G. L. Shaw, D. J. Silverman, J. C. Pearson, *Proc. Natl. Acad. Sci. U.S.A.* **82**, 3364 (1985); M. Y. Choi and B. A. Huberman, *Phys. Rev. A* **28**, 1204 (1983); T. Hogg and B. A. Huberman, *Proc. Natl. Acad. Sci. U.S.A.* **81**, 6871 (1984); M. A. Cohen and S. Grossberg, *IEEE Trans. Syst. Man Cybern.* **SMC-13**, 815 (1983); K. Nakano, *ibid.* **SMC-2** (no. 3) (1972). For recent work on stochastic models applied to two states, see G. E. Hinton, T. J. Sejnowski, and D. H. Ackley [*Technical Report CMU-CS-84-119* (Carnegie-Mellon University, Pittsburgh, 1984)].
12. We refer to the dynamics as "classical" because we are ignoring propagation time delays and the quantal nature of action potentials, in analogy to classical mechanics. Similar equations have been described: T. J. Sejnowski, in *Parallel Models of Associative Memory*, G. E. Hinton and J. A. Anderson, Eds. (Erlbaum, Hillsdale, NJ, 1981), p. 189.
13. T. Kohonen, *Self-Organization and Associative Memory* (Springer-Verlag, Berlin, 1984); T. Kohonen *et al.*, *Neuroscience* **2**, 1065 (1977); T. Kohonen, *Biol. Cybern.* **43**, 59 (1982); L. N. Cooper, F. Liberman, E. Oja, *ibid.* **33**, 9 (1979); D. Ackley, G. E. Hinton, T. J. Sejnowski, *Cognit. Sci.* **9**, 147 (1985); D. d'Humieres and B. A. Huberman, *J. Stat. Phys.* **34**, 361 (1984); K. Fukushima, *Biol. Cybern.* **36**, 193 (1980); A. G. Barto, R. S. Sutton, P. S. Brouwer, *ibid.* **40**, 201 (1981); *Parallel Models of Associative Memory*, G. E. Hinton and J. A. Anderson, Eds. (Erlbaum, Hillsdale, NJ, 1981). The capacity of associative memories constructed from networks of two-state neurons is discussed by P. Peretto [*Biol. Cybern.* **50**, 51 (1984)], D. J. Amit, H. Gutfreund, H. Sompolinsky [*Phys. Rev. Lett.* **55**, 1530 (1985)], R. J. McEliece and E. C. Posner [*JPL Telecommunications and Data Acquisition Progress Report 42-83* (1985), p. 209], Y.-S. Abu-Mostafa and J. St. Jacques [*IEEE Trans. Inf. Theory* **IT-31**, 461 (1985)], and L. Personnaz, I. Guyon, and G. Dreyfus [*J. Physique Lett.* **46**, L-359 (1985)].
14. J. J. Hopfield, *Proc. Natl. Acad. Sci. U.S.A.* **81**, 3088 (1984).
15. ——— and D. W. Tank, *Biol. Cybern.* **52**, 141 (1985).
16. D. W. Tank and J. J. Hopfield, *IEEE Circuits Syst.* **CAS-33**, 533 (1986).
17. J. J. Hopfield and D. W. Tank, in *Disordered Systems and Biological Organization* (Springer-Verlag, Berlin, 1986).
18. C. Koch, J. Marroquin, A. Yuille, *Proc. Natl. Acad. Sci. U.S.A.* **83**, 4263 (1986).
19. E. Mjolsness, *CalTech Computer Science Dept. Publication 5153:DF* (1984).
20. T. J. Sejnowski and G. E. Hinton, in *Vision, Brain, and Cooperative Computation*, M. Arbib and A. R. Hanson, Eds. (MIT Press, Cambridge, MA, 1985).
21. G. M. Shepherd, *The Synaptic Organization of the Brain* (Oxford Univ. Press, New York, 1979), p. 3.
22. For a review of observed input-output relations and their ionic basis, see W. E. Crill and P. C. Schwindt [*Trends NeuroSci* **6**, 236 (1983)].
23. K. G. Pearson, in *Simpler Networks and Behavior*, J. C. Fentress, Ed. (Sinauer, Sunderland, MA, 1976).
24. J. McCarragher and R. Chase, *J. Neurosci* **16**, 69 (1985).
25. M. V. L. Bennett and D. A. Goodenough, *Neurosci. Res. Program Bull.* **16**, 371 (1978).
26. W. Rall and G. M. Shepherd, *J. Neurophysiol.* **31**, 884 (1968).
27. C. Koch and A. Yuille, personal communication.
28. J. Platt, personal communication.
29. E. Harth, *IEEE Trans. Syst. Man Cybern.* **SMC-13**, 782 (1983).
30. W. J. Freeman, *Mass Action in the Nervous System* (Academic Press, New York, 1975).
31. D. O. Hebb, *The Organization of Behavior* (Wiley, New York, 1949).
32. S. Kirkpatrick, C. D. Gelatt, M. P. Vecchi, *Science* **220**, 671 (1983).
33. S. Geeman and D. Geeman, *IEEE Trans. Pattern Anal.* **6**, 721 (1984).
34. M. R. Garey and D. S. Johnson, *Computers and Intractability* (Freeman, New York, 1979).
35. L. A. Zadeh, *IEEE Trans. Syst. Man Cybern.* **SMC-3**, 38 (1974).
36. D. H. Ballard, *Pattern Recognition* **13**, 111 (1981); J. A. Feldman and D. H. Ballard, *Cognit. Sci.* **6**, 205 (1982); D. L. Waltz and J. B. Pollack, *ibid.* **9**, 51 (1985); J. B. Pollack and D. L. Pollack, *Byte Magazine* **11** (no. 2), 189 (1986).
37. T. Poggio, V. Torre and C. Koch, *Nature (London)* **317**, 314 (1985).
38. A. E. Gelperin, J. J. Hopfield, D. W. Tank, in *Model Neural. Networks and Behavior*, A. Selverston, Ed. (Plenum, New York, 1985).
39. J. Lambe, A. Moopenn, A. P. Thakoor, *Proceedings of the AIAA: Fifth Conference on Computers in Space*, in press; J. Lambe, A. Moopenn, A. P. Thakoor, *Jet Propulsion Lab Publication* **85-69** (Jet Propulsion Laboratory, Pasadena, CA, 1985).
40. M. Sivilotti, M. Emmerling, C. Mead, *1985 Conference on Very Large Scale Integration*, H. Fuchs, Ed. (Computer Science, Rockville, MD, 1985), p. 329.
41. L. D. Jackel, R. E. Howard, H. P. Graf, B. Straughn, J. S. Denker, *J. Vac. Sci. Tech.*, in press.
42. A. E. Owen, P. G. Le Comber, G. Sarrabayrouse, W. E. Spear, *IEE Proc.* **129** (part 1, no. 2), 51 (1982).
43. D. Psaltis and N. Farhat, *Optics Lett.* **10**, 98 (1985).
44. Supported in part by NSF grant PCM-8406049.

Arctic Research in the National Interest

A. L. WASHBURN AND GUNTER WELLER

The Arctic Research and Policy Act of 1984 was designed to advance arctic research in the national interest. Some of the research fields that require attention are weather and climate; national defense; renewable and nonrenewable resources; transportation; communications and space-disturbance effects; environmental protection; health, culture, and socioeconomics; and international cooperation. A research framework recommended by the Arctic Research Commission includes, in order of priority, integrated investigations to understand: (i) the Arctic Ocean (including the marginal seas, sea ice, and seabed) and how the ocean and atmosphere operate as coupled components of the arctic system; (ii) the coupled atmosphere and land components and how their interaction governs the terrestrial environment; and (iii) the high-latitude upper atmosphere and its extension into the magnetosphere with emphasis on predicting and mitigating effects on communications and defense systems. A separate recommendation is for high priority research to resolve the major health, behavioral, and cultural problems related to the arctic environment. Recommendations are also made concerning support services and management.

THE ARCTIC IS IMPORTANT FOR MANY REASONS—DEFENSE, economic, political, and scientific (*1–4*). The Arctic Research and Policy Act of 1984 has now put some of these interests into sharper focus. Its stated purposes are "to establish national policy, priorities, and goals and to provide a Federal program plan for basic and applied scientific research with respect to the Arctic, including natural resources and materials, physical, biological and health sciences, and social and behavioral sciences" [*5*, Section 102(b)(1)]. The act established two cooperating groups to carry out its intent: (i) an advisory Arctic Research Commission consisting of five presidential appointees and the director of the National Science Foundation, who serves as an ex officio, nonvoting member, and (ii) an executive Interagency Arctic Research Policy Committee, consisting of a representative from ten named federal agencies and possibly others, which is chaired by the National Science Foundation representative.

Passage of the act reflected an increasing awareness in Alaska, in Washington, and among scientists and others that U.S. arctic

A. L. Washburn is a professor emeritus in the Department of Geological Sciences and the Quaternary Research Center, University of Washington, Seattle, WA 98195, and is a member of the U.S. Arctic Research Commission. G. Weller is a professor in the Geophysical Institute, University of Alaska, Fairbanks, AK 99701, and is chairman of the Polar Research Board of the National Research Council.

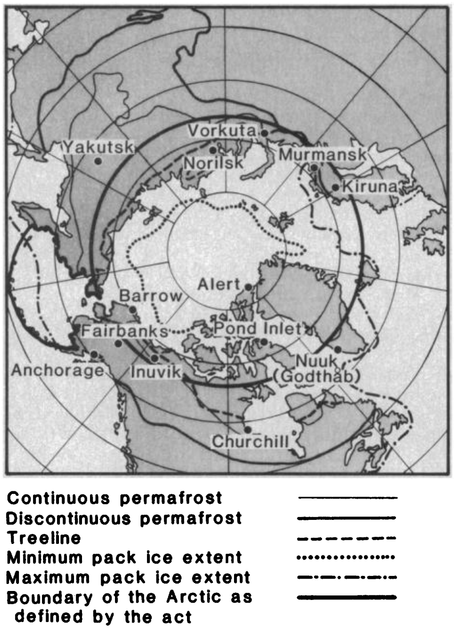

Fig. 1. The Arctic, showing various boundaries including the boundary defined by the Arctic Research and Policy Act of 1984.

research was lacking in continuity and overall direction (*6*). In contrast to antarctic research, where responsibility for programs and logistics is centered in the National Science Foundation whose focus is science, arctic programs are divided among numerous federal and state agencies whose work may include facets of science, but whose missions are generally in other domains that rarely focus on the Arctic.

The act specifies national concerns regarding arctic research, including energy resources, national defense, fisheries, global weather processes and forecasting, health and adaptation to arctic conditions, communications, arctic technologies and transportation, fragmented federal research, logistical support, gaps in research, cooperation with state and local governments in collecting basic data, long-range effects of development, international cooperation, and arctic policy [*5*, Section 102(a)].

Research imperatives abound if the United States is to attain a position in arctic research equal to U.S. interests and international status. In this article, no attempt is made to distinguish between basic and applied science except to emphasize the fundamental tenet that basic research is mandatory for long-range scientific progress in the Arctic, as elsewhere. To some extent emphasis is on the U.S. Arctic, but the act and many national concerns involve the entire Arctic.

The "Arctic"

Many definitions attempt to delimit the Arctic, the most common being (i) the Arctic Circle, which crosses many otherwise dissimilar areas; (ii) the region north of the 10°C isotherm for July; (iii) the region north of tree line; and (iv) the region north of the southern boundary of continuous permafrost (Fig. 1). The latter three boundaries are rather similar. The southern limit of pack ice is used for arctic waters. All definitions encompass high latitudes with their long summer days and long winter nights. As used in the Arctic Research and Policy Act of 1984 (*5*, Section 112), "'Arctic' means all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian Chain." This special definition emphasizes Alaska as the U.S. Arctic and the nation's international role as an Arctic-rim country. Whatever its exact definition, the Arctic includes many physical, biological, and anthropogenic attributes that, collectively, set it off from all other environments. In practice, what is termed "Arctic" may depend somewhat on the nature of the problem being addressed, and a flexible perspective is adopted for this overview.

The arctic climate is cold but mean annual temperatures range widely from 0°C at Murmansk in the Soviet Union through −12.2°C at Point Barrow, Alaska; −16.2°C at Resolute in Canada's High Arctic, and −18°C over the central Arctic Ocean, to −28.1°C at the crest of the Greenland Ice Sheet. Most of the Arctic is quite arid; precipitation at Point Barrow is 104 mm (roughly comparable to Yuma, Arizona) and at Murmansk is 401 mm (similar to Salt Lake City, Utah) (*7*). However, desiccation of the soil is retarded by permafrost.

While a few arctic areas have warmer winters than other areas farther south (*8*) and many have a rich tundra vegetation, some parts of the Arctic are cold deserts largely devoid of vegetation, with snow accumulating mainly as drifts, leaving many windblown stretches of bare ground the year-round.

Glaciers are common on highlands such as the Brooks Range of Alaska, and small ice caps occur on the mountains of Canada's Eastern Arctic islands, Norway's Svalbard Archipelago, and the Soviet Union's Novaya Zemlya. However, the huge Greenland Ice Sheet—1,802,000 km^2 in area and up to 3,400 m thick—accounts for over 80% of Northern Hemisphere glacier ice.

The central Arctic Ocean is covered with moving pack ice, often about 3 to 3.5 m thick but thinner or absent in newly opened leads and many meters thick in pressure ridges. This central pack normally blocks all ships except submarines and powerful icebreakers. Although most coastal waters and marginal seas are open to navigation in summer, hazardous ice floes can persist.

The natural resources of the Arctic that are globally important include energy sources, minerals, and fisheries. Soviet mineral development is partly responsible for such Arctic urban centers as Vorkuta and Norilsk, whose populations exceed 100,000; the population of Murmansk, primarily a naval base, also exceeds 100,000. The largest Scandinavian urban centers north of the Arctic Circle have a much smaller population (10,000 to 30,000), their main thrust being fishing and shipping in Norway, and mining in Sweden. In Svalbard, Greenland, Arctic Canada, and Arctic Alaska, the largest centers are still smaller (2,000 to 10,000) (*9*). However, Arctic resource development can be areally extensive without involving large urban centers, as shown by the Prudhoe Bay and Kuparuk oil and gas fields in Alaska, which have only a small year-round population but about 300 km of roads connecting numerous scattered buildings.

The total indigenous population of the Arctic is between 800,000 and 900,000, most of whom, except about 140,000, live in the Soviet Union (*9*, p. 18). The largest groups speak different languages, each having numerous dialects. Alaska as a whole has some 21,900 Indians (mostly in southeastern Alaska), 8,100 Aleuts, and 34,100 Inuits (Eskimos) (*10*).

Atmosphere and Climate

At high latitudes the upper atmosphere, with magnetosphere and ionosphere, serves as "the earth's window to space" in that particles from the sun are focused primarily on polar regions where they give rise to magnetospheric and ionospheric phenomena that have a direct impact on important space processes. The phenomena can also strongly affect communications and defense capabilities (*11*).

Thus the charged particles precipitating into the ionosphere, causing auroras, can interrupt radio communications during magnetic storms. Communications with satellite and radar systems become vulnerable; the high background noise that the aurora can induce in optical and infrared sensors used by surveillance spacecraft is of special concern. Electric currents induced in long conductors such as telephone cables, power lines, and pipelines can cause failure or serious damage.

Global weather and climate are sensitive to processes in the arctic atmosphere. Among them, the strong albedo feedback, which accompanies changes in the seasonal distribution of snow and ice, intensifies climatic variability, not only in the Arctic but also farther south (*12*). Moreover, any temperature increase due to the greenhouse effect from the buildup of various gases, including the release of carbon dioxide from the burning of fossil fuels, is intensified in the Arctic because of the melting of snow and ice and the accompanying reduced albedo and changes in energy balance. Temperature increases predicted by some numerical models (*13*) would affect the distribution of sea ice, navigation in the Arctic Ocean, the northward extent of agriculture, and tree line, and as land-based glaciers melted, perhaps cause global rise of sea level sufficient to significantly affect low-lying coasts. For Arctic Alaska a temperature rise of 6°C in winter and 1°C in summer, although rather speculative, has been considered possible. Such an increase would probably benefit oil exploration and agriculture, have a slight or no impact on the timber industry, and, because of thawing of permafrost, more or less adversely affect other industries (*14*). However, estimated global and polar temperature increases, their timing, the magnitude of projected sea-level rise, and the nature of other effects include many uncertainties (*15*); careful monitoring of even small climatic changes and effects becomes critical for prediction (*16*), whatever their cause.

Arctic haze due to industry-generated air pollution initially moving across the Arctic from lower latitudes is an increasing problem (*17*), affecting climate and, because of acidic pollutants, possibly food chains as well. Despite these large-scale climatic influences and the significance of arctic weather for regional forecasting and for understanding global weather, vital knowledge is lacking because Arctic observing stations are widely scattered and air-sea-ice interactions are physically complex.

The Hydrosphere

The Arctic Ocean influences (along with antarctic waters) about three-quarters of the world's oceans (*18*), and it is the focus of national defense imperatives and important geopolitical issues (*3*). Among other problems, the acoustical characteristics of the Arctic Ocean and adjacent seas as affected by differing water masses and the background noise of ice movement, internal waves, and other influences are of key interest in detecting submarines beneath the sea ice (*19*). The acoustical characteristics are also important in studying the effect on whales of offshore oil activities and possible tanker traffic (*20*). Improved understanding of the ocean's dynamics and interactions with the atmosphere and sea ice, including the complex air-sea-ice system of the fluctuating marginal ice zones, is important for advancing knowledge not only of ocean processes but also of weather and marine life (*21–23*). Overall, probably less is known about the Arctic Ocean than about the atmosphere, land, or biota—the other primary components of the Arctic system.

With respect to the freshwater hydrology of Arctic lands, "The potential future water needs of industry are great, but the paucity of water resources data in the Arctic Region hinders a full understanding of hydrologic processes and the efficient development and use of the resource" (*24*, p. 22). Better information is needed on groundwater movement, water supply, and sewage disposal in permafrost areas and on the freezeup and breakup of arctic rivers and lakes and their energy-generating potential.

The Cryosphere

The cryosphere—snow, ice, and frozen ground—forms a mantle on most Arctic lands and seas seasonally or perennially. As climatic responses to atmospheric and oceanic processes, glaciers and permafrost can store information on past environments. Permafrost temperature profiles can record former temperatures, and oxygen isotope and carbon dioxide research on cores from the Greenland Ice Sheet are furnishing vital information on climatic changes. Also, particulates in the snow and ice are providing significant data on hemisphere-wide pollution (*25*). In the physics of ice, such a fundamental characteristic as the flow law of ice for polar ice sheets is not yet firmly established (*26*).

The arctic pack ice not only influences defense strategy but is obviously critical in general maritime commercial transportation, including tanker traffic. Forecasting specific rather than average changes in ice distribution is problematical without having much more information than is currently available. Important strength characteristics of ice that affect the design of piers and offshore drilling structures are poorly known (*27–29*). The glacial history of large parts of the Arctic remains controversial (*30*). The fact that former widespread shelf ice in the Canadian Arctic Archipelago was only recently identified (*31*) illustrates how little is known about the history.

Permafrost, subsea as well as terrestrial, strongly influences engineering practices. Measures to prevent ground collapse should be taken if the construction could cause thermal changes and thawing of ice-rich permafrost. Knowledge of the distribution and thickness of permafrost, especially subsea permafrost, is inadequate (*32*). Off the Beaufort Sea coast it may occur in multiple layers and in places may impact drilling as far as 55 km offshore (*33*).

The cryosphere is an important resource. In most of the Arctic, water stored in snow and glacial ice and then released as runoff to rivers and lakes during seasonal thawing is much more significant than rain as a source of freshwater. Shelf ice can be a transportation resource in some places since sections may break off from their parent glaciers and drift around the Arctic Ocean as ice islands, measuring several kilometers in diameter. They may last for years and form platforms for research programs.

The Lithosphere

Little is known about the geologic evolution of the Arctic Basin; acquisition of deep cores from the ocean bottom and of paleomagnetic data are essential to determine its tectonic and sedimentary history (*34*). The sedimentary history may also provide clues to changes in climate and sea-ice cover. The interpretation of even the uppermost sedimentary layers of the lithosphere is still open to debate (*35*). The continental shelves are highly significant sources of oil and gas, and offshore exploration for these resources (Fig. 2) presents many geologic and engineering problems. The stratigraphy and structure of some Arctic lands are very complicated, and in Alaska this includes juxtaposition by extensive faulting and lateral displacements of terranes of quite different origin.

Overall, oil, gas, coal, and mineral resources of the Arctic are large, especially the energy resources of Alaska (*36*). In 1983, the Prudhoe Bay field had a proved crude oil reserve about a quarter that of the entire United States (*37*). However, mean-value estimates of still undiscovered, potentially recoverable oil and gas in Arctic Alaska (onshore and offshore) are speculative. For instance, they were drastically reduced by the Department of the Interior's Minerals Management Service in 1985 as a result of disappointing drilling results and revised analytical techniques. Thus offshore oil estimates were lowered from 1981 projections by 73%, from 12.2 billion to 3.30 billion barrels, and offshore gas estimates, by 78%, from 64.6 to 13.85 trillion cubic feet (1.8 to 0.39 trillion cubic meters). The methodology on which the revised estimates are based is now being reviewed (*38*).

Coal resources of the Alaska North Slope range from an identified 150 billion to a hypothetical 4 trillion short tons, reflecting limited surface exposures and scattered drilling. Alaska's coal resources as a whole have been estimated as making up 50% of the total in the United States and 15% of world resources (*39*).

Alaskan mineral resources are considerable, with eight world-class deposits ($1 billion or more) in Arctic Alaska. Minerals include barite, beryllium, cobalt, copper, fluorite, lead, silver, tin, tungsten, and zinc (*39*, pp. 14–15). The overall potential is unknown. Only 4.5% of the bedrock geology of Alaska has been mapped on a scale of 1 mile : 1 inch (*39*, p. 14), and "Less than 25 percent of the known mineral deposits in Arctic Alaska have been tested by even a single drill hole . . . " (*40*, p. 70). It was only recently that the Brooks Range Red Dog lead-zinc deposit was discovered, possibly one of the world's largest (*40*, p. 65).

Uncertainties regarding Alaskan oil, gas, coal, and mineral resources emphasize the large amount of research still required for accurate inventories and sound planning. Similar problems confront other Arctic-rim nations. Additional difficulties include unstable oil prices, assessing transportation systems for offshore oil and gas, addressing the associated pollution dangers, and, in some countries, sensitive sovereignty issues.

The Biosphere

Improved information is needed in research areas involving fishes, marine mammals, birds, and terrestrial wildlife and vegetation (*41*), especially in relation to ecosystems (*22, 42*).

The Arctic accounts for some 10% of the world's fish catch, the cod family, capelin, and herring among the most important. The Bering Sea is the world's most productive for the Pacific (walleye) pollock. The pollock has an estimated equilibrium yield of 1.1 million metric tons, and it accounted for 78% of the foreign Bering Sea catch in 1978; here, a single net haul may bring in 100 metric tons of fish (*43*). The Kotzebue Sound salmon fishery is particularly important for Alaska (*44*). Marine mammals, especially seals, are also valuable commercially, but some of the mammals such as the bowhead whale, and fish such as the arctic cisco, are endangered. The bowhead whale is a well-known example of a conservation problem for which critical data are still lacking (*45*). Data are also needed for the shelf ecosystem of the Bering Sea and for most other Arctic shelf ecosystems on which renewable marine resources depend.

Fig. 2. Concrete Island Drilling System (CIDS) about 10 miles off Cape Halkett, Beaufort Sea coast, Alaska, 27 March 1985. The thick ice was a protective barrier created by pumps spraying seawater around CIDS except for an opening at the back of CIDS to egress. The deck of CIDS measures 295 × 312 feet (90 × 95 m) and is about 45 feet (14 m) above sea level; the ice barrier averaged about 60 feet (18 m) high and rested on the sea floor at a depth of about 50 feet (15 m). [Photo by Air Photo Tech, courtesy of Exxon Company, U.S.A.]

Similarly, the renewable resources of the terrestrial ecosystem abound in unknowns (*46*), such as the cause of apparently long-standing, huge fluctuations in the size of caribou herds (*47*). Such questions are of concern to indigenous peoples and wildlife managers. The Arctic biota as a living resource is far more fragile than most nonliving resources, and long-term scientific monitoring is mandatory to determine changes in character and to mitigate effects of encroaching industrialization.

The Peoples

The first peopling of the Americas is commonly believed to have been by way of the Bering Land Bridge during a time when sea level was lowered by growth of ice sheets. There have been repeated immigrations, but the earliest is not established (*48*), and many Beringian problems remain (*49*).

Today, the descendants of the early immigrants face rapid and highly significant changes because of intruding industrial and governmental activities, personnel, and life-styles. Working schedules and other restraints conflict with long-established indigenous cultures based on subsistence living from local resources (*50*) (Fig. 3). However, industry is attempting to mitigate the problem by frequently rotating days on and days off work. Alcohol and drug abuse is creating social and behavioral difficulties in some areas.

These matters have social, economic, and political overtones far more complex than might first appear (*51*). In Alaska, the large economic benefits accrued by indigenous peoples in return for their release of native land claims entail serious problems for future generations (*52*). Many indigenous peoples of the Arctic recognize that their culture and heritage are threatened and believe that when nonrenewable resources are depleted and industry departs, they will have to rely on themselves and local resources once again. This feeling, obvious in Arctic Alaska, Canada, and Greenland, is stressed by the Inuit Circumpolar Conference which calls for approval by indigenous peoples before industrial and other intrusions into homelands occur (*53*). Social and behavioral research may help to clarify these complex matters and suggest approaches to them; it will also aid newcomers in understanding the Arctic and its peoples.

Arctic medicine and health are additional research areas. Health problems existed before contact with Europeans (*54*), but many are recent occurrences (*55*). For instance, there seems to be an increase in cancer in some populations (*56*); if confirmed, determination of the cause could also aid cancer research in general. Health problems of a different kind are cited in a 1984 report, which states: "Historical conditions have resulted in the reduction and fragmentation of health research on the American Arctic . . . lack of dissemination of findings . . . of responsiveness to local concerns and . . . of a clear federal commitment to arctic science . . . have contributed to uncertain and discontinuous support for research on Arctic health. The resulting decline in health science productivity is occurring at a time when research findings are most needed in the region" (*57*).

Engineering and Environmental Research

Engineering research and technology directly translate much other research into the economically feasible end products for people. Arctic engineering and technology are specialties because of the difficulties imposed by the unique marine and terrestrial environment (*28, 58*). Driving forces include the need for energy and mineral resources, for better housing, communications, logistics, and defense, as in the modernization of the Distant Early Warning line (now the North Warning System) by Canada and the United States (*59*). These fields mandate continuous improvements in arctic technologies, which in some areas, such as materials science and bioengineering, appear to be lagging (*60*).

In addition to furthering resource exploitation and industrial development, technological advances can alleviate or prevent accompanying disturbances and dangers—for example, marine and terrestrial oil spills. Engineering has a mandate and responsibility to do so in the environmentally sensitive Arctic, and it is to industry's credit that it recognizes this as being in the best interests of all concerned. Many problems arise from varying judgments concerning environmental risks and trade-offs, and basic and applied research are critical for informed decisions. Engineering and development must go hand in hand with environmental studies and protection. Such studies require long-term baseline observations and monitoring in all the natural systems, physical and biological, against which to measure effects of development (*61*).

Promotion of Research

The Arctic Research and Policy Act specifies promotion of arctic research as a concern. An oft-cited problem is the lack of career opportunities for arctic scientists, which has discouraged many, including indigenous peoples, from pursuing such careers. In contrast, the Leningrad Arctic and Antarctic Scientific Research Institute has a staff of some 1800, and "literally hundreds of other scientific institutions [exist] that work partially or exclusively in the Arctic" (*62*, p. 174).

Other problems are costly scientific platforms and logistics. Both need to be examined as long-range commitments. There is broad support for polar-orbiting satellites as platforms to advance atmospheric, terrestrial, and marine research (*63*). However, lack of enough support for earth-bound facilities has resulted in the United States being the only Arctic-rim nation without well-established, Arctic-based, scientific research stations or research support facilities. The former Naval Arctic Research Laboratory at Point Barrow (*64*), which closed because of budgetary retrenchment, is now operated on a much-reduced scale by the Barrow Village Inupiat Corporation. This facility's future is uncertain, and it cannot economically serve the eastern part of Arctic Alaska. In contrast, the Soviet Union has more than 100 Arctic stations. The Canadian government's Polar Continental Shelf Project uses chartered helicopters and fixed-wing aircraft and routinely establishes temporary camps throughout the Canadian Arctic Archipelago in summer and winter. It is a model of how to assist various independent and cooperative programs at minimal expense.

The United States is also the only Arctic-rim nation without an ice-worthy vessel dedicated to arctic science. Although the Coast Guard icebreakers can help to support research, the Coast Guard has overriding priorities and is not able to dedicate a suitably designed vessel and a research-trained and motivated crew to the needs of science. Here again, the Soviet Union leads with more than 20 ice-worthy vessels dedicated to polar research, mainly arctic; they also have the world's largest icebreaker fleet (*65*).

Fig. 3. Traditional Inuit blanket toss during festival celebrating bowhead-whale catch, Barrow, Alaska, 25 June 1985. The blanket, made of walrus hide, is rhythmically manipulated to launch the performer ever higher into the air. [Photo by A. L. Washburn]

International Cooperation

In promoting arctic research, international cooperation on appropriate problems, including joint logistical support, would be of mutual benefit. Arctic-rim nations have many scientific problems in common (*66*) and a tradition of cooperation in polar research established by two International Polar Years and the 1957–58 International Geophysical Year. The existing research ties between the United States and Canada (*67*), Greenland (*68*), and the Scandinavian countries offer many opportunities for strengthening cooperative endeavors. Svalbard, under Norwegian sovereignty, is of interest as a locus for international efforts, since all signatories to the Svalbard Treaty have equal rights to undertake research and development, provided the region remains demilitarized (*69*).

Significant difficulties in international science cooperation exist in the case of the Soviet Union, but there has been some success in nonsensitive areas, including anthropology and archeology, health, environmental protection, geophysics, permafrost, and wildlife.

Priorities

Advancement of U.S. arctic research requires continuity of effort and a sense of priorities, which are subject to change with time and circumstances. These priorities are addressed in a comprehensive report (*70*) prepared by the National Research Council. Figure 4 summarizes the issues and lists the research fields that the committee regarded as most critical to each issue. The research fields as such are not prioritized but the report lists research needs in each field in order of priority.

Subsequently, a working paper by the Arctic Research Commission (*71*) concluded that the paramount national needs to which arctic research should be directed comprise national security, weather and climate, natural resources, transportation, communications and space-disturbance effects, environmental protection, and health, culture, and socioeconomics, all of which conform to recently adopted arctic research policy (*72*). Regarding improved prediction ability as an important criterion, the commission recommended a broad research framework to meet the national needs. Building on the concept that the Arctic is an interactive system whose core components are the atmosphere, ocean, land, and biota, the commission recommended in order of priority (*71*):

- Research to understand the Arctic Ocean (including the Bering Sea and other marginal seas, sea ice, and seabed), and how the ocean and the Arctic atmosphere operate as coupled components within the Arctic system. In accordance with national needs, emphasis should be on gaining knowledge to advance (a) discovery of nonrenewable resources, especially offshore oil and gas, and their development with minimal adverse impact on the environment; (b) prediction of ecosystem reactions to natural (for example, climatic) and human-induced disturbances, including those affecting renewable resources of the Arctic continental shelves, particularly Alaska Bering Sea fisheries and the species on which the subsistence life-styles of indigenous peoples depend; (c) forecasting Arctic weather and its impact on worldwide weather patterns; (d) prediction of climatic change resulting from changing concentrations of carbon dioxide and other greenhouse gases, or from other causes as revealed by proxy information in marine sediments and fossils; and (e) prediction of sea ice and other conditions that affect maritime transportation and submarine operations.

■ Research to understand how the coupled land and atmosphere components operate within the Arctic system. Emphasis should be on understanding to advance areas of concern complementary to those of the coupled ocean and atmosphere, namely (a) discovery and development, with minimal adverse environmental impact, of terrestrial nonrenewable resources, especially oil, gas, mineral, and hydrologic resources; (b) prediction of ecosystem reactions, particularly the effects of natural and human-induced disturbances on renewable resources; (c) understanding of atmosphere-land interactions as a basis for improved weather forecasting; and (d) understanding of the history of climatic change as revealed in ice sheets, permafrost sediments, and fossils, thereby facilitating prediction of climatic change.

■ Research to understand the high-latitude upper atmosphere and its extension into the magnetosphere. Emphasis should be on advancing our ability to predict disturbances in space and mitigating their effects on high-latitude communication and defense systems.

Much of the foregoing priority research contributes to the health, culture, and socioeconomic concerns of Arctic residents. In addition, considered separately from the foregoing priorities, the commission recommended that:

■ The highest priority research in the health-culture-socioeconomic component of the Arctic system should be on studies to identify and resolve the major health, behavioral, and cultural problems that derive from distinctive characteristics of the Arctic environment and from increasing resource development, industrialization, and urbanization.

For support services and management, the commission recommended that the following matters receive high-priority attention:

Fig. 4. Matrix of major research priorities. Check marks indicate research fields having high priority in relation to national issues. No order of priority is implied (*70*).

RESEARCH TO ADDRESS NATIONAL ISSUES	NATIONAL ISSUES IN THE ARCTIC: ARCTIC AS A NATURAL LABORATORY	NATURAL HAZARDS	NATIONAL DEFENSE	CLIMATE AND WEATHER	ENERGY AND MINERALS	TRANSPORTATION	COMMUNICATIONS	RENEWABLE RESOURCES	POLLUTION	ENVIRONMENTAL PROTECTION	HEALTH AND ADAPTATION	NATIVE CULTURE
UPPER ATMOSPHERE AND NEAR EARTH SPACE PHYSICS	√		√				√					
ATMOSPHERIC SCIENCES	√	√		√					√			
PHYSICAL AND CHEMICAL OCEANOGRAPHY	√	√	√	√	√	√		√		√		
MARINE LIFE SCIENCES	√			√	√			√	√	√		√
GLACIOLOGY AND HYDROLOGY	√	√		√	√			√	√			
GEOLOGY AND GEOPHYSICS	√	√		√	√							
PERMAFROST RESEARCH	√	√	√	√	√	√		√		√		
ARCTIC ENGINEERING	√	√	√		√	√	√	√		√	√	
TERRESTRIAL AND FRESH-WATER BIOLOGY	√			√				√	√	√		√
MEDICINE AND HUMAN BIOLOGY	√								√		√	√
SOCIAL AND CULTURAL RESEARCH	√				√		√	√			√	√
ECONOMICS	√				√	√		√		√		√

■ Consolidation of an Arctic data and information transfer system and related management policy to facilitate the storage and distribution of data, ready access to up-to-date research results, and rapid flow of information about research needs, including statistics and surveys (human health, demographics, socioeconomics), glaciological, anthropological and other records of past climates, natural events, and human activity in the Arctic.

■ Providing continuity in Arctic research, including mapping, baseline studies, and long-term monitoring of phenomena.

■ Furthering platform and logistic systems, in particular, assessing needs for terrestrial research sites.

Finally, the commission has recommended that in the area of federal-state cooperative research in the U.S. Arctic, priority attention should be focused on arctic data and information transfer, fisheries ecosystem research, and health.

Conclusion

The position of the Arctic in world affairs is becoming increasingly significant, and the national interest must be met with respect to security, weather and climate, natural resources, transportation, communications, environmental protection, health, culture, and socioeconomics. To meet the evolving challenges requires foresighted research in basic and applied science and careful planning to provide the necessary continuity and integration of effort mandated by the Arctic Research and Policy Act.

REFERENCES AND NOTES

1. P. J. Amaria, A. A. Bruneau, P. A. Lapp, Eds., *Arctic Systems*, NATO Conference Series, Series II: Systems Science, vol. 2 (Plenum, New York, 1977); H. C. Bach and J. Taagholt, *Greenland and the Arctic Region—Resources and Security Policy* [The Information and Welfare Service of the Danish Defense (Forsvarets Oplysnings og Veldfaerdstjeneste), Copenhagen, 1982].
2. W. E. Westermeyer and K. M. Shusterich, Eds., *United States Arctic Interests—The 1980's and 1990's* (Springer-Verlag, New York, 1984).
3. O. R. Young, *Oceanus* **29**, 9 (spring 1986).
4. J. H. Zumberge, *ibid.*, p. 3.
5. U.S. Congress, *Arctic Research and Policy Act of 1984* (Public Law 98-373).
6. D. M. Hickok *et al.*, *United States Arctic Science Policy* (Alaska Division, AAAS, 1981); Polar Research Board, Committee on Arctic Research Policy, *A United States Commitment to Arctic Research* (National Academy Press, Washington, DC, 1982); J. G. Roederer, *Eos* **64**, 10 (1983).
7. Central Intelligence Agency, *Polar Regions Atlas* (Government Printing Office, Washington, DC, 1978), p. 8; W. G. Kendrew, *The Climates of the Continents* (Clarendon, Oxford, ed. 5, 1961), pp. 462–463.
8. For instance, the mean January temperature at Isfjord Radio in Svalbard (78°N) is −10.9°C [E. Vowinckel and S. Orvig, in *Climates of the Polar Regions*, vol. 14 in *World Survey of Climatology*, S. Orvig, Ed. (Elsevier, Amsterdam, 1970), pp. 129–252, table 48], whereas it is −17.2°C in Winnipeg, Manitoba (50°N) [W. G. Kendrew, *The Climates of the Continents* (Clarendon, Oxford, ed. 5, 1961), p. 416]. Isfjord is a coastal station affected by the Gulf Stream.
9. Central Intelligence Agency, *Polar Regions Atlas* (Government Printing Office, Washington, DC, 1978), p. 17.
10. U.S. Department of Commerce (Bureau of the Census), *1980 Census of Population*, vol. 1, *Characteristics of the Population*, chapter B, "General Population Characteristics," part 3, *Alaska* (PC80-1-B3) (Government Printing Office, Washington, DC, 1982), table 15, pp. 3–9.
11. Polar Research Board, Ad Hoc Committee on the Upper Atmosphere and Near-Earth Space, *Study of the Upper Atmosphere and Near-Earth Space in Polar Regions: Scientific Status and Recommendations* (National Academy Press, Washington, DC, 1982).
12. W. W. Kellogg, in *Climate of the Arctic*, 24th Alaska Science Conference, 15–17 August 1973, G. Weller and S. A. Bowling, Eds. (Geophysical Institute, University of Alaska, Fairbanks, 1975), pp. 111–116; Polar Research Board, Committee on the Role of the Polar Regions in Climatic Change, *The Polar Regions and Climatic Change* (National Academy Press, Washington, DC, 1984), pp. 18–26.
13. W. W. Kellogg, in *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska—The Proceedings of a Conference*, J. H. McBeath, Ed. (Misc. Pub. 83-1, School of Agriculture and Land Resources Management, University of Alaska, Fairbanks, 1984), pp. 59–66; G. Weller, in (*2*), pp. 158–177.
14. J. H. McBeath *et al.*, in *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska—The Proceedings of a Conference*, J. H. McBeath, Ed. (Misc. Pub. 83-1, School of Agriculture and Land Resources Management, University of Alaska, Fairbanks, 1984), pp. 193–195.
15. Board on Atmospheric Sciences and Climate, Carbon Dioxide Assessment Committee, *Changing Climate* (National Academy Press, Washington, DC, 1983); Polar Research Board, Committee on Glaciology, *Glaciers, Ice Sheets, and Sea Level: Effects of a CO_2-Induced Climatic Change* (National Academy Press, Washington, DC, 1985); M. C. MacCracken and F. M. Luther, Eds., *The Potential Climatic Effects of Increasing Carbon Dioxide*, U.S. Department of Energy, DOE/ER/0237, 1985; M. E. Schlesinger, *Adv. Geophys.* **26**, 141 (1984); United Nations Environmental Program/World Meteorological Office/International Council of Scientific

Unions, *An Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts* (Conference Statement, Villach, Austria, 9–15 October 1985).
16. G. Weller *et al.*, in *Changing Climate*, Board on Atmospheric Sciences and Climate, Carbon Dioxide Assessment Committee (National Academy Press, Washington, DC, 1983), pp. 292–382.
17. R. C. Schnell, Ed., *Geophys. Res. Lett.* **11**, 359 (1984).
18. J. L. Sarmiento and J. R. Toggweiler, *Nature (London)* **308**, 621 (1984).
19. I. Dyer, in *Arctic Technology and Policy*, Second Annual MIT Sea Grant College Program Lecture and Seminar, Proceedings, and Third Annual Robert Bruce Wallace Lecture, I. Dyer and C. Chryssostomidis, Eds. (Hemisphere, Washington, DC, 1984), pp. 11–37.
20. M. A. Fraker, *Balaena mysticetus: Whales, Oil, and Whaling in the Arctic* (Sohio Alaska Petroleum Co. and BP Alaska Exploration Inc., Anchorage, 1984), pp. 30–51.
21. D. J. Baker, *Oceanus* **29**, 41 (spring 1986).
22. M. J. Dunbar, *ibid.*, p. 36.
23. O. M. Johannessen *et al.*, in (*19*), pp. 133–146; H. Melling, Preparer, *Ventilation of the Arctic Ocean—A Report on a Workshop Funded by the Division of Polar Programs, National Science Foundation*, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL, 29–31 October 1984 (Institute of Ocean Sciences, Sidney, British Columbia, Canada, 1985); World Climate Programme, *Report of the Meeting of Experts on Sea Ice and Climate Modelling*, in Geneva, Switzerland, 12–16 December 1983 (World Meteorological Organization Report WCP-77, Geneva, 1984).
24. U.S. Geological Survey and State of Alaska Department of Natural Resources, *Alaska Water Resource Evaluation, 5-Year Plan 1984–1988* (Anchorage, 1984).
25. C. C. Langway, Jr., H. Oeschger, W. Dansgaard, Eds., *Greenland Ice Core: Geophysics, Geochemistry, and the Environment* (American Geophysical Union Monograph 33, 1985); G. deQ. Robin, Ed., *The Climatic Record in Polar Ice Sheets* (Cambridge Univ. Press, Cambridge, 1983); E. W. Wolff and D. A. Peel, *Nature (London)* **313**, 535 (1985).
26. C. S. M. Doake and E. W. Wolff, *Nature (London)* **314**, 255 (1985); G. Hattersley-Smith, *ibid.*, **315**, 462 (1985); W. S. B. Paterson, *ibid.*, **318**, 82 (1985); J. Weertman, *ibid.*, **314**, 227 (1985); R. L. Hooke, *Rev. Geophys. Space Phys.* **19**, 664 (1981).
27. Maritime Transportation Research Board, *Maritime Services to Support Polar Resource Development* (National Academy Press, Washington, DC, 1981).
28. W. F. Weeks and G. Weller, *Science* **225**, 371 (1984).
29. W. F. Weeks and M. Mellor, in (*19*), pp. 235–259.
30. B. G. Andersen, in *The Last Great Ice Sheets*, G. H. Denton and T. J. Hughes, Eds. (Wiley, New York, 1981), pp. 1–65; G. H. Denton and T. J. Hughes, *ibid.*, pp. 437–467; P. A. Mayewski, G. H. Denton, T. J. Hughes, *ibid.*, pp. 67–178; J. T. Andrews, J. A. Stravers, G. H. Miller, in *Models in Geomorphology*, M. J. Woldenberg, Ed. (Allen & Unwin, Boston, 1985), pp. 93–117; W. W. Shilts, *ibid.*, pp. 73–91; G. S. Boulton *et al.*, *Nature (London)* **298**, 437 (1982); I. D. Danilov, *Polar Geogr. Geol.* **4** (No. 1), 15 (1980); A. Elverhøi and A. Solheim, *Polar Res. (Oslo)* **1**, 23 (1983); J. England, *Can. J. Earth Sci.* **20**, 895 (1983); M. G. Grosval'd, *Polar Geogr. Geol.* **8** (No. 3), 194 (1984); *ibid.* (No. 4), p. 287; K. N. Nesis, *Sov. J. Mar. Biol.* **9**, 300 (1984); J.-S. Vincent, *Geol. Surv. Can. Pap. 84-10* (1984), p. 88.
31. D. A. Hodgson and J.-S. Vincent, *Quat. Res. (N.Y.)* **22**, 18 (1984).
32. Polar Research Board, Ad Hoc Study Group on Offshore Permafrost, *Problems and Priorities in Offshore Permafrost Research* (National Academy Press, Washington, DC, 1976).
33. K. G. Neave and P. V. Sellmann, in *The Alaskan Beaufort Sea—Ecosystems and Environments*, P. W. Barnes, D. M. Schell, E. Reimnitz, Eds. (Academic Press, New York, 1984), pp. 237–258.
34. L. A. Lawver, A. Grantz, L. Meinke, in (*19*), pp. 147–158.
35. R. Zahn, B. Markussen, J. Thiede, *Nature (London)* **314**, 433 (1985).
36. N. Davis, *Energy/Alaska* (Univ. of Alaska Press, Fairbanks, 1984).
37. J. N. Garrett, in (*2*), pp. 39–58.
38. U.S. Congress Office of Technology Assessment, *Oil and Gas Technologies for the Arctic and Deepwater* (OTA-0-270) (Government Printing Office, Washington, DC, 1985), pp. 21, 30–31.
39. W. W. Barnwell and K. S. Pearson, *Alaska's Resource Inventory* (Special Report 36, Department of Natural Resources, Division of Geological and Geophysical Surveys, State of Alaska, 1984), pp. 28–29.
40. T. P. Miller, in (*2*), pp. 59–74.
41. North Slope Borough Science Advisory Committee, *Research Needs in Environmental Science and Engineering for the U.S. Arctic (1985–1990)* (North Slope Borough, Barrow, Alaska, 1985), pp. 13–17.
42. E. F. Roots, in *The Arctic Ocean—The Hydrographic Environment and the Fate of Pollutants*, L. Rey, Ed. (Macmillan, London, 1982), pp. 215–232.
43. Central Intelligence Agency, *Polar Regions Atlas* (Government Printing Office, Washington, DC, 1978), p. 20; U.S. Department of Commerce, *Bering, Chukchi, and Beaufort Seas, Coastal and Oceanic Zones Strategic Assessment: Data Atlas*, preliminary edition (National Oceanic and Atmospheric Administration, November 1985), pp. 3.34 and 4.12.
44. J. J. Burns, in (*2*), pp. 75–104.
45. T. Berger, *Oceanus* **29**, 81 (spring 1986); *Annual Report of the Marine Mammal Commission, Calendar Year 1984—A Report to Congress* (Marine Mammal Commission, Washington, DC, 1985), pp. 100–105.
46. Polar Research Board, Committee to Evaluate DOE's Arctic Terrestrial Environmental Research Programs, *Arctic Terrestrial Environmental Research Programs of the Office of Energy Research, Department of Energy: Evaluation and Recommendations* (National Academy Press, Washington, DC, 1982).
47. J. A. Kruse, in (*2*), pp. 134–157.
48. C. V. Haynes, in *Paleoecology of Beringia*, D. M. Hopkins, J. V. Matthews, Jr., C. E. Schweger, S. B. Young, Eds. (Academic Press, New York, 1982), pp. 383–398; R. E. Morlan and J. Cinq-Mars, *ibid.*, pp. 353–381; H. Müller-Beck, *ibid.*, pp. 329–352; D. E. Nelson, R. E. Morlan, J. S. Vogel, J. R. Southon, C. R. Harington, *Science* **232**, 749 (1986).
49. D. M. Hopkins, J. V. Matthews, Jr., C. E. Schweger, S. B. Young, Eds., *Paleoecology of Beringia* (Academic Press, New York, 1982).
50. In view of its scale, the petroleum industry exerts a particularly influential role. See M. M. R. Freeman, in *Petroleum Effects in the Arctic Environment*, F. R. Engelhardt, Ed. (Elsevier, New York, 1985), pp. 245–273.
51. S. E. Fry, *Native Arctic Peoples: A Growing Political and Economic Identity* (26th session, Foreign Service Institute Executive Seminar in National and International Affairs, U.S. Department of State, 1983–1984).
52. The Alaska Native Claims Settlement Act (ANCSA) provided for a settlement of 44 million acres of land and almost $1 billion. After 1991, the land can be sold to outsiders; this and other threats to the land and the question of self-rule and subsistence living are key issues. See T. R. Berger, *Village Journey—The Report of the Alaska Native Review Commission* (Hill and Wang, New York, 1985).
53. E. Brower and J. Stotts, in (*2*), pp. 319–344; J. Motzfeldt, addresses, University of Alaska, Fairbanks, 13–14 May 1985. (In his addresses, at commencement and before the Comité Arctique International, Premier Motzfeldt of Greenland forcibly stressed self-determination of the native peoples); North Slope Borough Science Advisory Committee, *Research Needs in Environmental Science and Engineering for the U.S. Arctic (1985–1990)* (North Slope Borough, Barrow, Alaska, 1985); G. N. Ahmaogak, Sr., talk prepared for Unesco Man in the Biosphere Conference on Arctic Science Policy and Development: Local and International Perspectives (Fairbanks, Alaska, 28 August 1985).
54. For example, a low bone mineral content in some indigenous populations [A. B. Harper, W. S. Laughlin, R. B. Mazess, *Hum. Biol.* **56**, 63 (1984)].
55. Polar Research Board, Ad Hoc Committee on Polar Biomedical Research, *Polar Biomedical Research—An Assessment* (National Academy Press, Washington, DC, 1982); R. Fortuine, Ed., *Circumpolar Health 84—Proceedings of the Sixth International Symposium on Circumpolar Health* (Univ. of Washington Press, Seattle, 1985).
56. M. C. Brewer, oral and written communication to public meeting on Arctic Research and Policy Act, Anchorage, Alaska, 2 March 1985; C. Pierce, personal communication.
57. American Public Health Association Task Force, *The National Arctic Health Science Policy* (American Public Health Association Report Series, 1984), p. 7.
58. F. L. Bennett and J. L. Machemehl, Eds., *Civil Engineering in the Arctic Offshore* (Proceedings of the Conference Arctic '85, American Society of Civil Engineers, New York, 1985); B. C. Gerwick, Ed., *Arctic Ocean Engineering for the 21st Century*, First Spilhaus Symposium (Marine Technology Society, Washington, DC, 1985); V. Haneman and R. Carlson, Eds., *Arctic Research Needs in Civil Engineering* (School of Engineering, University of Alaska, Fairbanks, 1985); Marine Board, Committee on Assessment of Arctic Ocean Engineering Support Capability, *U.S. Capability to Support Ocean Engineering in the Arctic* (National Academy Press, Washington, DC, 1984); W. L. Ryan, Ed., *Cold Regions Engineering*, Proceedings of the Fourth International Conference (American Society of Civil Engineers, New York, 1986).
59. B. Keller, *New York Times*, 25 January 1985, p. A3; *ibid.*, 27 January 1985, p. E3; C. S. Wren, *ibid.*, 28 January 1985, p. A5; *Seattle Times/Seattle Post-Intelligencer*, 23 February 1986, p. E8.
60. Scientific Advisory Commission to the University of Alaska Foundation, *Trustees of Alaska's Future* (Alaska Research Development Project, Fairbanks, 1985), pp. 35–37.
61. R. B. Weeden, in *Alaskan Resources Development—Issues of the 1980's*, T. A. Morehouse, Ed. (Westview, Boulder, CO, 1984), pp. 135–168.
62. G. Weller, in (*2*), pp. 158–177.
63. U.S. Congress Office of Technology Assessment, *Research Needs for Arctic and Sub-Arctic Regions* (Washington, DC, 1982), pp. 62–63; NASA Science Working Group for the Special Sensor Microwave Imager (SSM/I), *Passive Microwave Remote Sensing for Sea-Ice Research* (Applied Physics Laboratory, University of Washington, Seattle, 1984); W. E. Westermeyer, in (*2*), pp. 105–133.
64. U.S. Departments of Interior, Defense, and Energy, *A Study of United States Arctic Research Policy and the Possible Roles of the Naval Arctic Research Laboratory* (U.S. Department of the Interior, Washington, DC, 1982).
65. L. W. Brigham, *Oceanus* **29**, 47 (spring 1986); R. Elsner, *Ice-Worthy Research Ships of the World* (Institute of Marine Science, University of Alaska, Fairbanks, 1985); U.S. Coast Guard, *United States Polar Icebreaker Requirements Study—Interagency Report* (U.S. Department of Transportation and U.S. Coast Guard, Washington, DC, 1984), pp. 5–29.
66. J. G. Roederer, in *International Symposium on Arctic Air Pollution, Cambridge, England, 2–5 September 1985* (in press); E. F. Roots, *International and Regional Cooperation in Arctic Science: A Changing Situation* (Nordisk Konferanse om Arktisk Forskning, Ny Ålesund, Svalbard, 2–8 August 1984).
67. Several unresolved territorial issues involving Arctic waters exist between Canada and the United States [R. L. Friedheim and M. Fry, *Final Report to the William H. Donner Foundation, Inc., on the U.S.–Canada Arctic Policy Forum*, 20–23 October 1984 (Institute for Marine and Coastal Studies and School of International Relations, University of Southern California, Los Angeles, 1984); K. M. Shusterich, in (*2*), pp. 240–267]. However, research and other ties remain strong.
68. Greenland was an integral part of Denmark before 1 May 1979 when Home Rule was introduced. Greenland is now independent except in foreign affairs, defense, and judicial and monetary matters, which remain under the control of Denmark.
69. W. Østreng, *Politics in High Latitudes—The Svalbard Archipelago* (McGill-Queen's Univ. Press, Montreal, 1978); Royal Ministry of Justice Report No. 39 to the Norwegian Storting (1974–1975), *Concerning Svalbard* (Oslo, 1975) (abridged translation).
70. Polar Research Board, *National Issues and Research Priorities in the Arctic* (National Academy Press, Washington, DC, 1985).
71. U.S. Arctic Research Commission, *National Needs and Arctic Research: A Framework for Action* (working paper) (U.S. Arctic Research Commission, Los Angeles, 27 February 1986); see also J. G. Roederer, *Eos*, in press.
72. National Science Foundation, news release PR 86-10 (3 February 1986), reporting on action of Interagency Arctic Research Policy Committee.
73. We thank J. G. Roederer for helpful suggestions during preparation of the initial manuscript. The comments of colleagues and the welcome criticism of an anonymous reviewer led to further improvements.