UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# SUMMARY GEOLOGIC REPORT FOR THE NORTH ALEUTIAN SHELF (OCS) PLANNING AREA, BERING SEA, ALASKA

by

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This report is preliminary and
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standards and nomenclature.

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## SUMMARY

This report provides the geologic framework, the petroleum geology, the regional hazards, and the hard minerals geology for resource development in the North Aleutian basin (OCS) planning area. This summary report is in response to a request by the Director of the Minerals Management Service.

Underlying a large portion of continental shelf, north of the Alaska Peninsula, is a sediment-filled structural depression known as the Bristol Bay basin or North Aleutian basin. The sedimentary deposits of part of the basin fill are exposed on the northern fringe of the Alaska Peninsula. This basin trends northeastward from the Alaskan Peninsula and about four-fifths of it lies offshore beneath the flat Bering Sea shelf. The offshore portion of this elongate structural sag is about 290 km by 75 km (180 x 47 mi.) and encompasses an area of about 21,750 sq. km (8,400 sq. mi.). The basin is asymmetrical in cross section; the basement rock of the northwest flank dips gently toward the basin axis, but the southeast flank of folded Jurassic basement rock is steeply inclined, probably faulted, and crops out in the northern foothills of the Alaska Peninsula. The basin's sedimentary section, more than 6000 m (20,000 ft) thick, is composed chiefly of Cenozoic deposits that are thickest in the southeast portion of the basin.

The northeast end of North Aleutian basin is bounded by exposures of highly deformed, locally intruded, metamorphosed Paleozoic and Mesozoic rocks. To the southwest, the basin is flanked by the offshore extension of the Black Hills, an anticlinal structure composed of Jurassic sedimentary rocks. South of the basin, economic basement consists mainly of Mesozoic and Cenozoic volcanic and plutonic units that form the core of the Alaska Peninsula. To the north, beneath the Bering shelf, "acoustic" basement (as resolved on geophysical records) flooring the basin, probably comprises Mesozoic sedimentary, volcanic, metamorphic, and crystalline rocks.

The basin probably began to form in earliest Tertiary time and formed in part by the subsidence of basement rocks of Mesozoic and older age, which were part of a volcanic-plutonic complex that extended from southern Alaska into the Bering Sea shelf and margin. The basin continued to subside and fill with sediment throughout the Cenozoic.

Nine wells have been drilled on the Alaska Peninsula adjacent to the axis of North Aleutian Bay basin. Although all the wells are effectively dry holes, several oil and gas shows were reported. Data from these wells suggest that the most prospective area for hydrocarbons is the southwestern, offshore portion of North Aleutian basin between Port Moller and Amak Island. One COST (Continental Offshore Stratigraphic Test) well has been drilled offshore in North Aleutian basin, but data from that well are currently proprietary and not reported here. Two COST wells have been drilled in the adjacent St. George basin planning area. These two wells suggest that the Cenozoic section on the flanks of St. George basin is not prospective for either source beds or reservoir beds for hydrocarbons. Possible source beds do exist within the Jurassic basement rocks in the well closest to North Aleutian basin. The two wells, which were drilled on the flanks of St. George basin, may not represent the hydrocarbon prospects in the thicker and older sedimentary sections of the central parts of St. George and North Aleutian basins.

The southeastern half of North Aleutian basin contains the thickest sedimentary section and may have the greatest potential for source and reservoir rocks. Some of the Mesozoic basement rocks beneath the basin may also be petroleum source or reservoir rocks.

Structural and stratigraphic traps associated with the faulted, southeastern edge of the North Aleutian basin are possible targets for exploration. These traps are mainly anticlinal structures in the Cenozoic sequence that formed by draping and differential compaction of strata over erosional and block-faulted highs that developed within the basement complex. Stratigraphic pinch-outs may have developed within marine and nonmarine transgressive sequences in the central area of the basin.

Major potential geo-environmental hazards in the North Aleutian basin area include faulting and earthquakes; sea ice; sea floor instability owing to sediment erosion, scour, transport, and deposition; and volcanic activity. Tidal effects in some bays and estuaries may be hazardous. Great earthquakes (magnitude greater than 8 on the Richter scale) have occurred along the nearby Aleutian arc and the Alaska Peninsula south of the basin. Smaller earthquakes occur west of the basin between the peninsula and the Pribilof Islands. The magnitude of ground motion generated by these shocks is unknown.

Tsunami (earthquake)-, tide-, and storm-induced waves affect sediment movement in the area. The physical properties (stability, etc.) of the sediment are unknown at present and their role as possible hazards to man-made structures has not been evaluated.

The North Aleutian basin OCS planning area is bounded on the south by the volcanically active Alaska Peninsula and the eastern Aleutian Islands. Hazards from volcanic activity are associated with the eruption of lava and ash (explosive activity) and attendant earthquakes. These forces, including ground motion from earthquakes, may affect man-made structures as well as disturbing pre-existing, unstable sediment deposits.

During the colder months, the North Aleutian basin is in part covered with ice; the average thickness of this sea ice is 1 to 1.5 m. Most of the ice is mobile, although stationary ice, in sheets 1-2 m thick and as wide as 80 km, forms along the shoreline of the Bay. Man-made structures could be affected by ice-ramming and bottom scouring.

Hard minerals prospects are at present unknown in the North Aleutian basin area. Exploration for hard minerals in the offshore area has not taken place to date.

## GEOLOGIC FRAMEWORK

A generalized geologic map of the onshore eastern Bering Sea region is shown in Figure 1. Detailed discussions of the geology of the Alaska Peninsula can be found in Burk (1965), Brockway et al. (1975), Mancini et al. (1978), Lyle et al. (1979), and McLean (1979a), of western Alaska in Hoare (1961), and Patton (1973), and of eastern Siberia in Churkin (1970), and by Scholl et al. (1975). Detailed descriptions of the geology of the Pribilof Islands are given by Barth (1956), and Cox et al. (1966); rocks dredged from the southern Bering Sea margin are described by Hopkins et al. (1969), Marlow et al. (1979a,b; 1983), McLean (1979b), and Vallier et al. (1980).

### Structural Setting

Complex geologic structures that include rocks as old as Precambrian are exposed in coastal mountains that flank the southeastern Bering Sea shelf. Most of the significant structures that flank the shelf include rocks of Mesozoic and Tertiary age. For example, the oldest rocks in the southern Alaska Peninsula are Upper Jurassic siltstone and sandstone of the Naknek Formation (Burk, 1965). The westernmost exposure of these rocks is in the Black Hills bordering the southern Bering shelf (Fig. 1). These shallow water rocks strike west toward the southern Bering shelf area and are paralleled to the north by a belt of Jurassic granitic rocks (Fig. 1; Burk, 1965).

Cretaceous and older Mesozoic rocks of southwest Alaska trend southwestward toward the southern Bering Sea shelf (Fig. 1; Payne, 1955; Hoare, 1961; Gates and Gryc, 1963; Patton, 1973). These complex allochthonous terranes are composed of diverse sedimentary and igneous belts that are thought to have been accreted as microplates to cratonic Alaska during Mesozoic and earliest Cenozoic time (Jones, 1978; Jones and Silberling, 1979; Marlow and Cooper, 1983).

Further, deformed deep water sedimentary rocks of Cretaceous age are exposed south of the Alaska Peninsula in the Shumagin Islands and are thought to be uplifted trench and slope deposits accreted to the southern Alaskan margin by late Mesozoic or earliest Tertiary time (Fig. 1; Moore, 1972, 1973a,b, 1974). Earlier hypotheses for the evolution of the southern Bering Sea margin included speculations that these deformed rocks extend to the northwest beneath the southern Bering Sea margin (Burk, 1965; Moore, 1972, 1973a,b, 1974; Patton et al., 1974, 1976; Scholl et al., 1975; and Marlow et al 1976a,b, 1977), a supposition later refuted by McLean (1979b).

Thus, the southeastern Bering Sea shelf is a focal area for several diverse structural trends that converge on the region. Unraveling these trends and determining whether they merge or end beneath this section of the shelf is critical to understanding the evolution of the Bering Sea.

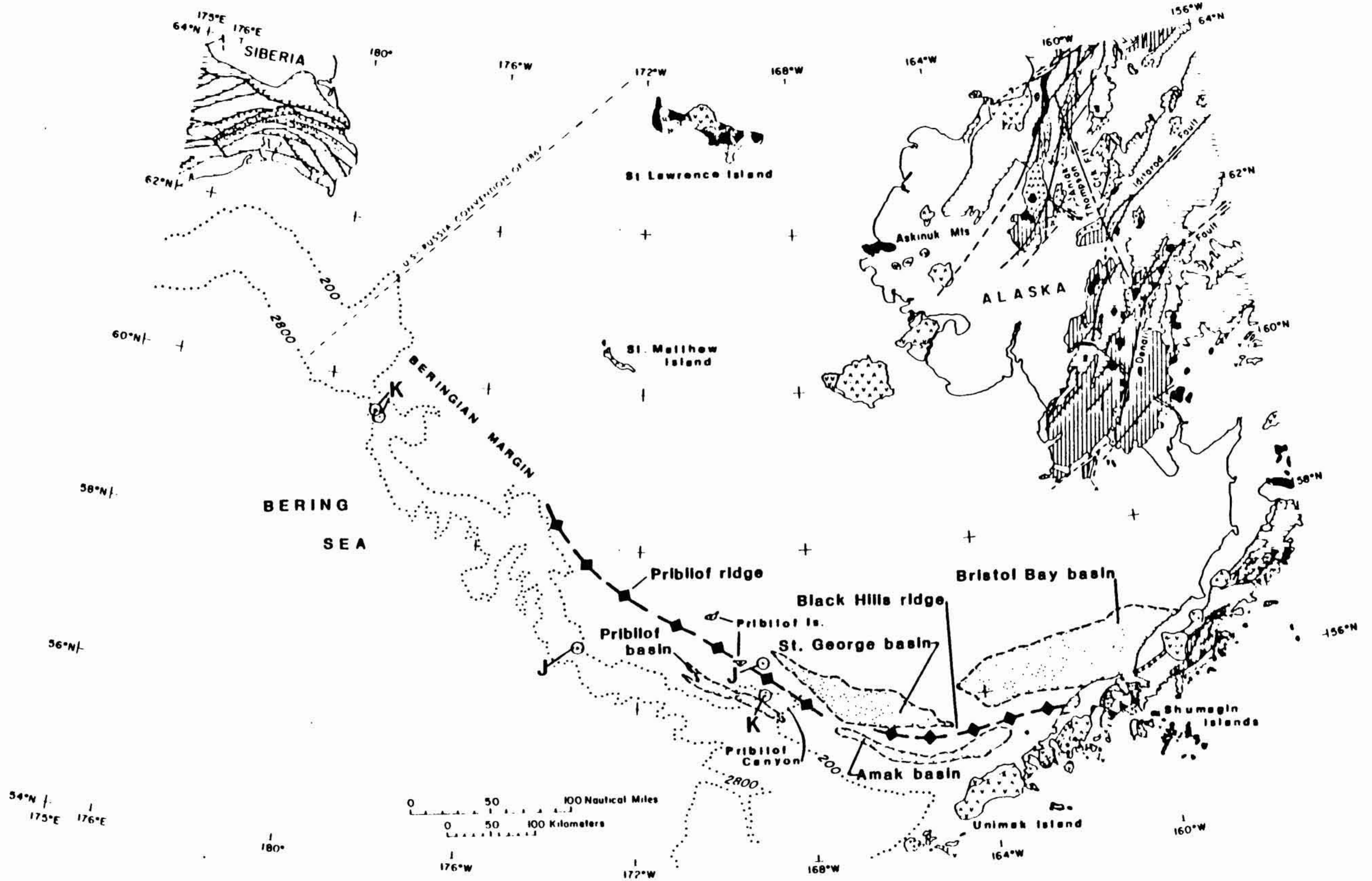


Figure 1. Generalized geology of western Alaska, Alaska Peninsula and eastern Siberia. Onshore geology is modified from Burk (1965), Yanshin (1966), and Beikman (1974). Offshore outlines of subshelf ridges and basins are derived from Marlow and Cooper (1980). Dotted open circles indicate sites where Jurassic (J) and Cretaceous sedimentary rocks were dredged from the continental slope (Marlow et al., 1979b; Vallier et al., 1980). Albers equal-area projection.

EXPLANATION

Surficial deposits including glacial drift.

Tertiary and Quaternary volcanic rocks. Includes basaltic rocks on Nunivak, Nelson, and St. Lawrence Islands, and interbedded basalt and andesite along the northern Alaska Peninsula.

Tertiary volcanic rocks. Basalt and andesite flows and some rhyolite, trachyte, and latite.

Tertiary sedimentary rocks.

Cretaceous and Tertiary volcanic rocks.

Jurassic, Cretaceous, and Tertiary granite rocks.

Undifferentiated Jurassic and Cretaceous volcanic and sedimentary rocks.

Undifferentiated Paleozoic and Mesozoic volcanic and sedimentary rocks. Includes the Gemuk Group of southwestern Alaska.

Undifferentiated Paleozoic volcanic and sedimentary rocks. (In part metamorphosed.)

Undifferentiated Precambrian volcanic and sedimentary rocks.

Ridge crest.

Normal fault, hachures on downthrown side, dashed where inferred.

Thrust fault, barbs on upthrown side.

200 Bathymetric contours in meters.

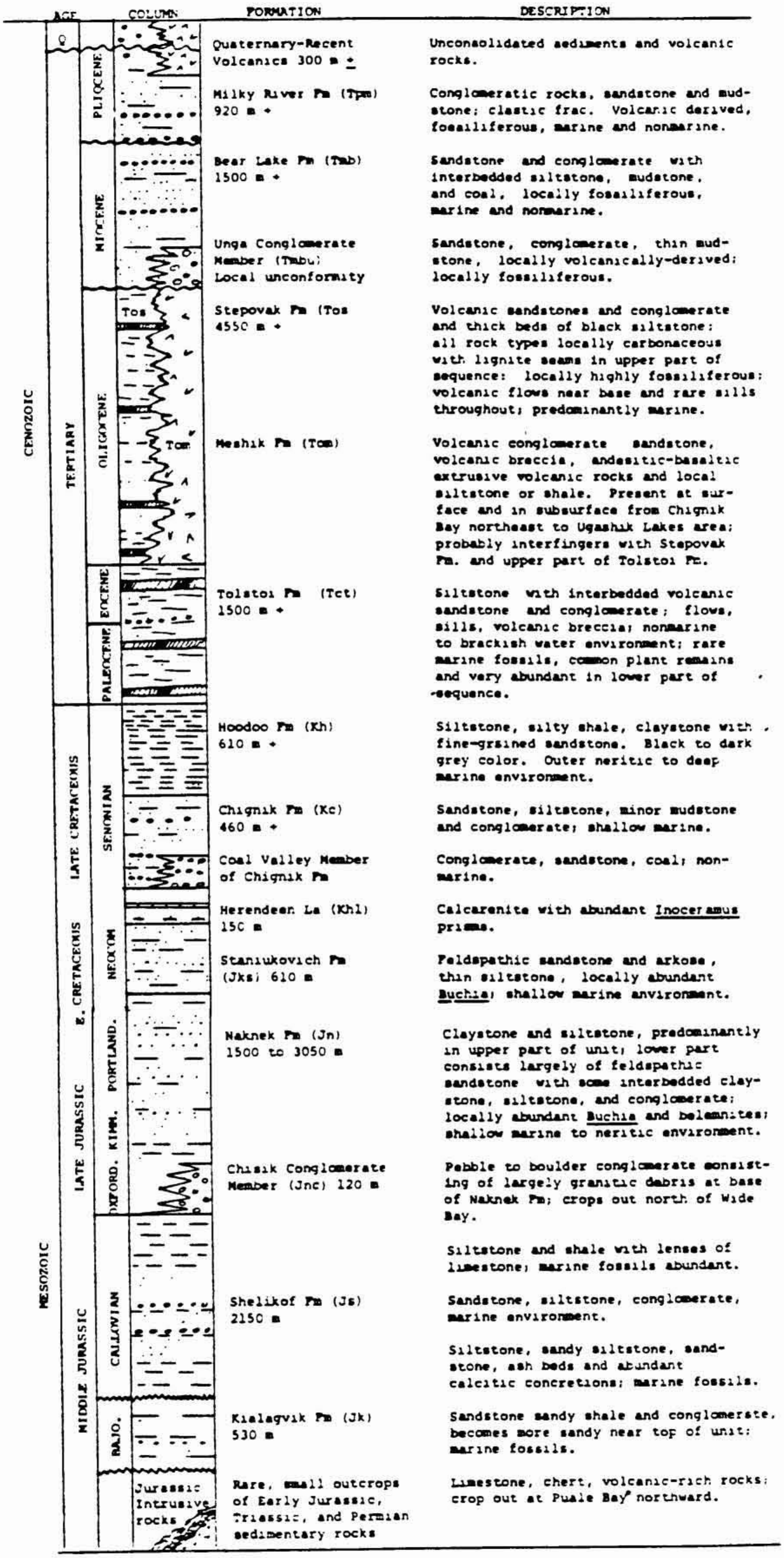


Figure 2. Composite columnar section of strata in the area of proposed lease sale #92 and the Alaska Peninsula. Derived from Burk (1965) and Brockway et al. (1975).

## Geologic Setting

### *Mesozoic Rocks*

The oldest rocks exposed near St. George, Amak, and outer Bristol Bay basins are Upper Jurassic siltstone and sandstone of the Naknek Formation, which crop out in the Black Hills of the western end of the Alaska Peninsula (Figs. 1, 2; Burk, 1965). The Cathedral River Unit 1 well spudded into the Black Hills and drilled to a total depth of 4,359 m (14,301 ft.); the well reportedly penetrated Triassic strata (McLean, 1979a). Rocks recently dredged from the outer shelf near the Pribilof Islands and from the continental slope west of the islands include fossiliferous, gray-green volcanic sandstone of Late Jurassic age (Fig. 1; Vallier et al., 1980; Marlow et al., 1979a,b; Marlow and Cooper, 1980).

Lithified mudstone, siltstone, and sandstone of Late Cretaceous age were dredged from acoustic basement exposed in Pribilof Canyon along the outer Bering Sea margin (Fig. 1; Scholl et al., 1966; Hopkins et al., 1969). To the northwest near Siberia, argillaceous limestone and sandy siltstone interbedded with volcanic sandstone were dredged from the continental slope along the Beringian margin. Both the limestone and the siltstone contain Campanian or Maestrichtian (Late Cretaceous) pollen and spore assemblages (Marlow et al., 1979b).

Ultramafic basement rocks are subaerially exposed on St. George Island in the Pribilof Islands (Barth, 1956). These ultramafic bodies consist of serpentized peridotites that are intruded by a granodiorite dike that has been dated radiometrically and has a minimum age of 50 to 57 m.y. (Hopkins and Silberman, 1978). We suspect that the peridotites are Mesozoic in age and that they either intrude the Jurassic basement rocks beneath the Pribilof Islands or that they may be allochthonous blocks within the basement complex. In this paper we will assume that the seismically-resolved acoustic basement beneath the southern outer Bering Sea margin, which flanks the western end of North Aleutian basin, consists mainly of indurated sedimentary rocks of Mesozoic age.

Near Port Moller along the western end of the Alaska Peninsula, the Upper Jurassic to Lower Cretaceous Naknek and Staniukovich Formations are unconformably overlain by Upper Cretaceous rocks of the Chignik and Hoodoo Formations (Fig. 12 in Burk, 1965). Middle Cretaceous strata are missing, probably as a result of deformation and uplift along the Alaska Peninsula in Middle to Late Cretaceous time (Burk, 1965).

### *Cenozoic Rocks*

Cenozoic rocks exposed on the Alaska Peninsula include assemblages representing all the Tertiary epochs (Figs. 1, 2, 3; Burk, 1965). The only parts of the Tertiary that may be missing include the Oligocene-Miocene transition and the early Paleocene. According to Burk, these were periods of uplift, deformation, and erosion on the Alaska Peninsula, although the major uplift and formation of the peninsula took place during Pliocene time.

Paleogene rocks on the Alaska Peninsula are composed almost entirely of volcaniclastic debris, containing principally andesitic and basaltic volcanic components (Burk, 1965; McLean, 1979a). These rocks, up to 9100m (30,000 ft.) thick, are both marine and non-marine; their volcanic content, which includes both detrital material as well as interbedded flows, shows that volcanism was ubiquitous throughout the peninsula in the early Tertiary. Paleocene and Eocene rocks overlie Upper Cretaceous strata with only slight discordance and, locally, lower Tertiary units rest on rocks as old as the Late Jurassic (Burk, 1965). Major Paleogene formations exposed on the Alaska Peninsula include the Tolstoi (Paleocene or Eocene), the Stepovak (Eocene(?) and Oligocene), the Meshik (Oligocene), and the Belkofski (Oligocene) Formations (Burk, 1965; McLean, 1979a).

Neogene rocks exposed on the Alaska Peninsula include marine and nonmarine volcaniclastic rocks, volcanic flows, and breccias. The thickest Neogene formation on the peninsula, the Bear Lake Formation, consists of 1500 m (5000 ft) of porous sandstones and conglomerates that are interbedded with siltstone, mudstone, and coal of middle and late Miocene age (Burk, 1965; Brockway et al. 1975; McLean, 1979a). Unconformably overlying the Bear Lake Formation are up to 500 m (1500 ft) of shallow marine to nonmarine sandstone, pebbly mudstone, and carbonaceous mudstone of the Talchilni Formation, which is late Miocene to Pliocene in age (Burk, 1965); the Talchilni Formation has been mapped only in the southwestern area of the Alaska Peninsula near Cold Bay (Burk, 1965, McLean, 1979a). Brockway et al., (1975), in a composite stratigraphic section of the peninsula and Bristol Bay, show that the Bear Lake Formation is overlain unconformably by the Milky River Formation, which consists of more than 1000 m (3000+') of conglomerate, sandstone, and mudstone that were deposited in a shallow marine environment (Fig. 2). Much of the Alaska Peninsula is capped by a flat-lying section of nonmarine clastic rocks that are poorly consolidated and interbedded with volcanic flows and breccias of Pleistocene and Holocene age (McLean, 1979a)

Cenozoic rocks exposed on the Alaska Peninsula are probably equivalent to strata that are buried beneath the adjacent Bering Sea shelf within North Aleutian basin (Burk, 1965; Hatten, 1971) and St. George basin ( Marlow et al., 1976a, 1977).

## Geologic History

North Aleutian or Bristol Bay basin, as a distinct structural trough, probably began to form in late Mesozoic time and has continued to subside during most of Cenozoic time. Publicly-available seismic-reflection data show that this basin is an elongate structural sag, which is asymmetrical in cross section. The northern flank of Mesozoic basement rock dips gently to the south but the southern flank is steeply inclined and crops out in the northern foothills of the Alaska Peninsula.

The basin probably began to form with the formation of the Aleutian Island arc and the trapping of a piece of Pacific oceanic crust in the adjacent abyssal Bering Sea at the end of the Mesozoic era or in earliest Tertiary time (Scholl et al., 1975; Marlow et al., 1976a, b). The rocks beneath the sediment fill in North Aleutian basin have subsided during much of Cenozoic time and the basin now contains more than 6 km of sedimentary rock.

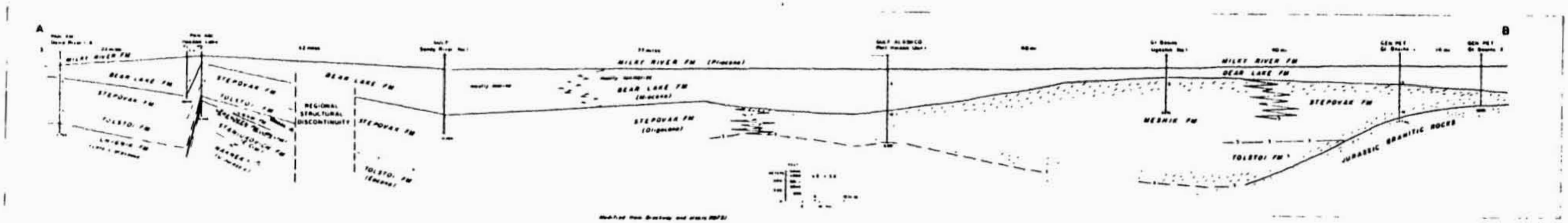


Figure 3. Generalized stratigraphic cross section along the northern side of the Alaska Peninsula. Modified from Brockway et al. (1975).

## Summary

The rate of subsidence of North Aleutian or Bristol Bay basin has about equaled the rate of deposition since late Mesozoic time. The maximum thickness of sedimentary rock in the deepest part of the basin is not well known but probably exceeds 6 km and may be as thick as 8 km. The basin fill does not appear to be deformed except locally near the southern basin edge along the northern shore of the Alaska Peninsula.

Most of the upper Mesozoic and Cenozoic sedimentary rock units exposed onshore along the Alaska Peninsula probably exist offshore beneath the south-eastern Bering Sea shelf. The position of the basin behind the Aleutian arc may have isolated it from the numerous episodes of volcanism and plutonism that substantially reduced the petroleum potential of the sedimentary sequences along the Alaska Peninsula (McLean, 1979a).

The northeastern half of North Aleutian basin contains as much as 3200 m of flat-lying Cenozoic sedimentary rocks that include marine and nonmarine sandstone, siltstone, shale units and local coal seams. From Port Heiden northward, the Neogene sedimentary sequence generally overlies Jurassic granitic rocks although locally it covers volcanic rocks of Oligocene age. Southwest of Port Heiden, the underlying Oligocene volcanic rocks appear to grade into marine sedimentary facies of Oligocene and Eocene age. In wells drilled south and west of Port Moller, Cenozoic sedimentary rocks unconformably overlie marine sandstone, siltstone, and shale beds of Late Jurassic and Late Cretaceous age, a relationship that may enhance the petroleum potential of the offshore area between Port Moller and Amak Island.

## PETROLEUM GEOLOGY

### Alaska Peninsula and North Aleutian Basin

*Drilling History - Onshore*

Since 1959, nine wells have been drilled along the northern coastal lowland area of the Alaska Peninsula. Only one well has been drilled offshore in North Aleutian basin and data from that well are proprietary. For descriptive purposes, the onshore wells are divided here into a northern group of four wells that bottomed in volcanic or granitic rocks and a southern group of five wells that bottomed in either Tertiary or Mesozoic sedimentary rocks. The northern group includes the General Petroleum Great Basins No. 1 and 2, Great Basins Ugashik No. 1, and the Gulf-Alaskco Port Heiden No. 1 (Fig. 4). The southern Group includes the Gulf Sandy River Federal No. 1, Pan American Hoodoo Lake No. 1 and 2, Pan American David River No. 1-A, and the Amoco Cathedral River No. 1 (Brockway et al., 1975). Of the nine wells drilled to date in the coastal lowlands of Bristol Bay along the Alaska Peninsula, the five wells located south and west of (and including) the Gulf Sandy River well contain the best shows of oil and gas (Hatten, 1971; Brockway et al., 1975). A thick marine section within the Miocene Bear Lake Formation may occur in the Port Moller area and adjacent offshore region. This suggests that better source or reservoir rocks may occur in the southwest portion of North Aleutian basin.

In the northern group of wells, the thickness of the flat-lying Tertiary sequence varies from about 1200 m to 3350 m and consists of interbedded nonmarine to shallow marine sandstone, siltstone, claystone and coal (Hatten, 1971). Granitic basement penetrated by the General Petroleum Great Basins No. 1 and 2 wells has been dated radiometrically as about 177 m.y. old (late Early Jurassic). Radiometric ages from the volcanic sequence underlying the flat-lying Tertiary sedimentary rocks in the Gulf Port Heiden and Great Basins Ugashik wells range from 33 to 42 m.y. (Oligocene to late Eocene) according to Berggren (1969) and Brockway et al. (1975). No significant shows of oil or gas have been reported from the northern group of wells. To the south the Gulf Sandy River well encountered gas associated with coal in the middle part of the Miocene Bear Lake Formation between 1790 and 1940 m. Oil and gas shows were also encountered in the basal sandstone beds beds of the Bear Lake Formation and in the Stepovak Formation (Brockway et al., 1975). Shows of oil and gas were reported from sandstone beds in the Stepovak and Tolstoi Formation in the Pan American Hoodoo Lake No. 1 well, which also penetrated 2258 m of the Bear Lake Formation. In the Pan American David River 1-A well, gas shows occurred in sandstone units of the Bear Lake and Stepovak Formations. Additional shows of oil and gas were reported in the Tolstoi Formation. Drilling in the same well revealed one gas show in the Chignik Formation at a depth of about 4175 m.

The Amoco Cathedral River Unit 1 well was spudded into Jurassic rocks of the Naknek Formation in the Black Hills near the western tip of the Alaska Peninsula and reached a total depth of 4,359 m (McLean, 1979a). Cuttings from the well, which reportedly bottomed in Triassic strata, were analyzed by McLean for organic carbon content. The samples have a total organic content of less than 1% and were contaminated below 2,621 m. Petrographic examinations of sandstone chips from the well show no visible porosity in any part of the section (McLean, 1979a).

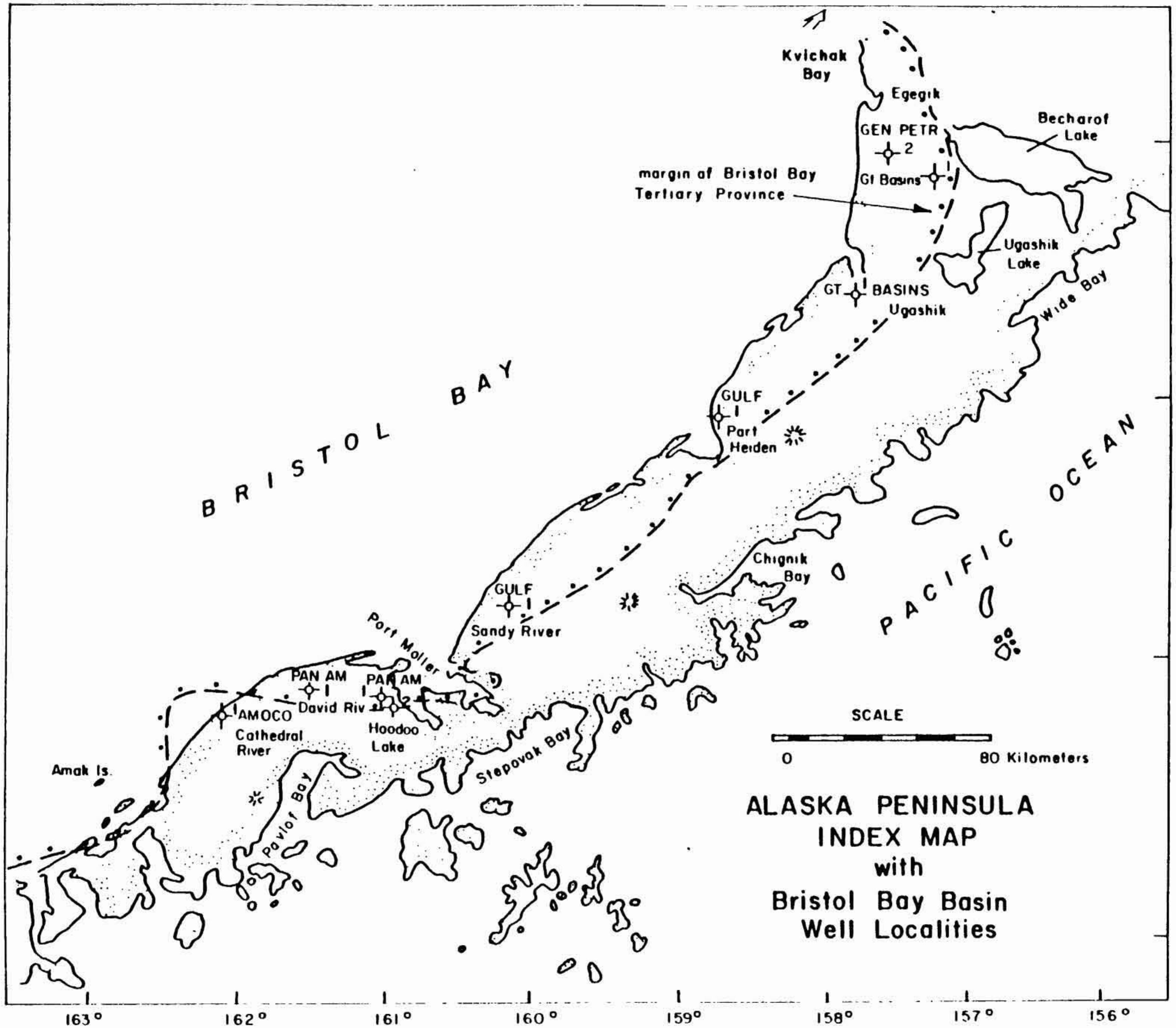


Figure 4. Index map of the Alaska Peninsula showing sites of wells drilled on the peninsula.

The thickness of the flat-lying Cenozoic sedimentary sequence and the lithology of the underlying basement rocks are the principal factors affecting the potential of offshore oil and gas accumulations in the adjacent North Aleutian basin. Thickness is important in that source rocks must attain a burial depth where temperatures are high enough to generate substantial quantities of oil and gas. There apparently has not been enough burial of most of the Bear Lake Formation to generate petroleum liquids; only one oil show has been reported in all the wells that have penetrated this formation. That oil show appeared at a depth of about 3050 m in the Gulf Sandy River well. However, in this well the oil encountered within the basal portion of the Bear Lake Formation may have been derived from source rocks within the underlying Stepovak Formation.

In offshore areas where the flat-lying Cenozoic sequence overlies older, folded and truncated sedimentary rocks, such as the Mesozoic strata of the Black Hills, oil may have migrated upward into the more porous sandstone beds of the overlying Bear Lake Formation. The possibility of oil and gas migration from older sedimentary formations renders the offshore area between Port Moller and Amak Island more prospective than the area north of Port Heiden, where the basement consists of volcanic and granitic rocks.

The arcuate gravity and magnetic discontinuity described by Pratt et al. (1972), which extends from the Pribilof Islands toward Port Moller, may define two different basement rock types beneath the flat-lying Cenozoic sequence. High amplitude magnetic anomalies on the northeast side of the discontinuity may represent volcanic or granitic-metamorphic basement rock, and the low amplitude anomalies on the southwest side may reflect a thick sequence of sedimentary rocks.

The flat-lying sequence of Cenozoic sedimentary rocks is locally folded and uplifted along the foothill belt of the Alaska Peninsula. Farther offshore, the strata may be depositionally draped over fault blocks within the acoustic basement (Hatten, 1971). The rocks considered to have the greatest petroleum potential in the offshore area are flat-lying to gently folded Cenozoic sandstone, siltstone, and shale beds. These rock units probably range in age from Eocene to Pliocene.

*Drilling History - Offshore*

To date, only one COST well has been drilled offshore into North Aleutian basin and data from that well are proprietary. However, west of North Aleutian basin, two COST wells were drilled into the St. George basin province and data from those two wells are extensively described by Turner et al. (1984a,b). Here we present a short summary of each well taken from Turner et al (1984a,b). We note here that the wells are over 75 km from North Aleutian basin and may not represent the section in the North Aleutian basin.

The first St. George COST well was drilled in 1976 to a total depth of 4197 m in water 135 m deep, some 170 km southeast of St. George Island, Alaska. The section drilled includes:

| AGE | DEPTH TO TOP (m) |
|---|---|
| Pliocene -Pleistocene | 488 |
| Pliocene | 1097 |
| Miocene | 1637 |
| Oligocene | 2563 |
| Eocene | 3164 |
| Igneous basement (age?) | 4197 |

The sedimentary section includes interbedded sandstone, siltstone, mudstone, diatomaceous mudstone, and conglomerate. The section was derived predominantly from volcanic source terranes and the detrital material is mechanically and chemically unstable, i.e. subject to cementation and ductile grain deformation. Thus, porosity and permeability in the sedimentary section have been reduced by ductile grain deformation, cementation, and authigenesis.

Geochemical analyses of sediment samples show that the most common organic material present is Type III humic kerogen, and that the average total organic carbon content of the samples is low (0.5%), the maximum value being 0.74%. The calculated geothermal gradient in the well is high, 36 degC/km (Turner et al., 1984a).

The second St. George COST well was drilled in 1982 to a total depth of 4458 m in water 114 m deep, about 180 km northwest of Cold Bay on the Alaska Peninsula. The section drilled includes:

| AGE | DEPTH TO TOP (m) |
|---|---|
| Pliocene-Pleistocene | 445 |
| Pliocene | 1294 |
| Miocene | 1844 |
| Oligocene | 3378 |
| Eocene(?) | 3822 |
| Early Cretaceous(?) or Late Jurassic(?) | 4075 |
| Late Jurassic | 4458 |

The Cenozoic sedimentary section includes interbedded sandstone, siltstone, mudstone, diatomaceous mudstone, and conglomerate, and like the first COST well, the section was derived predominantly volcanic source terranes. The detrital material is mechanically and chemically unstable. Also, porosity and permeability in the section are reduced by grain deformation, cementation, and authigenesis.

The Mesozoic sedimentary section at the bottom of the well consists of shallow marine sandstone, siltstone, shale, conglomerate, and minor amounts of coal. Porosities and permeabilities in this section are also low.

Like the first COST well, geochemical analyses of sediment samples show that the most common organic material present is Type III humic kerogen, and that the organic carbon content of the samples is low, generally less than 0.5 percent. Siltstones with organic carbon contents between 0.5 and 1.0 percent and in a few instances more than 1.0 percent are present below 1550 m, and enough maturity for peak oil generation may exist below 3780 m. The section is gas prone according to Turner et al. (1984b). Thermal maturation is low and the geothermal gradient is 27 degC/km.

According to Turner et al. (1984a,b), strata with better source rock and reservoir qualities than those in the two COST wells may be present in other parts of St. George basin, where the section is thicker in the central parts of the basin. The same relation may hold between the St. George COST wells and North Aleutian basin.

*Source Beds*

Drill cuttings from eight of the nine wells drilled along the Alaska Peninsula were analyzed by McLean (1977) for their organic geochemistry, lithology, and petroleum potential. Analyses of several of the wells show that Paleogene strata are rich in organic matter but are immature. However, coeval sedimentary sections offshore in the basin may be more deeply buried than those units on the peninsula and hence may be more mature. In general, fine-grained Neogene sedimentary rocks have a significantly lower carbon content than Paleogene strata, which suggests that the younger strata may have been deposited in brackish to nonmarine environments (McLean, 1979a)

The best source rocks in the Tertiary sequence appear to be the black marine siltstone and shale beds in the Oligocene Stepovak Formation. On the Alaska Peninsula, the Stepovak Formation is locally at least 4500 m thick (Burk, 1965). Scattered shows of oil and gas in Stepovak rocks have been reported from three Alaska Peninsula wells, Gulf Sandy River, Pan American Hoodoo Lake No. 2, and Pan American David River 1-A (Fig. 3; Brockway et al., 1975). Potential source rocks may also occur in the Miocene Bear Lake Formation because, locally, the basal portion containing marine siltstone and shale may have been buried deeply enough to generate hydrocarbons. Marine shale of Late Jurassic and Late Cretaceous age might also be considered as potential source rocks where they are in angular discordance with overlying Cenozoic sandstone reservoir beds.

*Reservoir Beds and Seals*

The rocks that have the greatest reservoir potential for oil and gas in the offshore portion of the basin are probably the sandstone units of the Bear Lake Formation that are middle to late Miocene in age. Bear Lake sandstone beds are both marine and nonmarine and contain a combination of volcanic grains, dioritic grains, chert, and sedimentary lithic fragments. Most of the sandstones could be classified as lithic subgraywackes and others as lithic arenites (Burk, 1965). In the Gulf Sandy River No. 1 well, Bear Lake sandstone above 6,300 feet has porosity values as high as 36.5% and permeability as high as 1,268 mds. Below 6,300 feet, high values for porosity and permeability are 29% and 43 mds, respectively (McLean, 1977). Shows of oil and gas have been reported from the basal Bear Lake Formation sandstones in the gulf Sandy River and Pan American David River wells.

Sandstones in the older Tertiary formations, Tolstoi and Stepovak, have an abundance of volcanic detritus as well as matrix clay. These rocks are dense and highly indurated and thus are not considered good reservoir beds.

*Traps and Timing*

Most potential oil and gas traps in North Aleutian basin are probably anticlinal structures. Anticlines in the Cenozic sequence are primarily formed by draping and differential compaction of strata over erosional and block-fault highs that developed within the acoustic basement complex. The resultant structures are large in area but have a limited amount of closure. Structural traps in the offshore area may have formed during the early filling of North Aleutian basin. Most structures decrease in amplitude upward through the Cenozoic section, and the Pliocene and Pleistocene strata are flat-lying and undeformed.

Stratigraphic traps formed by buttress onlap during transgression around topographic highs, by local truncation of sandstone beds, and by lenticular sandstone bodies probably occur in the Cenozoic sequence, but their size and number are unknown.

*Summary*

The petroleum potential of the southwest portion of the offshore North Aleutian basin between Port Moller and Amak Island is probably greater than that of the area to the northeast. The total thickness of Cenozoic sedimentary rocks is greater in the southwest portion and there may be petroleum prospects in the underlying Mesozoic strata. The petroleum potential may also be higher for the southwest portion of the basin because shows of oil and gas occurred in three or possibly four of the wells drilled on the adjacent Alaska Peninsula. This is in contrast to the four northern wells where no hydrocarbon shows were reported.

## REGIONAL GEOLOGIC HAZARDS

A general environmental analysis of the Bristol Bay region is available in Buck et al., 1974. In the adjacent St. George basin region, potential geologic hazards have been outlined by Gardner et al. (1979), who discuss faulting, potentially unstable sediments, and sedimentology of surface sediments.

For this preliminary analysis, therefore, we have relied on the data and analyses of others, specifically Lisitsyn (1966), Askren (1972), Nelson et al. (1974), Sharma et al. (1972), Sharma (1974, 1975), Molnia et al. (1982, 1983a,b), Schwab (1984), and Molnia and Schwab (1984).

The major potential geologic hazards in the Bristol Bay region include earthquakes, faulting, tsunamis, seafloor instability caused by rapid sediment movement (erosion, transport, and deposition), and volcanic activity. Sea ice, as well as tide-and storm-induced waves, can also affect man-made structures.

### Earthquakes and Faults

Earthquakes with magnitudes greater than 8 (on the Richter scale) have been recorded along Alaska Peninsula (Sykes, 1971) and some with magnitudes between 7 and 8 on the Richter scale have been recorded in the southeastern Bering Sea (Marlow et al., 1980). There is little known, however, about associated ground motion and tsunamis caused by the earthquakes. The ground motion probably decreases to the north across the shelf because of distance from the major epicenter belt. Most epicenters in the southern Bering Sea lie just north of the Alaska Peninsula- Aleutian Island chain. Shallow earthquake hypocenters ( 70 km depth) occur as far north as St. George Island.

Faults are extensive in the St. George basin region just west of Bristol Bay where they are classified as major, surface, and minor (Vallier and Gardner, 1977; Gardner et al., 1979). The faults are concentrated along and in the St. George basin and some offset the seafloor.

Near surface and seafloor-offsetting faults have been reported in the outer region of Bristol Bay centered around Amak basin (Figs. 1 and 5; Molnia et al. 1983a,b; Molnia and Schwab, 1984; Schwab, 1984). Many faults along the flanks of North Aleutian basin offset bedrock surfaces. Some faults show increasing offset with depth, indicating that these faults are growth-type structures.

### Sediment Movement

The distribution of surface sediments across the continental shelf of the southern Bering Sea is described by Lisitsyn (1966), Askren (1972), Sharma et al. (1972), and Sharma (1974. 1975). Based on their data, sediment size near the southeastern Bering shelf grades from coarse sand along the inner shelf to fine silt near the outer shelf, although grain size is somewhat coarser near the shelf break.

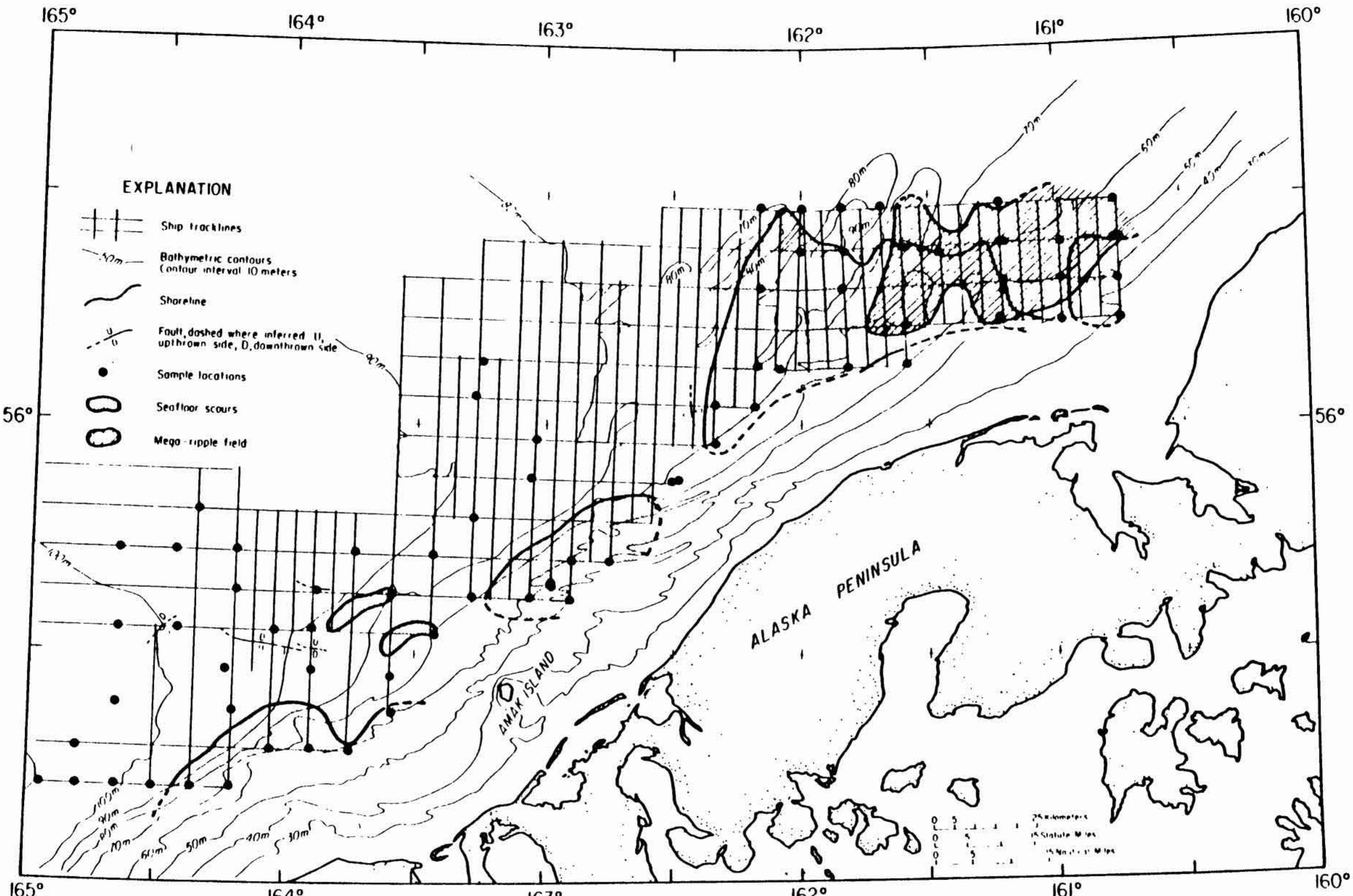


Figure 5. Map showing locations of seafloor scours, mega-ripples, and faults in Bristol Bay basin. Taken from Schwab (1984).

Molnia et al. (1982, 1983a) and Schwab (1984) reported thousands of parallel, linear scours cut into the seafloor in the Bristol Bay region (Fig. 5). The scours occur in groups, incise the seafloor as deeply as 5 m, and are found in water depths out to 90 m or more. Many scours have minimum lengths of 800 m and range in width from a few meters to more than 250 m. Other observations, such as current measurements and video scans, also show that active scouring and sediment transport are occurring in the Bristol Bay region (Molnia et al., 1982; Schwab, 1984). In addition, areas of mega-ripples and dunes cover more than 1,500 sq. km in the northeastern portion of the basin area north of Port Moller, also suggesting sediment transport here (Fig. 5; Molnia and Schwab, 1984).

Lisitsyn (1966, p. 96-98) does not believe that waves have much effect on sediment movement in the deeper parts of the southern Bering Sea. We do know, however, that waves (Tsunami-, tide-, and wind-induced) can greatly affect sediment movement in nearshore areas and probably are major agents for sediment movement along the north shore of the Alaska Peninsula. Tides can have a strong effect in shallow water, particularly in funnel-shaped estuaries such as Kuskokwim Estuary north of Bristol bay, where the tidal range is as great as 8 meters and current velocities can exceed 200 cm/sec (Lisitsyn, 1966). Wind-induced waves can move sediment in water depths of up to 100 meters in the Bering Sea. Storms are frequent, and the probability of storm waves several meters in height exceeds 20% during the year (Lisitsyn, 1966, p. 98). The strongest and most prolonged storms occur during the fall and early winter season. Wave-generated forces can redistribute large volumes of sediments in a short time and thereby are potential hazards to man-made structures on the sea floor and in near-shore areas on land.

## Volcanic Activity

The southeastern Bering Sea shelf is bounded on the south by the Alaska Peninsula and the eastern Aleutian Islands where several volcanoes are active. Coats (1950) lists 25 active volcanoes in the Aleutian Islands and 11 on the Alaska Peninsula and mainland. Hazards from volcanic activity are associated with the eruption of lava and ash and the attendant earthquakes. The distribution of ash is dependent on the magma composition, eruption character, wind speed and direction at the time of eruption, height of eruption, volume of material, and specific properties of the pyroclastic debris. Eruptions from the large andesitic cones on the Alaska Peninsula and Aleutian Islands are mostly the explosive type and can spread pyroclastic material such as ash-flow tuffs or related pyroclastic avalanche deposits over large areas (Miller and Smith, 1977).

The largest known quantity of volcanic material erupted in historic times in the Alaska area, some 21 cubic kilometers of ash, was erupted by Katmai volcano in 1912, when ash was carried over distances of 2000 km or more. At a distance of 180 km from the volcano, ash was deposited with a density of about 45 g/cm (Lisitsyn, 1966). According to historical data, individual ash deposits in the Bering Sea region extend 200 to 2000 km from the source, averaging about 500 km, and thus could cover North Aleutian basin if wind direction, eruption height, wind speed, volume and other factors were complementary. Hazards are associated not only with the volume of ash that might be deposited but also with ground motion that often accompanies major eruptions. These forces, including base surges from caldera eruptions, may affect man-made structures and also shake loose pre-existing, unstable, and under-compacted sediment bodies.

## Ice

Parts of the southern Bering Sea continental margin have ice cover during 10 to 50% of the year (Fig. 6; McRoy and Goering, 1974). Ice development is at its maximum in March and April when average ice thicknesses range from 1 to 1.5 m (Lisitsyn, 1966, p. 99). Both stationary and mobile ice are present. Stationary ice forms along the shorelines and ranges in width from a few meters to as much as 80 km from the shore. Some ice gouging occurs near the shorelines where the ice is thickest; man-made structures and pipelines may be affected by ice-ramming and bottom scouring.

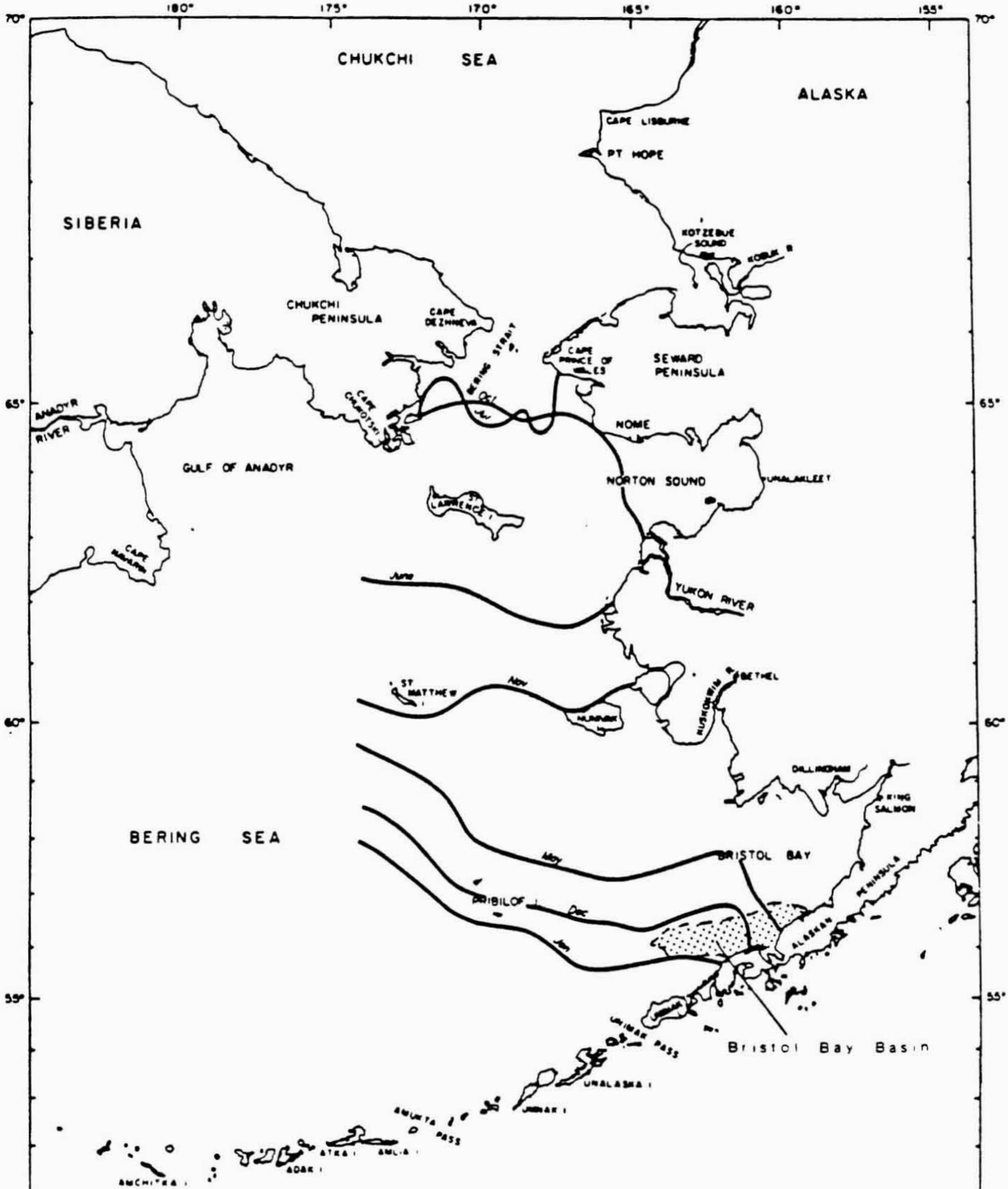


Figure 6. Extent of ice cover across the Bering Sea shelf for different months of the year. From McRoy and Goering (1974).

## HARD MINERALS GEOLOGY

Hard minerals deposits are unknown in the North Aleutian basin planning area.

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