antarctic ice sheet is important for comparative analysis of changes that are occurring in Antarctica in response to climate warming. The research is an existing component of the nine-Federal agency U.S. Global Change Research Program that is coordinated by the Office of Science and Technology Policy through the Committee on Earth and Environmental Sciences. It is also relevant to the objectives of the International Geosphere-Biosphere Programme.

SOCIETAL BENEFITS: The linkage of variations in Antarctic glacier area (and volume) to changes in sea level could lead to a predictive method for calculating future sea level. Sea level changes can have a large economic impact on low-lying coastal areas and islands.

NATIONAL POLICY GOALS: The U.S. Global Change Research Program, of which the coastal changes and glaciological maps project is but a small part, is one of several Presidential Initiatives.

POLAR MARINE AND CONTINENTAL GEOLOGY AND GEOPHYSICS

Geophysical Investigations of the Cenozoic West Antarctic Rift System

Paleozoic Tectonics of the Circum-Arctic

Development of Modern Over-Ice Seismic Capabilities

Antarctic Offshore Acoustic Stratigraphy (ANTOSTRAT)

Antarctic Seismic Data Library System for Cooperative Research (SDLS)

Geologic Framework of the Antarctic Continental Margin (Ross Sea, Wilkes Land, and Prydz Bay Regions)

Geology, Resource Endowment, Geologic Hazards, and Human Prehistory of the Aleutian Arc

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: MARINE AND CONTINENTAL GEOLOGY AND GEOPHYSICS

Title: **Geophysical Investigations of the Cenozoic West Antarctic Rift System**

Principal Investigator(s): John C. Behrendt and Uri ten Brink, USGS (OEMG/AMG) 964 Federal Center, Denver, CO, 80225

SCIENTIFIC IMPORTANCE: It seems inescapable that Cenozoic glacial history in Antarctica is directly related to rifting, uplift of the Transantarctic mountains and the rift shoulder, and active volcanism, all since early Oligocene time. Possibly the waxing and waning of the Antarctic ice sheet, during this time, has been the result of climate forcing associated with episodic mountain uplift (possibly also including the subglacial Gamburtsev Mountains). Marine seismic surveys (vertical incidence and large offset) in conjunction with Alan Cooper (OEMG/PMG) and in cooperation with Germany and Italy have revealed rift basins (probably originating in late Cretaceous time but active also in late Cenozoic time), underlain by about 20-km-thick rift stage crust. Aerogeophysical surveys in conjunction with Steve Hodge of WRD (and in cooperation with U. of Texas, Columbia Univ. and Nav. Res. Lab.), over the Ross Ice Shelf and Byrd Subglacial basin areas in progress at present and for at least the next four years are defining the extent of rifted crust (suggested by existing gravity data) and late Cenozoic volcanism beneath the ice covered area. Seismic investigations on the ice sheet are in progress in cooperation with Univ. of Texas and New Zealand.

PROGRAM RELEVANCY: The relation of tectonic activity to global climate change is widely recognized as an important research topic. Partially as a result of this, these geophysical programs are presently being supported by the National Science Foundation.

SOCIETAL BENEFITS: The history of glacial change in Antarctica related to tectonic activity is relevant to sea level change and formation of Antarctic bottom water (related to global climate).

NATIONAL POLICY GOALS: These studied form part of the U.S. Antarctic Program response to the Scientific Committee for Antarctic Research (SCAR) high priority Antarctic research objectives.

POLAR RESEARCH STRATEGIES WORKSHOP

Topics: Marine and Continental Geology and Geophysics;
Energy and Mineral Resources

Title: **PALEOZOIC TECTONICS OF THE CIRCUM-ARCTIC (proposed research)**

Project Chief: Dwight Bradley and others to be selected

SCIENTIFIC IMPORTANCE: Most published investigations of Arctic tectonic evolution have focused upon the Mesozoic and Cenozoic history of the present ocean basin, particularly the problematic origin of its western part, the Canada Basin. Paleozoic rocks around the Arctic record several earlier, even more problematic episodes of continental separation, seafloor spreading, subduction, and finally, collision: (1) the Caledonian Orogeny of Norway, Sweden, East Greenland, and Svalbard; (2) the Ellesmerian Orogeny of North Greenland and Arctic Canada; and (3) the Uralian Orogeny of northern Russia and Novaya Zemlya. Plate motions also drove the subsidence of major post-collisional sedimentary basins such as the oil- and gas-bearing Sverdrup Basin of Arctic Canada. Although some of the Paleozoic sedimentary basins and orogenic belts are reasonably well understood in specific localities, most of these features are truncated at the rifted margins, and there is no adequate unifying plate-kinematic rationale for these events at the Circum-Arctic scale. In the case of Alaska's Brooks Range, we know quite a few parochial facts - there existed a lower Paleozoic carbonate platform, an east-derived Devonian clastic wedge, a middle Paleozoic orogeny, and a Carboniferous carbonate platform punctuated by extensional basins (one contains the world's largest zinc deposit) - but these facts have little broader context. Future proposed research also would help constrain the controversial pre-drift fit of Circum-Arctic continents, because Paleozoic tectonic elements are regional-scale geologic markers.

The proposed research would be an interdisciplinary, multinational, iterative effort that would include: (1) acquiring new geologic data (from Alaska and elsewhere), (2) development of alternative tectonic models through synthesis and sharing of new and existing data, and (3) testing of these models by acquiring more data. Research in Alaska would include, but would not be restricted to, detailed geologic mapping in key Paleozoic outcrop areas; stratigraphy; biogeography; structural analysis of Ellesmerian-deformed rocks; geochronology; provenance studies; and paleomagnetism. Comparable studies in the Soviet Far East, Arctic Canada, etc., would be crucial to the success of the project. In this regard it is important to note that an ongoing cooperative arrangement between Soviet and Canadian scientists (with minor USGS participation) is addressing lower Arctic Paleozoic biostratigraphy with considerable success. Computer-based plate reconstructions would be done in cooperation with the Paleogeographic Atlas project at University of Chicago.

PROGRAM RELEVANCY: The proposed initiative would help achieve the aims of three USGS programs: Oil and Gas Investigations, Evolution of Sedimentary Basins, and NAMRAP. The project is extremely broad in scope and would involve cooperation with mainly goverment scientists from the USSR and Canada, and possibly also Norway, Denmark, and Sweden.

SOCIETAL BENEFITS: A plate tectonic framework would provide a context for world-class ore deposits such as Red Dog and Polaris, and for giant hydrocarbon fields such as the Sverdrup Basin, and accordingly, would suggest exploration models for undiscovered resources.

NATIONAL POLICY GOALS: The proposed initiative would contribute toward an assessment of the oil, gas, and mineral endowment of the United States.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Marine and continental geology and geophysics

Title: Development of modern over-ice seismic capabilities

Principal Investigator: Uri ten Brink, USGS, BAMG, Quissett Campus,
Woods Hole, MA 02543.

SCIENTIFIC IMPORTANCE: Study of the Antarctic continental geology is akin to study of the world's oceans because exposed outcrops are few (only 2% aerially in Antarctica) and often not representative of the bulk of the geology. In fact, the ocean floor is more accessible for sampling than the bedrock under the ice. Thus, seismic reflection and refraction methods are the principal techniques for study of the Antarctic bedrock. Given the probable effect of Antarctic continental geology on long-term changes in glacial cover and ocean circulation and given the importance of Antarctic geology to Gondwana reconstruction and general geodynamic processes it is surprising that little effort has been devoted to the study of the ice-covered Antarctic continent since the International Geophysical Year. The U.S. Antarctic program is the only national program which can presently provide logistical support for seismic work in the remote interior of the continent. Progress has been made since 1988 in adapting modern seismic methods to the special Antarctic conditions. This includes the use of towed receiving array, experimentation with sound sources, the use of stand-alone receivers for refraction work, and the development of a rapid acquisition procedure. In addition the capability of over-ice traverse with large vehicles is being renewed after a hiatus of 25 years. and finally, the effect of the near surface velocity structure on the seismic record has now been better understood. The future goal of this effort should be the capability of acquiring 500-750 km long seismic profiles in a single Antarctic season. Only then can grid surveys be carried out on the continent, (similar to marine seismic surveys) which will allow a true three-dimensional documentation of the extent of glacial and pre-glacial sedimentation and erosion, of recent tectonic activity, and of the gross lithospheric structure.

PROGRAM RELEVANCY: Rapid over-ice seismic acquisition techniques can be modified for use in other environments such as sea-ice, snow covered areas, and sand dunes. The results of seismic studies in Antarctica will advance our understanding of diverse topics such as the structure of the continental lithosphere, evolution of sedimentary basins, and the relation of tectonic activity to global climate change. Geophysical study of East Antarctica may also enhance our understanding of the pre-Paleozoic North America geology, since Antarctica may have been adjacent to North America at that time.

SOCIETIAL BENEFITS: Seismic study of the ice covered Antarctica is possibly the last exploration frontier on earth. In addition, changes in climate, water circulation, and glacial cover are relevant societal issues.

NATIONAL POLICY GOALS: The development of over-ice seismic capabilities is in direct response to recommendations made by the National Research Council and by the Scientific Committee for Antarctic Research (SCAR) and is in accord with environmental requirements outlined in the Antarctic Treaty and the Antarctic World Park and Protection Act.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topics: Marine and Continental Geology and Geophysics AND
Geologic Processes, Hazards, and Environmental Indicators

Title: Antarctic Offshore Acoustic Stratigraphy project (ANTOSTRAT)
(CURRENT PROJECT)

Principal Investigators: Alan Cooper, Steve Eittreim, Guy Cochrane

SCIENTIFIC IMPORTANCE: The ANTOSTRAT project seeks to use all existing offshore acoustic and geologic sample data from the Antarctic continental margin to better understand the relationships between Cenozoic terrestrial and marine glacial-interglacial histories and between Cenozoic ice-volume and global sea-level variations. Although extensive data exist, ANTOSTRAT is the first major international effort, led by the USGS, to compile and integrate the data sets for cooperative research studies related to global and regional problems. The Antarctic continental shelf is underlain in many places by thick Cenozoic sedimentary sequences that have internal acoustic geometries and geologic sample characteristics that suggest that the sequences were deposited by massive ice sheets that were grounded to the continental shelf edge. The paleo-grounding lines are up to several hundred kilometers from the present ice-sheet edge indicating many episodes of growth and decay of the Antarctic Ice Sheet since Eocene time, but more actively since late Miocene time. Many factors control the movement of massive ice sheets and deposition of glacial sediments. ANTOSTRAT research is aimed at studying these factors by mapping, sampling, and deciphering the glacial sedimentary record of changes in the Antarctic ice sheet and relating the changes to global sea levels. USGS efforts are concentrated principally in the Ross Sea, Wilkes Land, and Prydz Bay regions. Since inception in June 1990, ANTOSTRAT has held three workshops leading to many national and international publications.

PROGRAM RELEVANCY: The establishment of circum-Antarctic history of glaciation and size of the Antarctic Ice sheet is important for comparative analysis with northern hemisphere glaciations and with global sea levels. The research is in accord with priorities established under a) the U.S. Global Change program, b) International Geosphere-Biosphere Programme, and c) Scientific Committee on Antarctic Research. The project currently involves 65 scientists from 18 countries representing 31 institutions.

SOCIETAL BENEFITS: The linkage of variations in global sea level (potentially 60-70m) to the Antarctic Ice Sheet could lead to predictive methods for determining future changes in sea level. Such changes would have a large economic impact on low-lying coastal areas and islands.

NATIONAL POLICY GOALS: The research is in accord with a) HR 2826, the Antarctic World Park and Protection Act; b) the U.S. signature to the Environmental Protocols for the Antarctic Treaty; and 3) the U.S. position regarding recommendations of the Scientific Committee on Antarctic Research.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Marine and Continental Geology and Geophysics

Title: Antarctic Seismic Data Library System for Cooperative Research (SDLS) (CURRENT PROJECT)

Principal Investigators: Alan Cooper, Steve Eittreim, Jon Childs

SCIENTIFIC IMPORTANCE: Seismic data are the principal tool for mapping and determining the detailed structure and evolution of the earth's crust. High-resolution seismic data additionally provide regional information on the geologic processes resulting from glaciations, global sea-level fluctuations, ocean water-mass circulations, etc. that have had a great impact on climates and sea-levels in coastal and other areas now inhabited by man. The SDLS was created under the leadership of the USGS and by the consensus of the 13 countries owning multichannel seismic data, to coordinate existing data and to conduct and plan cooperative international research related to man's global paleoenvironments and Antarctica's geologic framework. The SDLS will comprise seismic research centers worldwide where all Antarctic digital MCS data can be accessed on CD-ROMs and can be used for cooperative studies with the MCS data collectors. As such, the SDLS will encourage greater research use of seismic data than possible today for multidisciplinary studies. Currently, two SDLS branches are planned for the US, in Reston, VA at the SCAR library and in Menlo Park, CA at Pacific Marine Geology. Until October 1993, the USGS will underwrite and distribute the CD-ROMs that hold the digital MCS data; thereafter, the USGS will assist with CD-ROM production but costs will be shared among data collectors and library users.

PROGRAM RELEVANCY: The SDLS is based on procedures and technology developed by DOI-USGS work on seismic data bases from the U.S. onshore and offshore. SDLS branches will be located worldwide in support of international cooperative Antarctic research programs including those of NSF-DPP, NASA, NOAA, and other U.S. agencies. Presently, the SDLS has commitments for nearly 140,000 km of MCS data contributions from 19 organizations in 13 countries.

SOCIETAL BENEFITS: The SDLS will provide all U.S. Antarctic researchers with open access to costly seismic and other Antarctic acoustic data that are critical to research on long-term global sea level and climate changes, especially to our understanding the fluctuations of present environments.

NATIONAL POLICY GOALS: The project is in accord with HR 2826, the Antarctic World Park and Protection Act, and is mandated by Recommendation XVI of the Antarctic Treaty to which the U.S. is a consultative party.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Marine and Continental Geology and Geophysics

Title: Geologic Framework of the Antarctic Continental Margin (Ross Sea, Wilkes Land, and Prydz Bay regions) (CURRENT PROJECT)

Principal Investigators: Alan Cooper, John Behrendt, Steve Eittreim, Uri ten Brink

SCIENTIFIC IMPORTANCE: The Antarctic continental margins are underlain by major sedimentary basins that are found in several tectonic settings that include passive margins (around most of Antarctic), continental rift zones (West Antarctic Rift), active rifts (Bransfield Straits and western Ross Sea), and active margins (Northern Antarctic peninsula). Many of these basins had their origins with the early Mesozoic breakup of Gondwana, and have been filled largely with pre-glacial (i.e. pre Eocene) strata. The margins are draped with up to several kilometers of Oligocene and younger glacial strata. The evolution of the continental margins and associated rift systems has greatly affected the present shape and configuration of geologic and glaciologic features now observed around Antarctica. This project seeks to map and decipher characteristics and processes of the Antarctic lithosphere (e.g. crustal thickness, lithosphere strength, volcanism/magmatism, rifting, stratal geometry, etc) that can explain the observed geologic phenomena that partly control Antarctic glaciation (e.g. major rift and erosion features, crustal uplift areas, overdeepened continental shelves, etc.). The project uses existing geophysical and geologic data from USGS and international sources principally in the Ross Sea, Wilkes Land and Prydz Bay areas for these studies. Future cruises on USGS, NSF, and foreign research vessels are needed and will be proposed.

PROGRAM RELEVANCY: The DOI-USGS has long conducted Antarctic geologic framework studies dating back to the IGY. Two offshore geophysical cruises were conducted by the USGS in 1984. The work supports onshore and offshore geologic investigations by NSF-DPP, NOAA and NASA. Project research currently involves international cooperation with Germany, USSR, Italy, France and Australia.

SOCIETAL BENEFITS: Research on Antarctic geologic framework provides data on the short-term and long-term factors that affect ice-sheet development and stability. Changes in the Antarctic Ice sheet, which greatly affects global climates, ocean circulations, and global sea levels, could greatly affect man's environment and the ocean food chain.

NATIONAL POLICY GOALS: The research is in accord with a) HR 2826, the Antarctic World Park and Protection Act; b) two National Research Council reports on Antarctic earth sciences; and c) National Science Foundation reports on long-range plans and U.S. Global Change Research.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Marine and Continental Geology and Geophysics
(Also applicable to the other 3 topics.)

Title: **Geology, Resource Endowment, Geologic Hazards, and Human Prehistory of the Aleutian Arc** (Proposed)

Principal Investigator(s): Frederic H. Wilson, USGS (OMR-BAG), 4200 University Dr., Anchorage, AK 99508; Thomas P. Miller, USGS (OIGP-AVO), Tracy L. Vallier and Dave W. Scholl, USGS (OEMG-PMG), 345 Middlefield Road, MS 999, Menlo Park, CA 94025; Douglas Veltre, Univ. of Alaska-Anchorage, Dept. of Anthropology, 3211 Providence Dr., Anchorage, AK 99508

SCIENTIFIC IMPORTANCE: Although the 6,000-km-long Aleutian arc is the principal zone of interaction between the Pacific and North American plates, its western part is virtually unstudied and few studies have attempted multidisciplinary integration of research in its eastern part. As a geologic feature, the Aleutian arc is unusual in several respects. Its northeastern part is built on continental or transitional crust; its western part is built on oceanic crust and traps a block of old oceanic crust on its north side. Three tectonic regimes now comprise the arc; 1) continental-arc-type subduction in southern Alaska, 2) island-arc-type subduction along the Aleutian Islands, and 3) oblique subduction-transform motion along the western Aleutian and Kommandorski (USSR) Islands.

The arc is a seismic zone in which many of the world's largest ($M > 8.0$) earthquakes have occurred. Historically important tsunamis generated along the arc have resulted in significant loss of life and damage as far away as Hawaii. Active volcanoes in parts of the arc are close enough to urban and industrial areas and major transportation corridors to constitute a significant potential hazard. In addition, the presence of many volcanic centers suggests potential for geothermal energy resources. The Aleutian Islands are essentially unexplored for mineral and energy resources. Potentially important mineral deposit types that may be present include copper porphyry, epithermal precious metal vein, skarn, and polymetallic vein deposits.

PROGRAM RELEVANCY: This proposed initiative directly applicable to the Geothermal Research, Volcano Hazards, Global Change Research, and National Mineral Resource Assessment Programs.

SOCIETAL BENEFITS: The Aleutian arc, and in particular the Aleutian Islands segment is one of the least studied island arcs in the world. Though human population is low, vital military installations, important fishing ports, and Aleut villages can be harmed by seismic and volcanic hazards or aided by the geothermal energy potential. Knowledge of this regions energy and mineral endowment, and better understanding and instrumentation of seismic and volcanic hazards can have significant social and economic benefits.

NATIONAL POLICY GOALS: Reduction of loss of life, property, and natural resources from volcanic and seismic events and assessment of the nature of geothermal and mineral resources of the US are all national policy as outlined above.

POLAR ENERGY AND MINERAL RESOURCES

Central and Eastern North Slope of Alaska Initiative

North Slope Petroleum Potential

Resource Potential of Arctic Gas Hydrates

Investigation of Dufek Intrusion, Antarctica

Brooks Range Transects

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Energy and Mineral Resources

Title: **Central and Eastern North Slope of Alaska Initiative**

Author: Thomas S. Ahlbrandt, USGS (OEMG/BPG), Denver CO 80225

SCIENTIFIC IMPORTANCE: The ongoing Congressional debate concerning future petroleum development of the ANWR 1001 and 1002 areas designated in the 1980 ANICLA legislation emphasizes the national importance of Arctic research. The ANILCA bill required the Secretary of Interior to assess the resources in not only the 1002 area but in many regions of Alaska; however, only the 1002 area was assessed. The assessment of the 1002 area (also known as the Coastal Plain of ANWR) was conducted by the USGS in 1985, but since that time new data, concepts and requirements need to be considered (e.g. new wells drilled, water supply and gravel supply for exploration wells, waste disposal, and gas hydrate location). New thermal maturity and well data and revised tectonic models of the North Slope suggest greater resource potential than previously believed in the central North Slope area, and in the southern part of the National Petroleum Reserve of Alaska (NPRA). This interdivisional (GD, WRD, NMD) initiative would provide a unified USGS effort to consolidate new and needed digital, hydrologic and geologic information in high resource potential areas both in the nearshore marine and onshore areas in the southern 1001 and NPRA regions. Pending legislation to designate NPRA as a wilderness area or to permit exploration of the 1002 area would need such information to adequately update our seven year old understanding of environmental concerns and resource potential of these crucial Arctic regions.

PROGRAM RELEVANCY: It is not often that three divisions of the USGS agree on a workplan important dealing with an issue of such national significance. The proposed Arctic Information Management System would greatly facilitate archiving and retrieval of the new information gained in the crucial region. Knowledge provided by this initiative would be equally valuable to environmental and energy development groups.

SOCIETAL BENEFITS: The USGS estimates that between 4.8 and 29.4 billion barrels of oil in place exist in the 1002 area. This represents the single largest undiscovered hydrocarbon resource potential area in the U.S. Development of this resource represents opportunities for both environmental and energy organizations and would alleviate our ever increasing dependence on Middle East petroleum supplies which can be easily interrupted.

NATIONAL POLICY GOALS: This proposed initiative supports the primary goal of U.S. Department of Energy's recently released National Energy Strategy (NES). Bills supporting the NES are currently active in both the Senate and House. This resulting information to be gained through this effort will be critical to land managing agencies including the Bureau of Land Management, U. S. Fish and Wildlife and the National Park Service which do not have adequate internal research capabilities to address issues raised in this remote region as evidenced by the uproar over BLM's revision of economically recoverable resources in the 1002 area.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Energy and Mineral Resources

Title: North Slope Petroleum Potential

Principal investigators: K.J. Bird and D.G. Howell, USGS (OEMG/BPG), Menlo Park, Ca 94025

SCIENTIFIC IMPORTANCE: The North Slope of Alaska is the source of nearly one-quarter of the Nations's daily oil production and where an estimated one-quarter of the Nation's undiscovered oil resources and one-seventh of its undiscovered gas resources remain to be found. More than one-half of the region is federal land. The USGS has maintained a leadership role in earth science and resource information in northern Alaska throughout this century. Because of the Survey's experience and information base in northern Alaska, credible, well documented, and timely resource assessments have been produced on at least ten occasions over the last 15 years.

Most North Slope geologic information is in the public domain. This set of information constitutes the most extensive public geologic data base in the world, most of which resides at the USGS. This data set offers a multitude of opportunities for petroleum geologic studies of both topical and regional scope. In addition, new data are constantly being generated by active, ongoing investigations by the petroleum industry as well as State, Federal, and academic institutions.

The principal focus of our work is on the practically unexplored fold and thrust belt of the Brooks Range, the region with the greatest unrealized petroleum potential and large amounts of federal land. The strategy for North Slope work includes a series of geologic transects across the northern Brooks Range and foothills provinces. Transect work addresses questions about the quality, quantity, and distribution of reservoir and source-rocks and the timing of trap formation relative to generation and migration of oil and gas. Answers to these questions will have an important bearing on this region's petroleum potential and, therefore, on resource assessment and exploration strategies. Findings in this region are expected to be applicable to similar geologic settings elsewhere in the world.

PROGRAM RELEVANCY: This project is aligned with the Oil and Gas Investigations Program, the National Mineral Resources Assessment Program, and the Evolution of Sedimentary Basins Program.

SOCIETAL BENEFITS: Improved estimates of amounts of undiscovered oil and gas are critical in land use planning and national energy projections. Additional oil and gas discoveries on the North Slope and in other domestic basins that might result from our studies would reduce United States dependance on imported hydrocarbons; those discoveries made on federal lands would also provide increased revenue to the federal treasury.

NATIONAL POLICY GOALS: This project is aligned with the President's National Energy Strategy for reducing our dependency on imported energy.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Energy and Mineral Resources

Title: **Resource Potential of Arctic Gas Hydrates**

Principal Investigator(s): Timothy S. Collett, USGS (OEMG/BPG), Denver, CO 80225

SCIENTIFIC IMPORTANCE: Sediments of the Arctic region may contain enormous quantities of natural gas in the form of gas hydrates, which are crystalline substances composed of water and mostly methane. These ice-like substances are generally found in two distinct environments: (1) offshore, in sediment of outer continental margins and (2) in nearshore to onshore areas associated with the occurrence of permafrost. The potential amount of methane in gas hydrates is very large. However, estimates of the amount of gas within the hydrates of the world are highly speculative and range over about three orders of magnitude, from 1.1×10^5 to 2.7×10^8 trillion cubic feet of gas. The amount of gas in the hydrate reservoirs of the world greatly exceeds the volume of known conventional gas reserves.

The presence of gas hydrates in offshore continental margins have been inferred mainly from the occurrence of anomalous bottom-simulating reflectors (BSR) on marine seismic records. Within the sediments of the Arctic Ocean, BSR's have been mapped at sub-bottom depths ranging from ≈100 to ≈1,100 meters. Onshore in the Arctic gas hydrates are present in the western Siberian platform, the Timan-Pechora province, the eastern Siberian craton, and in the northeastern Siberian and Kamachatka areas of the Soviet Union. In the North American Arctic, well-log responses attributed to the presence of gas hydrates, have been obtained in about a fifth of the wells drilled in the Mackenzie Delta, and in the Arctic Islands over half of the wells are inferred to contain gas hydrates. In northern Alaska gas hydrates have been identified in 50 industry wells using well-log responses calibrated to an interval in a well where gas hydrates were recovered in a core. The combined information from Arctic gas-hydrate studies shows that in permafrost regions, gas hydrates exist at subsurface depths ranging from ≈130 to ≈2,000 meters.

The production history of the Soviet Messoyakha field, located in the West Siberian basin, demonstrates that gas hydrates are an immediate producible source of natural gas and that production can be started and maintained by conventional methods. Geologic similarities between the Messoyakha and Prudhoe Bay-Kuparuk River gas hydrate accumulations suggest that the Alaskan gas hydrates may also be a producible source of natural gas.

PROGRAM RELEVANCY: The USGS is responsible for determining the quantity and distribution of oil and gas resources in the United States. As part of the USGS Oil and Gas Investigations Program the USGS is assigned the task of conducting topical and areal studies of unconventional resources, including gas hydrates

SOCIETAL BENEFITS: The production of natural gas from hydrates would significantly reduce the United States dependency on imported hydrocarbons.

NATIONAL POLICY GOALS: This project is aligned with the President's National Strategy of reducing our dependency on imported energy.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Polar Energy and Mineral Resources

Title: Investigation of Dufek intrusion, Antarctica (Proposed)

Principal Investigator: Arthur B. Ford (others will be involved as needed)
(OMR/BAG) Menlo Park CA 94025-3591

SCIENTIFIC IMPORTANCE: The Dufek intrusion is a unique complex of layered mafic cumulates and related rocks of a magnitude probably that of South Africa's Bushveld Complex. As such, in it's excellent exposures of unaltered (unweathered) rock, it provides a little-paralleled opportunity to investigate processes of magmatism such as fractionation and multiple intrusion. One chief study would be to investigate the origin of anorthosite and magnetite layers, which are a subject of great interest in similar complexes, and another to study the relation of the mafic cumulates to the capping layer of the Lexington Granophyre, which on preliminary evidence appears to be a fractionation end member unlike similar rocks of other complexes. Platinum-group elements (PGE) seem to be concentrated in Fe-rich layers, associated with sulfides, but occurrences are little studied. Studies of Sr and O isotopes will provide important data for evaluating magmatic processes. Field data will be compiled for publication of 1:50,000 scale geologic maps of the intrusion. (Present maps published at 1:250,000 scale show little detail.) The intrusion has presently been studied only by the USGS — as yet only in reconnaissance — but the availability of existing collections of about 3000 samples tied closely to stratigraphy, and of detailed field mapping allow potential study of this intrusion in unusual detail.

PROGRAM RELEVANCY: The knowledge of magmatic processes such as can be investigated in the Dufek intrusion is applicable to USGS programs in OMR and OEVE. The development of new techniques needed to evaluate Antarctic metallic resources would be an appropriate investigation under OMR's program *Development of Assessment Techniques.* Geologic mapping of the intrusion would similarly be appropriate under ORG's *National Geologic Mapping Program*, owing to US political interests in that continent.

SOCIETAL BENEFITS: Study of the Dufek intrusion would contribute to understanding of mineralization in other layered mafic complexes that supply many metals critically needed in modern technology, particularly those of the platinum group.

NATIONAL POLICY GOALS: The present US policy under H.R. 2826 (Antarctica World Park and Protection Act) precludes commercial Antarctic minerals exploration and development. This act does not precude the scientific study of resources needed for their evaluation. The US National Park Service will likely be called upon for the US role in establishing this World Park, and the USGS should become involved also, as it now is in precursory studies in establishing US National Parks and Wilderness areas.

POLAR RESEARCH PROGRAM STRATEGIES WORKSHOP

Topic: Energy and Mineral Resources

Title: **Brooks Range Transects** (Proposed)

Principal Investigators: John S. Kelley (USGS, OMR, BAG, Anchorage, AK), Larry S. Lane (GSC, ISPG, Calgary, Alberta, Canada), Chester T. Wrucke (USGS, OMR, WMR, Menlo Park, CA), William P. Brosgé (USGS, OMR, BAG, Menlo Park, CA, Emeritis), Irvin I. Tailleur (USGS, OMR, BAG, Sequim, WA, Emeritis), and others to be identified.

SCIENTIFIC IMPORTANCE: The proposed project is to relate the structural development of the eastern Brooks Range with the western Brooks Range, and to relate the development of the Brooks Range to that of the Colville basin. The Brooks Range fold and thrust belt and associated Colville basin underlie the Brooks Range and adjacent Arctic foothills and span Arctic Alaska. The fold and thrust belt extends westward and generally down plunges form the Alaska-Yukon border, where lower Paleozoic and Proterozoic rocks crop out, to the western Brooks Range, where mostly upper Paleozoic and younger rocks crop out. Most previous regional mapping projects in the Brooks Range have been centered on either the eastern or western Brooks Range or on either the Brooks Range or Colville basin. The proposed work is to provide serial mapping transects of the Brooks Range and Arctic foothills in order to relate the geology of the Brooks Range and that part of the Colville basin underlying the Arctic foothills. Serial transects will have the advantage of down-plunge projection by working from east to west. Work will rely heavily on previous work and involve the original mappers, currently emeritis. Mapping will focus on structural details necessary to construct balanced cross sections. Work will benefit from completed transects (Kelley and Brosgé, central Brooks Range), the Trans Alaska Crustal Transect, and partial transects (Kelley, Lane, and Wrucke, Alaska-Yukon border; Kelley, Wrucke, Armstrong, and Molenaar, northeastern Brooks Range; Kelley and Tailleur, western Brooks Range) accomplished under previous projects.

PROGRAM RELEVANCY: Analysis of thrust sheets in the Brooks Range and Arctic foothills to define relations between the geologic histories of the Brooks Range and the Colville basin would benefit three U.S. Geological Survey programs: the National Mineral Resource Assessment Program, the Oil and Gas Investigations Program, and the Evolution of Sedimentary Basins Program.

SOCIETAL BENEFITS: A refined geologic framework for much of the Brooks Range would benefit exploration for mineral deposits such as world class lead-zinc deposits in the western Brooks Range and oil and gas deposits in a little explored fold and thrust belt setting.

NATIONAL POLICY GOALS: The proposed work would support U.S. Arctic Research Plan long range goals, such as to advance knowledge of Arctic geologic framework and paleoenvironments, and to promote mutually beneficial international research programs and cooperation.

DRAFT

FY 1995 Program Initiative

INTEGRATED BIPOLAR REGIONS RESEARCH PROGRAM

I. SCIENCE PROGRAM:

Issue: Human activities continue to modify the Earth's surface and alter the natural land cover, decrease the quality and quantity of ground and surface water, alter the composition of the atmosphere, and destroy or fragment the Earth's ecosystems. Polar (and high-altitude) regions are characterized by the Earth's lowest winter temperatures and extended periods when water exists in frozen form (e.g, snow cover, glaciers, floating (sea, lake, and river) ice, ground ice and permafrost). The preponderance of ice in the polar regions makes them especially sensitive to global climate warming. Because of the high logistical costs and seasonal restrictions in working in polar regions on land, sea, and in the air, the overall state of geoscience knowledge is far from adequate. To improve our geoscience knowledge in polar regions an integrated bipolar regions research program should include the following components: (1) geological and geophysical transects of key areas; (2) onshore and offshore drilling and drilling of glaciers to provide sediment cores and glacier-ice cores, respectively, for analysis of past environments; (3) increase in studies of the cryosphere (especially glaciers, permafrost, and sea ice) and polar processes; (4) greater programmatic and budgetary focus, including inter- and intra-Office (and Division) support, through a Division-level (or Bureau-level) program manager, for U.S. Geological Survey (USGS) expertise and capabilities (specialized instruments and staff) in polar regions, and (5) signing of a Memorandum of Agreement (MOA) between the USGS and the National Science Foundation (NSF).

Effective management of the land, water, and biological resources of the Alaskan Arctic is a major responsibility of many of the nine bureaus in the U.S. Department of the Interior (DOI). In order to carry out its mission in the Alaskan Arctic, DOI requires a better understanding of: (1) the impact of global climate warming on the polar regions (e.g., changes in temperature, precipitation, sea level, geologic hazards, and greater understanding of long-term geologic processes on the evolution and modification of climate and the cryosphere) and (2) a need for more data on the mineral and energy resource potential of the Arctic. In addition, the USGS is mandated by the Antarctic Treaty (Recommendation XVI) to implement and initially operate an international seismic data library system (SDLS) for cooperative research. There is also a possibility that the Secretary of the DOI, through pending environmental legislation (H.R. 2826), may be required through its National Park Service [and with the assistance of other bureaus such as the U.S. Geological Survey (USGS)], to administer the "Antarctica World Park and Protection Act." Passage of the Act will require the DOI to develop the capability to carry out geoscience and other types of environmental studies in Antarctica, including the preparation of various types and scales of thematic maps, an existing national responsibility of the USGS. Obtaining a much better understanding of the past, present, and future environment (land, water, and biological resources) of polar regions requires an integrated research program that utilizes the full range of capabilities within the DOI and formal cooperation with other federal agencies; regional, state, and local governments; non-governmental organizations; private industry; universities; and other domestic and foreign institutions.

Study Elements: The USGS, through the Geologic Division's Office of Energy and Marine Geology, can make important contributions to an integrated bipolar regions research program. The four initial components of an integrated program are as follows: (1) Environmental History with emphasis on paleoenvironmental and paleoecological studies of polar regions in descending order of immediate relevancy to the past (historic, Holocene, Quaternary, and pre-Quaternary), present, and future impact of environmental change on the biosphere, including adaptation of native cultures to change ; (2) Geologic Processes, Hazards, and Environmental Indicators with emphasis on studies of

gas hydrates (potential source of methane, a greenhouse gas, and as a fuel source), analysis of temperature measurements in permafrost to detect historic change in polar climate, studies of coastal and nearshore processes, geologic hazards peculiar to polar regions (glacier outburst floods, ice jams, engineering geology of permafrost, etc.), and response of glaciers to climate change; (3) Marine and Continental Geology and Geophysics with emphasis on characteristics of the sea floor revealed through side-scan sonar imaging, high-resolution bathymetric mapping, and coring and shallow drilling, and geological and geophysical studies to determine the structure of the polar continents, margins, and adjacent sea floor and tectonic history; and (4) Energy and Mineral Resources with emphasis on economically developable mineral deposits and hydrocarbons [oil, gas (including hydrates), and coal] in the Arctic. Studies would be conducted in cooperation with other USGS divisions, DOI bureaus, and federal agencies, as well as universities, private industry, regional, state, and local governments, and domestic and foreign institutions.

Timeline and Funding: The Integrated Bipolar Regions Research Program is expected to take at least two decades to achieve its full objectives because of the logistical difficulties and costs associated with polar studies and the many millions of square kilometers encompassed by the polar regions (14,000,000 square kilometers in the continent of Antarctica, not counting adjacent offshore areas). The first five years of funding is as follows:

PROGRAM FUNDING (in millions of $)	FY95	FY96	FY97	FY98	FY99
Environmental History	1.5	3.0	4.5	5.5	7.0
Geologic Processes Hazards, and Environmental Indicators	1.5	2.0	3.0	4.0	5.0
Marine and Continental Geology and Geophysics	4.0	5.5	8.5	10.0	13.0
Energy and Mineral Resources	2.0	2.5	3.0	3.5	4.0
TOTALS:	9.0	13.0	19.0	23.0	29.0

More so in Antarctica, and less so in the Arctic, the success of any polar research program depends on cooperation and coordination with the National Science Foundation's (NSF) Division of Polar Programs (DPP). The USGS plans to implement a broad Memorandum of Agreement (MOA) with NSF as soon as possible, that includes the long-standing agreement by NSF with the USGS's National Mapping Division to produce various scales of planimetric, topographic, and thematic maps of Antarctica, to facilitate cooperative research and coordination in both the Antarctic and the Arctic. Even greater cooperation between DOI and NSF will be necessary if the "Antarctica World Park and Protection Act" is passed. The USGS, in association with the Institute for Arctic and Alpine Research (INSTAAR) at the University of Colorado, was recently given the national responsibility by NSF's DPP for operation of the U.S. glacier ice core facility. The USGS operates an international seismic data library system, actively participates in various committees of the multinational Scientific Committee on Antarctic Research (SCAR), operates a SCAR Library of maps, satellite images, geodetic-control data, and aerial photographs, and is an international leader in studies of changes in the cryosphere from analyses of satellite images of glaciers and sea ice. It has an experienced bipolar-regions research staff. The USGS has been conducting multidisciplinary geoscience studies in the Arctic for more

than a century and in the Antarctic for more than 40 years.

Products: Typical products from the Integrated Bipolar Research Program will be primarily in the form of integrated and synthesized digital databases to provide easy access by DOI and non-DOI users. Various scales of thematic maps, including satellite image maps, will be available on both paper and in digital format (e.g, CD-ROM's). Analyses of data from a single geographic site (e.g., sediment or ice core, rock sample, water sample, etc.) will be provided in tabular format on a geographic information system (GIS) database. In addition to the publication of scientific papers in in-house series or outside journals, USGS Circulars in the "Public Issues in Earth Science" series will be prepared for decisionmakers and the lay public.

II. SCIENCE JUSTIFICATION: The international scientific community, through the various Scientific Committee on Antarctic Research (SCAR) committees for the Antarctic, the International Geosphere-Biosphere Programme for both polar regions, and numerous other international scientific councils have endorsed a much greater emphasis on improving our knowledge of the Arctic and Antarctic. The National Research Council's Polar Research Board (1991) in a recent report stated that, "There is broad agreement in the scientific community that the floor of the Arctic Ocean Basin contains potential answers to major unsolved problems in the earth sciences and that many of them pertain to questions that are of global scientific significance or pressing societal concern. ... Aspects of arctic solid-earth geoscience with important implications for science and society beyond the Arctic include its tectonic evolution, resource potential, paleooceanographic and climatic history, and geologic processes." Scientific needs in the Antarctic were noted in a 1986 Polar Research Board report and included environmental management, improved geomagnetic observatories, marine geological and geophysical studies (high-resolution seismic imaging of the continental margins, complemented by drilling and sampling), continental geological and geophysical studies (regional crustal and upper mantle structure and evolution of the continent), glaciological studies (including areal extent, thickness, and surface elevation and changes over time), and sea ice studies (changes in seasonal and inter-annual concentration, area covered, and mass-balance).

III. PROGRAM JUSTIFICATION: Past research in the polar regions by the USGS, including independent and cooperative efforts with outside organizations, has been criticized sometimes by upper-level USGS management, DOI, and the Office of Management and Budget for being piecemeal in either a geographic or topical sense, instead of being better integrated internally. Since the successful International Geophysical Year 35 years ago, in which all nations and various scientific disciplines endeavored to understand Planet Earth as an entity, technological advances in shipborne, airborne, and satellite instrumentation, development of powerful computer workstations, supercomputers, and digital database programs, now make a holistic study of the polar regions a reality. An "Integrated Bipolar Regions Research Program," adequately funded and managed by the USGS through the Geologic Division's Office of Energy and Marine Geology (because of the large number of scientists and technicians who have many years of experience in both polar regions within the Office), working in concert with other USGS divisions, DOI bureaus, and federal agencies, and outside institutions, could provide the proper organizational framework and leadership to create a truly integrated national program. The USGS has been a pioneer in the development and application of new technology, including radio-echosounding of glacier thickness, airborne magnetometry surveys, side-scan sonar imaging of the Exclusive Economic Zone (with NOAA), analyses of satellite images of the world's glaciers, and the acquisition, analyses, and distribution of large geophysical datasets. The USGS, therefore, has the proven capabilities to provide the federal leadership needed to acquire, process, analyze, and archive geoscience and related environmental datasets of the polar regions to achieve an integrated picture of these regions.

IV. SOCIOECONOMIC JUSTIFICATION: The USGS is a mission-oriented agency, one of the nine bureaus in the DOI, with a 112-year history of geoscience research, and in the collection, analyses, synthesis, distribution, and archiving of data. It has established itself as the premier geoscience agency in the federal government with an unparalleled track record for analyses of large and small datasets and for the preservation of geoscience datasets in various in-house archives (e.g, the world-renowned Earth Resources Observation Systems (EROS) Data Center (EDC), the national repository for Landsat images and other remotely sensed data of the land areas of the Earth). Although the DPP of the NSF has the Congressionally mandated responsibility for the development of all U.S. basic and applied research programs in the polar regions, it primarily provides scientific funding through grants to academic scientists (only part of the U.S. scientific community presently working or wanting to work in polar regions) and provides the logistical support for all U.S. scientific activities in Antarctica (academic and governmental scientists). NSF does not generally provide funds for non-academic scientists to work in Antarctica (with few exceptions, only considers proposals from universities) nor does it provide programmatic continuity, in-house analyses, synthesis, and archiving of digital datasets of geoscience and related environmental data. It does not have an effective long-term means of integrating, analyzing, and synthesizing the vast amounts of polar-region data acquired by instruments on overland vehicles, ships, aircraft, and satellites.

NSF does provide funds to the USGS's National Mapping Program (NMD) to support map preparation and geodetic-control requirements of scientists funded through the DPP grant program, including salaries for NMD geodetic engineers conducting field surveys in Antarctica and cartographers preparing maps of scientific areas of interest in Antarctica. NSF also provides partial support for the operation of NMD's SCAR Library, the national repository and distribution center for published maps of Antarctica, geodetic-control information collected in the field by the USGS, and aerial photographs (copies ordered from and distributed by the EROS Data Center).

Better geoscience information of the polar regions is vitally important to achieving a better understanding of: (1) some of the causes of global environmental change, (2) the relationship between changes in global glacier ice volume and changes in sea level. and (3) availability of economically exploitable minerals and energy resources. Decisionmakers at the present time and during the next several decades need ready access to objective geoscience and related environmental information about the Arctic and Antarctic. On the basis of its experience, the USGS can provide the needed federal focus for obtaining and providing the necessary information as a cooperative endeavor with other DOI bureaus, other federal agencies, and outside institutions.

V. POLITICAL JUSTIFICATION: According to a recent report by the NSF (1990), "The polar regions, the coldest and most remote areas of the Earth, have [for more than 150 years] attracted our [U.S.] interest for many reasons, strategic, economic, social, and environmental as well as scientific." The political importance of the polar regions continues to increase for four reasons: (1) their special sensitivity to human-induced changes in the global environment, (2) increased need for implementation of mandates of the Antarctic Treaty regarding the protocols for protection of the environment, the possible establishment of a World Park, and the USGS lead in implementing an international seismic library system and strengthening its existing SCAR Library, (3) mineral and energy resource potential of the Arctic, and (4) significant opportunities for the U.S. to forge important new multilateral relationships in the management of land, water, and natural resources of the Arctic, especially with the reorganized Soviet Union, and a strengthened existing relationship with Canada. An Integrated Bipolar Regions Research Program, led by the USGS and DOI, responds directly to programmatic needs stipulated in the nine-federal agency U.S. Global Change Research Program, for wise stewardship of ecosystems in the Arctic and Antarctic [e.g., the Antarctic Treaty, the Antarctic Protection Act of 1990, and the following pending legislation in the 102nd Congress: Seven bills and two concurrent

resolutions have been introduced that are directly related to environmental concerns about Antarctica: Antarctica Environmental Protection Act of 1991 (H.R. 1920), Oil Pollution Act of 1990, Amendment (H.R. 1921), Antarctica Tourism Act of 1991 (H.R. 2051), Antarctica World Park and Protection Act (H.R. 2826), National Science Foundation Antarctic Environmental Protection Act of 1991 (H.R. 3065), Antarctica Environmental Protection Protocol Act of 1992 (H.R. 5459), World Environment Policy Act of 1991 (S. 201), Resolution Concerning the Antarctic Treaty of 1961 (H.C.R. 109), and Resolution Concerning the Environmental Protection of Antarctica (S.C.R. 26). In addition, five other bills, not including appropriation bills, were introduced in both the House of Representatives and/or the Senate that involved some Antarctic issue.], and our national strategy for access to mineral and energy resources of the Arctic, both domestic and foreign.

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MEMORANDUM OF UNDERSTANDING
BETWEEN
U.S. GEOLOGICAL SURVEY AND NATIONAL SCIENCE FOUNDATION

This memorandum of understanding (MOU) is a general agreement for cooperation between the U.S. Geological Survey (USGS) and the National Science Foundation (NSF) in geoscientific disciplines of mutual interest, including geology, geochemistry, and geophysics (marine and terrestrial), hydrology, glaciology, geographic sciences, etc. Such cooperation is desirable and should promote and enhance the scientific productivity of both federal agencies through collective use of human, logistical, and programmatic resources. An MOU between both agencies is particularly appropriate at this time because of several factors: (1) the USGS and NSF are deeply involved in leadership roles in the nine-federal agency U.S. Global Change Research Program (Presidential Initiative); (2) the USGS and NSF conduct ocean-science studies [Exclusive Economic Zone (EEZ), the polar oceans, and other marine areas] that would be enhanced by cooperative use of major, expensive scientific and logistical facilities; (3) the "Antarctica World Park and Protection Act" that is under consideration by Congress (H.R. 2826), would mandate the Secretary of the Interior to carry out a comprehensive environmental and geoscience assessment of Antarctica and surrounding areas and would require close cooperation between the USGS and NSF; (4) the long-standing cooperative support of earthquake-research programs by the USGS and NSF; and (5) funding by NSF to the USGS for topographic and related mapping activities in Antarctica in support of NSF-funded scientific programs.

Background: Historically, the USGS and NSF have differed in their approach to conducting science programs. The USGS generally operates long-term (more than 5 years), internally generated, "mission-oriented" ("basic and applied research") programs usually with USGS scientists and logistics, whereas the NSF conducts mostly short-term (less than 5 years) "basic-research" proposal-driven projects using academic scientists and NSF logistics. Effective science is accomplished under both operational modes, but each mode has its limitations. Except for a few programs in the Geologic Division's Office of Earthquakes, Volcanoes, and Engineering (OEVE) and some programs in the Water Resources Division and the National Mapping Division, most USGS operations no longer include much academic participation and are generally geographically restricted (carried out mostly within the U.S. and its territories); NSF operations usually do not provide long-term continuity and expertise in thematic and regional surveys and research nor an effective means of preservation of large, long-term geoscience databases. Closer cooperation between USGS and NSF will help resolve these operational limitations, would yield more effective science programs, by complementing their traditional organizational capabilities, and will help both agencies attain their programmatic goals.

Agreements: Recognizing that the USGS and NSF have somewhat different mandates and programmatic goals, nevertheless, the following general agreements are made to promote, whenever possible, greater interchange of agency resources for the enhancement of programs in the geosciences. In implementing these agreements:

1. The USGS and NSF will cooperate to the greatest extent feasible and practicable in supporting joint science programs on topics and in regions of common interest.

A case in point would be a joint multi-year geoscience program, in both polar regions, that would focus on regional geophysical (including earthquakes), geological (including shallow drilling), hydrological, and glaciological work for addressing

paleoenvironmental, geographic (cartography and GIS), global-environmental-change, and earth-structure topics. USGS would provide greater programmatic support for Arctic studies and NSF could do the same for the Antarctic.

2. The USGS and NSF will provide, whenever possible, logistical support for field and laboratory studies in regions and on topics of mutual interest.

An example would be a joint field operation in which NSF would provide a ship and logistical support and the USGS would provide technical assistance, scientists, and laboratory facilities for the science program.

3. Each agency will respect the existing directives and operational procedures of the other agency for non-interagency projects; further, for cooperative interagency projects, the agencies will work together to establish appropriate new procedures.

Examples of the two modes would be a) a USGS researcher who desired to conduct an individual (or joint with academia) NSF-funded research project would follow usual NSF procedures for research proposal submittal and external review; and b) a joint USGS/NSF research project (e.g., USGS supporting a science survey program on an NSF-supplied aircraft) would be handled as an interagency project (e.g., with joint funding and science review provided by the USGS and NSF program managers).

4. USGS and NSF will encourage and solicit greater participation of scientists from the other agency (or academia) in advisory roles and in science programs of their own agency.

An example would be NSF representation on a USGS advisory committee for projects of mutual interest in the Alaskan Arctic and USGS representation on an NSF advisory committee for projects of mutual interest in the Antarctic.

5. Cooperation on existing USGS-NSF projects will continue and will be facilitated by new and more-timely procedures for interagency funding.

A case in point is the long-standing Antarctic mapping project by the USGS National Mapping Division. Except for global environmental change-related mapping of Antarctica, that is funded by the Geologic Division through the multi-agency U.S. Global Change Research Program, the Antarctic mapping project is almost totally funded by NSF. Such jointly funded projects are mutually beneficial, and, when optimized administratively, will better serve short-term NSF needs, long-term USGS objectives, and national needs for local and regional thematic maps.

6. A small interagency working group, reporting to the Directors of the USGS and NSF, would be established to assist and facilitate, when appropriate, the planning and implementing of joint programs and projects of the two agencies. Further, both agencies would designate liaison scientists to spend periods of time (TDY), as desirable, to help develop science programs of mutual interest.

Benefits: Closer cooperation between the USGS and NSF will clearly benefit both agencies in attaining their individual and collective goals. In particular, the USGS would gain from access to NSF academic research and logistical support, and NSF should profit from access to long-term USGS expertise in scientific and logistic programs (field and laboratory), satellite-image analysis and mapping techniques, and acquisition, analyses,

and archiving of large regional geoscience databases. Such cooperation will give both agencies greater breadth and potential in the scope of their future science programs.

Implementation: This agreement will become effective when signed by the Directors of USGS and NSF. The specific guidelines for individual cooperative projects under this agreement will be arranged either a) by direct contact between USGS and NSF program or project managers using administrative procedures of the individual agencies, or b) if requested, through guidelines recommended by the joint interagency working group (i.e., established under item 6. above). This MOU will be in effect for 10 years or until mutually nullified by the agency heads.