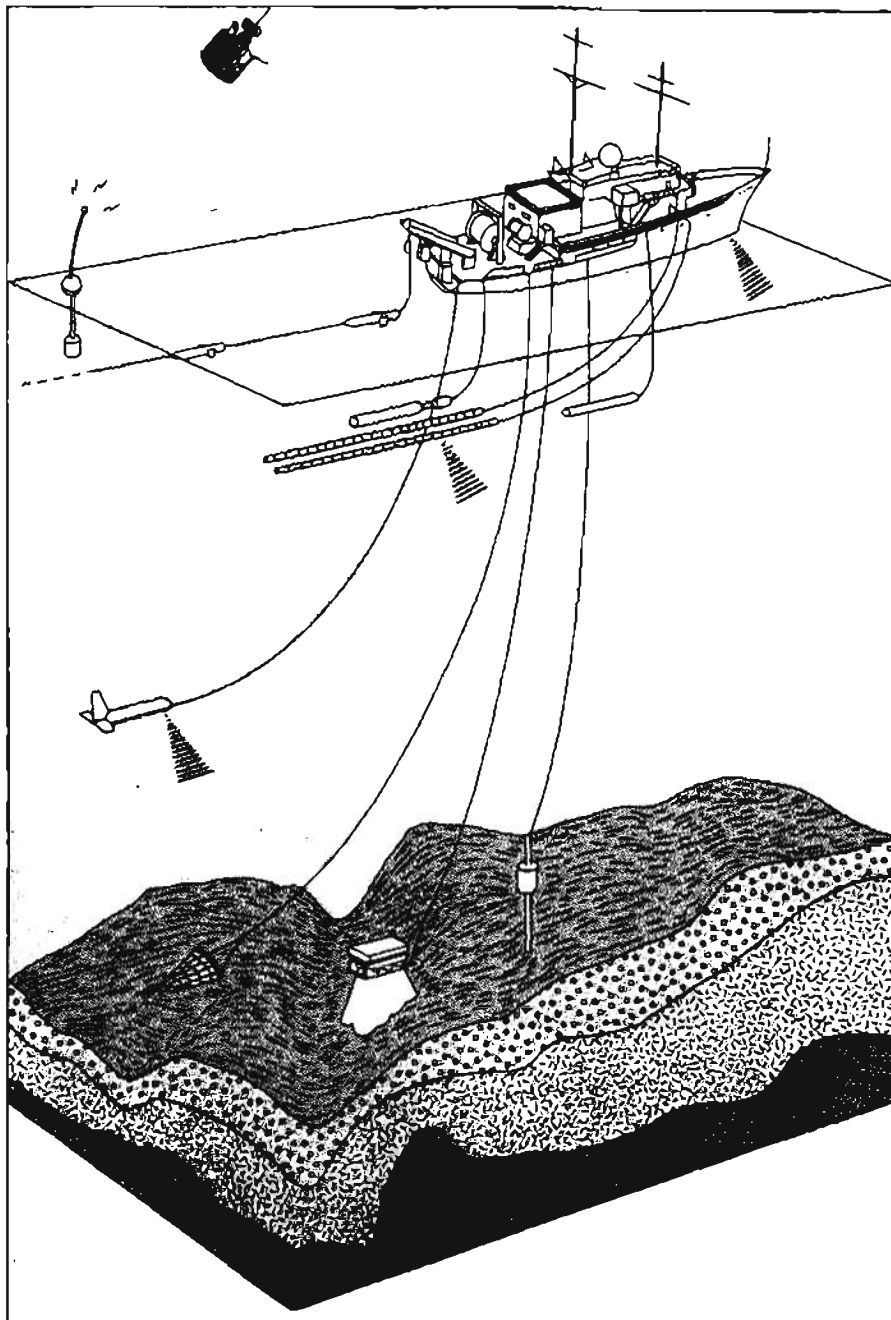


Proceedings of the 1987 Exclusive Economic Zone Symposium on Mapping and Research: Planning for the Next 10 Years

U.S. GEOLOGICAL SURVEY CIRCULAR 1018



Proceedings of the 1987 Exclusive Economic Zone Symposium on Mapping and Research: Planning for the Next 10 Years

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Sponsored by the USGS-NOAA Joint Office for Mapping and Research in the EEZ

Meetings held at the USGS National Center, Reston, Virginia, November 17-19, 1987



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PART 2: WORKSHOP RESULTS

Workshop 1: Scientific Mapping and Research to Characterize the EEZ—Alaska

Panel Co-chairpersons:

Michael S. Marlow, U.S. Geological Survey

Douglas A. Wolfe, National Oceanic and Atmospheric Administration

INTRODUCTION

The Alaskan Exclusive Economic Zone (EEZ) has an enormous area of approximately 4.8×10^6 km², or about 60 percent of the total EEZ area that is associated with the contiguous United States and Alaska. The Alaskan EEZ is composed of diverse geologic elements and supports a rich and productive assemblage of biological resources. For purposes of mapping in the U.S. Geological Survey (USGS) Continental Margin Map Series (Peck and Hill, 1986), the Alaskan EEZ is divided into 8 areas (of the 20 for the entire United States, including Hawaii). The Minerals Management Service (MMS) has further divided these areas into a current total of 14 planning areas for exploration and potential development of oil and gas reserves on the Alaskan Outer Continental Shelf (OCS) (fig. 1). For this presentation, however, the offshore Alaskan EEZ will be discussed as three regions: the Gulf of Alaska and Aleutian Island Arc, the Bering Sea, and the Arctic region north of the Bering Strait. The tectonic elements of these regions are diverse, ranging from the actively subducting margin in the western Gulf of Alaska and the eastern and central Aleutian Arc, through the actively transforming margins of the eastern Gulf of Alaska and western Aleutian Arc, to the formerly active margin of the Bering Sea as well as the rifted and totally passive Arctic margin.

A large number of major sedimentary basins occur within the Alaskan EEZ (fig. 2). In the Bering Sea the EEZ extends to the 1867 U.S.-U.S.S.R. Convention Line and includes the deepwater Aleutian and Bowers Basins.

The purposes of this report are:

1. To outline scientific objectives for characterizing and evaluating the mineral, energy, and other nonliving resources of the seabed and subsoil of the Alaskan EEZ and for understanding the geological framework and processes in which and by which those resources are formed and
2. To identify the consequent research and mapping activities needed to support effective development and use of those resources.

Although the research program developed in this report focuses primarily on nonliving resources, it is recognized that any eventual development of those resources must be carried out in an environmentally sound manner, with due regard for resource-use conflicts that may arise, for example, with interests such as transportation, commercial and subsistence fisheries, or threatened and endangered species. These concerns are being addressed by the Information Needs for Seafloor-Seabed Utilization Panel (Silva and others, this volume) and will not be discussed here.

This report presents a brief introduction to the diverse environmental characteristics and major geological and structural features within each Alaskan region. Existing programs and data coverage in each area are discussed relative to the outstanding problems and needs in each region. Programs are then outlined and recommended for acquiring and managing additional information needed for effective exploration of the Alaskan EEZ.

AREA DESCRIPTIONS

The Gulf of Alaska and Aleutian Island Arc

The Gulf of Alaska region is geologically very dynamic. Located at the juncture of the North American and subducting Pacific crystal plates, the region exhibits a large amount of seismotectonic activity, manifested by ground shaking, tsunamis, and submarine slumping. The Gulf of Alaska is bounded by the south coast of Alaska, which is arcuate and extends for hundreds of kilometers, from the Alaska panhandle on the east side of the Gulf to the Alaska Peninsula on the west. To the west of the Alaska Peninsula, the North Pacific Ocean is bounded by the Aleutian Arc. Altogether this EEZ area is about 2.2×10^6 km². This coastline is the most complex in the State and contains a large variety of geomorphological features, dominated by the presence of rugged mountains. Many of the volcanic mountains in the Alaska and Aleutian ranges are active and have erupted in historical times, including Augustine in lower Cook Inlet, Katmai at the base of the Alaska Peninsula, and Pavlof on the southwest end of the peninsula.

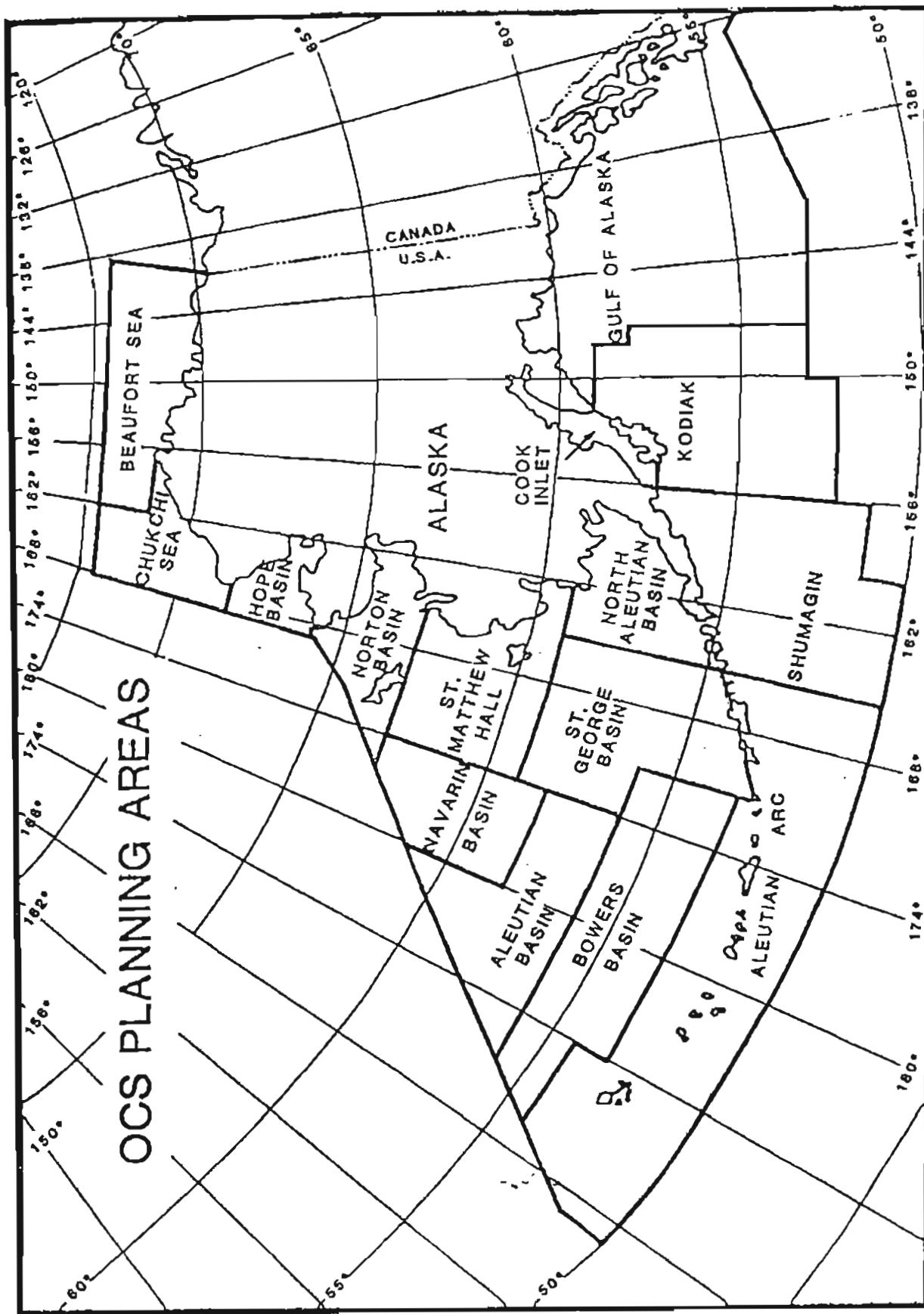


Figure 1. Planning areas under consideration by the U.S. Minerals Management Service for potential oil and gas development on the Outer Continental Shelf of Alaska.

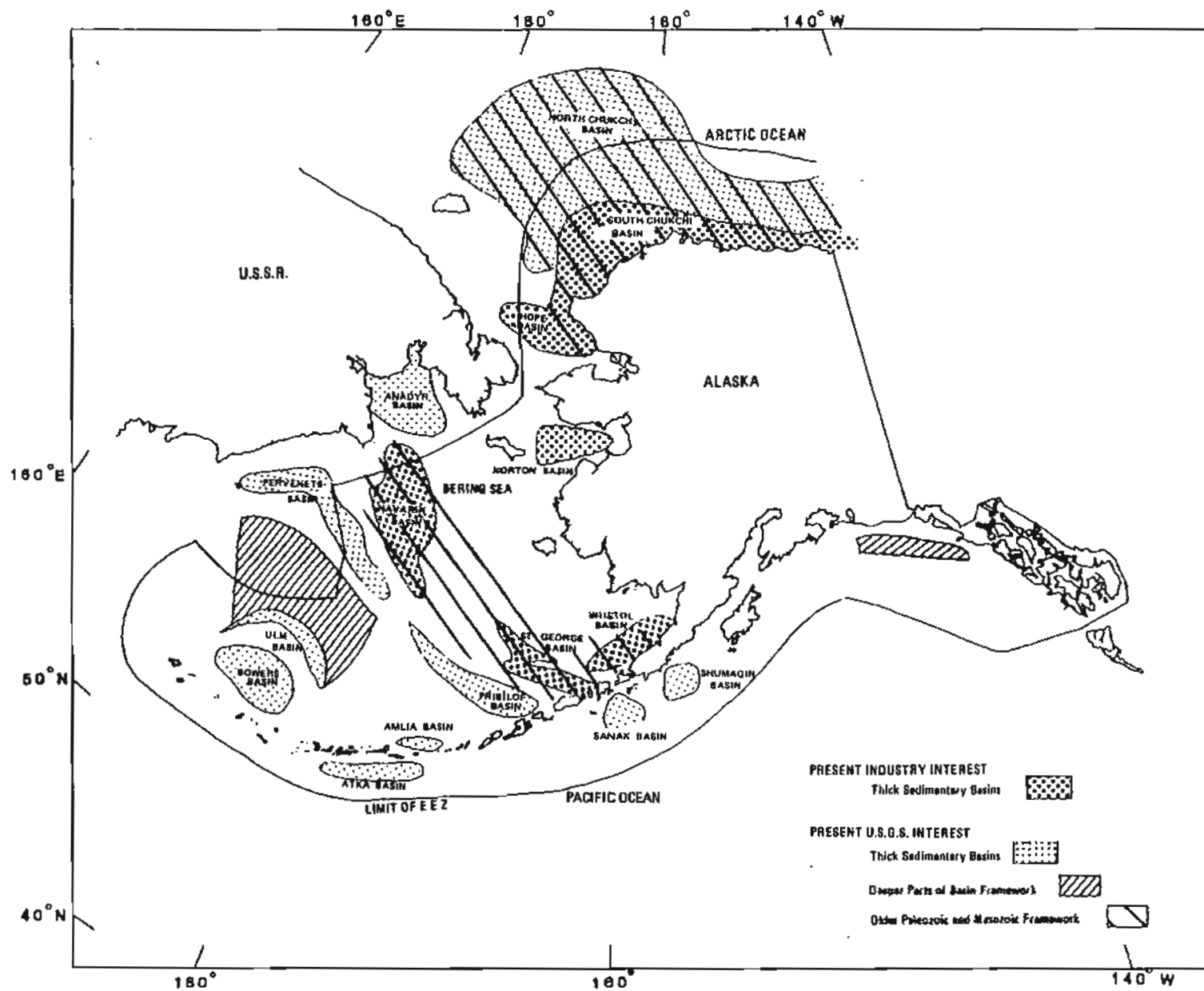


Figure 2. Locations of major basins within the EEZ of Alaska and adjacent areas (modified from Klitgord and Watkins, 1984).

Coastal plains are few in the Gulf of Alaska region. The only flatlands of any significant extent occur on the east side of Cook Inlet and between Dry Bay and Yakutat. The coastal segment extending from Cross Sound in southeastern Alaska westward to Prince William Sound is typified by unprotected shorelines and has only three embayments of consequence: Lituya, Yakutat, and Icy Bays. Prince William Sound is in essence an inland sea, being a complex of islands and fjords relatively sheltered from the open gulf. The rocky coastlines of the Kenai Peninsula and Kodiak Archipelago are indented by numerous fjords and embayments. Cook Inlet is a large, shallow estuary, some 250 km long and from 25 to 100 km wide. The south coast of the Alaska Peninsula is steep and rugged. Bays are numerous along the peninsula, as are islands along its western half.

The continental shelf in the Gulf of Alaska is narrow in comparison to the shelf in the Bering and Chukchi Seas. Some 100 km wide in the vicinity of the Fairweather Ground south of Yakutat, the shelf narrows to about 10 km off Bering Glacier, then widens to about 150 km in the vicinity of Kodiak before progressively decreasing in width toward the tip of the Alaska Peninsula. The shelf is dissected by numerous sea valleys and troughs, a number of which appear to be glacial in origin. Major topographic highs include the Fairweather Ground southeast of Yakutat, Portlock and Albatross banks off Kodiak Island, and emergent features such as Middleton Island in the northern gulf and the many islands in the western gulf.

The climate in the Gulf of Alaska is maritime, characterized by heavy precipitation, cool summers, and relatively warm winters. Due to the mild climate prevalent in the outer Gulf of Alaska, sea ice does not form in winter. However, the more rigorous climatic conditions and shallow water in parts of Cook Inlet promote ice formation, typically north of the Forelands and along the west side of the inlet, for about 2 months during the winter. Much of the snowfall deposited on the mountains along the Gulf coast feeds icefields, piedmont glaciers, and valley glaciers. Many glaciers and icefields extend to near the coast and some enter tidewater and are localized sources of icebergs, for example in Icy Bay and near Columbia Glacier in Prince William Sound.

Major storms are commonplace in the Gulf of Alaska. They are most intense in winter, when the storm tracks frequently lie along and south of the Aleutian Islands and Alaska Peninsula. Storms generally move eastward through the region and stagnate in the eastern gulf. In late summer and fall, by contrast, many storms move into the Bering Sea. High coastal winds also occur as episodic, katabatic events, flowing downward through mountain passes and river valleys and sometimes extending 30 km offshore. They are commonplace at the Copper River Delta and Dry Bay in the eastern gulf and near Cape Douglas on the west side of Cook Inlet.

Streams associated with the coastal mountains are mainly short and often of the glacial outwash type: typically of steep gradient, braided, and carrying high sediment loads. Only the Alsek and Copper Rivers penetrate through the coastal mountains from the interior and enter the Gulf of Alaska. Coastal waters turbid with glacial rock flour prevail in the eastern gulf westward to Prince William Sound, and in much of Cook Inlet. Elsewhere in the gulf the waters are relatively free of sediment. Tides in the gulf of Alaska are mixed, predominantly semidiurnal, with amplitudes averaging 3 to 5 m but attaining as much as 10 m at the head of Cook Inlet.

The Gulf of Alaska is rich in biotic resources. Diverse fish communities and marine mammals such as sea otters and harbor seals are associated with widespread kelp beds. Salmon, crab, herring, and halibut form the basis for domestic fisheries in the region, while foreign fisheries target on ground fish. Coastal and shelf waters also support large populations of birds and marine mammals.

Major goals of geologic studies in the Gulf of Alaska have included detailed investigation into the tectonic processes and geologic history of both convergent and transform margins or the transition between these margin types. Past research in the gulf has focused on the regional geologic framework, the processes active in subduction zones, and hydrocarbon generation along transform and convergent margins. In the western half of the Gulf of Alaska (west of 148°W.) no exploratory wells have been drilled for petroleum. Development of possible hydrocarbon resources may be adversely affected by the high seismicity of the margin beneath the gulf. The allochthonous Yakutat block is colliding with the continent below the eastern Gulf of Alaska, and investigations are continuing into the processes within this collision zone and into the structural transition that connects the collision zone with the adjacent subduction zone. Marine geologic and geophysical data show the structure of the Yakutat block, and in the future, these data may suggest the location boundaries of other tectonostratigraphic terranes.

To the west of the Gulf of Alaska, the Aleutian Ridge forms much of the northern rim of the Pacific Ocean. The island-crested ridge extends roughly 2,200 km westward from the tip of the Alaska Peninsula to near Kamchatka, 1,700 km of this length being part of the United States EEZ (fig. 3). The ridge, which divides the Pacific Basin from the Bering Sea Basin, defines an areal expanse of the EEZ of about 800 km × 1,700 km, or 1.4×10^6 km² (400,000 nautical mi²). Geomorphically the ridge averages 160 km in width, and the ridge relief is a spectacular 9,300 m, measured from the floor of the Aleutian Trench at 7,300 m below sea level to the volcanic summits of Umnak Island.

The vast bulk and diverse geomorphic form of the Aleutian Ridge record important North Pacific tectonic events and crust-forming processes. Volumetrically large masses of sedimentary deposits have accumulated over the

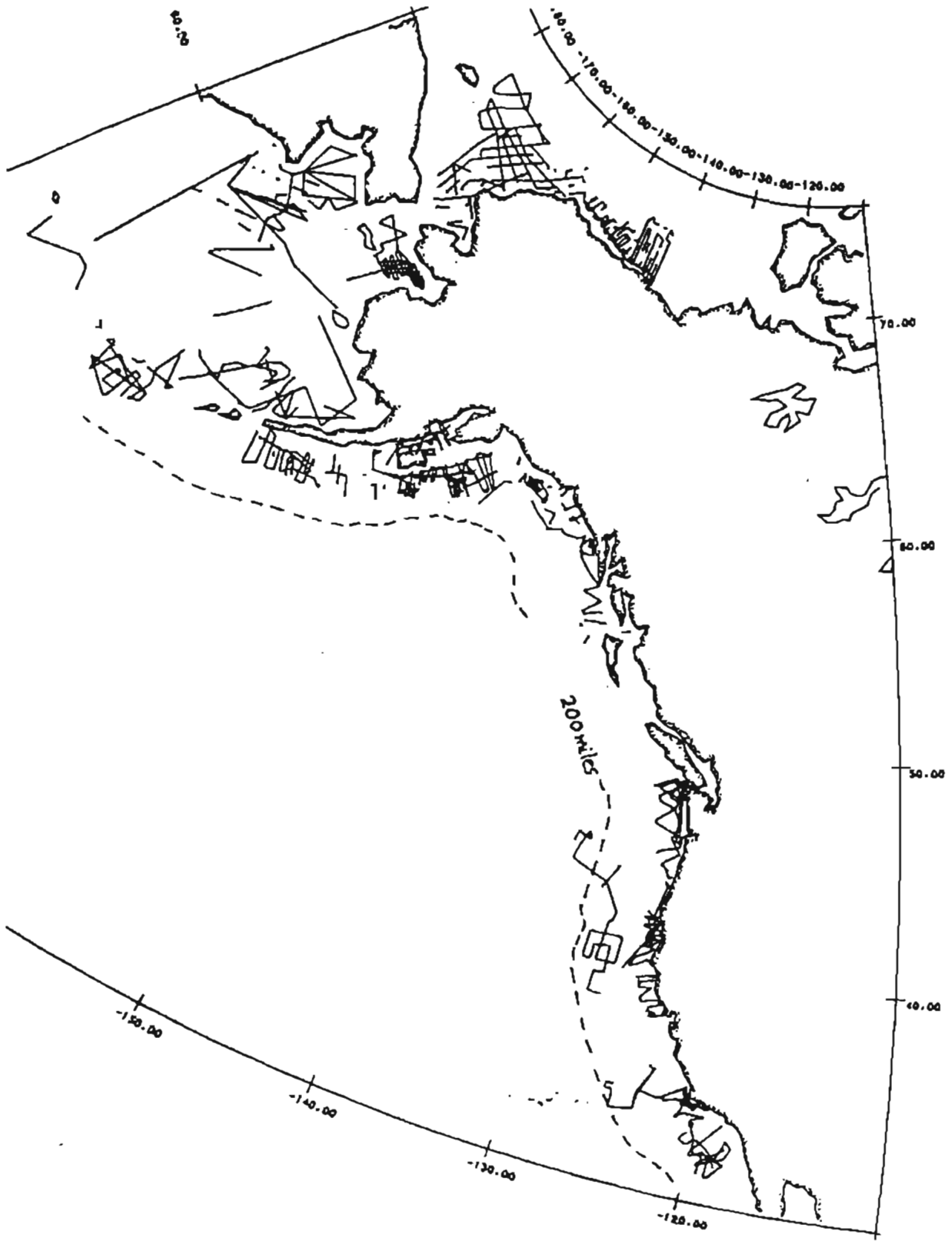


Figure 3. Tracklines for existing geophysical information available from the U.S. Geological Survey for the west coast of North America and Alaska.

submerged flanks of the ridge and in crestal or summit basins. However, only a limited amount of reconnaissance seismic reflection data are available to study these deposits and their resource potential. The combined line-mileage of multichannel seismic reflection (MCS) profiles collected over the Aleutian Ridge is roughly 3,000 km. Eighty-five percent of these tracks are confined to the ridge's 300-km-long Adak-Amliia sector (172°–176°W. long; fig. 4). Single-channel reflection profiles are also mostly confined to this ridge sector, as are samples of submerged outcrops. Thus, for the remaining 1,400 km of ridge length, only 400 km of MCS data and a few hundred pounds of rocks are available for study. Owing to this paucity of research-quality MCS and other related geophysical data, and offshore rock samples, the geologic history of the Aleutian Ridge is poorly known and the resource potential of the Aleutian Island Arc region is, accordingly, even less understood.

Bering Sea

The eastern Bering Sea, with about 2×10^6 km² of EEZ area, borders the western coast of Alaska and extends approximately 1,500 km from the Aleutian Islands to the Bering Strait. Seasonal contrasts are extreme: during winter over half of the sea surface is covered with ice; during summer, sea surface temperatures may become almost temperate, exceeding 16°C in the eastern portion of Norton Sound.

The strong westward flow of the Alaska Stream provides the waters that penetrate into the Bering Sea through deep passes in the Aleutian Islands. In the eastern part of the sea, three fronts (regions of enhanced horizontal gradients of properties) separate the water overlying the shelf into distinguishable domains with distinctive hydrographic and stratification properties. Shelf circulation is generally sluggish and characterized by the presence of nonstationary eddies.

Advances and retreats of the ice edge are correlated with fluctuations in sea and air temperatures, surface winds, and regional meteorological events. Ice formation usually begins in mid-October and may persist in some areas through June, although the retreat of the ice edge begins in April. In extreme years ice may extend as far south as Unimak Island; generally the southern limit is from northern Bristol Bay to the vicinity of St. George Island in the Pribilof Islands.

The continental shelf in the eastern Bering Sea is very broad, extending over 640 km offshore in the northeastern sector. More than 44 percent of the Bering Sea is covered by the shelf, with the 200-m isobath approximately dividing the sea in half. This extensive shelf area supports high abundances of commercially valuable fish and shellfish and large populations of marine mammals and seabirds.

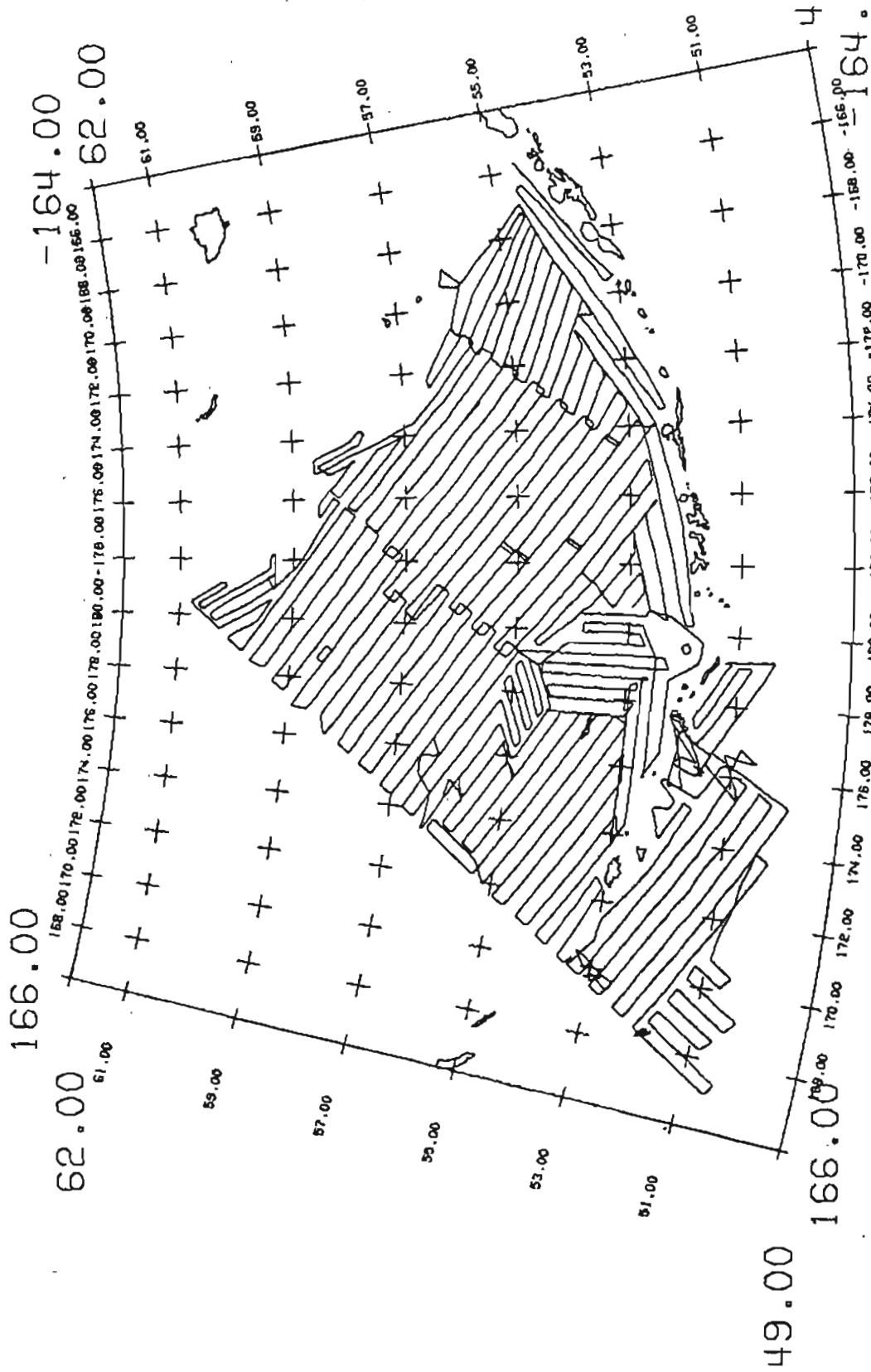
North of Bristol Bay the coastline flattens out into the broad, deltaic lowlands of the Yukon and Kuskokwim Rivers. Here, intertidal areas are often wide and storm surges extend as far as 40 km inland. Although this section of the Bering Sea is dominated by the sediment-laden waters of the Yukon and Kuskokwim Rivers, so-called clearwater areas occur between the major distributaries. The clearwater areas have recently been pinpointed as being among the most biologically productive areas in the central portion of the eastern Bering Sea coast.

Norton Sound, in the northeastern Bering Sea, is a rather isolated body of water; its hydrography and circulation are dominated by local wind and atmospheric patterns. Recent evidence indicates that the outer part of Norton Sound is distinguishable from the inner by persistent oceanographic features. The water of the outer sound is dominated by a northerly flow between the sound and St. Lawrence Island. Nearshore regions of Norton Sound are subjected to regular scouring by seasonal ice.

The eastern Bering Sea supports a rich and diverse biota. The bulk of the commercial fishery resources, principally king crab, snow crab, and salmon, occurs in the southern portion of the region. Nineteen species of cetaceans and eight species of pinnipeds occur in the eastern Bering Sea. The Pribilof Islands are the primary breeding ground for most of the world population of northern fur seals, while the northern Bering Sea and southern Chukchi Sea are the feeding grounds for about 95 percent of the world population of gray whales. Several species of seals and walrus are commonly associated with sea ice and depend upon it as a substrate for their breeding and molting. Bowhead and beluga whales also winter along the ice edge or in ice-infested areas. In addition, the bird populations in the eastern Bering Sea compose one of the richest avian faunas on Earth. These birds depend upon the exceptionally high productivity of the Bering Sea waters for maintenance of their dense populations.

The Beringian continental margin extends about 1,500 km northwest from the Alaska Peninsula to the U.S.S.R. (fig. 2). The outer part of the margin is underlain by a series of linear basement ridges and extensional sedimentary basins, which contain up to 15 km of Cenozoic and possibly late Mesozoic strata. Oceanic crust of Cretaceous age and 3 to 10 km of overlying Cenozoic sedimentary rocks are believed to lie beneath the Aleutian Basin, adjacent to the margin.

The assessment of the resource potential of the Beringian margin is predicated on the understanding of the geologic processes that formed hydrocarbons and other minerals along the margin. Possible commodities on the margin and Bering shelf include oil and gas, heavy metals such as platinum and gold, and sand and gravel. Many other minerals may exist offshore, but they await exploration and discovery. Appraisal of the resource potential of the margin requires interdisciplinary studies of terrane accretion, basin



BERING SEA AREA: LE COCO PROJECTION AT 1:11000000

Figure 4. Tracklines for GLORIA data in the deep portion of the Bering Sea.

formation, deep crustal structure, and margin collapse to assess the tectonic history of this portion of western North America. The deepwater region beyond the margin (the Aleutian Basin) is unexplored with respect to resource potential. Only reconnaissance single-channel seismic reflection and GLORIA surveys have systematically covered the basin, except for a couple of widely spaced multichannel seismic reflection lines.

Arctic

The American sector of the Arctic Ocean extends from the Bering Strait (66°N., 168°W.) to Demarcation Bay (69°N., 141°W.). This region of the EEZ, about 660×10^3 km² in area, comprises portions of the Chukchi and Beaufort Seas and is bounded by over 1,000 km of coastline.

The Chukchi Sea is a shallow marine basin with water depths of less than 100 m extending several hundred kilometers offshore. Its circulation is influenced by ocean currents flowing predominantly northward and carrying relatively warm Alaskan coastal water into the region. These northward coastal currents combine with a westward drift along the southern margin of the Arctic ice pack to establish a broad counterclockwise summer circulation in the Chukchi Sea.

The Beaufort Sea has a relatively narrow continental shelf extending 50 to 100 km offshore. The adjoining Canada abyssal plain is more than 3,000 m deep. Circulation patterns in the Beaufort Sea are generally dominated by the circulation patterns of the Arctic Ocean. Ocean currents flow westward between Mackenzie Bay and Point Barrow under the influence of the clockwise Arctic gyre. These waters are generally colder than those in the Chukchi Sea, although recent studies have indicated that a narrow band of warm, brackish water flows along the coast with the prevailing westward currents. This band is usually 1 to 4 km wide and periodically attains temperatures up to 10° to 12°C, as compared to offshore water temperatures of well below 5°C.

In both the Beaufort and Chukchi Seas lunar tides are very small, reaching a maximum of 1.3 m at Kotzebue. Wave heights and storm surges pose more severe hazards in the Chukchi than in the Beaufort Sea, primarily due to the longer reaches of open water in summer and fall.

The Beaufort Sea coast is predominantly low-lying wetland tundra dotted by numerous thaw lakes. Offshore islands determine the nature of much of the nearshore physical and biological environment along the Beaufort coast. These islands effectively moderate the influence of polar pack ice where they occur, and in the few weeks of summer, partially separate the cold, saline waters of the open Beaufort from the warmer, brackish waters near shore. Some of these islands are true barrier islands, bounding shallow lagoons (for example, Jones Islands and Simpson Lagoon), while others lie farther offshore, with deeper

waters between them and the mainland (for example, Narwhal Island and Stefansson Sound). The islands themselves, and the mainland coast, where unprotected by these islands, are subject to considerable erosion by wave action.

The coast of the Chukchi Sea is more complex than the Beaufort coast. It has sections of higher relief, such as dry tundra meeting the sea at a bluff, and occasional cliff faces, as at Skull Cliffs and Cape Lisburne. In these bluff and cliff face regions there are no barrier or other offshore islands. Elsewhere, however, extensive lagoon and semi-protected embayment systems exist in association with islands, spits, and bars.

Ice dominates the entire Arctic OCS area. Sea ice cover is close to 100 percent for 9 to 10 months each year and freezes up to 2.4 m thick in one season. Multiyear ice, up to 4 m thick, and icebergs with drafts of as much as 50 m are present. Landfast ice forms during the winter, extending from less than 1 km to as much as 50 km offshore. The ice pack moving westward past the Alaskan coast shears against the landfast ice, forming an extensive pressure ridge system. Pressure ridges and hummocks may exceed 10 m in height and are matched on the underside by ice keels several tens of meters deep. The sea floor of the continental shelf is scoured by dragging ice keels that form deep gouges. Ice gouges of indeterminate age have been found as far out as the 50-m isobath, though they are more numerous in shallower waters, especially along the ice shear zone. The ice season is somewhat shorter in the Chukchi Sea than in the Beaufort Sea, but ice conditions and ice hazards are more severe in the Chukchi. The extent of landfast ice along the Chukchi coast between Barrow and Cape Lisburne is much narrower than along the Beaufort coast. Thus, with the exception of Kotzebue Sound, severe ice conditions are encountered much closer to the coast.

The presence or absence of ice profoundly affects the occurrence of fish, birds, marine mammals, and other biota in the Arctic. During the period when ice cover is minimal, most of the annual primary production occurs and biological utilization of the area is high. Anadromous fish move seaward from their overwintering areas in rivers and are joined by large populations of waterfowl and shorebirds that also feed heavily in the barrier island areas and the band of warmer, brackish water along the coast. During the ice-free period, bowhead whales, beluga whales, and several species of seals also frequent the nearshore areas of the Arctic Ocean. In ice-covered periods, by contrast, primary production virtually ceases and the large populations of fish, birds, and marine mammals generally disappear.

The Chukchi Shelf is a broad, flat, shallow, submerged portion of northern Alaska's Arctic coastal plain that is equal in area to all of Alaska north of the Brooks Range. A reconnaissance grid of USGS MCS data (line spacing on average about 50 km) has been obtained in seasonally ice-free waters, but the data are of variable quality. Data quality and spacing, and the limits imposed by

working only in ice-free waters, have left major regional geologic, tectonic, and economic questions unanswered in the Arctic region.

ACTIVITIES—PAST AND FUTURE

Much of the explorational work in the Alaskan EEZ has focused on the identification and evaluation of potential reserves of recoverable oil and gas in Outer Continental Shelf areas and on assessment of the potential environmental impacts of developing those resources. Geophysical survey work has been carried out primarily by the USGS and by private industry. NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP), with funding primarily from the Minerals Management Service, has supported major research efforts on (1) geological and ice-related hazards to OCS oil and gas development, (2) the physical oceanographic and circulation regimes of Alaskan OCS areas, and (3) the distributions and sensitivities of living marine resources, including endangered species, potentially vulnerable to impacts that might result from oil and gas development. These programs and other related efforts are described briefly below.

Geological Framework and Environmental Studies by the USGS

Since 1965 the USGS has conducted numerous oceanographic expeditions to the Alaskan EEZ, often in cooperation with other Federal Agencies such as NOAA, the U.S. Navy, and the U.S. Coast Guard (USCG). Tracklines of many of these cruises are summarized on figure 3. Many of the data sets are available from the NOAA National Geophysical Data Center in Boulder, Colorado. Several of the USGS cruises have been cooperative endeavors with Canada and Great Britain. An extensive bibliography of USGS reports and publications on Alaskan work is appended.

Gulf of Alaska.—Seafloor geologic hazards studies of the continental shelf in the Gulf of Alaska between Prince William Sound and Dixon Entrance were conducted between 1974 and 1980. The high-resolution seismic reflection data and seafloor sediment samples allowed delineation of large areas of seafloor instability in areas of rapid sediment accumulation. These areas are largely on the inner shelf seaward of important sediment sources such as the Copper and Alsek Rivers and the Malaspina and Bering Glaciers.

The triggering mechanisms of the seafloor slides and slumps, which were mapped on the shelf and slope and in the adjacent bays and fjords, include large storm waves and frequent strong earthquakes. Several earthquake faults have surface or near-surface offset, suggesting recent movement. The seaward extension of the Fairweather Fault extends

from Cross Sound to Dixon Entrance and connects with the Queen Charlotte Fault. Together these faults form the boundary between the Pacific and North American plates.

GLORIA imagery plus acoustic, magnetic, and gravity profiles were collected across a small segment (TACT area) of the continental margin in the northern Gulf of Alaska in 1986. The remainder of the deepwater portion of the EEZ in the Gulf of Alaska will be insonified by GLORIA in 1988, 1989, and if necessary, 1990. Follow-up "ground-truth" cruises are also planned and include sampling, bottom camera and TV, and more detailed seismic reflection profiles plus high-resolution side-scan and submersible dives.

The current research program in the gulf is divided into four overlapping categories: hydrocarbon resources; neotectonics, including geohazards and sea-floor utilization studies; geologic framework; and crustal structure. Studies of neotectonics will be based heavily on swath-mapping bathymetry and partly on MCS data, whereas studies in the hydrocarbon and geologic framework categories will require mainly MCS data and results from geologic sampling, which may include shallow drilling. Crustal studies can be accomplished by using MCS, large-airgun refraction, as well as gravity and geoidal and possibly two-ship seismic data.

Bering Sea.—Geologic hazards in the southern half of the Beringian continental margin in the Bering Sea were investigated in the 1970's and the northern half of the margin in the 1980's. The main seafloor hazards mapped on the outer shelf of this frontier petroleum area are shallow (less than 250 m subsea depth) acoustic anomalies interpreted to be caused by gas in the sediment. Biogenic methane was dominant, but thermogenic hydrocarbons were detected. Hydrocarbon anomalies observed on seismic reflection profiles obtained on the lower slope and rise are attributed to gas hydrates.

Evidence for seafloor instability was observed on nearly all seismic-reflection records collected on the Beringian continental slope. The types of mass movement mapped ranged from small debris flows and slides a few meters thick and tens of meters wide to massive slide or slump blocks hundreds of meters thick and several kilometers in areal dimension.

Newly collected GLORIA imagery (1986 and 1987) shows the ubiquitous nature of sediment instability on the slopes surrounding the Aleutian Plain. The Beringian margin, Aleutian Arc, and Bowers Ridge slopes all show abundant evidence of erosion and transport by mass-movement phenomena. Sheet flow is prevalent in the northern part of the Aleutian abyssal plain, whereas GLORIA imagery of the southern half of the plain shows domination by turbidite sedimentation.

GLORIA imagery has been obtained for the entire deepwater portion of the Bering Sea. The data are being

processed for inclusion in an atlas. Follow-up cruises are needed to the Bering Sea to "ground-truth" the GLORIA and associated geophysical data.

Arctic.—The USGS has worked on environmental problems of the Alaskan Arctic since 1970, supported for several years by NASA's ERTS-1 project and for 10 years under the sponsorship of NOAA's OCSEAP. Except for several cruises on coast guard ice breakers and on NOAA vessels, most of the work has been done from small USGS vessels or from the winter ice cover. The main research tools employed over the years include high resolution seismic systems, fathometer, side-scan sonar, underwater TV, vibrocorers and box corers, grab samplers, scuba equipment, and remote sensing.

Maps prepared by the USGS for the Arctic region include those for sediment distribution and thicknesses, ice gouges, strudel scours, and ice movement and zonation. Much of the USGS research has been on unique ice-related processes and hazards. The Arctic shelf is shallow, has little relief out to the break at 60 m, is blanketed by a very thin cover of sandy Holocene sediment, and everywhere is impacted and plowed at different repetition rates by massive ice keels. Although not sediment starved, ice-related processes seem to prevent sediment accretion and even lead to erosion. In the Beaufort Sea, relict ice-bonded sediment occurs at shallow depths out to at least the middle shelf. Very little is known about offshore permafrost in the Chukchi Sea, but it apparently is not widespread.

Future environmental work in the Arctic should attempt to define precisely how, and how fast, ice is moving sediment as a key to understanding the future dispersal of pollutants in ice-covered waters. Electric resistivity techniques should be developed for mapping the top and the bottom of ice-bonded sediment, and such techniques should be applied to better define offshore permafrost. This in turn would provide a better understanding of the distribution of gas hydrates known to occur on the shelf and slope. Future work should also deal with the problem of extensive slumping on the continental slope. Studies of slumping, diapirs, possible pingos, and canyons would best be accomplished by the use of Sea Beam and by developing an under-ice GLORIA capability.

Additional MCS data are also required to define the deep structure of the North Chukchi Basin, which is interesting for both the basin tectonics and petroleum potential, and the character of the almost unexplored Chukchi continental borderland. These investigations require an icebreaker, and a jointly sponsored U.S. Navy-USGS investigation of the borderland is planned for 1988 using a Coast Guard Polar-class icebreaker. In addition, selected conventional and deep-penetration MCS profiles should be acquired to supplement existing data in the Chukchi and Beaufort Seas.

Industry Studies

Private industry has been actively collecting geophysical and sample data from the Alaskan EEZ since the 1960's. Initially, this activity anticipated lease sales held in the 1970's and 1980's, and it is ongoing. Several Continental Offshore Stratigraphic Test (COST) and exploratory wells have been drilled, but except for the North Slope, no significant hydrocarbon discoveries have resulted from exploration to date. Except for the COST well data, the industry data are generally proprietary and not available to the public.

GLORIA Surveys

In 1986, the U.S. Geological Survey began systematically collecting GLORIA and other geophysical data from the Alaskan EEZ as part of a cooperative program with Institute for Oceanographic Sciences (IOS) of Great Britain. At the end of 1987, some 50,000 km of trackline data had been collected (fig. 4). GLORIA images are being digitally processed for those EEZ areas deeper than 200 m in the whole Bering Sea and along the western Aleutian Arc. The eastern Aleutian Arc and the Gulf of Alaska will be covered in 1988 and beyond. The Arctic will not be covered because of shallow water and ice cover.

OCSEAP Studies (NOAA and MMS)

In 1972, the Minerals Management Service (then BLM) began a greatly expanded program of marine environmental studies in support of exploration and development of OCS oil and gas nationwide. In Alaska the MMS program was initiated in 1974, through an interagency effort with NOAA, as the Outer Continental Shelf Environmental Assessment Program. From 1975 to 1984 the OCSEAP included major geological and geophysical study components, carried out largely by the USGS and the Geophysical Institute of the University of Alaska. These studies focused primarily on potential geohazards associated with OCS oil and gas development, including (1) definition of the seismicity of the Alaskan OCS regions, especially in the northern Gulf of Alaska and Aleutian areas and in the vicinity of the Seward Peninsula, (2) identification of areas with unconsolidated or gas-charged sediments and potential for sediment instability or slumping, (3) mapping of submarine permafrost distributions, (4) identification of areas susceptible to ice scouring, and (5) mapping the distribution of near-surface sediment types. Additional data on surficial sediments have also been gathered in conjunction with distributional studies on benthic fauna.

In addition to the geohazards studies, OCSEAP has supported major efforts in meteorology, physical oceanography, and ice motion throughout the Alaskan OCS and has

acquired extensive data on the seasonal distributions of living marine resources potentially vulnerable to impacts from the development of OCS oil and gas reserves. These data will be invaluable also for estimating the potential environmental risks associated with development of other categories of mineral resources from Alaskan EEZ regions.

Nearly all OCSEAP studies are well documented, both by original reports from the Principal Investigators (table 1) and by regional synthesis reports. In addition, OCSEAP has produced major regional environmental summaries for the Bering Sea (Hood and Calder, 1981) and for the Gulf of Alaska (Hood and Zimmerman, 1986). A complete bibliography of all OCSEAP publications and reports is also available (U.S. Department of Commerce, 1986). Geological and geophysical data from OCSEAP studies are available from NOAA's National Geophysical Data Center, while other data types (oceanographic, chemical, biological) are available from NOAA's National Oceanographic Data Center. These latter data types can be accessed also through the Alaska Office of NOAA's Ocean Assessments Division in Anchorage.

Strategic Assessment Program (NOAA)

The Strategic Assessment Branch (SAB) of NOAA's Ocean Assessments Division conducts comprehensive, interdisciplinary assessments of multiple resource use throughout the Nation's EEZ and adjacent coastal areas. One major SAB product is a series of regional data atlases of the EEZ. The atlases contain regional thematic maps that present interdisciplinary technical information to policy makers in a consistent and comprehensible form. The Bering, Chukchi, and Beaufort Seas Data Atlas will be published in early 1988; and the West Coast and Gulf of Alaska Data Atlas is scheduled for late 1988. Each data atlas brings together four general types of information relevant to decision making: (1) physical and chemical characteristics of resources and their surrounding environment; (2) biological characteristics, including species distribution, abundance, life history, and habitat; (3) economic characteristics, including resource extraction and production activities; and (4) environmental quality, including pollutant discharges and hazardous materials disposal. The Bering, Chukchi, and Beaufort Seas Data Atlas will contain 108 maps. These maps synthesize and present the best available information on important characteristics of the Arctic region. This regional atlas emphasizes living marine resources with over 80 maps in this category. In addition to maps on biological, physical, and economic aspects, this atlas also contains thematic maps depicting Native subsistence activities in a variety of Alaska coastal habitats. An explicit assessment of the content and quality of the information underlying each map is portrayed in the atlas.

A national atlas folio series, also under development by SAB, presents comprehensive information on the use

Table 1. A sampling of recent Principal Investigator final reports from NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP)

OCSEAP Final Reports	
47:	Molnia, B.F., 1982, Erosion, deposition, faulting and instability of shelf sediments: Eastern Gulf of Alaska, 638 p.
48:	Hampton, M.A., 1983, Geotechnical framework study of the Kodiak Shelf, Alaska, 94 p. Lee, H.J., and Schwab, W.C., 1983, Geotechnical framework, Northeast Gulf of Alaska, 452 p.
49:	Latham, G.V., Dorman, H.J., and Ibrahim, A.B.K., 1980, Coordinated ocean bottom seismograph measurements in the Kodiak Shelf area, 28 p. Lahr, J.C., and Stephens, C.D., 1983, Earthquake activity and ground shaking in and along the eastern Gulf of Alaska, 54 p. Frohlich, C., and Donoho, P., 1982, Measurement and location of earthquakes in western Alaska, the Gulf of Alaska, and the Bering Sea, 48 p. Jacob, K.H., and Hauksson, E., 1983, A seismotectonic analysis of the seismic and volcanic hazards in the Pribilof Islands-Eastern Aleutian Islands region of the Bering Sea, 232 p. Pulpan, H., and Kienle, J., 1984, Seismic risk studies, western Gulf of Alaska, 65 p. Kienle, J., and Swanson, S.E., 1980, Volcanic hazards from future eruptions of Augustine volcano, Alaska, 139 p.
52:	ERTEC Western, Inc., 1983, Seafloor geologic hazards on the northern Aleutian Shelf, 342 p. Phillips, L., Barnes, P., Reimnitz, E., and Hunter, R., 1985, Geologic processes and hazards of the Beaufort and Chukchi Sea shelf and coastal regions, 477 p.

and health of the coastal waters of the United States. This series presents a national coastal and oceanic perspective and framework for environmental quality research, assessment, and monitoring. The first 5 of the 20 themes to be mapped are currently available: (1) estuarine systems, (2) NOAA's National Status and Trends Program, (3) dredging activities, (4) ocean disposal sites, and (5) oil production. Subsequent maps will include hazardous waste sites, commercial ports and shipping routes, operational discharges of petroleum hydrocarbons from ships, harvest-limited shell-fishing areas, Federally funded marine pollution research, marine mammals, and fisheries management areas.

U.S. Arctic Research Planning Activities

Under the mandate of the Arctic Research and Policy Act of 1984 (P.L. 98-373), the Interagency Arctic Research Policy Committee (IARPC) has prepared a U.S. Arctic Research Plan (IARPC, 1987) that outlines and discusses

major research needs for the U.S. Arctic region (defined for purposes of the plan to include the entire Alaskan EEZ area north of the Aleutian Chain). One aspect of stated U.S. Arctic policy is to support sound and rational development in the Arctic region while minimizing adverse effects on the environment. Research needs identified by the IARPC (1987) to support this policy goal include mapping of energy and mineral resources both onshore and offshore and understanding the basic structural and functional aspects of marine ecosystems in terms of both productivity of renewable resources and their potential vulnerability to impact from development activities. The purpose of mentioning this Arctic planning activity here is merely to note the obvious parallels with the EEZ planning effort as it pertains to Alaska and to call for appropriate coordination between the two activities.

RECOMMENDATIONS

In each of the five regions within the Alaskan EEZ, we suggest a series of studies and measurements made along area transects, or swaths. These transects would be corridors some 20 to 30 km wide and extending at right angles across the major structural elements in each region. Although specific locations have not been formulated, for these swaths in each area, they should extend from beyond the edge of the EEZ to the beach, where they would connect with existing onshore geologic data or cross sections.

Along each transect, the objectives are to derive:

1. A three-dimensional cross section of the regional framework (more than one transect may be necessary in each of the regional subdivisions of the Alaskan EEZ);
2. The characteristics of geologic processes and hazards within the corridor that are representative of the region; and
3. A reconnaissance estimate of the resource potential of the region.

Each transect would require the use of two ships working together to obtain three-dimensional deep crustal structure from seismic reflection and refraction data including Expanding Spread Profiles (ESP). Both ships would then operate separately to obtain the following data:

1. Geopotential: gravity and magnetic profiles;
2. High-resolution seismic reflection profiles (0-1,000 m subbottom);
3. Bathymetry;
4. Sample information involving:
 - a. Coring (20 m)
 - b. Dredging

- c. Grab sampling; and
5. Bottom photographs and sonographs.

Following the collection and analysis of the transects, a systematic drilling program should commence to provide "ground-truthing" of the geophysical data. At least one hole should be drilled in each transect and should collect the following:

1. Continuous cores;
2. Basement samples if possible; and
3. A series of down-hole logs.

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REFERENCES CITED

- Hood, D.W., and Calder, J.A., eds., 1981, *The eastern Bering Sea shelf: Oceanography and Resources*, two volumes: National Oceanic and Atmospheric Administration Office of Marine Pollution Assessment, 1339 p.
- Hood, D.W., and Zimmerman, S.T., eds., 1986, *The Gulf of Alaska: Physical environment and biological resources*: United States Government Printing Office, Washington, D.C., 655 p.
- Interagency Arctic Research Policy Committee (IARPC), 1987, *United States Arctic Research Plan*: IARPC, Washington, D.C., 334 p.
- Klitgord, K.D., and Watkins, J.S., 1984, Panel IA, *Geologic studies related to oil and gas development in the EEZ*, in *Symposium proceedings: A national program for the assessment and development of the mineral resources of the United States Exclusive Economic Zone*, November 15, 16, 17, 1983: U.S. Geological Survey Circular 929, p. 107-184.
- Peck, D.L., and Hill, G.W., 1986, *The United States Geological Survey's program in the Exclusive Economic Zone (EEZ)*, in Lockwood, Millington, and Hill, Gary, eds., *Proceedings: Exclusive Economic Zone Symposium, Exploring the new ocean frontier*: National Oceanic and Atmospheric Administration, National Ocean Service, Charting and Geodetic Services, Rockville, Maryland, p. 21-30.
- U.S. Department of Commerce, 1986, *Outer Continental Shelf Environmental Assessment Program (OCSEAP): Comprehensive bibliography*: National Oceanic and Atmospheric Administration Ocean Assessments Division, Alaska Office, Anchorage, 705 p.

BIBLIOGRAPHY OF USGS PUBLICATIONS PERTINENT TO THE ALASKA EEZ

[AA, Aleutian Arc; AR, North Slope; BS, Bering Sea; GA, Gulf of Alaska]

- Barnes, P.W., Jeffery L. Asbury, Douglas M. Rearic and C.Robin Ross, 1987, Ice erosion of a sea-floor knickpoint at the inner edge of the stamukhi zone, Beaufort Sea, Alaska; *Marine Geology*, v 76, p. 207-222 . (AR)
- Barnes, P.W., McDowell, D.M., and Reimnitz, Erk, 1978, Ice gouging characteristics: their changing patterns from 1975-1977, Beaufort Sea, Alaska: U.S. Geological Survey Open-File Report 78-730, 42 p. (AR)
- Barnes, P.W., D.M. Rearic and Reimnitz, E., 1984, Ice gouge characteristics and their relation to ice gouging and ice dynamics, in P.W. Barnes, D.M. Schell, and E. Reimnitz (eds.), *The Alaskan Beaufort Sea - Ecosystems and Environment*: Academic Press, San Francisco, California, p. 466. (AR)
- Barnes, P.W., and Reimnitz, Erk, 1974, Sedimentary processes on arctic shelves off the northern coast of Alaska, in, Reed, J.C., and Sater, J.E., eds., *The Coast and Shelf of the Beaufort Sea*, The Arctic Institute of North America, Arlington, Virginia, p. 439-576. (AR)
- Barnes, P.W., Reimnitz, E., and Fox, D., 1982, Ice Rafting of fine- grained sediment, a sorting and transport mechanism, Beaufort Sea, Alaska: *Journal of Sedimentary Petrology*, v. 52, p. 493-502. (AR)
- Boucher, Gary, Reimnitz, Erk, and Kempema, E.W., 1981, Seismic evidence for an extensive gas-bearing layer at shallow depth offshore from Prudhoe Bay, Alaska: *Cold Regions Science and Technology*, no. 4, p. 63-71. (AR)
- Carlson, P.R., Molnia, B.F., Bruns, T.R. and Page, R., 1975, Preliminary report on geologic hazards in the outer continental shelf of the eastern Gulf of Alaska, submitted to BLM up request for hazards data pertaining to lease sale 39, 11 p. (GA)
- Carlson, P.R. and Molnia, B.F., 1976, Faulting and instability of shelf sediment: eastern Gulf of Alaska: Annual progress report, R.U. #216, Alaskan continental shelf, Principal Investigators reports for year ending March 1976, NOAA, v. 13, (*Geology Report*), p. 107-124. (GA)
- Carlson, P.R. and Molnia, B.F., 1977, Submarine faults and slides on the continental shelf, northern Gulf of Alaska: *Marine Geotechnology*, v. 2, no. 1, p. 275-290. (GA)
- Carlson, P.R., Molnia, B.F., Kittelson, S.C. and Hampson, J.C., Jr., 1977, Distribution of bottom sediments on the continental shelf, northern Gulf of Alaska: U.S. Geological Survey Miscellaneous field studies maps and text, MF 876, 2 map sheets and 13 p. pamphlet. (GA)
- Carlson, P.R., 1978, Holocene slump on continental shelf off Malaspina Glacier, Gulf of Alaska, *American Association of Petroleum Geologists Bulletin*, v. 62, p. 2412-2426. (GA)
- Carlson, P.R., Molnia, B.F., and Wheeler, M.C., 1980, Seafloor geologic hazards in OCS lease area 55, eastern Gulf of Alaska: *12th Offshore Technology Conference*, Houston, Texas, *Proceedings*, v. 1, p. 583-603. (GA)
- Carlson, P.R., and Karl, H.A., 1981, Seafloor geologic hazards, sedimentology, and bathymetry. Navarin Basin province, northwestern Bering Sea: U.S. Geological Survey Open-File Report 81-1217, 149 p. (BS)

- Carlson, P.R., Bruns, T.R., Molnia, B.F., and Schwab, W.C., 1982, Submarine valleys in the northeastern Gulf of Alaska: characteristics and probable origin: *Marine Geology*, v. 47, p. 217-242. (GA)
- Carlson, P.R., Karl, H.A., Fischer, J.M., and Edwards, B.D., 1982, Geologic hazards in Navarin Basin province, northern Bering Sea: 14th Offshore Technology Conference, Houston, Texas, Proceedings, v. 1, p. 73-87. (BS)
- Carlson, P.R. and Schwab, W.C., 1982, Northern Gulf of Alaska environmental geology, in T.R. Bruns (ed.), Hydrocarbon resource report for proposed OCS lease sale 88: southeastern Alaska, northern Gulf of Alaska, Cook Inlet, and Shelikof Strait, Alaska: U.S. Geological Survey Open-File Report 82-928, p. 73-86. (GA)
- Carlson, P.R., Karl, H.A., and Edwards, B.D., 1982, Puzzling mass movement features in the Navarinsky Canyon head, Bering Sea: *Geo-Marine letters*, v. 2, p. 123-127. (BS)
- Carlson, P.R., Plafker, G., and Bruns, T.R., 1985, Selected seismic profiles and map of the seaward extension of the Fairweather fault, eastern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1722, 2 sheets, scale 1:500,000. (GA)
- Carlson, P.R. and Karl, H.A., 1984, Discovery of two new large submarine canyons in the Bering Sea: *Marine Geology*, v. 56, p. 159-179. (BS)
- Carlson, P.R., and Marlow, M.S., 1984, Discovery of a gas plume in Navarin Basin: *Oil and Gas Journal*, v. 82, no. 14, p. 157-158. (BS)
- Carlson, P.R. and Karl, H.A., 1984-1985, Mass movement of fine-grained sediment to the basin floor, Bering Sea, Alaska: *Geo-Marine Letters*, v. 4, p. 221-225. (BS)
- Carlson, P.R., Golan-Bac, M., Karl, H.A., and Kvenvolden, K.A., 1985, Seismic and geochemical evidence for shallow gas in the sediment on the Navarin continental margin, Bering Sea: *American Association of Petroleum Geologists Bulletin*, v. 69, p. 422-436. (BS)
- Carlson, P.R., and Karl, H.A., in press, Morphologic, seismic, and sedimentologic characteristics of the world's largest submarine canyons, Bering Sea: *Geological Society of America Bulletin*, 93 msp. (BS)
- Childs, J. R., Cooper, A. K., and Wright, A. W., 1981, Residual magnetic map of Umnak Plateau region, southeastern Bering Sea: U.S. Geological Survey Geophysical Investigations Map GP-939, 1 sheet. (BS)
- Childs, J.R., Magistrale, H. W., and Cooper, A. K., Cooper, A. K., Marlow, M. S., and Scholl, D. W., 1976a, Mesozoic magnetic lineations in the Bering Sea marginal basin: *Journal of Geophysical Research*, v. 81, p. 1916-1934. (BS)
- Cooper, A. K., Scholl, D. W., and Marlow, M. S., 1976, Plate tectonic model for the evolution of the eastern Bering Sea basin: *GSA Bulletin*, v. 87, p. 1119-1126. (BS)
- Cooper, A. K., Bailey, K. A., Howell, J. I., Marlow, M. S., and Scholl, D. W., 1976, Preliminary residual magnetic map of the Bering Sea basin and Kamchatka Peninsula: U.S. Geological Survey Miscellaneous Field Studies Map MF-715, scale 1:2,500,000. (BS)

- Cooper, A. K., Marlow, M. S., and Scholl, D. W., 1977, Bering Sea: a multifarious marginal basin, in Island arcs, deep sea trenches and back-arc basins: v. 1, American Geophysical Union, p. 437-450. (BS)
- Cooper, A. K., 1978, Heat flow and organic gas measurements from the Aleutian Basin, Bering Sea: U.S. Geological Survey Circular 772-B, p. 92-93. (BS)
- Cooper, A. K., Marlow, M. S., Parker, A. W., and Childs, J. R., 1979a, Structure contour map on acoustic basement in the Bering Sea: U.S. Geological Survey Miscellaneous Field Investigations MF-1165. (BS)
- Cooper, A. K., Scholl, D. W., Marlow, M. S., Childs, J. R., Redden, G. D., Kvenvolden, K. A., and Stevenson, A. J., 1979b, Hydrocarbon potential of Aleutian Basin, Bering Sea: AAPG Bulletin, v. 63, p. 2070-2087. (BS)
- Cooper, A. K., Marlow, M. S., and Scholl, D. W., 1979, Thick sediment accumulations beneath continental margin of outer Bering Sea: AAPG Bulletin, v. 63, p. 436. (BS)
- Cooper, A. K., Scholl, D. W., Vallier, T. L., and Scott, E. W., 1980, Resource report for the deep-water areas of proposed OCS lease sale #70, St George basin, Alaska: U.S. Geological Survey Open-File Report 80-246, p. 90. (BS)
- Cooper, A. K., Marlow, M. S., and Ben-Avraham, Z., 1981, Multichannel seismic evidence bearing on the origin of Bowers Ridge, Bering Sea: GSA Bulletin, v. 92, p. 474-484. (BS)
- Cooper, A. K. and Marlow, M. S., 1984, Geologic and geophysical studies of the inner Bering Sea shelf during 1982: U. S. Geological Survey in Alaska: accomplishments in 1982, U.S. Geological Survey circular 939, p. 123-126. (BS)
- Cooper, A. K., Marlow, M. S., and Vallier, T. L., 1984, Summary Geologic Report for the St. George Outer Continental Shelf (OCS) Planning Area Bering Sea, Alaska: U.S. Geological Open-File Report 84-418, p. 81. (BS)
- Cooper, A. K., Marlow, M. S., and Childs, J. R., 1985b, Digital shipboard gravity and magnetic data collected in 1976 in the southern Bering Sea: U.S. Geological Survey Open-File Report 85-237. (BS)
- Cooper, A.K., Scholl, D.W., and Marlow, M.S., 1986, Structural framework, sedimentary sequences, and hydrocarbon potential of the Aleutian and Bowers basins, Bering Sea, in D.W. Scholl, A. Grantz, J. Vedder, eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins - Beaufort Sea to Baja California: v. Memoir ?, Tulsa, Ok, American Association of Petroleum Geologists, p. ?. (BS)
- Cooper, A.K., Marlow, M.S., and Scholl, D.W., 1986, Geologic framework of the Bering Sea crust, in D.W. Scholl, A. Grantz, J. Vedder, eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins - Beaufort Sea to Baja California: v. Memoir ?, Tulsa, OK, American Association of Petroleum Geologists, p. ?. (BS)
- Field, M.E., Carlson, P.R., and Hall, R.K., 1983, Seismic facies of shelf edge deposits, U.S. Pacific continental margin, in D.J. Stanley and G. Moore (eds.), the Shelfbreak: critical interface on continental margins, Soc. Econ. Paleont. and Mineralogists, Special Publication, p. 299-313. (GA)

- Hampton, M.A., Bouma, A.H., Carlson, P.R., Molnia, B.F., Clukey, and Sangrey, D.A., 1978, Quantitative study of slope instability in the Gulf of Alaska, 10th Offshore Technology Conference, Houston, Texas, Proceedings, v. 4, p. 2307-2318. (GA)
- Jones, D. M., Kingston, M. J., Marlow, M. S., Cooper, A. K., Barron, J. A., Wingate, F. H., and Arnal, R. E., 1981, Age, mineralogy, physical properties, and geochemistry of dredge samples from the Bering Sea continental margin: U.S. Geological Survey Open-File Report 81-1297, 68p. (BS)
- Karl, H.A. and Carlson, P.R., 1982, Large sand waves in Navarinsky Canyon head, Bering Sea: *Geo-Marine Letters*, v. 2, p. 157-162. (BS)
- Karl, H.A., Carlson, P.R., and Cacchione, D.A., 1983, Factors influencing sediment transport at the shelf break, in D.J. Stanley and G. Moore, (eds.), *The shelfbreak: critical interface on continental margins*, Soc. Econ. Paleont. and Mineralogists, Special Publication, p. 219-231. (BS)
- Karl, H.A. and Carlson, P.R., 1984, Surface and near-surface geology, Navarin Basin province: results of the 1980-1981 field seasons: U.S. Geological Survey Open-File Report 84-89, 118 p. (BS)
- Karl, H.A., Cacchione, D.A., and Carlson, P.R., 1986, Internal-wave currents as a mechanism to account for large sand waves in Navarinsky Canyon head, Bering Sea: *Journal of Sedimentary Petrology*, p. 706-714. (BS)
- Karl, H.A. and Carlson, P.R., 1987, Surface current patterns suggest by suspended sediment distribution over continental margin, Bering Sea: *Marine Geology*, v. 47, p. 1-8. (BS)
- Marlow, M. S., Alpha, T. R., Scholl, D. W., and Buffington, E. C., 1975, Physiographic diagrams of the Bering Sea shelf, Alaska: U.S. Geological Survey Open-File Report 75-1, 2 sheets. (BS)
- Marlow, M. S., Scholl, D. W., Cooper, A. K., and Buffington, E. C., 1976, Structure and evolution of Bering Sea shelf south of St. Lawrence Island: *AAPG Bulletin*, v. 60, p. 161-183. (BS)
- Marlow, M. S., McLean, H., Vallier, T. L., Scholl, D. W., Gardner, J. V., and Powers, R. B., 1976, Prenomination report on the regional geology, oil and gas potential and environmental hazards of the Bering Sea shelf south of St. Lawrence Island, Alaska: U.S. Geological Survey Open-File Report 76-785, 60 p. (BS)
- Marlow, M. S., Scholl, D. W., and Cooper, A. K., 1977, St. George basin, Bering Sea shelf: a collapsed Mesozoic margin, in M. Talwani and W. C. Pitman III, eds., *Island Arcs, Deep Sea Trenches and Back-Arc Basins*, Maurice Ewing Series, V. I: American Geophysical Union, Washington, D.C., p. 211-219. (BS)
- Marlow, M. S., Cooper, A. K., Parker, A. W., and Childs, J. R., 1979, Isopach map of strata above acoustic basement in the Bering Sea, scale 1:2,500,000: U.S. Geological Survey Miscellaneous Field Studies Map 1164. (BS)
- Marlow, M.S., 1979, Hydrocarbon prospects in the Navarin basin province, northwest Bering sea shelf: *Oil and Gas Journal*, October 29, p. 190-196. (BS)

- Marlow, M. S., Scholl, D. W., Cooper, A. K., and Jones, D. L., 1979, Mesozoic rocks from the Bering Sea: The Alaska-Siberia connection: GSA Abstracts with Programs, v. 11, p. 90. (BS)
- Marlow, M. S., Cooper, A. K., Scholl, D. W., Vallier, T. L., and McLean, H., 1979, Description of dredge samples from the Bering Sea continental margin: U.S. Geological Survey Open- File Report OF 79-1139, 5p. (BS)
- Marlow, M. S. and Cooper, A. K., 1980b, Multichannel seismic- reflection profiles collected in 1976 in the southern Bering Sea shelf: U.S. Geological Survey Open-File Report 80-389, 2p. (BS)
- Marlow, M. S. and Cooper, A. K., 1980, Mesozoic and Cenozoic structural trends under southern Bering Sea shelf: AAPG Bulletin, v. 64, p. 2139-2155. (BS)
- Marlow, M. S., Carlson, P., Cooper, A. K., Karl, H., McLean, H., McMullin, R., and Lynch, M. B., 1981, Hydrocarbon resource report for proposed OCS sale no. 83, Navarin basin, Alaska: U.S. Geological Survey Open-File Report 81-252. (BS)
- Marlow, M. S., Cooper, A. K., Scholl, D. W., and McLean, H., 1982, Ancient plate boundaries in the Bering Sea region, in J. K. Leggett, ed., Trench-forearc geology: sedimentation and tectonics on modern and ancient active plate margins: Geological Society of London Special Publication No. 10, p. 201-211. (BS)
- Marlow, M. S. and Cooper, A. K., 1983, Wandering terranes in southern Alaska: The Aleutia microplate and implications for the Bering Sea: Journal of Geophysical Research, v. 88, p. 3439-3446. (BS)
- Marlow, M. S., Vallier, T. L., Cooper, A. K., Barron, J. A., and Wingate, F. H., 1983, A description of dredge samples collected in 1982 from the Bering Sea continental margin west of Navarin basin: U.S. Geological Survey Open-File Report 83-325, 4p. (BS)
- Marlow, M. S., Cooper, A. K., and Childs, J. R., 1983, Tectonic evolution of Gulf of Anadyr and formation of Anadyr and Navarin basins: AAPG Bulletin, v. 67, p. 646-665. (BS)
- Marlow, M. S. and Cooper, A. K., 1985, Regional geology of the Beringian margin, in N. Nasu et al., eds., Formation of Active Ocean Margins: Tokyo, Terra Scientific Publishing Company (TERRAPUB), p. 497-515. (BS)
- Marlow, M. S., Cooper, A. K., and Fisher, M. A., 1985, Framework geology of the eastern Bering Sea continental shelf: DNAG volume. (BS).
- Marlow, M.S., Cooper, A.K., and Fisher, M.A., 1986, Petroleum geology of the Beringian continental shelf, in D.W. Scholl, A. Grantz, J. Vedder, eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins - Beaufort Sea to Baja California: v. Memoir 7, Tulsa, OK, American Association of Petroleum Geologists, p. 7. (BS)
- McCarthy, J., Stevenson, A. J., Scholl, D. W., and Vallier, T. L., 1984, Speculations on the petroleum geology of the accretionary body: an example from the central Aleutians: Marine and Petroleum Geology, v. 1, p. 151-167. (AA)

- McCarthy, J. and Scholl, D. W., 1985, Mechanism of subduction accretion along the central Aleutian Trench: Geological Society of America Bulletin, v. 96, p. 691-701. (AA)
- Molnia, B.F., Carlson, P.R. and Bruns, T.R., 1975, U.S. Geological Survey, NEGQA, Geology project FY 75 year end report, 53 p. (GA)
- Molnia, B.F., Carlson, P.R. and Burns, T.R., 1977, Large submarine slide in Kayak Trough, Gulf of Alaska, in D. Coates, Ed., Landslides: Engineering Geology Reviews, Geol. Soc. Am., v. III, p. 137-148. (GA)
- Molnia, B.F., and Carlson, P.R., 1978, Surface sedimentary units of the northern Gulf of Alaska continental shelf: American Association of Petroleum Geologists Bulletin, v. 62, no. 4, p. 633-643. (GA)
- Molnia, B.F., and Carlson, P.R., 1980, Quaternary sedimentary facies on the continental shelf of the northeast Gulf of Alaska, in M.E. Field and others (ed.) Quaternary depositional environments of the Pacific Coast: Pacific Coast Paleogeographic Symposium 4: Soc. Econ. Paleontol. and Mineral., Los Angeles, California, p. 157-168. (GA)
- Reimnitz, Erk, and Barnes, P.W., 1974, Sea ice as a geologic agent on the Beaufort Alaska, in, Reed, J.C., and Sater, J.E., eds., The Coast and Shelf of the Beaufort Sea, The Arctic Institute of North America, Arlington, Virginia p. 301-351. (AR)
- Reimnitz, Erk, and Barnes, P.W., 1987, Sea-ice influence on arctic coastal retreat, in, N.E. Kraus (ed.), Proceedings, Coastal Sediments '87, New Orleans, L.A., Amer. Soc. Civ. Eng., New York, v. 2, p. 1578-1591. (AR)
- Reimnitz, Erk, Barnes, P.W., Forgatsch, T.C., and Rodeick, C.A., 1973, Influence of grounding ice on the Arctic shelf of Alaska: Marine Geology v. 13, p. 323-334. (AR)
- Reimnitz, Erk, Barnes, P.W., Toimil, L.J., and Melchoir, John, 1977, Ice gouge recurrence and rates of sediment reworking, Beaufort Sea, Alaska: Geology, v. 5, p. 405-408. (AR)
- Reimnitz, Erk, Kempema, E.W., 1982, Dynamic ice-wallow relief of northern Alaska's nearshore - a dynamic bed-form: Journal of Sedimentary Petrology, v. 52, n. 2, p. 451-462. (AR)
- Reimnitz, Erk and Kempema, E.W., 1983, High rates of bedload transport measured from infilling rate of large strudel-scour craters in the Beaufort Sea, Alaska: Continental Shelf Research, v. 1, no. 3, p. 237-151.. (AR)
- Reimnitz, Erk and Kempema, E.W., 1984, Pack ice interaction with Stamukhi Shoal, Beaufort Sea, Alaska, in P.W. Barnes, D.M. Schell, and Erk Reimnitz (eds.), The Alaskan Beaufort S, - Ecosystem and Environment: Academic Press, San Francisco, CA, p. 159-184. (AR)
- Reimnitz, Erk, and E.W. Kempema, 1987, Field observations of slush ice generated during freeze-up in arctic coastal waters; Marine Geology, v. 77, p 219-231. (AR)

- Reimnitz, Erk, Rodeick, C.A., and Wolf, S.C., 1974, Strudel scour: A unique arctic marine geologic phenomenon: *Journal of Sedimentary Petrology*, v. 44, no. 2, p. 409-420. (AR)
- Reimnitz, Erk, Toimil, L.J., and Barnes, P.W., 1978, Arctic continental shelf morphology related to sea-ice zonation, Beaufort Sea, Alaska: *Marine Geology*, v. 28, p. 179-210. (AR)
- Scholl, D. W., Buffington, E. C., and Hopkins, D. M., 1966, Exposure of basement rock on the continental slope of the Bering Sea: *Science*, v. 153, p. 992-994. (BS)
- Scholl, D. W., Buffington, E. C., and Hopkins, D. M., 1968, Geologic history of the continental margin of North America in Bering Sea: *Marine Geology*, v. 8, p. 297-330. (BS)
- Scholl, D. W. and Hopkins, D. M., 1989, Newly discovered Cenozoic basins, Bering Sea shelf, Alaska: *AAPG Bulletin*, v. 53, p. 2067-2078. (BS)
- Scholl, D. W. and Buffington, E. C., 1970, Structural evolution of Bering continental margin, Cretaceous to Holocene (abs.): *AAPG Bulletin*, v. 54, no. 2503. (BS)
- Scholl, D. W., Buffington, E. C., Hopkins, D. M., and Alpha, T. R., 1970, The structure and origin of the large submarine canyons of the Bering Sea: *Marine Geology*, v. 8, p. 187-210. (BS)
- Scholl, D. W. and Creager, J. S., 1973, Geologic synthesis of Leg 19 (DSDP) results: far North Pacific, Aleutian Ridge and Bering Sea, in *Deep Sea Drilling Project Initial Reports: v. 19*, Washington D.C., U.S. Government Printing Office, p. 897-913. (BS) (AA)
- Scholl, D. W., Buffington, E. C., and Marlow, M. S., 1975, Plate tectonics and the structural evolution of the Aleutian- Bering Sea region, in R. B. Forbes, ed., *Contributions to the geology of the Bering Sea basin and adjacent regions: GSA Special Paper 151*, p. 1-32. (BS) (AA)
- Scholl, D. W., Buffington, E. C., and Marlow, M. S., 1976, Aleutian-Bering Sea region seismic reflection profiles: U.S. Geological Survey Open-File Report 76-748. (BS) (AA)
- Scholl, D. W. and Cooper, A. K., 1978, VAMPs: possible hydrocarbon-bearing structures in the Bering Sea basin: *AAPG Bulletin*, v. 62, p. 2481-2488. (BS)
- Scholl, D. W., Vallier, T. L., and Stevenson, A. J., 1983, Geologic evolution of the Aleutian Ridge - Implications for petroleum resources: *Journal of the Alaska Geological Society*, v. 3, p. 33-46. (AA)
- Scholl, D.W., T.L.Vallier,, and Stevenson, A.J., 1986, Terrane accretion, production, and continental growth - a perspective based on the origin and tectonic fate of the Aleutian-Bering Sea region: *Geology*, v. 14, p. 43-47. (BS) (AA)

- Scholl, D.W., Vallier, T.L., and Stevenson, A.J., 1986, Geologic evolution and petroleum geology of the Aleutian Ridge, in D.W. Scholl, A. Grantz, J. Vedder, eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins - Beaufort Sea to Baja California: v. Memoir 7, Tulsa, OK, American Association of Petroleum Geologists, p. 7. (AA)
- Weeks, W.F., Barnes, P.W., Rearic, D.M., and Reimnitz, Erk, 1984, Some probabilistic aspects of ice gouging on the Alaskan shelf of the Beaufort Sea, in, P.W. Barnes, D.M. Schell, and Erk Reimnitz (eds), The Alaskan Beaufort Sea - Ecosystem and Environment: Academic Press, San Francisco, CA, p. 213-236. (BS)
- Wolf, S.C., Reimnitz, Erk, and Barnes, P.W., 1985, Pleistocene and Holocene Seismic Stratigraphy between the Canning River and Prudhoe Bay, Beaufort Sea, Alaska, Canning River to Prudhoe Bay; U.S. Geological Survey Open file Report, 85-549, 50 p. (AR)
- Wolf, S.C., Barnes, P.W., Rearic, D.M., and Reimnitz, Erk, 1987, Quaternary seismic stratigraphy of the inner continental shelf north of ANWR; U. S. Geological Survey Bulletin 1778, ed. K.J. Bird and L.B. Magoon, p. 61-78. (AR)