ALASKA PENINSULA/BECHAROF NATIONAL WILDLIFE REFUGES OIL AND GAS ASSESSMENT

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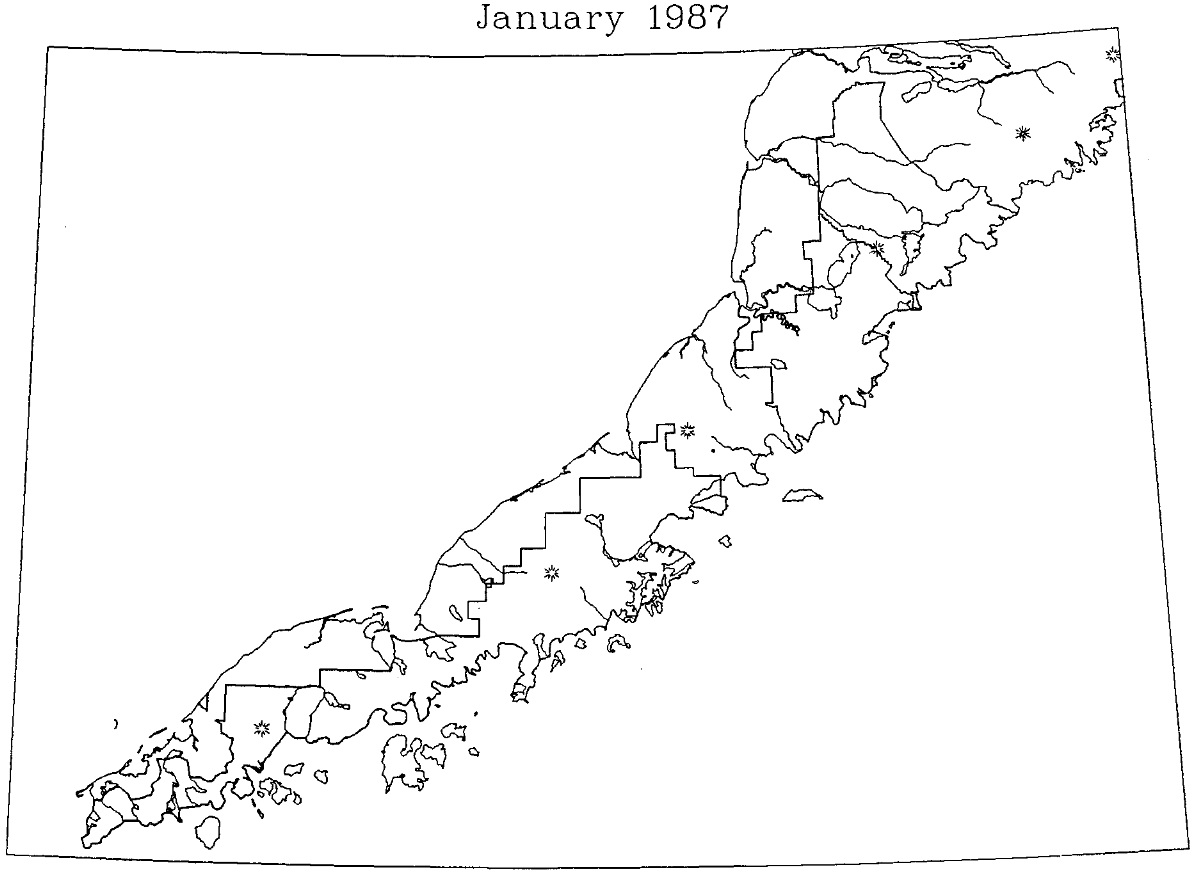

U.S. Department of the Interior
Bureau of Land Management - Alaska
Division of Mineral Resources
Branch of Minerals Assessment

DEPARTMENT OF THE INTERIOR
U.S. BUREAU OF LAND MANAGEMENT - ALASKA
DIVISION OF MINERAL RESOURCES
BRANCH OF MINERALS ASSESSMENT

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EXECUTIVE SUMMARY

The area in the vicinity of the Alaska Peninsula and Becharof National Wildlife Refuges (NWR) has attracted oil exploration activity since the early 1900s. This interest continues to the present; the last well in the area was drilled and abandoned in 1985, and the oil industry still expresses an interest in exploring the Alaska Peninsula. Twenty-six wells have been drilled on the Alaska Peninsula, in the vicinity of the refuges. Eight have been drilled within the current boundaries of the Becharof NWR and five have been drilled within the current boundaries of the Alaska Peninsula NWR. To date, no commercial quantities have been found, but oil and gas shows have been found in some Peninsular wells, and oil and gas seeps are known in the area. Our analysis of the geology indicates that the oil and gas potential for the area ranges from no potential to high potential, with moderate and high potential areas covering most of the area.

One area of high potential (plate 3) extends along the Pacific Ocean coast from the northern boundary of the Becharof NWR to just north of Ivanof Bay. It extends inland to a line running southwestward through the middle of Becharof Lake to just southeast of Black Lake and then swings out to the coast. An area of moderate potential lies northwest of this area, along the Bristol Bay coast. The other area of high potential runs along the Bristol Bay/Bering Sea coast from about 20 miles southwest of Port Heiden to Moffet Lagoon. Areas of no, low, and moderate potential lie to the southwest of this high potential area, along the Pacific Ocean coast.

Interest in oil and gas exploration on the Alaska Peninsula ranks as none to moderate (plate 4), based on current oil prices, and should remain at that level to the year 2000. An upturn in the price of oil could, however, cause an upswing in exploration interest. And, a significant discovery, on or in the vicinity of the Peninsula, could generate a high level of interest in the area.

INTRODUCTION

The Bureau of Land Management (BLM) has entered into a Memorandum of Understanding with the U.S. Fish and Wildlife Service (FWS) to assess the oil and gas resources of the National Wildlife Refuge System in Alaska. Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) requires the Secretary of the Interior to initiate an oil and gas leasing program on the Federal lands of Alaska. ANILCA exempts " . . . those units of the National Wildlife Refuge System where the Secretary determines, after having considered the national interest in producing oil and gas from such lands, that the exploration for and development of oil and gas would be incompatible with the purpose for which such unit was established."

The BLM's role is to help fulfill that part of Section 1008 that mandates:

> "In such areas as the Secretary deems favorable for the discovery of oil or gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this Section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas."

This report is intended to assist the FWS in deciding which lands within the Alaska Peninsula and Becharof NWRs should and should not be opened to oil and gas leasing/development. This report identifies those areas in and around the refuges which are favorable for the discovery and development of oil and gas.

LOCATION AND PHYSIOGRAPHY

The Alaska Peninsula and Becharof National Wildlife Refuges are located on the Alaska Peninsula which lies west and southwest of Cook Inlet (plate 1). It extends in a curving sweep from the vicinity of Lake Illiamna, at the base of the Peninsula, for over 400 miles (644 km) to Isanotski Strait, at its tip. The Peninsula decreases in width from about 100 miles (161 km) across its base to about 3 miles (4.8 km) at its tip.

The Peninsula, a sparsely populated expanse of land, exhibits a diversity of topography and landforms (Wahrhaftig, 1965). The Pacific coast, rugged and abrupt, shows evidence of glaciation in the form of U-shaped valleys, cirques, and other features of glacial erosion. Numerous bays indent the coast; some offer excellent protection from the storms of the northern Pacific Ocean.

The Aleutian Range forms the backbone of the Peninsula. It consists of rounded, east-trending ridges which range in height from 1,000 to 4,000 feet (330 to 1,315 m) above sea level. Volcanoes, ranging from 5 to 85 miles (8 to 137 km) apart, punctuate the range with peaks that reach 4,500 to 8,500 feet (1,476 to 2,790 m) above sea level. To the north and west, the Aleutian Range merges with the Bristol Bay-Nushagak Lowland.

The Bristol Bay-Nushagak Lowland runs down the northern and western slopes of the Aleutian Range to the Bering Sea. In contrast to the Pacific coast, the Bering Sea coast is gentle, with long, curving shorelines interrupted occasionally by wide, shallow bays. Beaches, spits, and barrier islands also occur along this coast. Lagoons lie landward of some of the spits and barrier islands.

The drainage divide of the Peninsula generally lies along the highest ridges and is within 10 miles (16 km) of the Pacific coast. Short, steep gradient streams flow off the mountains to the Pacific Ocean. Longer, braided streams flow northward and westward into the Bering Sea. Numerous lakes, some formed by glacial moraine, characterize the Bristol Bay-Nushagak Lowland west and north of the mountains.

Most volcanoes of the Alaska Peninsula support glaciers on all sides, and some have summit ice fields.

Becharof National Wildlife Refuge (NWR) occupies about 1.2 million acres (486,000 ha) in the vicinity of Becharof Lake. It extends from the Pacific Coast to just west of Becharof Lake, and it lies south and west of Katmai National Park and Preserve. It spans the Aleutian Range physiographic province and extends into the Bristol Bay-Nushagak Lowland to the north and west.

The Alaska Peninsula National Wildlife Refuge occupies about 4.3 million acres (1.8 million ha). It is divided into two portions. The northern portion of the Refuge lies just south of, and is contiguous with, the Becharof NWR and extends southwestward to Cape Kunmik. The southern portion is separated from the northern by about 25 to 30 miles (40 to 48 km) and by Aniakchak National Monument and Preserve. It then extends to the tip of the Alaska Peninsula. Like the Becharof NWR, the Alaska Peninsula NWR lies along the Pacific Coast, spans the Aleutian Range, and extends northward and westward into the Bristol Bay-Nushagak Lowland.

HISTORY OF GEOLOGIC EXPLORATION

G. W. Steller, a biologist who visited the Alaska Peninsula with Vitus Bering in 1741, made the first geological observations of the Peninsula. Constantine Grewingk, in 1850, published a geologic report based on data compiled from prospectors, traders, trappers, and reports from scientific expeditions. After the purchase of Alaska from Russia in 1867, W. H. Dall laid the groundwork for direct study of the Alaska Peninsula (Burk, 1965).

The U.S. Geological Survey, over the years, has sent numerous investigators to the Alaska Peninsula. The Peninsula also has attracted prospectors for oil and gas as well as for hard rock minerals, over the years. Based on the presence of oil and gas seeps in the vicinity of Puale Bay, then known as Cold Bay, several oil exploration wells (Table 1 and Plate 1) were drilled in the early 1900s.

In 1910, oil lands in Alaska were withdrawn from entry (Martin, 1921). The Mineral Leasing Act of 1920 brought renewed interest in the search for oil on the Alaska Peninsula. Oil claims were staked in the vicinity of Puale Bay in the early 1920s (Brooks, 1922). Associated Oil Company and Standard Oil Company of California drilled wells in the early to mid-1920s (Table 1). Two of Standard Oil's wells were shallow, and one was drilled to about 5,400 feet (1,772 m) without striking commercial quantities of oil (Brooks, 1925; Moffitt, 1927). Both companies abandoned drilling on the Peninsula by early 1926 (Smith, 1929).

Interest in the Puale Bay area revived in the the mid-1930s. Geologists from Standard Oil Company of California, the Associated Oil Company, and the Union Oil Company performed a critical field examination. Geologists also made extensive reconnaissance surveys of much of the prospective areas of the south-central part of the Alaska Peninsula (Smith, 1939).

A joint venture, including Standard Oil Company of California, the Tide Water Associated Oil Company, and Union Oil Company of California, drilled the Bear Creek Unit area near Jute Bay in 1939 (Table 1). The venture reported no showings of commercial quantities of oil (Smith, 1941).

Interest in the oil potential of the Alaska Peninsula lay dormant throughout the 1940s and into the mid-1950s. In 1957 through 1959, the Humble Oil and Refining Company drilled the Bear Creek Unit No. 1 (Table 1) to a depth of 14,375 feet (4,716 m) and encountered no commercial quantities of oil (Blasko, 1976). Several wells (Table 1) have been drilled on the Alaska Peninsula in recent years. The last one was drilled and abandoned in 1985.

A total of 26 wells have been drilled on the Alaska Peninsula, in the vicinity of these refuges, since the turn of the century. Eight of these exploratory wells have been drilled within the area of the Becharof NWR and five within the area of the Alaska Peninsula NWR. To date, no commercial quantities of oil have been reported.

This brief history identifies the Alaska Peninsula as an area which generates continuing, albeit intermittent, interest in the search for oil and gas.

STRATIGRAPHY AND LITHOLOGY

The Alaska Peninsula is primarily a province of Mesozoic and Cenozoic sediments heavily influenced by volcanic and plutonic activity. Figures 1 through 5 illustrate a stratigraphic section and four cross-sections for the Peninsula. This section presents the stratigraphy, and plate 2 shows the general geology of the Alaska Peninsula.

MIDDLE PALEOZOIC

Two small exposures of middle Paleozoic limestone that crop out near Gertrude Creek, about 10 miles (16 km) north of Becaharof Lake (Detterman et

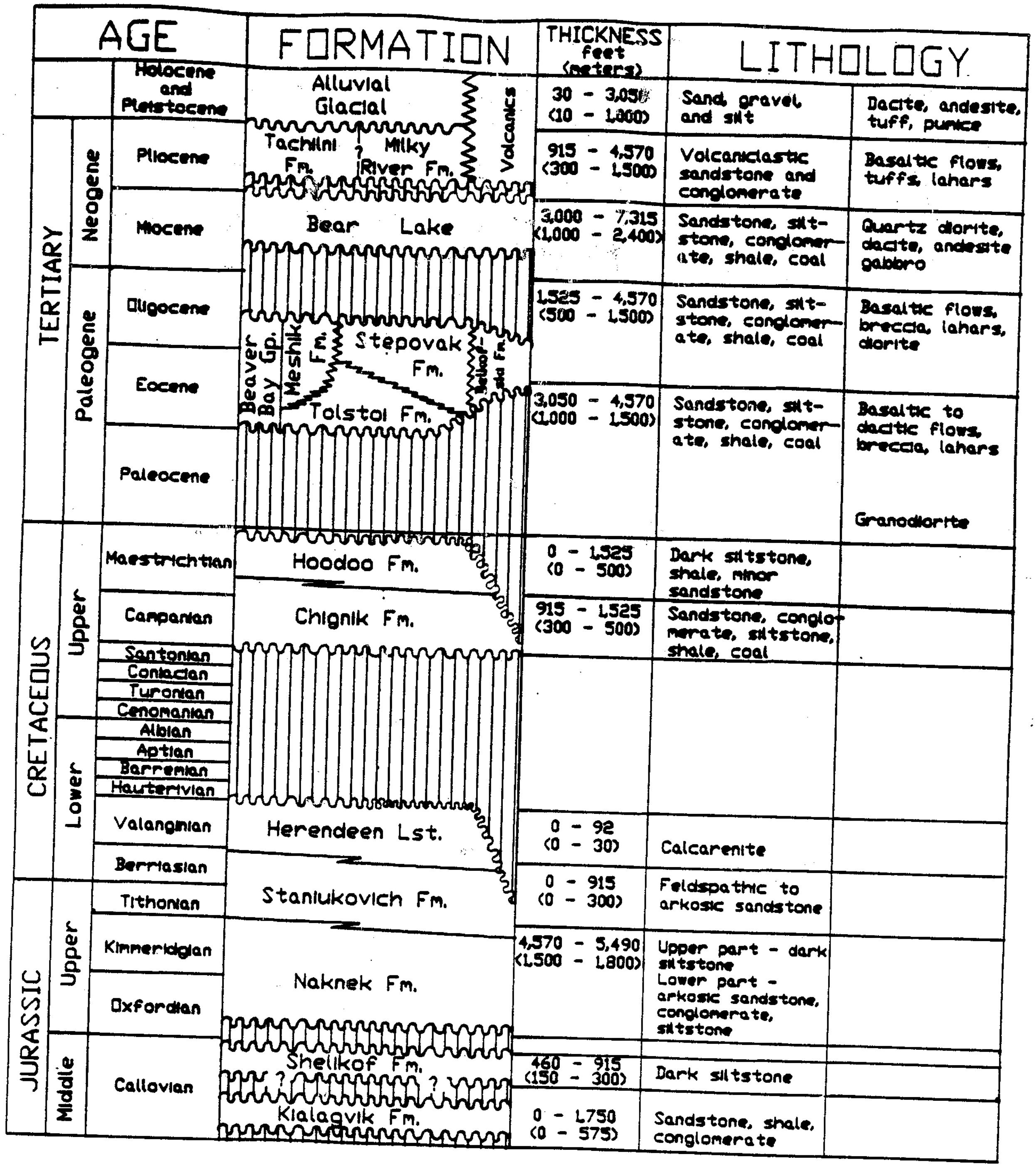
Table 1. Wells drilled on the Alaska Peninsula.
(from Blasko, 1976; McLean, 1977; American Stratigraphic, 1982; Alaska Oil and Gas Conservation Commission, 1981 and 1984)

Company	Well	Location	Completed	Total Depth, feet	Status
J.H. Costello	No. 1	sec 10, T29S, R40W	1903	728	Plugged & abandoned
Pacific Oil and Commercial Co.	No. 1	sec 36, T28S, R40W	1904	1,421	Do.
Do.	No. 2	sec 2, T29S, R40W	1904	1,542	Do.
J.H. Costello	No. 2	sec 10, T29S, R40W	1904	([1])	Do.
Tidewater Associated Oil Co.	Finnegan No.1	sec 30, T29S, R43W	6/30/23	569	Do.
Standard Oil Co. of Calif.	Lathrop No. 1	sec 17, T29S, R43W	1925	500	Do.
Do.	McNally No. 1	sec 29, T29S, R43W	1925	510	Do.
Do.	Lee No. 1	sec 20, T29S, R43W	1/16/26	5,034	Do.
Tidewater Associated Oil Co.	Alaska Well No. 1	sec 20, T29S, R43W	1/16/26	3,033	Do.
Standard Oil Co. of Calif.	Grammer	sec 10, T30S, R41W	3/30/40	7,596	Do.
Humble Oil and Refining Co.	Bear Creek Unit No. 1	sec 36, T29S, R41W	3/4/59	14,375	Do.
General Petroleum Corp.	Great Basins No. 1	sec 2, T27S, R48W	9/14/59	11,080	Do.

1 - Depth unknown.

Table 1. Wells drilled on the Alaska Peninsula (cont.)

General Petroleum Corp.	Great Basins No. 2	sec 35, T25S, R50W	11/12/59	8,865	Do.
Pure Oil Co.	Canoe Bay No. 1	sec 8, T54S, R78W	10/27/61	6,642	Do.
Richfield Oil Co.	Wide Bay No. 1	sec 5, T33S, R43W	10/24/63	12,566	Do.
Gulf Oil Co.	Sandy River No.	sec 10, T46S, R70W	12/3/63	13,068	Do.
Great Basins Oil Co.	Ugashik No. 1	sec 8, T32S, R52W	8/25/66	9,476	Do.
Cities Service Oil Co.	Painter Creek No. 1	sec 14, T35S, R51W	7/16/67	7,912	Do.
Pan American Petroleum Corp.	David River No. 1 & 1A	sec 12, T50S, R80W	8/14/69	13,769	Do.
Do.	Hoodoo Lake No. 1	sec 21, T50S, R76W	1/9/70	8,049	Do.
Do.	Hoodoo Lake No. 2	sec 35, T50S, R76W	4/28/70	11,243	Do.
Gulf Oil Co.-Alaskco	Port Heiden No. 1	sec 20, T37S, R59W	9/14/72	15,015	Do.
Amoco Production Co.	Cathedral River No. 1	sec 29, T51S, R83W	8/13/74	14,301	Do.
Phillips Petroleum Co.	Big River No. 1	sec 15, T49S, R68W	1/10/76	11,371	Do.
Chevron Oil Co.	Koniag No. 1	sec 2, T38S, R49W	7/9/81	10,907	Do.
Amoco Production Co.	Becharof No. 1	sec 10, T28S, R48W	1/19/85	9,023	Do.



(from Burk, 1965 and Wilson, 1980)

Fig. 1 . Stratigraphic section for the area near Becharof/Alaska Peninsula NWR's. (Note: Triassic, Permian, mid-Paleozoic not included.)

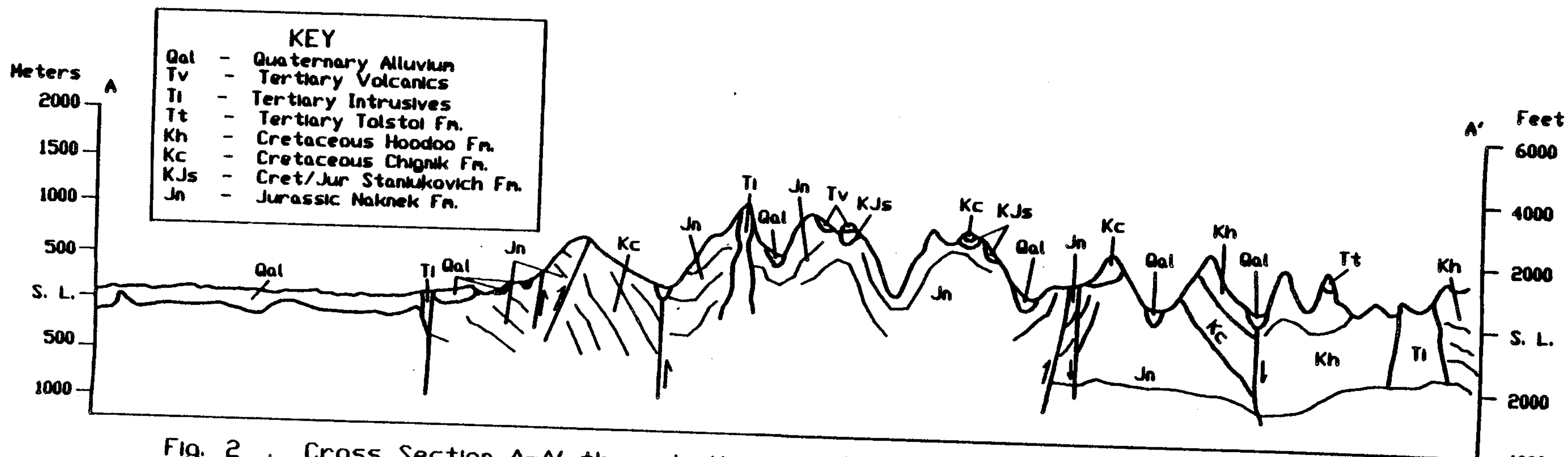


Fig. 2 . Cross Section A-A' through the Alaska Peninsula.
(modified from Detterman et al, 1981)

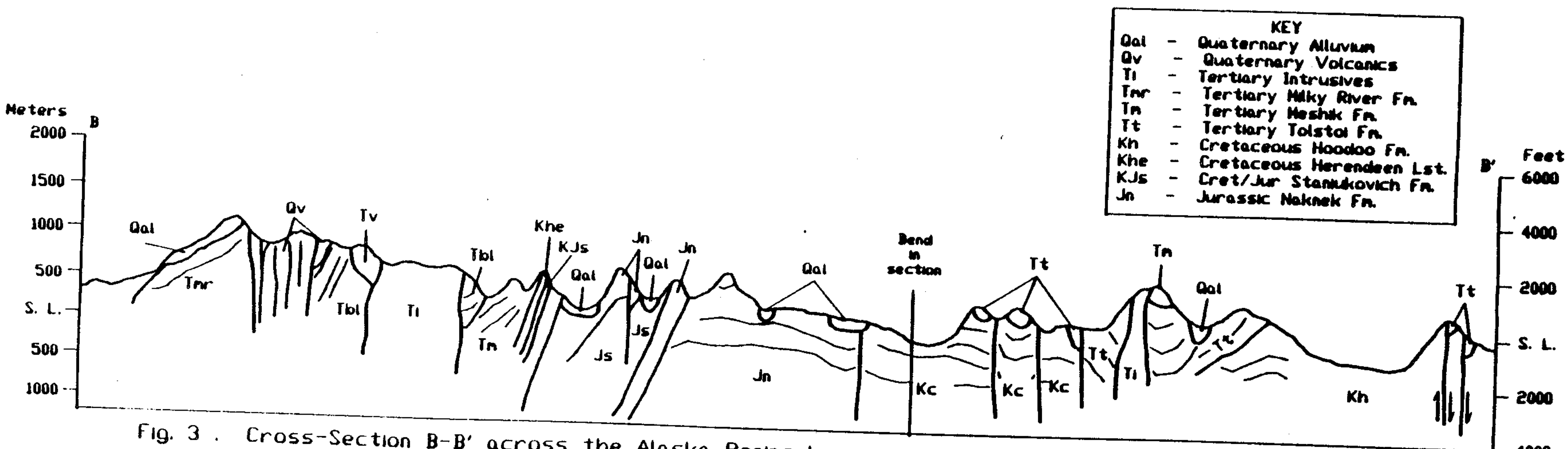


Fig. 3 . Cross-Section B-B' across the Alaska Peninsula.
(from Detterman et al, 1981)

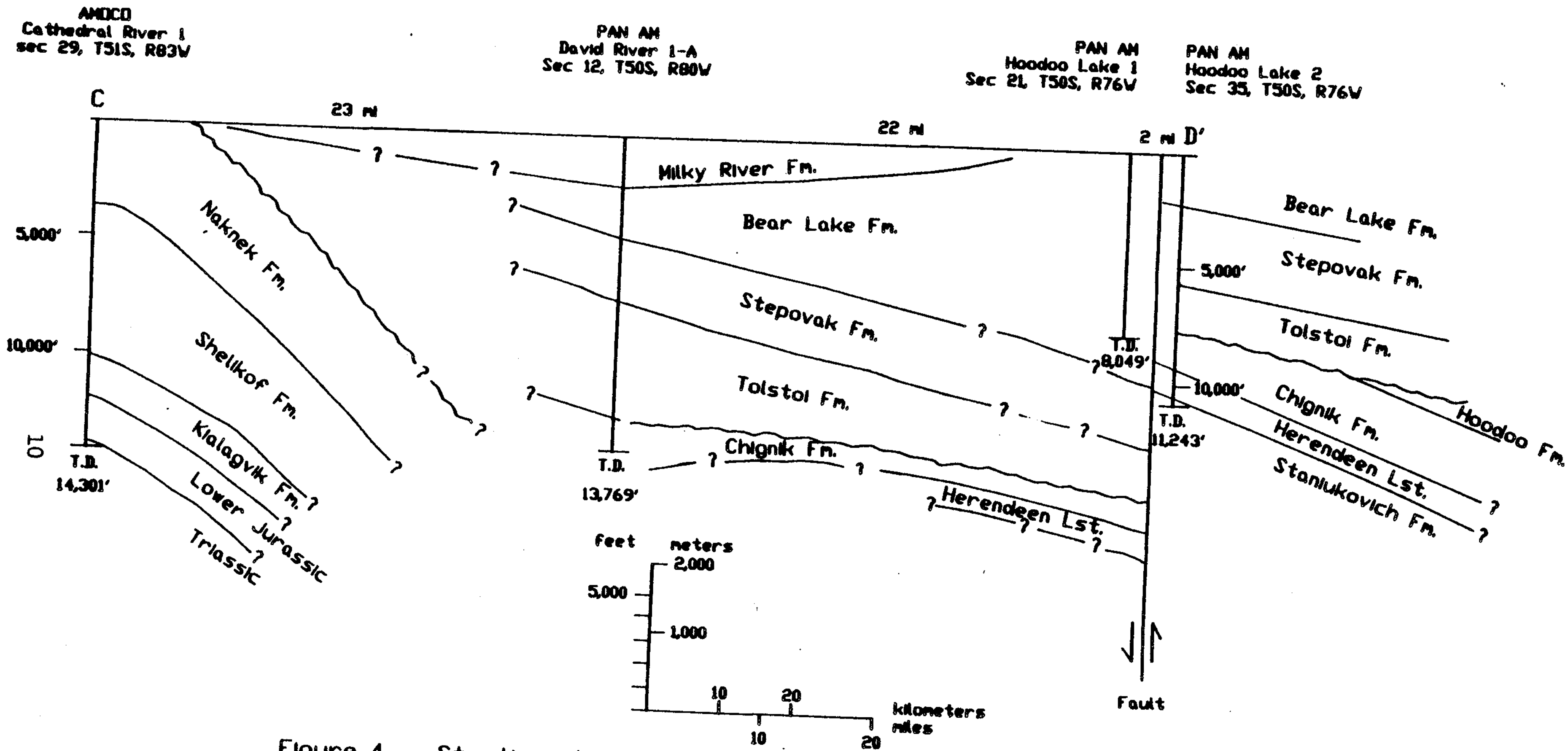


Figure 4 . Stratigraphic Cross Section, Bristol Bay Region, Alaska Peninsula
(modified from Brockaway et al, 1975 and McLean, 1977)

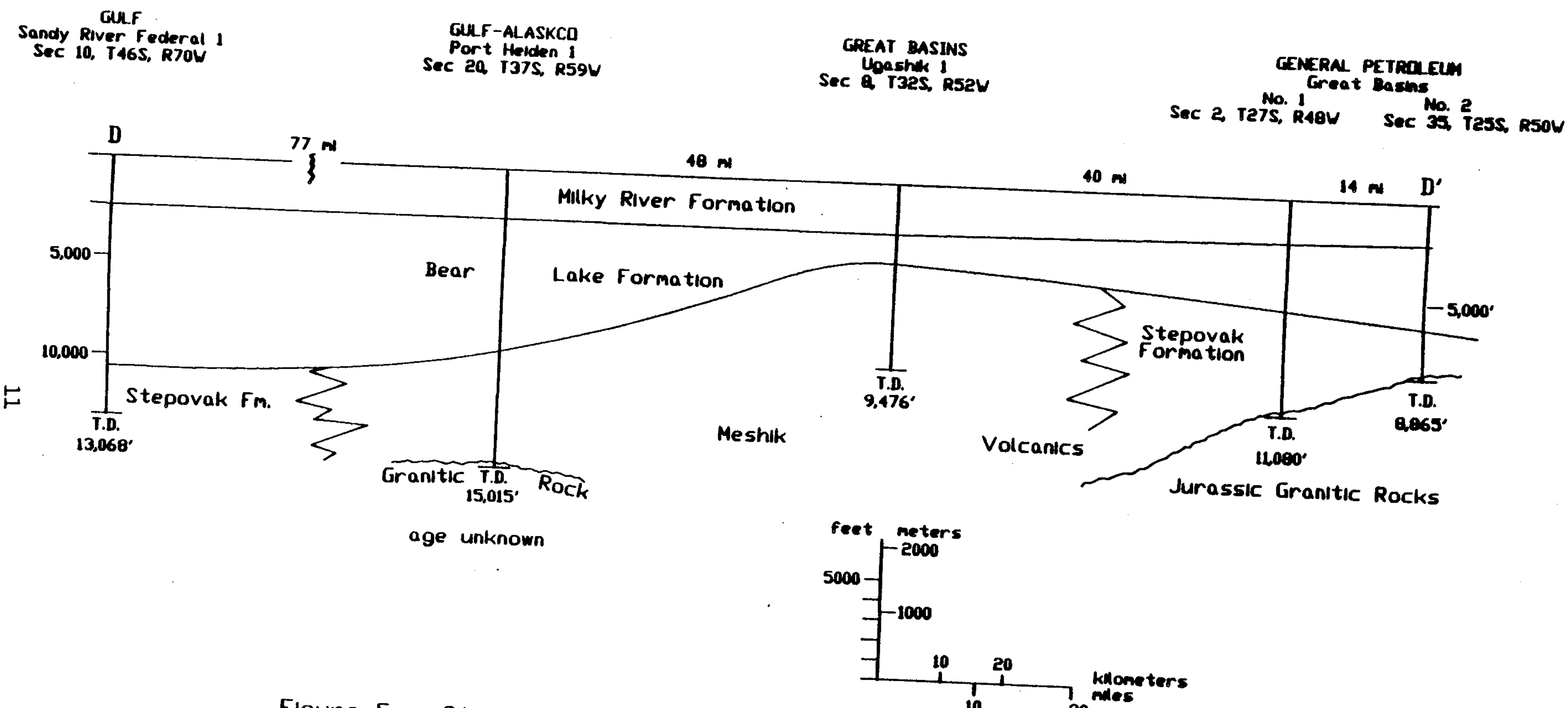


Figure 5 . Stratigraphic Cross Section, Bristol Bay Region, Alaska Peninsula
(modified from Brockaway et al, 1975 and McLean, 1977)

al, 1979), are the only reported occurrences of Paleozoic rocks in what is considered a Mesozoic and Cenozoic Province. These outcrops consist of light-gray, medium- to coarse-grained limestone. They have mainly medium-to-massive bedding and contain small chert nodules and thin interbeds of dark-gray, fine-crystalline limestone. They exhibit slight thermal metamorphism and recrystallization to a sugary texture.

The northeastern hill has distinct bedding that dips 30 to 55 degrees to the northwest. This outcrop consists of several hundred meters of limestone with several dikes cutting through it. These dikes have introduced pyrite and magnetite to the limestone and have altered the wallrock. It contains preserved corals and gastropods, identified as Favositidae and Bellerophon, respectively. Favositidae has a probable range of Late Ordovician to Devonian, but it more likely represents Silurian to Middle Devonian age. Bellerophon indicates Devonian age.

The southwestern outcrop, nearly all massive, is somewhat more metamorphosed.

These limestones probably represent roof pendants in the Alaskan-Aleutian Range batholith. They show lithologic and paleontologic similarities to rocks found 340 miles (550 km) to the northeast at Shellbarger Pass, in the Alaskan Range, and to Devonian age limestones 320 miles (515 km) to the northwest in the Hagemeister Island and Goodnews quadrangles.

PERMIAN

Permian age rocks occur only in the Puale Bay/Cape Kekurnoi area of the Alaska Peninsula. They are found on two small islets at the northern entrance of Puale Bay (Hanson, 1957). These rocks are fossiliferous limestones and associated volcanic rocks that include basaltic breccias, agglomerates, and flows (Churkin, 1973). Triassic age rocks conformably (?) overlie the Permian section.

TRIASSIC

Triassic rocks on the Alaska Peninsula, first identified by Martin (1905), occur in the Puale Bay area and on Cape Kekurnoi. These rocks consist of limestone, chert, shale, and volcanic and igneous rocks (Brooks, 1918; Martin, 1921; Capps, 1923). Jones et al (1981) described the Upper Triassic rocks as a well-stratified sequence of limestone, chert, tuff, and agglomerate which reaches a thickness of 2,250 feet (740 m) (Keller and Reiser, 1959).

Kellum et al (1945) described the limestones, along the northeastern shore of Puale Bay, as dark, blue-gray, dense, thin-bedded limestones that weather light-gray to buff. Near Cape Kekurnoi, the limestones become more massively bedded with beds ranging up to 85 feet (28 km) in thickness. The shale occurs as very thin beds often accompanied by fine-grained, calcareous sandstone. Calcareous shale is common in the upper parts of the section, but is less common than limestone. Much of the material is thought to be tuffaceous, and where the amount of volcanic material is high, the rocks are greenish. Tuffaceous sandstone interbedded with the limestone and shale in the upper part of the section, and, near the top, is nearly as abundant as limestone.

Capps (1923) described the volcanic and igneous rocks as basaltic dikes and sills. Stone and Parker (1979) described them as chiefly detrital volcanic rock and extrusive flows, and Jones et al (1981) described them as tuff and agglomerate.

Jurassic rocks unconformably overlie the Triassic sequence at this location (Martin, 1905; Imlay, 1981). The overlying Lower Jurassic consists of andesitic volcanic and volcanoclastic rocks up to several thousand meters thick (Jones et al, 1981).

JURASSIC

Unnamed Lower Jurassic

Lower Jurassic rocks are exposed on the Alaska Peninsula in the vicinity of Puale Bay and Alinchak Bay (Capps, 1923). Rocks exposed on Cape Kekurnoi represent the oldest Jurassic rocks in the area. The section exposed at Puale Bay consists of two lithologic units. The lower unit has 780 to 1,000 feet (256 to 328 m) of mainly calcareous sediments, and the upper unit has 1,040 to 1,300 feet (341 to 427 m) of mainly clastic sediment (Kellum et al, 1945). The lower unit consists of massive to thin-bedded calcareous sandstone with interbedded calcareous shale and limestone. Agglomerate and conglomerate make up a considerable portion of the unit. Coarser clastic material accounts for about 70 percent of the lower unit.

The upper unit consists mainly of dark, gray-black shale with a few thin beds of light colored, coarse-grained, well-indurated sandstone (Kellum et al, 1945). The amount of sandy shale and sandstone increase near the top of the unit. This upper, more sandy part contains limey concretions and partings. It is overlain by a conglomerate that contains boulders up to two feet in diameter and sand lenses that form a crude bedding.

The Lower Jurassic rests unconformably on latest Triassic age limestone. The lower unit contains ammonites of Hettangian age (Imlay, 1981); the upper unit contains ammonites of Sinemurian age. Sandy siltstone of the Kialagvik Formation overlies the unnamed Lower Jurassic, possibly by fault contact.

Kialagvik Formation, Middle Jurassic

The Kialagvik Formation represents the Middle Jurassic rocks of the Alaska Peninsula. At Kialagvik Bay, it consists of 500+ feet (164+ m) of sandstone and shale. It is known to crop out in the southwestern half of the Wide Bay area where it consists of sandstone and sandy shale. The wells drilled in the area are believed to have penetrated the Kialagvik Formation. Some of the strata that crop out on the north shore of Puale Bay have been referred to it by some geologists (Capps, 1923; Smith and Baker, 1924). About 1,750 feet (574 m) of Kialagvik have been measured along Short Creek. Oil seepages have been reported from the Kialagvik on Wide Bay. Onshore geology and offshore seismic data indicate that the Middle Jurassic (?) rocks occur in the subsurface throughout the area between the Bruin Bay Fault to somewhere offshore in the Shelikof Strait. No Kialagvik occurs in the Aniakchak area.

Shelikof Formation, Middle Jurassic

The Middle Jurassic Shelikof Formation is the main formation on the northwest shore of Shelikof Strait (Capps, 1923; Smith and Baker, 1924; Kellum et al, 1945; Wilson, 1980) from Katmai Bay at least as far southwest as Wide Bay. It is not present in the Aniakchak area. It ranges from 5,000 to 7,000 feet (1,640 to 2,300 m) thick and consists of three lithologic units.

The lower member, as represented in the Wide Bay area, is generally soft and brown weathering in the lower part, but becomes harder and darker gray upward on both fresh and weathered surfaces (Imlay, 1953; Wilson, 1980). The lower member, about 800 feet (260 m) thick, contains many sandy interbeds that range from a few inches to as much as 200 feet (66 m) thick. Thin beds of white to yellowish-brown, fine-grained material, probably volcanic ash, are fairly common in the lower part of the member and serve to distinguish the basal siltstones from the underlying Kialagvik Formation. Limestone concretions are abundant at many levels. The brown appearance of the outcrops is attributed to ashy beds similar to those in the lowest Shelikof Formation in the Wide Bay area. About 100 feet (33 m) of coarse conglomerate underlies the siltstone and rests on the Lower Jurassic siltstone. The ammonite fossil Cadoceras occurs throughout the lower member (Detterman et al, 1981). The middle and upper parts of the member contain many specimens of Pseudocadoceras and Lilloettia.

The middle member consists dominantly of massive gray sandstone, but contains interbeds of siltstone and lenses of conglomerate (Imlay, 1953; Wilson, 1980). The conglomerate consists of granitic and dioritic rocks. It is generally fine, but in places contains boulders up to two feet in diameter. Locally, the sandstone in the upper part appear to pass laterally into siltstones of the upper member. This unit has yielded fossils of pelecypods, gastropods, belemnites, ammonites, and brachiopods.

The upper member consists mostly of hard, dark-gray, gray-weathering siltstone (Imlay 1953; Wilson, 1980). Near Wide Bay, the siltstone contains thin interbeds of sandstone and limestone. Near Puale Bay, the siltstone contains lenses of yellowish-weathering limestone that greatly resembles limestone lenses in the upper part of the Chinitna Formation on the Iniskin Peninsula. The fossils found in this unit include pelecypods, gastropods, and belemnites.

Naknek Formation, Upper Jurassic

The Naknek Formation, named the Naknek Series by Spurr (1900), consists of well- to poorly-bedded arkosic sandstone, conglomerate, siltstone, and mudstone (Capps, 1923; Smith and Baker, 1924; Lyle et al, 1979). These are either interbedded or form relatively thick exposures of a simple lithology. The matrices of the sandstones and conglomerates typically consist of feldspar, quartz, volcanic rock fragments, and chert. Granitic and metamorphic rocks are predominant among coarser clasts in the siltstones and mudstones. Quartz is typically more abundant than feldspar in the fine-grained rock types, whereas feldspar is commonly more abundant than quartz in the sandstones and conglomerates.

The Naknek Formation is exposed along most of the length of the Peninsula and reaches a thickness of about 10,000 feet (3,000 m) in the Wide Bay area. The Chignik area has over 1,000 feet (328 m) of sandstone, conglomerate, arkose, and shale (Martin, 1925). At Chignik Lagoon, it has yielded fossils of Aucella concentrica and certain undescribed species of the ammonite Phylloceras, the pelecypod Lima, and the gastropod Delphinula (Keller and Cass, 1956). Aucella concentrica is good evidence of late early to middle Late Jurassic age and indicates a position low in the Naknek.

In the Mount Katmai area, it crops out in a continuous mountain belt 20 to 38 miles (32 to 61 km) wide (Keller and Reiser, 1959). This belt trends northeast across the entire area. On the northwest side of its outcrop belt, it is in fault contact with igneous rocks of Early and/or Middle Jurassic age. In the northeast part of this area, it is overlain by rocks of Cretaceous age. Both here and over much of the central part of the area, it is overlain by volcanic rocks of Tertiary and Quaternary age. A high organic content is reported in the Katmai National Monument area and in rocks of this age at Hallo Bay.

In the Chignik-Sutwik Island area (Detterman et al, 1981), it consists of two unnamed members with a combined thickness of 4,570 to 5,485 feet (1,500 to 1,800 m). The lower member is mainly arkosic sandstone and conglomerate. It is light- to medium-gray, fine- to coarse-grained, and generally thick bedded to massive. It is commonly cross-bedded and laminated with magnetite grains forming the dark laminae. Granitic clasts form the major part of the conglomerate. Clasts of chert and white quartz, in about equal amounts, form the remainder. The unit was deposited in a fluvial nonmarine environment. Its fossil assemblage includes carbonized plant debris, sparse Aucella pelecypods, and sparse ammonites. It disconformably overlies the Shelikof Formation and gradationally and conformably underlies the Staniukovich Formation.

The upper member consists of a thick sequence of arkosic conglomerate and arkoses that grade upward to feldspathic siltstone, and with increasing grain size, to a boulder conglomerate toward the west near Lower Ugashik Lake. The unit is at least 5,000 feet (1,640 m) thick and may be as great as 10,000 feet (3,280 m). No exposures are known west of this unit's intersection with the Bruin Bay Fault.

Blasko (1975) reported oil seepages from the Naknek in the Puale Bay area. There the Naknek has been described as consisting of a series of dark shales with some limestone beds. It is also reported to have over 5,000 feet (1,640 m) of conglomerate and arkosic sandstone overlain by sandy shale at Puale Bay.

In the Aniakchak region, the Naknek consists of mudstone, shale, and fine sandstone with minor amounts of limestone (Knappen, 1929). The sandstone grades into a shale or light-gray to chalky-white arkose with quartz, feldspar, and granite fragments 1 to 4 mm in diameter. The arkose is rare in the southwest portion of the area and more abundant in the northwest portion. The sandstone and arkose, in a few places, contains lenses of conglomerate.

Black or dark-gray mudstone and shale constitutes fully 65 percent of the Naknek and grades into fine sandstone. Together, these constitute more than 95 percent of the formation. Few of the sand grains exceed 0.2 mm in diameter. The sandstone is almost indistinguishable from the enclosing black and dark-gray mudstone and shale. The arkose is olive drab, yellowish, or light gray and coarse grained. Beds cannot be traced over long distances. Boulder size decreases steadily north to south and northeast to southwest, as does the percentage of conglomerate, the amount of arkose, and the evidence of contemporaneous erosion. Cross-bedding and ripple marks indicate transport to the south and southwest. No plant fossils were found in the Aniakchak area, only numerous marine fossils. The formation reaches a thickness of about 6,400 feet (2,100 m) in the Aniakchak area.

The Naknek is the oldest formation exposed on the northern shore of the Alaska Peninsula (Marlow et al, 1979). The siltstone of the Naknek grades upward into arkosic sandstone of the Staniukovich Formation in the Port Moller area.

The Naknek is exposed in bluffs and low beach cliffs in the Black Hills area (McLean 1979). There it consists of gently-dipping, fine-grained or arkosic sandstone. Strata are massive- to thin-bedded and nearly devoid of structure. Clayey matrix, calcite, and laumontite comprise the cementing material. The average composition of four fine- to medium-grained sandstones is reported as 18 percent quartz, 80 percent feldspar, and 2 percent lithic fragments. The sandstone composition indicates a volcanic and granitic source terrane. The molluscan assemblage of pelecypods, belemnites, and rare ammonites and gastropods indicates a shallow marine environment of deposition.

Staniukovich Formation, Upper Jurassic-Lower Cretaceous

The Upper Jurassic to Lower Cretaceous Staniukovich Formation, named by Atwood, (1911), consists of uniformly bedded arkosic marine sandstone and siltstone (marlow et al, 1979). It conformably and gradationally overlies the Naknek Formation southwest of Wide Bay, and it conformably and gradationally underlies the Herendeen Limestone. In other areas, it unconformably underlies the Chignik Formation. It is composed of fine-grained, feldspathic sandstone and arkose. It has been described as a shallow-marine, tidal sandstone. It contains an average of 48 percent quartz, 42 percent feldspar, and 10 percent lithic fragments, whereas, the underlying Upper Jurassic Naknek Formation contains 4 percent quartz, 58 percent feldspar, and 38 percent lithic fragments. Its color varies from mainly tan to greenish-yellow with the greenish-yellow rock commonly spotted with laumontite. Characteristically, it contains abundant pelecypods throughout.

CRETACEOUS

Herendeen Limestone, Lower Cretaceous

Detterman et al (1981) describe the Lower Cretaceous Herendeen Limestone, named by Atwood (1911) as about 91 feet (30 m) of thin-bedded calcarenite. Inoceramus prisms impart the limey character to the thin sandstone beds. The formation is light gray in color. It gradationally overlies the Staniukovich Formation and unconformably underlies the Chignik Formation.

Hanson et al (1981) describe the Lower Cretaceous Herendeen Limestone in the Port Moller-Herendeen Bay area. It conformably interfingers with the Staniukovich Formation and consists of about 800 feet (260 m) of dense arenaceous limestone and calcareous sandstone. Lithologically similar units are exposed in a 900-mile long (1,450 km) belt to the Chitina Valley in southeast Alaska. It has been reported as the only Lower Cretaceous Formation the Alaska Peninsula. But, Jones and Detterman (1966) report the occurrence of Lower Cretaceous in the Kamishak Hills near Cape Douglas. In the Herendeen Bay to Port Moller area, the Herendeen Limestone consists of aremaceous limestone. Wilson (1980) described the Herendeen as a light gray to gray, dense arenaceous limestone and calcareous sandstone, that reaches a maximum thickness of 500 feet (150 m). In the Chignik region, it measures 91 feet (28 m) in thickness. The clasts are well-sorted, angular to subrounded quartz and feldspar. Quartz is about twice as abundant as feldspar. Hornblende and biotite are the most common accessory minerals. The noncalcareous material comprises one-fourth to three-fourths of the rock at any locality (Wilson, 1980). Except for the large component of calcareous material, it is very similar to the conformably underlying Staniukovich Formation.

Inoceramus shell fragments constitute the calcareous portion of the Formation. Inoceramus is the only known fossil. The Herendeen is assigned to the latest Valanginian based on its distinct lithologic divergence from and conformity with the overlying Chignik and Hoodoo Formations. The Herendeen conformably overlies the Staniukovich and grades into it over a short vertical distance. Burk (1965) suggested that the Herendeen might better be considered a member of the Staniukovich Formation due to the great lithologic similarities exclusive of the carbonate content. Wilson (1980) suggests that the Herendeen and Staniukovich should be considered as facies of the Naknek Formation.

Chignik Formation, Upper Cretaceous

Detterman et al (1981) describe the Upper Cretaceous Chignik Formation, named by Atwood (1911) as a cyclic and nonmarine sedimentary rock unit consisting of sandstone, pebble-cobble conglomerate, siltstone, shale, and coal. It measures 1,525 feet (500 m) thick. The sandstones are medium dark gray to brown, fine- to medium-grained, medium- to massive-bedded, carbonaceous, and friable. They consist mainly of quartz, chert, and feldspar grains with as much as 25 percent lithic fragments. The sandstones are commonly channeled and cross-bedded with pebble-lag gravel in the channels. The sandstones of the Chignik consist of subgraywackes and lithic arenites that contain one-fourth to three-fourths volcanic and sedimentary (claystone, siltstone, and argillite) grains. The clasts in the conglomerates mainly consist of black, gray, green, and red chert, white quartz, granitic rocks, and minor volcanic rocks. Some conglomerates are entirely black chert pebbles. Siltstone are dark, sandy, and micaceous. The abundant coal and moderately abundant molluscan fauna indicate deposition in a nonmarine to shallow marine environment. The bituminous coal occurs in beds 1 to 7 feet (0.3 to 2 m) thick. The rocks are commonly calcareous with some sideritic sandstone. Fossils are locally abundant and consist mainly of Campanian and Early Maestrichtian pelecypods and ammonites. It was deposited unconformably on a gently dipping erosional surface cut into mildly folded pre-Chignik Formation rocks.

The Coal Valley Member is a basal conglomeratic member of the Chignik (Burk, 1965; Conwell and Triplehorn, 1978; Lyle et al, 1979). It unconformably overlies the Herendeen limestone, the Staniukovich Formation, and the Naknek Formation. The Coal Valley Member consists of carbonaceous to lignitic shales, siltstones, and sandstones. It is locally bentonitic and weathers to orange or reddish brown. This member locally grades into the overlying Chignik sandstones and can be located only approximately in many places.

The Coal Valley is composed mainly of well-bedded sandstone in which large carbonaceous plant fragments are common. These are often found in association with abundant marine fossils. Sedimentary and volcanic rock fragments are major constituents of these sandstones. Carbonate commonly occurs as a cement and as a replacement of silicate clasts, it may make up to 50 percent of the rock. Minor conglomerates, carbonaceous shales, and coal streaks are interbedded with sandstone of the marine portions of the Chignik. The maximum thickness is about 1,200 feet (395 m) in Coal Valley and in the area southeast of Staniukovich Mountain. The Coal Valley Member has been interpreted as a nonmarine facies deposited simultaneously with the rest of the Chignik and Hoodoo Formations.

The Chignik is coal-bearing at Chignik Bay (Atwood, 1911) and at Amalik. The coal is chiefly lignitic with some good bituminous. An 18-foot (6 m) bed of coal occurs in a 250-foot (82-m) sequence of sandstone and conglomerate near Amalik Harbor. In the extreme northeast and southwest section of the coal belt, igneous rocks come into close contact with coal. But, the coal does not appear to have been affected by the igneous activity. The Chignik is divided into three informal units in the Chignik area. The lower member consists of 200+ feet (66+ m) of shale with marine fossils. The middle member consists of 300+ feet (98+ m) of coal with many coal beds and some sandstone. The upper member consists of 300 to 500 feet (98 to 164 m) of conglomerate, sandstone, and shale. The coal-bearing rocks on the southwest side of Chignik Lagoon are of fresh water origin. Boulders range in size up to 2 feet (0.66 m) in diameter, but mostly they are less than three inches.

Three complete cycles of a nearshore marine to nonmarine sequence have been identified in the Chignik Lagoon area (Detterman, 1977). Each of these sequences ranges from 323 to 418 feet (106 to 137 m) in thickness. They represent sedimentation in a cyclic nearshore-to-continental, high-energy environment. This section contains numerous massive sandstone and conglomerate beds having good to fair visual porosity. The entire section measures 1,495 feet (490 m) thick between Boomers Cove and the sandspit at the mouth of Chignik Lagoon.

The Chignik crops out in a nearly continuous band from Chignik Lagoon northeastward to the head of the spit in Chignik Bay and then to Hook Creek (Knappen, 1929). At Hook Head and near the sand spit in Chignik Bay, the lower part of the Chignik contains light-green and gray agglomerate and tuff. Volcanic material is not common elsewhere. Petroliferous marine sands in the Chignik have been reported along the shore of Chignik Lagoon. The Inocerami fossils found in the Chignik at this location indicate a Late Cretaceous, possibly Campanian, age for the formation.

The Chignik is not well-exposed on the north side of the mountain range, but occurs at several localities (Knappen 1929). It is found as far west as the Blue Lake/Chignik Lagoon depression. Southwest of this lowland, it is not found, and Tertiary strata lie on the Naknek. These two outcrop zones represent the flanks of a very gently plunging anticline whose axis pitches below the crest of the mountains east of Hook Creek. It is not recognized northeast of Black Creek. North of the Meshik River, Tertiary beds lie on the Naknek. The Chignik generally forms poor exposures and is distinguished from the Naknek by its distinctive fossil suite.

At Herendeen Bay, the Chignik Formation consists of conglomerate, sandstone, shale with plant and invertebrate fossils and coal. The Chignik crops out on the east and southwest side of Herendeen Bay and to the west of Herendeen Bay. It is partly of nonmarine origin and contains workable deposits of coal. The Chignik underlies at least 40 square miles between Herendeen Bay and Port Moller. The beds are moderately folded and broken by several small faults. The coal is mostly bituminous (Barnes, 1967) and occurs in a large number of closely spaced beds which range from a few inches to seven feet thick (a few cm to 2.3 m). Most of these beds are less than two feet (0.66 m) thick.

The upper marine portion of the Chignik reaches a maximum of about 2,000 feet (660 m) near Herendeen Bay. The irregularly abundant marine fauna is dominated by pelecypods, principally Inoceramus schmidti, of Campanian age.

Hoodoo Formation, Upper Cretaceous

The Hoodoo Formation is a widely exposed, predominantly well-bedded, black and gray siltstone with some interbedded fine-grained sandstone and conglomerate (Burk, 1965; Lyle et al, 1979; Wilson, 1980). The conglomerate typically contains well-rounded chert and volcanic, granitic and argillitic pebbles and cobbles. Black siltstone or fine-grained sandstone form the matrices of the conglomerates.

The predominant lithologies are incompetent. This leads to deformation characterized by extreme folding and shearing. Together these account for the absence of any known complete and undisturbed stratigraphic section. Detterman et al (1981) identified the Upper Cretaceous Hoodoo Formation as a 1,525 feet (500 m) thick, rhythmically bedded black shale, splintery dark siltstone, and thin dark sandstone. The sandstone beds range from 1 to 3 feet (0.3 to 1 m) thick, and the siltstone and shale beds measure 3 to 6 feet (1 to 2 m) thick. Sandstone beds are graded and overlain by siltstone with convolute bedding, flame structures, and rip-up clasts. These, in turn, are overlain by laminated siltstone and shale. All of these are characteristic of turbidite deposition in deep water. Exposures are limited to areas near the Pacific Ocean coastline. It conformably overlies the Chignik Formation with gradational contact. It unconformably underlies the Tolstoi Formation. Early Maestrichtian ammonites and pelecypods indicate that it is slightly younger than the Chignik.

The Hoodoo Formation conformably overlies the Upper Cretaceous Chignik Formation. At Port Moller, the Chignik is, however, overlain by Tertiary strata, and the Hoodoo has been completely eroded. Here, the Upper Cretaceous Chignik is unconformably overlain by Paleocene and Eocene rocks of the Tolstoi Formation.

The greatest known thickness of the Hoodoo Formation is over 2,000 feet (660 m), and maybe as much as 3,000 feet (985 m), in the area between Herendeen and Pavlof Bays. Fossils are extremely rare. The few marine pelecypods, cephalopods, and ammonites suggest an age of Campanian to Maestrichtian.

In the Canoe Bay area (McLean, 1979), the Hoodoo consists of a monotonous sequence of thin-bedded, black mudstone and shale. These are interbedded with fine-grained turbidite sandstones. On the northeast shore of Canoe Bay, it consists of channel conglomerates and mudstones and shales. These are interbedded with fine-grained turbidite sandstones. On the northeast shore of Canoe Bay, it consists of channel conglomerates and mudstones and shales. The conglomerates are massively bedded and consist of dioritic cobbles. The mudstones and shales have thin turbidite sandstones.

Burk, (1965) interpreted the Hoodoo as a distal facies in a single marine transgressive sequence. Mancini et al (1978) interpreted the Chignik Formation and the overlying Hoodoo Formation as time-equivalent lithofacies in the same stratigraphic interval. An alternative interpretation combines aspects of both of these models. This calls for simultaneous deposition with the marine environment migrating landward. Together they represent deposition in nonmarine to inner neritic and outer neritic to bathyal environments, respectively.

TERTIARY

Lower Tertiary

The Lower Tertiary strata on the Alaska Peninsula have been divided into four formations. These include the Belkofski Formation, the Tolstoi Formation, the Stepovak Formation, and the Meshik Formation. For the purposes of this report, these formations are considered as part of the Beaver Bay Group (Burk, 1965).

Belkofski Formation

Kennedy and Waldron (1955) applied the name, "Belkofski Tuff" to a sequence of volcanic sandstones, conglomerates, and breccias exposed along the shore between Pavlof Bay and Cold Bay. They estimated the thickness of this unit at more than 3,000 feet. Burk (1965) mapped these rocks and the underlying "green arkose" as the Belkofski Formation.

The Belkofski consists mostly of nonmarine, volcanic sandstone with thin beds of black carbonaceous mudstone. More specifically, it consists of fine- to coarse-grained sandstone, pebble to cobble conglomerate, and breccia. All of these are made up of volcanic debris of various types. Typically, this sequence of rocks shows rapid facies changes. The rocks generally are somber shades of gray, greenish-gray or gray-brown.

The Belkofski also contains a welded ash-flow tuff, andesitic dikes and sills, and several quartz diorite stocks. Overall, the rocks of the Tolstoi show a marked similarity to the rocks of the Tolstoi Formation to the east.

The Belkofski contains molluscan fauna and numerous, poorly preserved plant fossils. *Andara* sp., *Macoma* sp., and *Mya* sp. are pelecypod generally found in the Belkofski Formation. These probably indicate an Oligocene age.

Pliocene-Pleistocene fluvial gravels capped by probable Pleistocene andesitic and basaltic flows probably overlies the Belkofski.

Tolstoi Formation

Knappen (1929) examined the Chignik Bay area in 1925 and reported on the general sequence of rocks in the area (Burk, 1965). He included black siltstones and conglomerates of the Upper Cretaceous Hoodoo Formation with the younger black siltstones of his "Eocene Series." Otherwise, Knappen accurately portrays the Tolstoi Formation in this area (Burk, 1965). The Tolstoi consists of about 5,000 feet (1,640 m) of non-marine black siltstone and shale interbedded with fine- to coarse-grained, poorly sorted, volcanic sandstone and volcanic conglomerates. Coarser volcanic material increases upward, and the upper half of the Formation contains much angular, volcanic breccia interbedded with coarse volcanic conglomerates, a few sills, and possible volcanic flows (Burk, 1965).

The Tolstoi crops out extensively along the Pacific coast of the Alaska Peninsula and in the adjacent mountains. It is exposed from Pavlof Bay northward, along the coast, to the Wide Bay area. Throughout much of this area, it rests upon Upper Cretaceous strata. In the valleys above the head of Stepovak Bay, it reaches a thickness of about 5,000 feet (1,640 m). It extends inland and northeastward, from Stepovak Bay, to the flanks of Mt. Veniaminof where it reaches a thickness of about 10,000 feet (3,280 m). It lies atop the Upper Jurassic Naknek Formation in the mountains between the head of Kuiukta Bay and Chignik Bay. In the vicinity of Mt. Chiginagak and Aniakchak Crater, it reaches a thickness of about 3,000 feet (985 m). On the south flank of Aniakchak Crater, it overlies the Upper Cretaceous Staniukovich Formation. It overlies the upper Cretaceous Hoodoo Formation north of Chignik Bay. Between Chignik Bay and the Ugashik Lakes, rocks considered equivalent to the Tolstoi crop out. The Meshik Formation conformably overlies the Tolstoi along the Pacific coast. Here, the Tolstoi rests with gentle unconformity upon the Hoodoo and Chignik Formation. Pliocene volcanics overlie the Tolstoi, elsewhere.

The Tolstoi shows channeling into the Hoodoo Formation in the Cape Kunmik area. South of Chignik Lake, the Tolstoi unconformably overlies the Naknek Formation. Detterman (1980) recommends identifying the Tolstoi as all the sedimentary rocks above the Hoodoo Formation and unconformably below the Meshik Formation.

Plant fossil collections from the southwest shore of Chignik Bay and northeast of Aniakchak Crater indicate a Paleocene or Eocene age. The Mt. Veniaminof area has produced a rich Paleocene to Eocene fossil flora and a middle to late Eocene marine molluscan assemblage.

Stepovak Formation

C. Palache, in 1899, (Burk, 1965) named a sequence of rocks along the shore in a small cove on the west side of Stepovak Bay and in the mountains adjacent to Chicagof Bay, the "Stepovak series." Atwood (1911) abandoned Palache's terminology and correlated strata equivalent to the "Stepovak series" with the Kenai Formation. Burk (1965) used Stepovak Formation to describe the sequence first examined by Palache. The type Stepovak Formation, more than 7,000 feet thick, consists of interbedded volcanic sandstones and conglomerates with units to nearly a thousand feet of black siltstone containing abundant calcareous concretions.

Throughout much of its area, the Stepovak conformably overlies and gradationally interfingers with the Tolstoi Formation. Northeast of Chignik Bay, the Stepovak and Tolstoi both interfinger with more extensive volcanogenic rocks that include flow, breccia, and conglomerate units.

The Stepovak greatly resembles the Tolstoi, and in some outcrops, it is extremely difficult to distinguish from the Tolstoi. The Stepovak rocks, however, tend to show better sorting with fewer angular grains and more even bedding than the Tolstoi. The Stepovak has been described as a lithologic continuation of the Tolstoi. The strata of the Stepovak vary considerably in appearance. The type section in the vicinity of Stepovak Bay consists of more than 7,000 feet (2,295 m) of interbedded volcanic sandstones and conglomerates, and units of black siltstone that measure nearly 1000 feet (330 m) thick. The outcrops near Coal Bay consist of thin-bedded, tuffaceous, fine-grained sandstone and mudstone. This section also contains interbeds, up to 6 feet (2 m) thick, of light-colored, angular, pyroclastic pebbles. At McGinty Point, the outcrops show as tuffaceous, turbidite sandstones and mudstones. A massive andesitic pebble and cobble conglomerate occurs near the middle of the section. The section below the conglomerate has asymmetric ripple marks which indicate a southeasterly current flow. Below the conglomerate, massive, fine-grained, tuffaceous sandstones contain numerous calcareous concretions and locally abundant fossil bivalves.

The fossils of the Stepovak include petrified wood zones, plant fossils in many carbonaceous zones, questionable foraminifera fossils, and shell fragments. Marine fossils indicate neritic to bathyal depths and late Eocene (?) and Oligocene age. Plant fossils in the Coal Bay area suggest the possibility of deposition into the early Miocene. These age designations place the Stepovak, at least partly, age equivalent to the Meshik and Belkofski Formations.

Meshik Formation

Knappen (1929) proposed the name Meshik Formation for a series of sediments along the sides of the Valley of Meshik River and Meshik Lake. These sediments are predominantly of volcanic origin. The sequence is at least 5,000 feet (1,640 m) thick and consists of interbedded volcanic conglomerates, sandstones, volcanic breccias, and occasional fine siltstone and shale.

In the type section, the Meshik has erratic to regular bedding with individual beds reaching thicknesses up to 30 feet (10 m). The Meshik consists of at least 5,000 feet (1,640 m)of strata in the Mt. Chiginagak area. There, coarse volcanic breccia, coarse volcanic conglomerates, some sandstone, and carbonaceous siltstone comprise the formation. Very irregular stratification and poor sorting characterize this section. In the Chignik area, virtually no fine-grained, interbedded sediments occur within the Meshik. The Meshik of the central Peninsula consists of basaltic lava, breccia, tuff, and lahars (Detterman, 1980).

The Meshik contains no identifiable marine fossils, but it does have poorly preserved, but abundant, carbonaceous plant fragments. Pliocene and younger volcanic rocks and alluvial and glacial deposits south of Chignik Bay and in a few other localities. Several thousand feet of poorly consolidated sedimentary rocks which contain late Miocene marine fossils overlie the Meshik east of Black Peak. This area is complicated by local deformation, and angular discordance between this unit and the Meshik is suggested.

The predominance of black siltstone in the Tolstoi, southwest of Chignik Bay, and the abundance of volcanic debris in the Stepovak on the Kupreanof Peninsula suggests correlation of the Meshik and Stepovak. The Meshik may be entirely or partly equivalent to the younger beds of the type Tolstoi. Whitney et al (1985) assigns an Oligocene age to the Meshik in the Chignik area. In the Mt. Chiginagak area, the Meshik conformably overlies the Tolstoi. It rests, without evidence of erosion, on Eocene beds in the Meshik River and Meshik Lake area.

Detterman (1985) cites a K-Ar age of 27-38 m.y., (Eocene-Oligocene) for the Meshik Formation and describes it as similar to the Belkofski Formation. The Belkofski Formation, however, contains interbedded sediments, and Detterman (1985) apparently considers the Meshik as free of sedimentary rocks.

Beaver Bay Group

Burk (1965) proposed the name Beaver Bay Group for 20,000 to 25,000 feet (6,560 to 8,200 m) of volcanic sandstones, conglomerates, breccias, and black siltstones exposed along the shores of Beaver Bay and in the mountains bordering the lower part of the Beaver River. Burk defined the Beaver Bay Group to include the Tolstoi and Stepovak Formations in areas where it is difficult to distinguish the two. The Beaver Bay Group represents the first great flood of volcanic material deposited on the Peninsula after the Jurassic.

The Beaver Bay Group strata show a wide-spread distribution of coarse volcanic debris and extrusive rocks. The volcanic sandstones are poorly sorted and have a great range in grain size. Non-volcanic grains, consisting of chert, argillite, and dense volcanic siltstone, are more noticeable in the upper part than in the lower.

The Ivanof Bay to Chignik Bay area has a thick, highly faulted and folded sequence of black siltstones and interbedded sandstones. These rocks are typical of the Tolstoi, but Burk (1965) believed that Stepovak strata were also present, but could not be separated on field evidence. In the Ivanof Bay area, black siltstones occur interbedded with volcanic sandstones and conglomerates. The sandstones here resemble those of the Stepovak. But, regional stratigraphic relations and fossil collections indicate these volcanic strata, which consist of much coarse volcanic breccia interbedded with coarse volcanic conglomerate, volcanic sandstone, and black siltstone, grade into beds believed to represent the Stepovak.

The Stepovak crops out on the southern half of the Kupreanof Peninsula. There, abundant marine fossils occur in the upper half of a 16,000-foot (5,250 m) sequence of rocks typical of the Stepovak, except for a great abundance of coarse and angular volcanic debris. The basal few thousand feet is very similar to the Tolstoi at Ivanof Bay. Several thousand feet of coarse volcanic sandstone and agglomerate overlies the fossiliferous beds.

The top of the Stepovak crops out above 10,000 feet (3,280 m) of strata in the mountains between Mt. Veniaminof and Port Moller. The outcrops of this area show no strong indication of a disconformity between the Stepovak and Bear Lake Formations.

The marine and nonmarine macrofossils and the marine microfossils indicate Paleocene, Eocene, and Oligocene ages for the Beaver Bay Group. Plants of Paleocene and earliest Eocene have been collected from within 200 feet (66 m) of the Chignik Formation in the mountains above Ivanof Bay and from near the top of the 10,000 feet (3,280 m) of strata exposed along the shore of Ivanof Bay. Fresh water gastropods of the same age were obtained from this sequence on the western shore of Humpback Bay.

McLean (1979) suggested that the Oligocene portion of the Stepovak Formation at Coal Bay and McGinty Point and the Oligocene Belkofski Formation at Belkofski Bay are age correlative. Wilson (1980) described the late Eocene to Oligocene Stepovak Formation as an andesitic (?) volcanic and volcaniclastic unit which conformably overlies the Tolstoi Formation. He describes it as a lithologic continuation of the Tolstoi Formation. Wilson (1980) claims that the Stepovak generally is a volcanic unit consisting of andesitic rubble flows, waterlaid tuffs, volcanic breccia, and lahars and that it is virtually indistinguishable from the Meshik Formation. Wilson also cites an oral communication from Detterman recommending abolishment of the name Stepovak Formation and including the volcanic portions in the Meshik Formation. Hanson et al (1981) described the Belkofski Formation as consisting of the Tolstoi and Stepovak, collectively, in the vicinity of Cold Bay. They also state that in the Chignik Bay and Chiginagak areas that the Stepovak is called the Meshik.

Considering the lithologic similarities, the difficulties distinguishing among the four formations, and the various correlations by various investigators, it seems reasonable to consider the Lower Tertiary sequence of the Alaska Peninsula as one related group of rocks. In this report, they are all included in an expansion of Burk's (1965) Beaver Bay Group.

This group of rocks represent deposition in a setting very similar to that now found along the Alaska Peninsula. That is, the type of rocks deposited is highly dependent on the local geographic and geologic setting and the short distances between differing local depositional environments. The Peninsula has several active volcanic centers that supply volcanic material. In close association are various nonmarine-volcanic, nonmarine-nonvolcanic, marine-volcanic, and marine-nonvolcanic depositional environments. In the rock record, this close association of depositional environments shows up as a rather confusing interfingering of different sediment types, as is found for the sediments here described as the Beaver Bay Group. The percentages of the different types are controlled by the distance to volcanic centers, the activity of the volcanic centers through time, the migration of depositional centers through time, the relative marine-nonmarine character of the local depositional environment, and the regional and local tectonics.

The local climate also exerts control on various aspects of the resulting rock sequence. The climate has significant effects by exerting controls on the local flora and fauna and on the erosional regime.

Bear Lake Formation, Miocene

Burk (1965) named a sequence of rocks exposed along the shore of Port Moller and in the mountains to the northeast the Bear Lake Formation. This sequence measures about 5,000 feet (1,640 m) thick. It consists of interbedded sandstone, conglomerate, and a few siltstones. The sandstones and conglomerates have a great abundance of nonvolcanic clasts. They also show greater rounding and better sorting than the older Tertiary rocks. In composition, they have about one-third quartz and chert, one-third sedimentary lithic clasts, and one-third volcanic fragments. They can be classified, mostly, as lithic subgraywackes with many lithic arenites. The sandstones also contain perthitic feldspars, some orthoclase and microcline, and large, well-zoned, pagioclase grains. These indicate erosion of intrusive igneous rocks, such as the Shumagin batholiths and mid-Tertiary batholiths now found along the Pacific coast.

The conglomerates show the same abundance of nonvolcanic debris. These contain black and white chert, black argillite, dark-gray, bedded siltstone and claystone, quartz-veined argillite, and silicified wood. The clasts of the sandstones and the cobbles of the chert-rich conglomerates and the conglomeratic sandstones resemble the early Tertiary rocks. The conglomerates contain well-rounded and fairly well-sorted clasts, commonly smaller than cobble size.

The beds are evenly bedded to cross-bedded and, generally, less than five feet thick. In color, they range from yellow to brown, with lesser amounts of gray; minor amounts of dark-gray siltstone and carbonaceous shale occur regularly interbedded with the sandstone.

The Bear Lake has been divided into a coarser-grained lower part named the Unga Conglomerate Member, a finer-grained, unnamed upper part (Burk (1965). The Unga Conglomerate locally contains a greater amount of volcanic material than does the upper part. Coarse volcanic breccias occur in several localities (Burk, 1965) The Unga Conglomerate represents the basal nonmarine portion of the Bear Lake Formation, and the finer-grained upper part represents the shallow-marine portion.

In the Beaver Bay area, gently dipping unfossiliferous volcanic conglomerates and breccias overlie steeply dipping beds of the Stepovak Formation. Bear Lake strata appear to rest on the Tolstoi Formation along the west shore of Port Moller. Here, Pliocene and younger rocks overlie the Bear Lake. From Port Moller to the west flank of Mt. Veniaminof, a series of long ridges expose more than 5,000 feet (1,640 m) of the Bear Lake. Probable outcrops of the Bear Lake are found at the northeast base of Mt. Veniaminof, north of Knife Peak, and at the western base of Aniakchak Crater. Rocks typical of the Bear Lake farther to the southwest are exposed near Black Peak (Burk, 1965).

The exposures from Kuiukta Bay to Chignik Lake show very complex stratigraphic and structural relationships. A thick sequence of unfossiliferous conglomerate apparently overlies rocks as old as the Chignik Formation. The relationships suggest that the conglomerates have a post-Oligocene age.

Marine invertebrates, including oysters, clams, and others in large fossiliferous banks, occur in great abundance in the upper part of the Formation. The lower part of the Formation is less consistently fossiliferous. The Unga Conglomerate Member, the basal part of the Formation, is characterized by specimens of Mytilus middendorffi, which indicate a mid-Miocene age. In many exposures, the M. middendorffi zone occurs not far above the mid-Oligocene Acila shumardi zone; this suggests that the latest Oligocene and earliest Miocene may be absent. The Unga Conglomerate, on Unga Island, contains Upper Oligocene plants, including fossilized Sequoia.

Tachilni Formation, Pliocene

Waldron (1961) named several hundred feet of marine sedimentary rocks on the cape separating Cold Bay from Morzhovoi Bay the Tachilni Formation. They consist of brown to greenish-gray sandstone and pebble conglomerate and some black shale. The Tachilni Formation rocks are poorly consolidated and locally very fossiliferous. The sequence, locally, grades into the overlying volcanic rocks.

The Tachilni crops out in the sea cliffs between False Pass and Morzhovoi Bay and on the west side of Deer Island. In the False Pass area, marine and nonmarine facies interfinger. Rapid facies changes occur both vertically and laterally, and beds tend to be lenticular. Trough cross-beds suggest bimodal current flow and deposition in a tidally influenced environment.

The fossil assemblage of the Tachilni indicates sublittoral water depths (0-300 feet; 0-100 m) and late Miocene to early Pliocene age. The assemblage consists of gastropods, pelecypods, barnacles, and echinoids representative of a shallow-marine, cold-water facies. The marine fossils occur dispersed throughout the sandstone.

Milky River Formation, Pliocene

Detterman et al (1980) named the Milky River Formation for 4,650 feet (1,525 m) of volcanogenic, nonmarine, sedimentary rock interlayered with andesite flows and sills. The Milky River seldom crops out at the surface, but it has been encountered in drill holes in the Bristol Bay-Nushagak Lowland. The upper parts of the unit consist of numerous, interlayered, prophyritic, andesite flows, lahars, tuffaceous units, and volcaniclastic rocks. The proportion of volcanic rocks increases upward.

The lower part consists of about 3,050 feet (1,000 m) of fluvial, coarse, volcanic sandstone and cobble-boulder conglomerate. The lower part is highly cross-bedded and channeled. It is generally dark-brown to gray. Its clast content consists almost entirely of volcanic debris.

The Milky River Formation unconformably overlies the Bear Lake Formation.

PLEISTOCENE AND RECENT

The Pleistocene and Recent deposits show no sharp break between them and can be considered as one unit. The Pleistocene glaciers retreated gradually and remnants of them remain on the Peninsula to this day. Erosion by glaciers and rivers and deposition along the coasts have been two of the main forces acting upon the Peninsula during this time. Active tectonic uplift and the build-up of large volcanoes have worked as counterforces to erosion.

The debris eroded from the mountains is carried either to the north toward the Bering Sea or south to the Pacific shore. The debris carried to the north forms the extensive alluvial cover of the Bristol Bay/Nushagak Lowland. The debris carried to the Pacific shore is mainly dumped into the deep waters of the Pacific Ocean (Burk, 1965).

IGNEOUS ROCKS

The Alaska Peninsula has had a long history of igneous activity and, as would be expected, igneous rocks account for a substantial proportion of the rocks of the Peninsula. These igneous rocks run the range from massive intrusive batholiths through intrusive dikes and sills to volcanic extrusives and ejecta.

The Permian and early Triassic rocks exposed at Puale Bay record continuous volcanic activity from the Late Paleozoic to the early Triassic. This was followed by intermittent volcanism at least through the Lower Jurassic. Pre-Cenozoic volcanic debris has andesitic to basaltic character (Burk, 1965); Hanson et al, 1981). A few thin ash beds record volcanic activity in the Middle Jurassic. Then, the strata of the peninsula record no volcanic activity until the great accumulations of the Cenozoic (Burk, 1965).

The Naknek Lake batholith is the only known Mesozoic batholith in southwestern Alaska (Burk, 1965; Hanson et al, 1981). It intrudes strata of probable Early Jurassic age, and its debris formed the arkosic sandstones of the Upper Jurassic Naknek Formation. Coarse Upper Jurassic and Lower Cretaceous arkosic rocks to the southwest suggest the presence of buried plutonic source rocks buried beneath the Bristol Bay-Nushagak Lowlands along the Bering Sea coast (Burk, 1965).

Volcanic debris makes up most of the Paleogene strata and records a period of extensive volcanism during the Early Tertiary. Volcanic flows and sills are interbedded in this sequence. Individual flows are generally less than 20 feet (6.6 m) thick, but some flows reach a thickness of over 200 feet (66 m). In composition, they range from rhyodacite to basalt, with the more felsic rocks predominating. Volcanic ash is fairly ubiquitous and forms beds which range in thickness from a few inches to tens of feet thick. More detail on the volcanic rocks of the Early Tertiary is included in the Formation descriptions given above (Burk, 1965; Hanson et al, 1981).

The Pliocene brought continued volcanic activity. Much of the Peninsula has volcanic flows and breccias of this age. This volcanic activity has continued into the Recent, and a progression of Pliocene to Recent strato-volcanoes can be observed on the Peninsula (Burk, 1965).

Two periods of intrusion mark the Tertiary, the early Tertiary and the mid-Tertiary. The early Tertiary plutons have a quartz monzonite to granodiorite composition and occur mainly on the islands off the Pacific coast of the Peninsula. The mid-Tertiary plutons occur mainly along the Pacific coast. These range in composition form quartz diorite to granodiorite. The compositions of all of these coastal batholiths is quite similar and they many be continuous at depth (Burk, 1965).

Numerous small Tertiary age intrusions occur on the Peninsula and appear to bear some spatial relationship to the volcanoes.

STRUCTURE

The general structure of the Alaska Peninsula is that of a broad anticline with igneous intrusions emplaced along the axis of the Peninsula (Brooks, 1906; Knappen, 1929) and flanked by dipping beds of sedimentary and volcanic rocks. While this may somewhat adequately describe the regional structure, it by no means tells the whole story. The detailed structure is quite complex and varies from one end to the other. The structure consists of numerous faults and folds at both large and small scale.

The Bruin Bay fault ranks as the dominant structural feature northwest of Wide Bay (Burk, 1965). It extends from the vicinity of Becharof Lake to the northeast for nearly 150 miles (242 km). It juxtaposes the Upper Jurassic Naknek Formation on the southeast side of the fault with the Early Jurassic Naknek Lake batholith on the northwest side (Burk, 1965; Hanson et al, 1981). The southeast side has moved downward with respect to the northwest side. Where it is observed, the fault plane dips 60 to 70° northwest and all known displacement northeast of Becharof Lake is reverse. The thick sequence of very coarse Upper Jurassic arkose southeast of the fault suggests movement during Middle and Late Jurassic. The absence of Cretaceous strata beneath the Tertiary strata northwest of the fault suggests that the fault was active during the Cretaceous also. Minor local displacement may have occurred during the Tertiary.

Southwest of Becharof Lake, the Bruin Bay fault is unknown. Exploratory wells drilled just west of Becharof Lake penetrated granite (presumably of early Jurassic age) at the base of a Tertiary section. This suggests that some relative Jurassic movement occurred for at least a short distance southwest of Becharof Lake. The occurrence of very coarse Naknek Formation conglomerate along the eastern shore of the Ugashik Lakes also suggests such movement (Burk, 1965).

On the southeastern side of the Bruin Bay fault from Lake Illiamna to the vicinity of Wide Bay, the structure consists mainly of folded Mesozoic rocks. Gentle dips of 5 to 20°, predominantly to the northwest, characterize the structure of this area. This region is little deformed except in the southern area near the Ugashik Lakes and Wide Bay where the dips increase to about 60° in a few, narrow en echelon folds (Hanson et al, 1981). A few large anticlines lie onshore along the Pacific coast (Fisher et al, 1981).

Northwest of the Bruin Bay fault, the early Jurassic Naknek Lake batholith intrudes the Lower Jurassic and older sedimentary rocks. These older rocks are gently to sharply folded with tight folding along the Bruin Bay fault. The Lower Tertiary volcanic-rich deposits dip gently to the northeast.

South of Wide Bay to the Kujulik Bay area, the regional structure changes character abruptly from the gentle, open folds of the area to the northeast. Tight en echelon folds and faults dominate here. High-angle reverse faults bound parallel-striking, northeast-trending anticlines and synclines. The reverse fault that runs from Nakalilok Bay, in the north, to Aniakchak Bay, in the south, shows the greatest displacement in this area. It becomes a thrust fault above Aniakihak Bay and places the Jurassic Naknek Formation over the

Cretaceous Chignik Formation. A steepening of dips, shearing and gouge, and drainage abnormalities mark the area of thrust. The largest number of Tertiary intrusives occur in this area (Hanson et al, 1981).

A broad northeast-trending anticline, with the Naknek Formation in its core, characterizes the area from Kujulik Bay to Mt. Veniaminof. Rocks as young as the Oliogocene Meshik Formation line the flanks of this anticline. Faults are less predominant than to the north. The major fault on the southeast flank of the anticline cuts all but the most recent sedimentary rocks. Most of the faults, except for a few of large displacement, apparently do not cut rocks younger than Eocene (Hanson et al, 1981).

Widely spaced, northeast-striking, monoclines, anticlines, and synclines characterize the area from Mt. Veniaminof to Cold Bay. The faults in this area are all large. The reverse fault near Beaver Bay displaces Paleocene and Eocene rocks from the Oligocene rocks. Dips up to 80^{o} occur in the vicinity of this fault (Hanson et al, 1981).

TECTONIC SETTING

The Alaska Peninsula lies at the northern edge of the Pacific Ocean and, also, at the northern edge of the lithospheric plate which underlies the Pacific Ocean. The Pacific plate moves northward with respect to the Alaska Peninsula and Aleutian Islands and is subducted beneath them in the Aleutian Trench. As the Pacific plate underthrusts the Peninsula/Arc system, it creates great tectonic stresses and is also consumed into the mantle. Relief of these stresses occurs through earthquake and volcanoic activity which has been important in the geologic development of the Alaska Peninsula and Aleutian Island Arc.

Paleomagnetic evidence indicates that the rocks of the Peninsula formed at a more southerly latitude than that at which they are currently located. Lithospheric plates carried these rocks northward and plastered them on to what is now Alaska as the Alaska Peninsula.

Volcanic rocks, indicative of former volcanic island arcs, are common on the Alaska Peninsula back to the Late Paleozoic. The Alaska Peninsula, apparently, has had a long and complex tectonic history related to the movement of lithospheric plates over the surface of the earth.

Two distinct, but related tectonic provinces comprise the Alaska Peninsula. These have been identified and defined as the "Illiamna" and "Chignik" sub-terranes of the Alaska Peninsula Terrane. North of Becharof Lake, the Bruin Bay fault separates these two terranes. How far south the Illiamna terrane may extend in the subsurface is unknown. These two sub-terranes have shared a "limited common geologic history." They share some rock units in common and one has serves as a source terrane for the other from time to time (Wilson et al, 1985).

The Illiamna sub-terrane consists of "Paleozoic and early Mesozoic rocks intruded by the Alaska-Aleutian Range batholith of Jurassic to mid-Tertiary age and including the batholith itself." The sub-terrane lies north of the Bruin Bay fault and "is composed of moderately deformed early Mesozoic marine sedimentary and volcanic rocks and schist, gneiss, and marble of Paleozoic and Mesozoic age . . . in close proximity to and intruded by . . . batholith," (Wilson et al, 1985).

The Chignik sub-terrane consists of "little deformed shallow marine to continental clastic sedimentary rocks." Important constituents of the older rocks of the sub-terrane include deep marine, volcaniclastic, and calcareous rocks (Wilson et al, 1985). The sedimentary formations described elsewhere in this paper comprise the Chignik sub-terrane. The Chignik sub-terrane lies to the south and east of the Bruin Bay fault and extends to the tip of the Peninsula.

GEOLOGIC HISTORY

The two small exposures of middle Paleozoic limestone that crop out near Gertrude Creek represent deposition in warm shallow seas. The significance of these two outcrops in the geologic history of the Alaska Peninsula is, however, difficult to assess. This difficulty arises from the extremely limited size of the outcrops and the lack of correlatable units in the vicinity. Detterman et al (1979) have interpreted them as possible roof pendants in the Alaska-Aleutian Range batholith.

The outcrops of fossiliferous limestones at Cape Kekurnoi, again, tells us of deposition in warm shallow seas during Permian time. The volcanic rocks associated with the limestones indicates a possible island arc setting similar to the Aleutian Island arc, but in a warmer climate. This warmer climate could be due to a more southerly position for these rocks or to a more widespread "tropical" climate. This situation continued through the Triassic and into the lower Jurassic as more limestones and volcanic rocks collected, as seen at Cape Kekunoi. Although violent volcanic activity left its record in the rocks of Permian through Lower Jurassic age, the general environment recorded is one of long-lasting persistence with little change.

The middle Jurassic Kialagvik Formation overlies the unnamed Lower Jurassic rocks, whether by fault contact or unconformity is unclear. These rocks indicate a change in depositional environment, and they consist of sandstone and shale. Ammonites in the Kialagvik Formation indicate deposition in a marine environment, but one that is no longer conducive to the deposition of limestone. Volcanoes left no record in the rocks of the Kialagvik Formation.

Volcanic activity apparently resumed in the Upper Jurassic as the marine Shelikof Formation contains beds of probable volcanic ash. A new feature shows up in the Shelikof, conglomerates containing boulders of granitic and dioritic rocks. These rocks probably derived from the Naknek Lake batholith now uplifted to the north of the Bruin Bay fault. The uplift of the Naknek Lake batholith becomes more evident in the overlying Naknek Formation, which consists of arkosic sandstone, conglomerate, siltstone, and mudstone. The Naknek Formation was deposited in a marine environment as indicated by its fossil content. The Staniukovich Formation gradationally overlies the Naknek and consists of arkosic marine sandstone and siltstone. It can be considered a facies of the Naknek and indicates that the source terrane for the arkose has worn down significantly and is no longer shedding large amounts of coarse, conglomerate-sized material. Alternatively, it could indicate a cessation of uplift of the Naknek Lake batholith.

The Lower Cretaceous Herendeen Limestone shows a further quieting in the clastic source areas or a more distal marine facies of the Naknek-Staniukovich sequence. The limestone content of the Herendeen indicates deposition in warmer, shallow marine conditions.

A period of uplift and erosion followed deposition of the Naknek-Staniukovich-Herendeen sequence. This uplift produced an angular unconformity between this sequence and the overlying Upper Cretaceous Chignik Formation. The unconformity represents differential uplift of the older rocks and brings the Chignik Formation into contact with the youngest Herendeen through to the Naknek part of the sequence. It represents subaerial exposure of the older rocks followed by a change to non-marine and near-shore marine deposition.

After the differential uplift and erosion which occurred in the area during the middle and early Late Cretaceous time, the area experienced a general subsidence. The non-marine, coal-bearing lower part of the Chignik Formation, the Coal Valley Member, represents the basal unit of a transgressive sequence. The Coal Valley member grades laterally and vertically into more marine sedimentary rocks which represent a deepening of water in the late Cretaceous. The marine environment continued to deepen and allowed the more marine facies to migrate over the non-marine and near-shore marine sandstones and shales of the Chignik. The deeper-water marine environment in which the Hoodoo Formation collected migrated over the Chignik rocks and deposited a sequence of black mudstones and siltstones. The occurrence of little volcanic material in the Upper Cretaceous indicates a low level of volcanic activity during Late Cretaceous time. A period of uplift and erosion occurred in the Late Cretaceous which allowed the formation of an angular unconformity between the Upper Cretaceous and Lower Tertiary rocks.

The Tertiary brought a renewal of volcanic activity to the Alaska Peninsula area. The Beaver Bay Group, as defined in this report, shows a large percentage of volcanic material accumulated during the Early Tertiary. Peaks of volcanic activity apparently shifted around through time, and greatly influenced the local nature of the deposits. These deposits range from non-marine alluvial to fully marine with volcanic character varying from virtually nil to totally volcanic in nature. Not only did the volcanic activity shift around through time, but the centers of deposition also shifted from place to place in response to volcanic and tectonic activity. Plutons were emplaced during the Early Tertiary in the islands off the Pacific coast of the Alaska Peninsula. Plutons were emplaced during the mid-Tertiary into Paleogene and older rocks along the coast.

A period of uplift and erosion followed deposition of the Paleogene Beaver Bay Group that lasted into the Miocene. The Miocene Bear Lake Formation records erosion of the Early Tertiary batholiths and older sedimentary and volcanic rocks. The coarse rocks of the basal Unga Conglomerate Member record rapid uplift in the source areas and deposition in nearby, mainly non-marine, environments. The Unga Conglomerate also contains volcanic rocks indicating volcanically active source areas. The fine-grained sediments overlying, and interfingering with, the Unga Conglomerate record deposition in shallow-marine environments as marine waters once again deepened over parts of the Alaska Peninsula. Uplift and erosion, in the late Miocene or early Pliocene, once again overtook the Alaska Peninsula after deposition of the Bear Lake Formation.

In some locales, subsidence again allowed marine conditions to transgress over parts of the Peninsula during the Pliocene. Also, volcanism continued to play a role in the shaping of the Peninsula. The Tachilni Formation and the Milky River record the occurrence of these conditions, respectively. Uplift and erosion once again followed deposition of these units.

The Pleistocene and Recent rocks and sediments record the advance and retreat of glaciers and continued volcanic activity. The most recent rocks and sediments continue to record the types of conditions that have shaped the Peninsula through much of its history. Volcanic activity, older sedimentary and volcanic rocks, and plutons provide abundant material for deposition in non-marine and marine environments. Details have changed, but the general picture remains much the same.

The history of the Alaska Peninsula has been explained in terms of plate tectonics. One of the current theories calls for the Peninsula to have formed as microplates which have migrated from a more southerly position through time. This theory is used to explain the changes from warm climate conditions as evidence by the Permian and Triassic limestones and the Jurassic Herendeen Limestones to cold climate conditions extant on the Peninsula today. It also explains the paleomagnetic data which indicates not only a more southerly position, but also a rotation of the Peninsula into its current position. Plate tectonics also explains the igneous plutons and the abundance of volcanic material present in the rocks of the Peninsula. These formed as a result of subduction of one plate under another. Each of the three major batholiths may record the presence of an island arc.

RESERVOIR ROCKS

Any rocks with interconnected pore space can serve as a reservoir rock. Sandstones, limestones, and dolomites, however, generally make the best reservoir rocks. In special circumstances, other types of rocks also form oil reservoirs. Oil has been found in shales, slates, and igneous rocks (Levorsen, 1967). For the purposes of this report, sandstones and limestones are considered as the possible reservoir rocks on the Alaska Peninsula. Dolomites have not been identified on the Peninsula, and the probability of shale, slate, or igneous rocks acting as reservoirs is considered unlikely.

The lack of detailed data on the Paleozoic, Triassic, and Jurassic limestones found on the Peninsula makes it difficult to assess the likelihood of these rocks serving as reservoirs. About the most that can be said is, given the right combination of a structural or stratigraphic trap and the occurrence of porosity in the limestone, that these limestones could serve as oil reservoirs. The most likely location to look for possible reservoirs in these limestones would be in the vicinity of Puale Bay and Wide Bay. The distribution of these limestones in the subsurface is unknown.

The Lower Cretaceous Herendeen Limestone occurs over a significant portion of the Peninsula and more is known about its distribution. Martin (1926) described it as an arenaceous limestone. Wilson (1980) notes that noncalcareous material makes up one-fourth to three-fourths of the Herendeen and Inoceramus fragments form the calcareous portion. The Herendeen Limestone could form good hydrocarbon reservoirs if secondary porosity has formed in the proper trap setting. Choosing a locality where this set of conditions could exist is difficult and will require a great deal of detailed information.

Sandstone accounts for a large portion of the stratigraphic section of the Alaska Peninsula. The major drawbacks to these sandstone serving as oil reservoirs is their large percentage of volcanic rock fragments, plutonic rock fragments, sedimentary rock fragments, and feldspars. The presence of rock fragments and feldspars tends to degrade a sandstone as a potential reservoir. Through diagenesis, they can convert to clays which can clog pore spaces. Through applied pressure, they can deform around more rigid grains and squeeze pores out of existence. Intergranular cement, such as calcite and laumontite, also reduce porosity in the sandstones of the Alaska Peninsula.

Some of the sandstones of the Alaska Peninsula have been found to have good porosities despite these drawbacks. Most reported porosities are, however, quite low. Lyle et al (1979) report that "selected outcrop samples and well log analyses indicate that the porosity of some of the potential reservoir rocks has been preserved." They report porosities of up to 6.9 percent in the Naknek Formation, 8.7 percent in the Chignik Formation, 11.8 percent in the Tolstoi Formation, 19.6 percent in the Stepovak Formation, 17.7 percent in the Bear Lake Formation, and 20.1 percent in the Tachilni Formation. Keller and Cass (1956) report an effective porosity of 13.1 percent in a petroliferous sandstone of the Chignik Formation. Marlow et al (1979) report porosities as high as 36.5 percent in the Bear Lake Formation in the Gulf Sandy River No. 1 well. Porosities as low as 8 percent in sandstones can form producible reservoirs and porosities of 15 percent can form reservoirs of good quality. See Table 2 for a synopsis of potential reservoir rock formations.

Table 2 . Possible reservoir rock formations. (See Stratigraphic Section for stratigraphic relationships.)

FORMATION		THICKNESS feet (meters)	LITHOLOGY
Bear Lake		3,000 - 7,315 (1,000 - 2,400)	Sandstone, siltstone, conglomerate, shale, coal
Stepovak Fm.	Belkofski Fm.	1,525 - 4,570 (500 - 1,500)	Sandstone, siltstone, conglomerate, shale, coal
Tolstoi Fm.		3,050 - 4,570 (1,000 - 1,500)	Sandstone, siltstone, conglomerate, shale, coal
Chignik Fm.		915 - 1,525 (300 - 500)	Sandstone, conglomerate, siltstone, shale, coal
Herendeen Ls.		0 - 92 (0 - 30)	Calcarenite
Staniukovich Fm.		0 - 915 (0 - 300)	Feldspathic to arkosic sandstone
Naknek Fm.		4,570 - 5,490 (1,500 - 1,800)	Lower part - arkosic sandstone, conglomerate, siltstone
Kialagvik Fm.		0 - 1,750 (0 - 575)	Sandstone, shale, conglomerate

The early migration of hydrocarbons into a sandstone can preserve the primary porosity of a sandstone. Diagenesis may create secondary porosity which can be filled and preserved by later formed hydrocarbons. It may also be possible for secondary porosity to form during the genesis of liquid and gaseous hydrocarbons. This may arise through the release of carbon dioxide during maturation of the organic source material. This carbon dioxide can combine with water to produce carbonic acid which can leach out some of the constituents of the reservoir rocks and create secondary porosity.

Given the right set of circumstances and the amount of sandstone available on the Peninsula, it is possible that significant reservoirs exist on the Peninsula.

HYDROCARBON INDICATORS AND GEOCHEMISTRY

DIRECT HYDROCARBON INDICATORS

Oil and gas seeps on the Alaska Peninsula have been known for many years. Martin (1904, 1905) reported on the oil and gas seeps located between Becharof Lake and Puale Bay (then known as Cold Bay). These seeps led to some of the earliest exploratory drilling, in 1903, for petroleum on the Peninsula. Martin (1905) reported one or more of these seeps as having a large, constant flow of petroleum. They occur along the crest of an anticline and along the west shore of the southern arm of Becharof Lake. Numerous investigators have mentioned these seeps in varying degrees of detail over the years (Brooks, 1923; Knappen, 1929; Blasko, 1976; Magoon et al, 1979).

Other seeps on the Peninsula have been reported on over the years. Brooks (1923) reported a seep at Douglas River, seeps between Douglas River and Puale Bay, a seep on the Aniakchak River, and a seep near Chignik. Kellum et al (1945) mentioned the reported occurrence of two seeps from the Kialagvik Formation on Wide Bay, but were unable to confirm their presence. They did, however, locate and describe a 10-foot interbedded unit of coaly shale and fine- to medium-grained, shaly-weathering sandstone with some conglomerate that was 75 percent oil saturated. Keller and Reiser (1959), quoting Smith (1925), report gas seepage at Gas Creek near the headwaters of the Kejulik River (just north of Becharof NWR). Blasko (1976) reported on the occurrence of seeps in the Demian Hills just west of the southern portion of Becharof Lake. He mentioned other seeps listed above and described in detail the seeps found in the area between Becharof Lake and Puale Bay.

Shows of oil and gas in various wells drilled on the Alaska Peninsula provide other direct indicators of hydrocarbon occurrence. One of the wells drilled in 1903 reportedly penetrated strata filled with thick residual oil (Martin, 1905). Five of the nine wells (Table 1) drilled along the northern shore of the Peninsula between 1957 and 1979 reportedly had oil and gas shows. The best shows of oil and gas occurred in the Gulf Sandy River No. 1 well, the Pan American Hoodoo Lake No. 2, and the Pan American David River 1-A

(Marlow et al, 1979). Hanson et al (1981) described the shows in the Pan American David River 1-A as weak gas flows in three intervals, a trace of oil between 9,965 and 10,020 feet (3,270 to 3,287 m). Pan American Hoodoo Lake No. 2 had very weak gas shows and minor oil near 7,550 feet (2,477 m). The Gulf Oil Sandy River No. 1 encountered oil and gas shows below 10,000 feet (3,281 m). See Table 3 for a synopsis of potential source rock formations.

GEOCHEMISTRY

Knappen (1929) reported that considerable organic material lay buried in the dark shales of the Naknek and Chignik Formations in the Aniakchak area. Some of the rocks have a distinct petroliferous odor on a freshly broken surface; this is especially notable on the northwest side of Chignik Bay in Chignik Sandstone along the shore of Chignik Lagoon.

McLean (1977) reported on the geochemistry of samples from eight of the nine wells that had been drilled on the Alaska Peninsula since 1957. He reported that the Lower Tertiary rocks are richer in organic carbon than are the Upper Tertiary rocks and that both are thermally immature. Woody kerogen predominates in these strata with a minor amount of amorphous-sapropel kerogen. Upon thermal maturity, woody kerogen tends to produce dry gas and amorphous-sapropel tends to produce liquid hydrocarbons.

McLean (1977) reported that the Chignik Formation, Herendeen Limestone, and Staniukovich Formation are locally cut by intrusives, have a variable organic count (average 4 percent), have low values of extractable bitumen (average 41 ppm), have low hydrocarbon fraction (average 16 ppm), and have predominantly woody kerogen with minor amounts of amorphous-sapropel. The organic matter is mature with an average vitrinite reflectance of 1.76 percent, an absence of odd carbon preference, and C15-C22 hydrocarbons more common.

Lyle et al (1979) reported that, based on outcrop samples, the Tertiary rocks are moderately mature and the Cretaceous rocks are moderately mature to very mature. They reported that herbaceous-spore/cuticle kerogen predominates with secondary amorphous, woody or coaly grain. This mix of kerogen types is, also, most likely to generate dry gas with minor amounts of liquid hydrocarbons.

GEOPHYSICS

Proprietary restrictions and a lack of onshore exploration work limits the availability of seismic data for evaluating the petroleum potential of the Alaska Peninsula. Consequently, we used available aeromagnetic and gravity reports to augment the geological evaluation of the oil and gas potential of the Peninsula.

Table 3. Possible source rock formations. (See Stratigraphic Section for stratigraphic relationships.)

FORMATION	THICKNESS feet (meters)	LITHOLOGY	
Bear Lake Fm.	3,000 - 7,315 (1,000 - 2,400)	Sandstone, siltstone, conglomerate, shale, coal	*
Stepovak Fm.	1,525 - 4,570 (500 - 1,500)	Sandstone, siltstone, conglomerate, shale, coal	*
Tolstoi Fm.	3,050 - 4,570 (1,000 - 1,500)	Sandstone, siltstone, conglomerate, shale, coal	*
Hoodoo Fm.	0 - 1,525 (0 - 500)	Dark siltstone, shale, minor sandstone	*
Chignik Fm.	915 - 1,525 (300 - 500)	Sandstone, conglomerate, siltstone, shale, coal	*
Naknek Fm.	4,570 - 5,490 (1,500 - 1,800)	Upper part - dark siltstone	
Shelikof Fm.	460 - 915 (150 - 300)	Dark siltstone	
Kialagvik Fm.	0 - 1,750 (0 - 575)	Sandstone, shale, conglomerate	*

* - Denotes that the siltstone and/or shale is a possible source rock.

MAGNETICS

Throughout the Alaska Peninsula region, large magnetic anomalies indicate the presence of buried plutons and volcanics. These volcanics may well overlie sedimentary basins. Unfortunately, the extreme complexity of the magnetic anomalies around the volcanics makes a qualitative analysis difficult. Gravity and magnetic analysis indicate the possible presence of sedimentary basins underlying the Bristol Bay/Bering Sea side of the Alaska Peninsula. These basins and the ones which may underlie the volcanics could be a viable source of hydrocarbons. Generally, most of the region's magnetic character is disrupted by the extensive volcanics and buried plutons; in areas apart from volcanics, topography is, however, indicated accurately (except where anomalies may be caused by magnetically altered rocks). Magnetic lows and flattened magnetic gradients superimposed on the highs may indicate zones of hydrothermal alteration and thus serve as direct exploration guides (Case et al, 1981).

GRAVITY

Strong, positive gravity anomalies extend over the Alaska Peninsula to Becharof Lake. Gravitational features show discontinuities and magnitude variations that reflect the complex geologic setting.

Gravity highs dominate the mountainous parts of the Alaska Peninsula - a relative low occurs over the Bristol Bay basin; separating the two is a major northeast trending zone of steepened gravity gradient that reflects a major tectonic boundary and may represent a concealed segment of the Bruin Bay fault (see Burk, 1965, part 3), although there is no direct evidence that the Bruin Bay fault extends south of the Upper Ugashik Lake. Several prominent zones of steepened magnetic gradients trend northwest across the area. Some of these zones coincide with mapped faults, others may indicated concealed features in the subsurface. The very thick sections of low density sedimentary rocks in the Bristol Bay sedimentary basin produce low gravity values to the north of the Peninsula. Gravity indicates that the lowest Bouguer anomalies, and probably the greatest thickness of sedimentary rocks, occur in the Ugashik quadrangle. Readings suggest the deepest part of the basin is onshore at this point and offshore elsewhere. Well logs show a sedimentary thickness of 13,868 feet (4,550 m) in the Bristol Bay/Nushagak lowlands.

A basin consisting of up to 9,145 feet (3,000 m) of sedimentary material, is indicated along the Meshik River. A distinct gravity low indicates another such basin underlying Mt. Veniaminof. This low could represent either the absence of terrain corrections, a thick accumulation of low-density volcanic material, an underlying sedimentary section, or some combination of the above. Other volcanics do not show gravity lows. Strong gravity highs to the southwest of Mt. Veniaminof along the Alaska Peninsula strongly suggest that the crust is oceanic rather than continental. A major gravity high coincides very closely with the Chignik anticline - here, too, large anomalies suggest oceanic rather than continental crust. An isolated gravity high near the head of Aniakchak Bay may be part of the same anticlinal trend. These gravity highs indicate existence of a basement anticline and suggests the possibility of a shallower structure which could be a good hydrocarbon trap (Case et al, 1981).

AREAS OF HYDROCARBON POTENTIAL (GEOLOGIC)

To assist the U.S. Fish and Wildlife Service in their planning process for the Alaska Peninsula NWR and the Becharof NWR, it is necessary to identify areas of no, low, moderate, and high oil and natural gas potential. One object of this report is to classify these areas and to present the reasons as to why the areas were so classified. Arguments as to the validity of the areas so classified can, and probably will, be raised. But, based on the geological and geophysical information available to the authors of this report and the BLM Manual guidelines for classification categories (Appendix 1), this is a reasonable and defensible assessment of the oil and natural gas potential for the area.

Two areas (Plate 3) have been classified as having high potential for the occurrence of a concentration of oil and gas. One area (Plate 3) runs along the Pacific coast from the Becharof NWR/Katmai National Park and Preserve (NPP) boundary to just north of Ivanof Bay. The presence of oil and gas seeps (in the vicinity of Puale Bay and Becharof Lake), a petroliferous sand outcrop (along the shore of Chignik Bay), and a report of a thick residual oil (in a well drilled in 1903) provide direct evidence for the accumulation of oil and gas. The seeps and the oil accumulation occur in rocks of Jurassic age, and the general outcrop pattern of Jurassic age rocks provides the basis for defining this area. Three areas of no-to-low potential lie entirely within this area.

The other area of high potential (Plate 3) occurs along the Bering Sea coast. It runs from about 20 miles south of Port Heiden to Moffett Lagoon. The occurrence of oil and gas shows in the wells drilled in this area provide direct evidence for the accumulation of oil or gas within this area. The northeastern limit to this area is drawn about midway between the Gulf Sandy River No. 1 well, which had shows of oil and gas, and the Gulf Port Heiden No. 1 well, which had no shows. Three areas of no-to-low potential abut this area to the southeast and to the west.

Two areas are classified as having moderate potential (Plate 3) The northern area lies along the Bering Sea coast north of the high potential area described in the preceding paragraph and northwest of the first described high-potential area. It extends from about 20 miles south of Port Heiden to the vicinity of the Becharof NWR/Katmai NPP boundary. The wells drilled in this area failed to encounter oil and gas, and no seeps are reported in this area. The wells, however, penetrated 8,865 to 15,015 feet (2,908 to 4,926 m) of sedimentary rock. McLean (1977) reported these rocks as rich in immature woody kerogen with a minor amount of amorphous-sapropel. If these rocks reached thermal maturity anywhere within this area, they could have produced dry gas with minor amounts of liquid hydrocarbons. So, although this area has no direct evidence of oil and gas accumulations, given the right set of local conditions, oil and gas accumulations could exist in this area. Three areas of no-to-low potential lie between this moderate potential area and the high-potential area to the southeast.

The other area of moderate potential lies along the Pacific Ocean coast from just north of Ivanof Bay to the southwestern shore of Pavlof Bay (Plate 3). This area has no reported oil or gas seeps, and the result of the drilling of the Canoe Bay No. 1 well is unknown to the authors. It was classified as having moderate potential because of the fairly thick sequence of Cretaceous and Tertiary strata in the area and because of the occurrence of the Jurassic strata just to the northwest. That is, the Jurassic strata, known to be oil-bearing to the northeast, may underlie this area.

Several areas have been classified as having no-to-low potential (plate 3). The same reasons apply to all of these areas, except the southermost has additional reasons. Each of these areas are associated with the location of an active volcano and/or plutonic intrusives. Oil and gas accumulations do occur in these types of rocks, as was pointed out in the discussion of reservoir rocks. These occurrences are, however, rare and require special sets of circumstances. We have insufficient information to determine whether these necessary sets of circumstances occur in this area.

The southermost area has two active volcanoes within the area, but a large part of the area does not. This area still rates a low potential classification because of the nature of the rocks of the Belkofski Formation (see above). Briefly, the rocks of the Belkofski Formation are lacking in good source rock and good reservoir rock potential.

The sizes, and even the classification, of the areas marked as having no-to-low potential can be argued against. It is possible that special circumstances beneficial to the occurrence; and accumulation of oil and gas could occur in any or all of these areas. One possibility is that the heat from the magma chambers or intrusives could have raised the maturity of the source rock and produced oil or gas. But, we have insufficient evidence to make such a case, or any other one, to change the classification of these areas.

PRODUCTION SCENARIO

Since the Alaska Peninsula National Wildife Refuge (APNWR) and the Becharof National Wildlife Refuge (BNWR) are adjacent to each other, one scenario is presented and discussed. This scenario represents future development in either or both of the refuges. An oilfield infrastructure does not exist near this area. All structures needed to produce and transport hydrocarbons to market would have to be built.

Should an economic field be discovered in APNWR and/or BNWR, development and production activities would operate on a year-round basis. Proposed plans for the production and transportation facilities are developed during the economic study of the discovery and submitted to Local, State, and Federal agencies for approval. After the required review process, the plans are either approved or denied pending further information, studies, and/or modifications. Once approved, construction of permanent drilling/production pads, air support facilities, roads, pipelines, and port facilities could begin. The first activity is to establish a temporary camp to support the construction workers who would begin constructing the permanent pads, connecting roads, airport, port, and a main road between the port facilities and the field. Selection of the port site depends upon the location of the field, economic, environmental, and water depth factors. The permanent camp and production facilities would be transported to the field and assembled onsite upon completion of the main road and port facilities. These buildings would be designed to last the life of the field. A field should produce for 15 to 30 years, depending upon the size of the field and reservoir characteristics.

For illustrative purposes, figure 6 shows the location of the facilities needed to produce the hypothetical prospect. Table 4 summarizes the acreage disturbed and gravel requirements for each facility, and table 5 summarizes total acres disturbed and gravel required for the development of our hypothetical projects. Drilling/production pads used in these scenarios are each designed to produce about 5,000 acres (2,023 ha). Once the hydrocarbons are depleted from the prospect, the wells would be plugged and abandoned, the facilities would be removed, and the disturbed surface would be reclaimed per Federal regulations.

PRODUCTION FACILITIES

Facilities needed for the production of oil and gas are the central production facilities, drilling/production pads, airstrip, pipelines, port facilities, and roads.

CENTRAL PRODUCTION FACILITY (CPF)

The CPF serves as the headquarters and primary operations center for the field. The example shows only one CPF, but surface and subsurface conditions may require more than one to adequately produce a field. Pads needed to support housing and production modules would be about two feet thick and cover 90 surface acres (36.5 ha). Each of these pads would require about 290,000 cubic yards (222,000 cu. m) of gravel.

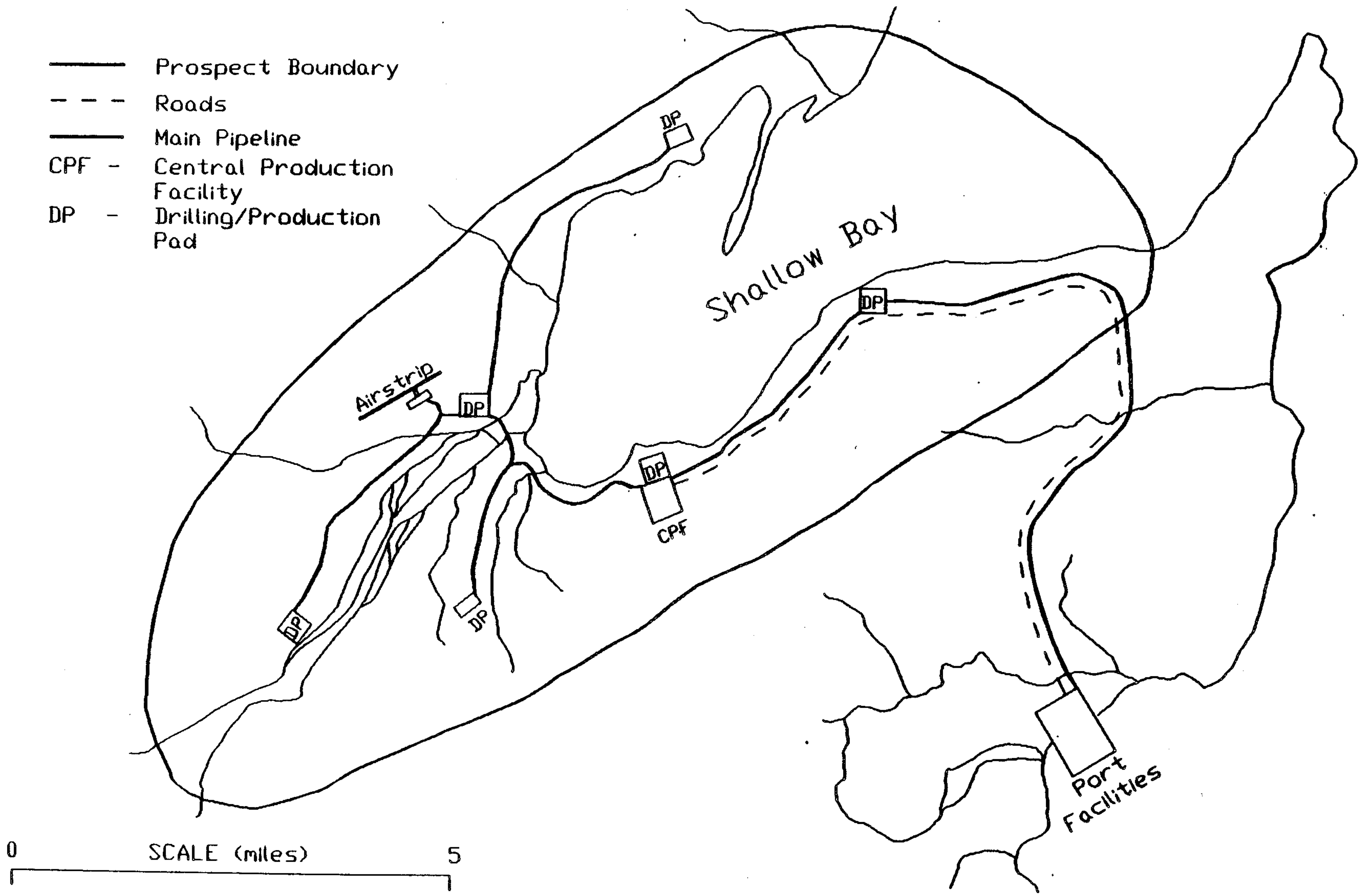


Figure 6. Development Scenario for a Hypothetical Prospect Alaska Peninsula and/or Becharof NWR.

TABLE 4

PRODUCTION FACILITIES
APNWR AND/OR BNWR

Facility	Acres Disturbed (each)	Cubic Yards of Gravel to Construct (each)
Central Production Facility Pad	90	290,000
Drilling/Production Pads	20-30	65,000-100,000
Airstrip and Facilities	30-35	100,000-125,000
Roads and Parallel Pipelines	5 acres/mile	16,000 yd^3/mile

TABLE 5

TOTAL ACRES DISTURBED AND TOTAL GRAVEL REQUIREMENTS FOR THE DEVELOPMENT OF THE APWR AND/OR BWR HYPOTHETICAL PROSPECT

Facility	Acres Disturbed	Cubic Yards of Gravel to Construct
Central Production Facility Facility Pad (1)	90	290,000
Drilling/Production Pads (6)	160	550,000
Airstrip and Facilities (1)	35	125,000
Roads and Parallel Pipelines (15.5 miles)	78	250,000
Port Facilities	250	500,000
TOTALS	613	1,715,000

Local sources probably would be mined for the gravel needed for the construction of the production facilities. To minimize environmental impacts, two or three small deposits may be excavated rather than removing the gravel needed from one source.

Housing modules would include sleeping and eating quarters, food storage area, and recreational and sanitation facilities. The modules would be designed to accommodate 150-300 workers. Adjoining offices would house administration, engineering, communications, and other support services.

Production facilities would include the equipment necessary to process the crude oil into salable oil and usable gas. This process begins by separating the production fluid into oil, gas, and water. Oil would be dehydrated and piped to the port facility. Produced gas could be dehydrated and compressed for facility use, reinjected into the subsurface structure, or piped to a NGL plant located at the port. Produced water would be pumped to injection wells for disposal.

Water for domestic use could be obtained from local lakes or water-filled pits (abandoned gravel source areas). Insulated tanks would store a sufficient amount of potable water for human consumption. Sewage treatment facilities and the incinerator would eliminate most of the human waste and trash. Items which could not be burned would be transported to an approved disposal site.

Fuel storage would hold diesel and other refined petroleum products necessary for operating the equipment of the CPF. A dike around the area would contain any spills which may occur. A diesel powered generation plant would provide electricity.

DRILLING/PRODUCTION PADS

Drilling rigs and support modules would be the initial equipment located on the drilling/production pads. As wells are completed, wellheads, pipelines,and the gathering facility would be put in place. The size of these pads depends upon the number of wells drilled and the distance between wellheads. In our example, four pads are shown to cover 30 acres (12.1 ha) and two pads cover 20 acres (8.1 ha). A 30-acre (12.1 ha) pad would support 60-90 wells, and a 20-acre (8.1 ha) pad would support 40-60 wells. All pads would be approximately two feet thick and would require 65,000 to 100,000 cubic yards (50,000 to 76,500 cu. m) of gravel per pad.

Depending upon the proposed depth and subsurface conditions, production wells will take 10-60 days to drill and complete. Production from each well is piped to the gathering facility where it is metered and piped to the CPF.

Most production wells are directionally drilled from the pads to various bottom hole locations within the hydrocarbon reservoir. This procedure allows maximum depletion of the reservoir and minimizes the surface acreage disturbed. Unusable drilling mud and cuttings are temporarily stored in reserve pits located on the pad. As wells are completed, this material may be buried when the reserve pit is filled in or transported to a disposal site.

AIRSTRIP, PIPELINES, ROADS, AND PORT FACILITIES

The airstrip would be permanent and maintained year-round for the lifetime of the project. Minimum length of the airstrip would be 6,000 feet (1,970 m) and minimum width would be 150 feet (49.2 m). Twenty acres of surface are covered by the airstrip itself and another 10 to 15 acres are required for the taxiway, apron, and support facilities. Approximately 115,000 cubic yards (87,900 cu. m) of gravel would be required to construct this facility.

Roads will connect all of the above facilities. They will be built with a crown width of 35 feet (11.5 m) and will be two feet (0.66 m) thick. Each mile of road will cover five acres (1.25 ha/km) of surface and require 16,000 cubic yards (12,230 cu. m) of gravel. Total road length varies between projects, depending on the size and surface features of each prospect.

Gathering lines will run from each production pad to the CPF. One line will transport the crude oil to the CPF and a parallel set of lines will transport the gas and water from the CPF to the production pads for fuel, injection, or disposal. Diameter of the pipe will range from three to twelve inches, and the pipelines will probably be buried parallel to the roads.

The main production pipeline leaving the field would probably be 8 to 16 inches in diameter for oil production, and 3 to 8 inches in diameter for gas production (if an NGL plant is built). These lines would most likely be buried parallel to the main road.

Port facilities would include, as a minimum, oil storage, barge loading equipment, oil spill treatment center, ballast water treatment equipment, and, if enough gas is produced, a NGL plant. Also, a seawater treatment plant may also be built if it is economically feasible to initiate a waterflood program.

When developing a scenario for these Refuges, consideration must be given to the possibility of activity in the Bristol Bay area. Should a major discovery be made there, combined use of production and transportation facilities could be feasible. This would benefit both areas in the development of their "prospective" hydrocarbon resources.

DEVELOPMENT POTENTIAL

When we speak of the development or economic potential of an area, we must consider not only the geologic environment concerning the existence of mineral resources but also the nongeologic environment as well.

These nongeologic features incude such considerations as market availability, the existing infrastructure in the subject area, price projections, costs of production and marketing, anticipated rate of return, and also alternative investment opportunities.

Current petroleum price projections compiled from a variety of sources are significantly lower than previous forecasts completed earlier in the 1980s (Appendix B). The range of oil prices projected in these forecasts vary from $18 to $42 per barrel by the year 2000 (constant 1984/85 dollars). With such a wide spread in forecasts, it is difficult to assess future impacts of this variable on future exploration activities. It was of interest to note that both a private research firm and a major oil company forecast a crude oil price of $35/barrel, whereas the most optimistic level of $42/barrel was a forecast of the U.S. Department of Energy (DOE) and was dependent on high economic growth. Assuming that high economic growth is not achieved, the DOE forecast is only about $2/barrel higher than those of the private sector. This level ($37/barrel by the year 2000) is approximately $5/barrel or 12 percent less than the average annual agencies cost of imported crude in 1981/82 (constant 1984 dollars). This scenario does reflect an optimistic picture as compared to the current pricing structure and may provide incentives for the exploration/production of high cost areas such as the Alaska Peninsula.

Other forecasts from the same sources indicate an upward trend in petroleum demand, but conversely project a decline in domestic production which is indicative of a decrease in domestic exploration activities.

Presently, the closest production to the Alaska Peninsula is in the Kenai/Upper Cook Inlet Basin, about 200 miles distant from the northern corner of the Becharof Refuge.

The interest in further exploration in the Alaska Peninsula by the petroleum industry must be weighed and ranked against alternative investment opportunities available to them from the standpoint of both domestic and foreign investments. Alternative areas with higher geologic potential or greater anticipated rates of return will likely rank higher for near-term investment. Part of the reason for this would be the relative high cost of exploration and development in the Alaskan Peninsula. This would be attributable to lack of infrastructure including roads and housing, distance from market, and the costs of moving manpower and supplies via boat. Based on this reasoning, as well as the fact that quantitatively minimal data was available to classify the geologic potential, the economic or development potential has been determined to be a scale below the geologic potential as seen on plate 3. Areas determined to have a high geologic potential were assessed as having a moderate potential for development by the year 2000. Areas determined to have a moderate to low geologic potential were assessed as having a low economic potential for development (see plate 4).

OVERVIEW

If these refuges were open to exploration and development, some small scale economic benefits could accrue to the nation. These benefits would, of course, be dependent upon locating commercial quantities of oil and could be further quantified by the size of the discovery made. To date, with the drilling of 26 wells between 1903 and 1985, no commercial quantities of oil have been reported. Sufficient geologic, engineering, and economic data are not available to estimate the probable range of hydrocarbon resource requirements necessary for development (i.e., minimim economic field size).

Alaska has become a major source of domestic crude oil production, which is largely from the North Slope. In 1985, Alaska contributed nearly 20 percent of domestic petroleum production (United States Department of Energy, Energy Information Administration 1986). In comparison, Alaska is a relatively minor producer of natural gas, with production of approximately 300 billion cubic feet per year in 1985 (United States Department of Energy, Energy Information Administration 1986a). However, Alaska is an exporter of natural gas in the form of liquified natural gas (LNG), which is primarily shipped to Japan.

Fundamental changes in the petroleum industry since the early 1970s will certainly be a force in shaping the industry's future. This period brought two major crude oil price shocks, rapid expansion in petroleum demand and heavy reliance on foreign sources of supply to meet domestic needs. Similarly, the consumer experienced shortages in natural gas supply which resulted in a new era of gas price regulation (see Appendix B for a detailed discussion of these changes). The rapid growth of the energy sector in the late 1970s and early 1980s resulted in the highest petroleum prices ever experienced by the industry. This set the stage for a period of energy conservation efforts followed by declining demand and excess world productive capacity with falling petroleum prices. By the middle of 1986, crude oil prices had dropped to levels at or below prices received in 1973 before the Arab oil embargo. Natural gas price increases stimulated drilling and production in the early 1980s which has resulted in domestic surplus capacity (gas bubble) and depressed prices. The present unstable nature of the oil and gas industry has resulted in a great deal of restructuring within the industry and expectations for the future are very uncertain.

Recent long-term price forecasts project an upward trend that will be realized in the 1990s and possibly beyond (see Appendix B for specific prices and trends). Domestic petroleum demand is expected to rise slightly above the 1985 level of 15.7 million barrels per day to a range from 15.9 to 18.1 million barrels per day by the year 2000. Natural gas demand could also increase from 17.4 trillion cubic feet per year in 1985 to a possible range from 17.1 to 20.4 trillion cubic feet per year in the year 2000. In contrast, domestic production of petroleum and natural gas is projected to decline below 1985 levels by the year 2000 (see Appendix B for a more detailed discussion of historic and future petroleum and natural gas demand and supply relationships). Therefore, the United States' dependency on foreign sources of hydrocarbon supplies is expected to increase above current levels. Based on these projections, there is a considerable gap between domestic consumption and production that can only be filled nationally by exploring new areas and developing any commercial discoveries that are made.

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Appendix A

Mineral Potential Classification System

Mineral Potential Classification System*

I. Level of Potential

O. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of No Potential use O/D. This class shall be seldom used, and when used it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholithic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

* As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

Consideration of the Potential for Development and the Economic Potential

Whenever known, the quality, quantity, current, and projected development potential or economic potential should be part of the mineral resource assessment. Although this is not necessary or required for most BLM actions, it is often useful to the decision maker. Assessments of economic potential should not be attempted for actions requiring low levels of detail, or when data are scant.

Development potential means whether or not an occurrence or potential occurrence is likely to be explored or developed within a specified timespan under specified geologic and nongeologic assumptions and conditions. Economic potential means whether or not an occurrence or a potential occurrence is exploitable under current or foreseeable economic conditions. The time period applicable to the economic or development potential assessment should be specified in the assessment report (e.g., the occurrence is likely to be exploited within the next 25 years). Conditions that could change the economic potential, such as access, world energy prices, or changing technology, shall be an important part of every economic potential assessment. Determining the economic or development potential of either an actual or an undiscovered mineral occurrence is a matter of professional judgment based on an analysis of geologic and nongeologic factors. The rationale for that judgment shall be part of the Mineral Assessment Report, when the economic potential is assessed. The rationale may include data on the current marketing conditions for the mineral commodity, technological factors affecting exploitability, distance from roads, anticipated capital costs, etc. In other words, if the economic or development potential is assessed, the rationale for the conclusions regarding that potential must be thoroughly documented.

Calculating the quality and quantity of an occurrence, where the quality and quantity are not known from existing data, is only done for actions requiring a high level of detail. These calculations involve methods appropriate to the type of action and are described in the pertinent Bureau Manual (e.g., appraisal, validity, etc.).

Appendix B

Oil and Gas Demand and Supply Relationships

Appendix ______

OIL AND GAS DEMAND AND SUPPLY RELATIONSHIPS

The importance of potential oil and gas resources from this Refuge is dependent on the hydrocarbon potential of the area, national need for additional sources of oil and gas, and the economics of exploring and producing any hydrocarbons that might be discovered. This Appendix provides a detailed review of the factors that have contributed to the present domestic oil and gas situation and possible future demand for oil and gas, which is directly linked to the national need for oil and gas resources from the Refuge.

Domestic Energy Trends

The domestic energy situation, as it relates to oil and gas consumption and production, has changed dramatically since the early 1970s. In 1970 petroleum and natural gas supplied 44 and 33 percent (United States Department of Energy, Energy Information Administration, 1984), respectively, of the total energy consumed in the United States (Figure 1A). By 1977 petroleum accounted for nearly 49 percent of domestic energy consumption and natural gas consumption had declined to approximately 26 percent of total energy demands. The relative contribution of both petroleum and natural gas declined through 1985 when petroleum supplied nearly 42 percent and natural gas contributed approximately 25 percent of total energy demand. Figure 1 graphically depicts the contribution of each major primary energy source to total national energy demand in 1970, 1980 and 1985. Coal, nuclear and geothermal energy were the primary forms of energy to increase their market share of total energy consumption during this time period at the expense of petroleum and natural gas resources.

FIGURE 1

PRIMARY ENERGY CONSUMPTION BY SOURCE

FIGURE 1A
1970
Total = 66.4 Quadrillion Btu

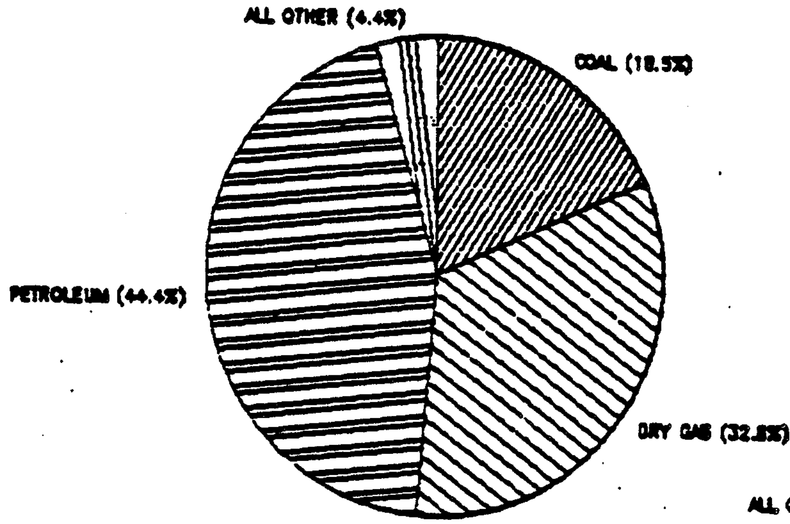


FIGURE 1B
1980
Total = 78.0 Quadrillion Btu

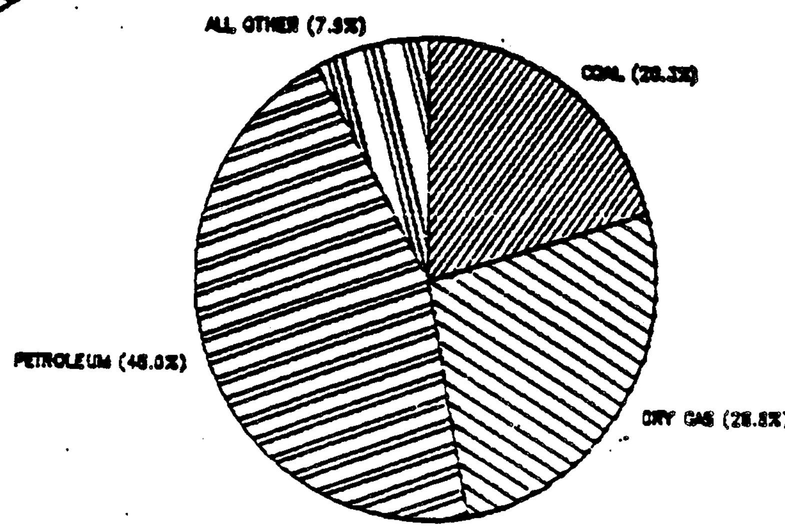
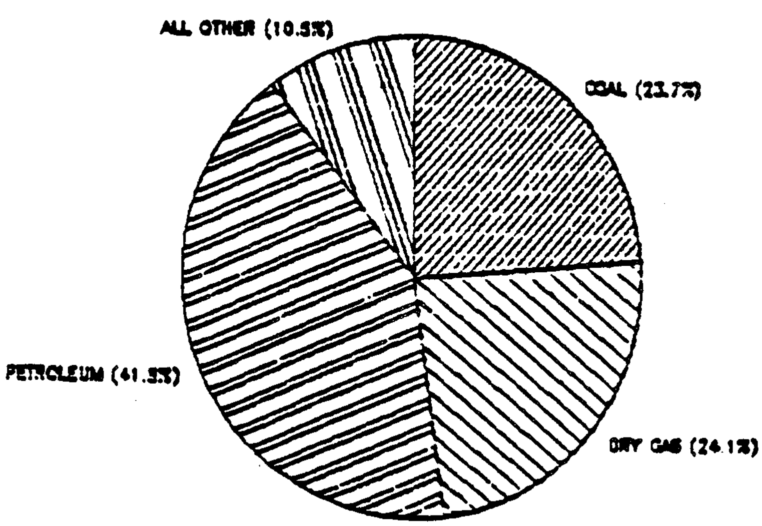


FIGURE 1C
1985
Total = 73.8 Quadrillion Btu



Total domestic energy consumption peaked at 78.9 Quadrillion (QUAD) British thermal units (Btu) in 1979 and subsequently declined to 73.8 QUADS in 1985 (United States Department of Energy, Energy Information Administration, 1986). Over the 15 year period from 1970 to 1985 total primary energy consumption increased 11 percent from 66.4 QUADS to 73.8 QUADS; however, the rapid increase in energy consumption and escalation in the cost of energy (the cost of energy more than doubled from 1.35 constant 1972 dollar per million Btu in 1970 to 2.90 in 1981) during this time period resulted in a dramatic change in national energy consumption patterns. Total energy consumed per constant 1972 dollar of Gross National Product (GNP) ranged from 56,500 to 61,000 Btu's per 1972 dollar of GNP from 1960 through 1976 (United States Department of Energy, Energy Information Administration, 1985a). A decline in the intensity of energy utilization was realized in 1977 when total energy consumption dropped to 55,700 Btu's per 1972 dollar of GNP, and this downward trend continued through 1985 when energy consumption was reduced to 42,900 Btu's per 1972 dollar of GNP (United States Department of Energy, Energy Information Administration, 1986). The decline in energy consumption was led by the reduction in the intensity of petroleum and natural gas utilization. In 1985 only 68 percent as much petroleum and natural gas were consumed per dollar of GNP than in 1977, as compared to 77 percent for total energy consumption. The reduction in intensity of energy utilization was indicative of a national conservation effort which may be attributed to many factors including: increased real energy prices, the increased service orientation of the economy and changes in the mix of product production (United States Department of Energy, Energy Information Administration, 1985a).

Historical Oil and Gas Demand, Supply and Price Relationships

The relationship between price and domestic petroleum supply and demand is shown in Figures 2 and 3. Import prices utilized for petroleum in Figure 3 are represented by the national average refiner's acquisition cost of imported crude oil and wellhead prices are presented on the basis of the national average from all producing wells. Domestic crude oil prices were not completely decontrolled until January, 1981; and therefore, domestic wellhead prices do not follow import prices during the 1970's. Petroleum product demand rose throughout the early 1970's until it peaked at 18.8 million barrels per day (MBPD) in 1978 (United States Department of Energy, Energy Information Administration, 1986a). Crude oil price increases began with the Arab oil embargo in 1973 and a second major price run-up was triggered in 1978 by the Iranian revolution and subsequent oil stock building in anticipation of world oil shortages. Real import prices peaked at $44.00 per barrel (1985 dollars) in 1980.

Domestic petroleum product demand began a downward slide in 1979 which continued through 1983. The Organization of Petroleum Exporting Countries (OPEC) members sought to maintain the higher prices, that resulted from oil price shocks of the 1970's, by production restraints. However, oil prices have steadily declined since 1981 as a result of slow economic growth with subsequent declining petroleum demand and excess world productive capacity (United States Department of Energy, Energy Information Administration, 1986b). Domestic oil prices in the second quarter of 1986 had declined to the lower teens in nominal terms which is comparable to 1973 prices in real

FIGURE 2
NATIONAL PETROLEUM DEMAND
AND SUPPLY 1970 – 1985

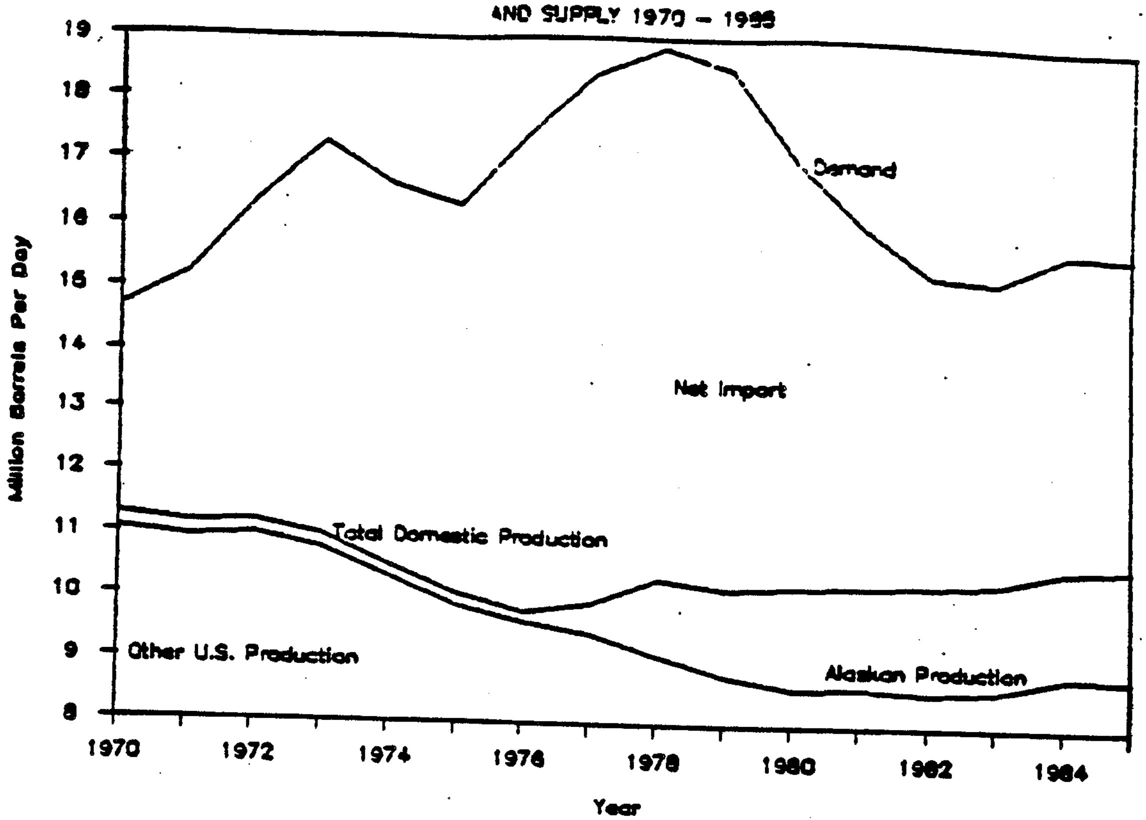
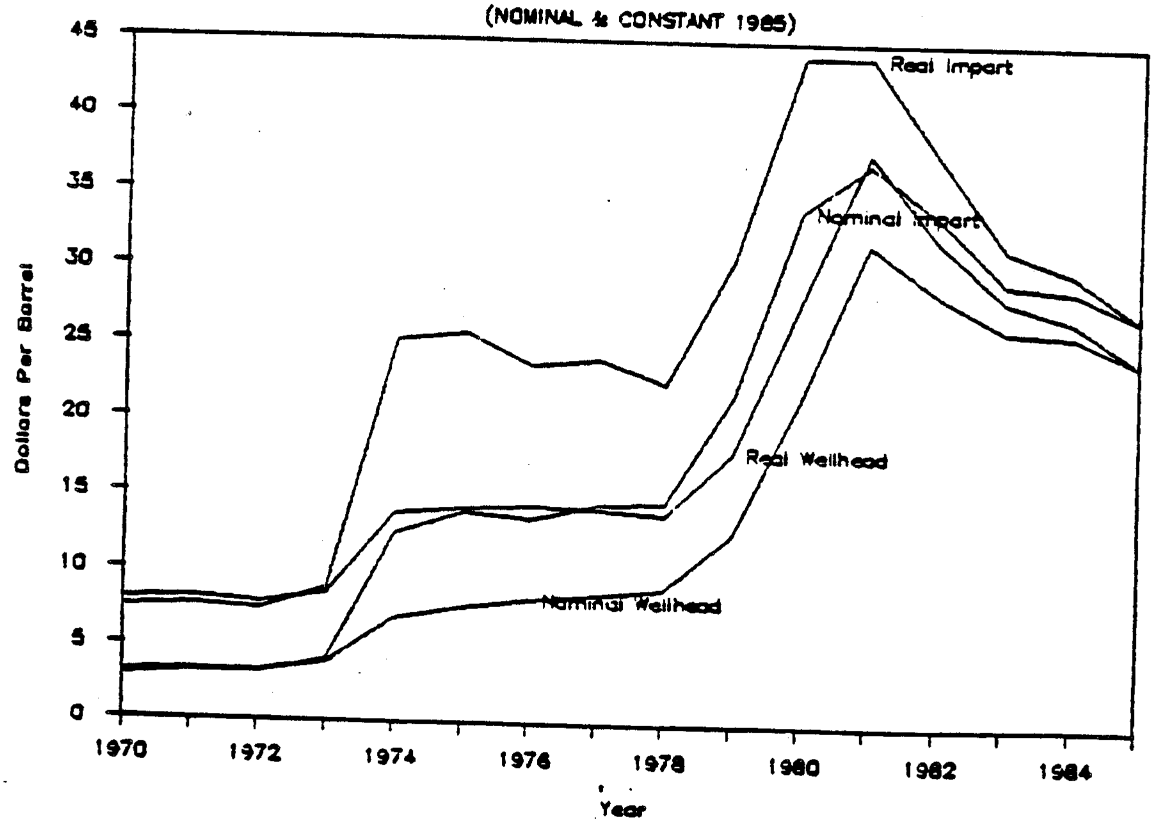


FIGURE 3
CRUDE OIL PRICES
(NOMINAL & CONSTANT 1985)



dollars. Figures 2 and 3 show that petroleum demand is sensitive to price and is characterized by long lags and high elasticities.

Domestic petroleum production has been much more stable than petroleum product demand. Figure 2 shows that Alaskan production, primarily from the North Slope, contributes a significant portion of domestic supply. In 1985, Alaska accounted for more than 20 percent of the national crude oil production (United States Department of Energy, Energy Information Administration, 1986a). Price increases of the 1970's provided incentive for exploration and production from higher cost areas such as Alaska. Foreign imports have been required to fill the gap between domestic supply and demand. Crude oil and petroleum product imports peaked in 1977 when net imports accounted for more than 46 percent of domestic petroleum consumption. Net petroleum import levels declined to 27 percent of product demand in 1985, but the United States still remains highly dependent on foreign petroleum supply sources.

The history of natural gas production and consumption in the United States is quite different from petroleum and has a direct bearing on gas pricing policies, demand and supply relationships in the 1970's and 1980's (Figures 4 and 5). Natural gas went from a little used waste by-product of oil production in the 1930's to a source of energy that supplied nearly 33 percent of national consumption in 1970 (Figure 1A). By 1970 gas was being delivered to consumers at prices well below those of competing petroleum products (United States Department of Energy, Energy Information Administration, 1984). Prices paid to gas producers by interstate pipeline companies were

FIGURE 4
NATIONAL NATURAL GAS DEMAND

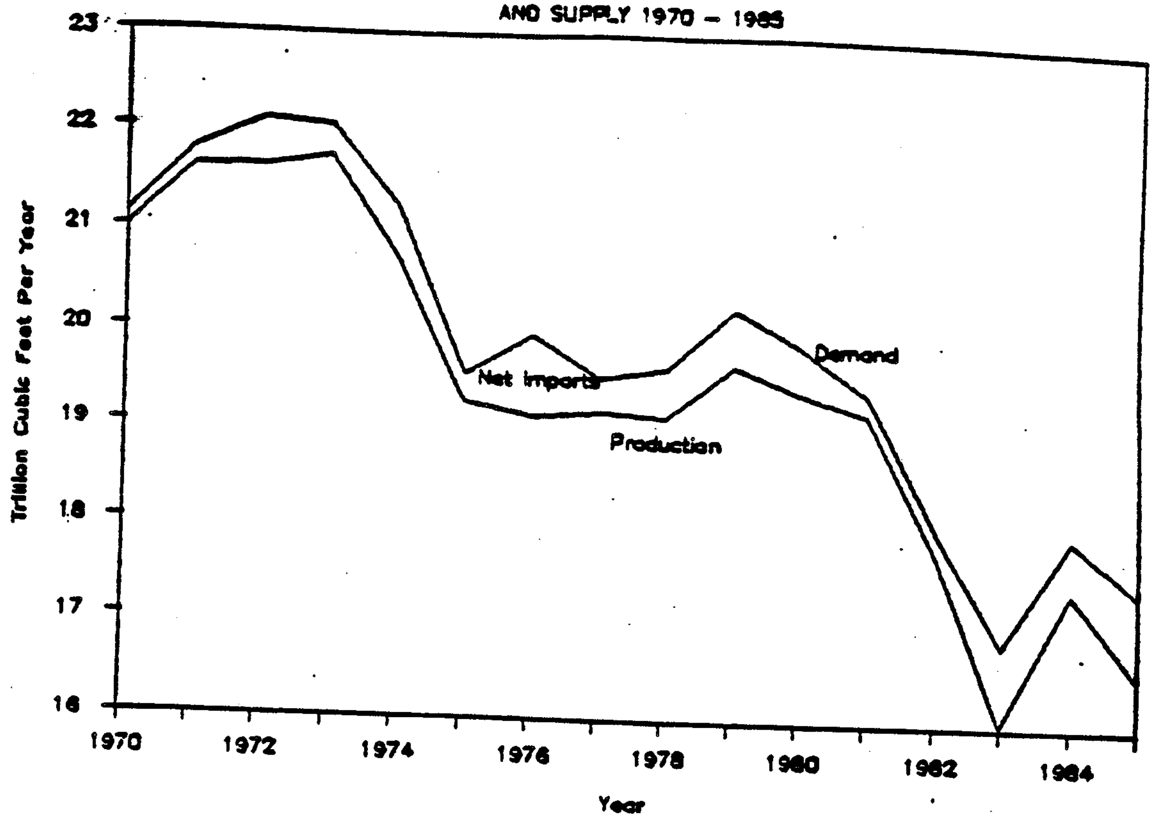
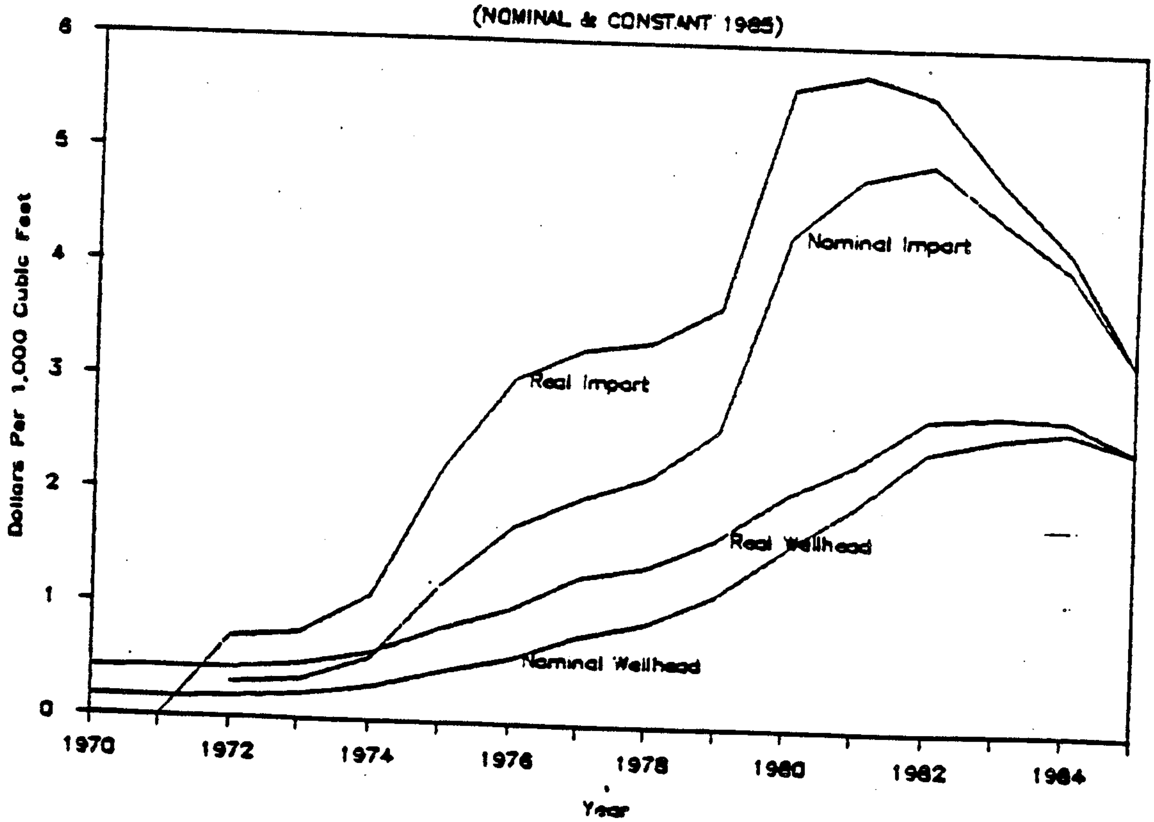


FIGURE 5
NATURAL GAS PRICES



held at low levels through regulation by the Federal Power Commission, which resulted in increased demand and reduced incentives for producers to explore and develop new gas reserves. Regulated prices allowed intrastate transmission companies and distributors to bid natural gas supplies away from interstate carriers (Tussing and Barlow, 1984). The 1970's has been noted for the gas supply shortages in the midwest and northern states. Imported gas prices increased in a pattern similar to oil prices, but domestic prices remained under regulation. The Natural Gas Policy Act was passed in 1978 which allowed wellhead prices to increase and deregulated certain categories of gas. Price increases provided incentives to explore and develop new sources of gas. Natural gas consumption started a sharp decline after 1980 under the influence of higher gas prices, a weak economy, warm winters and since 1981 falling oil prices (United States Department of Energy, Energy Information Administration, 1984). This trend continued through 1985 with the exception of a small increase in gas demand realized in 1981 which may be attributed to the strong economic growth in the national economy in that year.

Net imports of natural gas are primarily received through pipelines from Canada and Mexico, although there are some liquified natural gas (LNG) imports from Algeria. Net imports generally ranged near five percent from 1970 to 1985. Alaska is a relatively small producer of natural gas, ranging from approximately 100 to 325 billion cubic feet per year from 1970 to 1985 (United States Department of Energy, Energy Information Administration, 1985b). Alaska is, however, a net exporter of natural gas in the form of LNG, which is delivered to Japan. Huge gas reserves have been identified on the Alaskan North Slope, but this resource has not been commercially produced due to a lack of transportation infrastructure.

Future Oil and Gas Demand, Supply and Price Relationships

From the review of historic petroleum and natural gas price, demand and supply relationships it is apparent that there have been fundamental changes, such as petroleum price deregulation and energy conservation efforts, in the national energy market since the early 1970's that will likely affect future petroleum and natural gas production and consumption. At the present time the national petroleum market is directly linked to the world petroleum market by price and supply. The situation is characterized by excess productive capacity in the world market, a strong desire by exporting nations to sell petroleum to meet financial obligations, a time of relatively slow economic growth, and declining petroleum prices. The domestic natural gas industry is currently working off surplus reserves added during the early 1980's, but depressed prices have resulted in a sharp reduction in drilling which could have serious implications for future domestic gas production.

Implications of the petroleum price slide during the first half of 1986 are not yet fully discernable. Middle eastern nations have been unable to reach accord in setting and adherence to self-imposed oil production quotas. In the past Saudi Arabia has taken the position as swing producer for OPEC and thereby reduced production to maintain quota levels. However, Saudi Arabia changed policies in 1986 to concentrate on achieving a "fair market share" of the international petroleum market with little concern for output quotas. The strategy behind this policy was not disclosed, but speculation as to the potential motivation and results of this action includes:

1. Saudia Arabia is making a show of strength to discipline OPEC members that have cheated on production quotas and prices with hopes of bringing member and possibly non-member nations together as a unified market group;

2. Saudia Arabia sought to increase revenue, but underestimated the effects additional production would have on price;

3. Saudia Arabia is flooding the world oil market in an effort to eliminate producers with higher costs of production and thereby reduce competition;

4. Saudia Arabia is acting to reduce prices and stimulate growth in petroleum demand to reverse conservation efforts initiated in the late 1970's and 1980's.

In any event, a tremendous amount of uncertainty exists in the national petroleum industry, which has resulted in major financial restructuring. The most evident signs of restructuring are major employment reductions and reduced capital expenditures for exploration and drilling.

The interest in mineral exploration and possible development in this Refuge is driven by the future national demand for oil and gas, the cost and availability of domestic supplies and the hydrocarbon potential of the area. The rate of future economic growth and hydrocarbon prices will be the major determinants of petroleum and natural gas demand. Future domestic production is dependent on resource availability and market prices. However, political forces are having an increasingly important affect on world oil prices, which will ultimately dictate future market conditions. The instability in the world oil market results in tremendous uncertainty in predicting future hydrocarbon prices and market conditions. Table 1 presents three recent crude oil and natural gas price forecasts by the United States Department of Energy, a private research firm and a major oil company. The prices shown in these forecasts are significantly lower than previous forecasts completed earlier in the 1980's. The range of oil prices projected in these forecasts is $18.00 to $42.00 (constant 1984 and 1985 dollars) per barrel in the year 2000. The high price range is approximately equivalent to the average annual refiner's acquisition cost of imported crude received in 1981 and 1982 (constant 1984 dollars). The range of prices projected for the year 2010 is $47.00 to $67.00 per barrel. These prices would be substantially above the peak levels paid in the early 1980's. Natural gas prices are projected to range between $4.10 and $5.50 per thousand cubic feet (MCF) in the year 2000 and $6.00 to $9.10 per MCF in the year 2010. The magnitude of projected natural gas price increases is similar to forecast changes in world oil prices.

Projections of future domestic petroleum and natural gas demand and supply conditions is presented in Table 2. All three forecasts projected an upward trend in petroleum demand above current levels. Petroleum consumption is projected to range from 15.9 to 18.1 MBPD in the year 2000 and possibly increase to 19.4 MBPD by the year 2010. In comparison domestic petroleum production is projected to decline to levels ranging from 6.1 to 8.9 MBPD by the year 2010. Domestic natural gas demand is projected to increase to a

TABLE 1

PETROLEUM AND NATURAL GAS PRICE FORECASTS[1/]

Reference	Crude Oil ($/Barrel) 1990	2000	2010	Natural Gas ($/MCF) 1990	2000	2010
U.S. Department of Energy, 1985[2/]						
Low Economic Growth	20.27	31.31	47.42	2.64	4.13	6.02
Reference Case	22.89	36.75	56.77	2.76	4.80	7.68
High Economic Growth	25.02	42.17	67.12	2.88	5.42	9.14
Data Resources Incorporated, 1986[2/]	16.91	34.32	49.99	1.69	3.80	5.76
Chevron Corporation, 1986[3/]						
Low Case	12.00	18.00	N/A	Rise to parity with fuel oil prices.		
High Case	27.50	35.00	N/A			

1/ Some of the price estimates presented in this Table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

2/ Reported on the basis of constant 1984 dollars.

3/ Reported on the basis of constant 1985 dollars.

TABLE 2

FUTURE DOMESTIC PETROLEUM AND NATURAL GAS DEMAND AND SUPPLY RELATIONSHIPS[1/]
(See Table 1 for Price Forecasts)

Reference	Demand 1990	Demand 2000	Demand 2010	Supply 1990	Supply 2000	Supply 2010
	Petroleum (Millions of Barrels Per Day)					
U.S. Department of Energy, 1985						
Low Economic Growth	16.1	15.9	15.5	9.8	9.0	7.8
Reference Case	16.7	16.6	16.5	10.0	9.4	8.3
High Economic Growth	16.8	17.0	17.3	10.0	9.7	8.9
Data Resources Incorporated, 1986	16.9	18.1	19.4	9.5	7.3	6.1
Chevron Corporation, 1986	16.0	16.8	N/A	9.2	7.0	N/A
	Natural Gas (Trillion Cubic Feet Per Year)					
U.S. Department of Energy, 1985						
Low Economic Growth	18.6	18.8	17.2	17.4	16.1	14.7
Reference Case	19.1	19.7	17.4	17.6	16.3	15.0
High Economic Growth	19.5	20.4	18.3	17.9	16.6	14.7
Data Resources Incorporated, 1986	18.9	18.1	16.7	16.7	15.3	13.9
Chevron Corporation, 1986	17.3	17.1	N/A	N/A	N/A	N/A

1/ Some of the numeric estimates presented in this Table were interpreted from graphic displays and/or extrapolated from data series, so the reported values may vary slightly from the actual values.

level ranging from 17.1 to 20.4 TCF per year by the year 2000 and then decline to a level of 16.7 to 18.3 TCF per year by 2010. Domestic gas production is projected to follow a similar trend with domestic oil production and decline to levels ranging from 13.9 to 15.0 TCF per year by the year 2010.

Conclusion

National hydrocarbon markets have undergone substantial changes since the early 1970's. Energy conservation trends initiated by real price increases of the 1970's are expected to continue through the end of this decade and possibly beyond. However, future economic growth is expected to result in some increased demand for petroleum and natural gas, while domestic production of these finite resources is projected to decline. As a result, the United States will become increasingly depend on foreign hydrocarbon sources to meet national requirements. New areas will need to be explored and any economically viable resources that are discovered will need to be brought into production in order to meet domestic needs. The potential contribution of this Refuge to national oil and gas production is dependent on its resource potential and the potential cost at which any discovered hydrocarbon resources could be extracted and marketed within the constraints of future oil and gas prices.

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