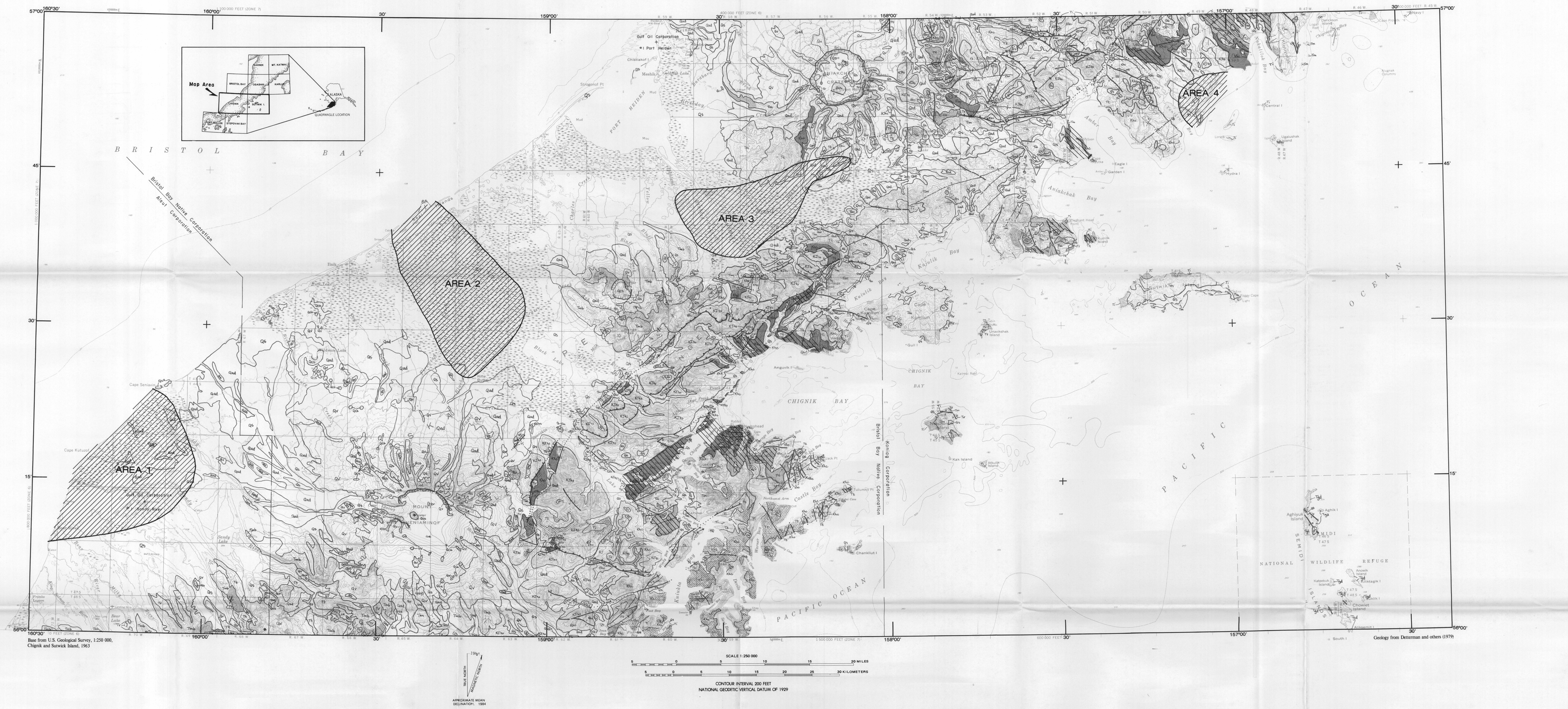
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

FOLIO OF CHIGNIK AND SUTWIK ISLAND QUADRANGLE, ALASKA
MISCELLANEOUS FIELD STUDIES MAP MF–1053–L
SHEET 1 OF 2
DETTERMAN AND OTHERS—ENERGY RESOURCES



Base from U.S. Geological Survey, 1:250 000,
Chignik and Sutwik Island, 1963

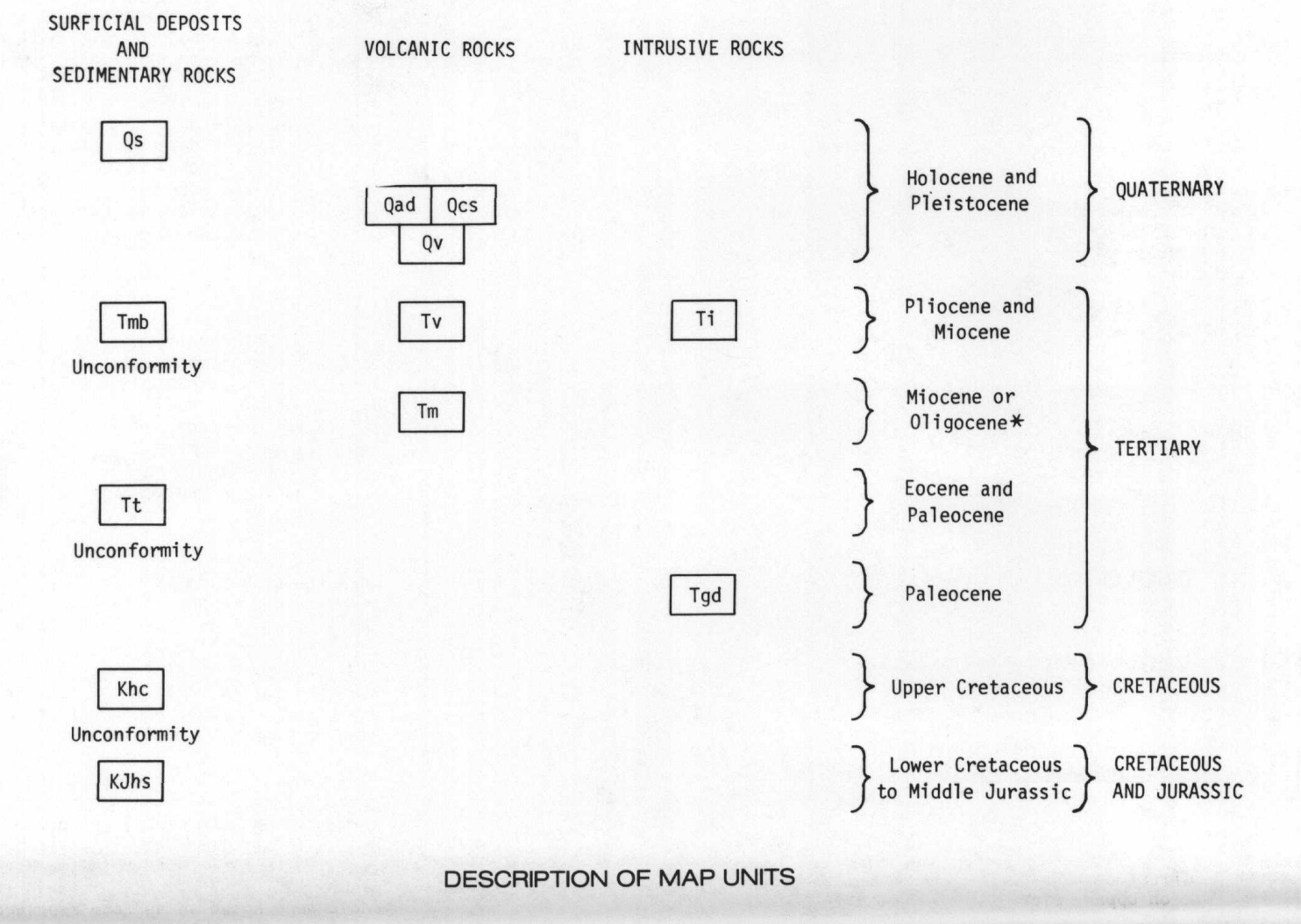
Geology from Detterman and others (1979)

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

APPROXIMATE MEAN DECLINATION, 1984

ENERGY RESOURCE MAP

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS AND SEDIMENTARY ROCKS

Qs	SURFICIAL DEPOSITS--Unconsolidated alluvium, colluvium, glacial, marine, swamp and eolian deposits; mainly sand, silt, gravel and pumice
Tmb	MILKY RIVER FORMATION OF GALLOWAY (1974) AND BEAR LAKE FORMATION--Milky River Formation (Pliocene); mainly volcanogenic sandstone and conglomerate, non-marine. Bear Lake Formation (Miocene); sandstone, conglomerate, siltstone, shale, and coal; shallow marine to non-marine
Tt	TOLSTOI FORMATION OF BURK (1965) (Paleocene and Eocene)--Sandstone, conglomerate, siltstone, dark shale, coal; high percent volcanic debris; mainly non-marine
Khc	HOODOO AND CHIGNIK FORMATIONS--Hoodoo Formation (Upper Cretaceous); dark shale and siltstone; deep water deposit. Chignik Formation (Upper Cretaceous); sandstone, shale, conglomerate, siltstone, and coal; shallow water to non-marine
KJhs	HERENDEEN LIMESTONE AND STANIUKOVICH, NAKNEK, AND SHELIKOF FORMATIONS--Herendeen Limestone (Lower Cretaceous); thin-bedded calcarenite composed of *Inoceramus* prisms and thin calcareous sandstone. Staniukovich Formation (Upper Jurassic and Lower Cretaceous); thin-bedded feldspathic and laumontitic sandstone. Naknek Formation (Upper Jurassic); dark siltstone and shale in upper part, light arkosic sandstone and conglomerate in lower part. Shelikof Formation (Middle Jurassic); dark siltstone and shale

VOLCANIC ROCKS

Qad	ASH AND DEBRIS FLOW DEPOSITS--Volcanic ash, pumice, tuff, and breccia; includes air-fall, ash flow, and avalanche deposits; unsorted to well-sorted; poorly- to well-stratified; includes some lava flows
Qcs	CINDER AND SPATTER CONES, AND DOMES--Cinders, scoria, and associated pyroclastic rock
Qv	VOLCANIC ROCKS--Andesite and dacite flows, tuff, volcanic breccia, and lahars
Tv	VOLCANIC ROCKS--Rhyolite, andesite, dacite, and basalt flows; tuff, volcanic rubble flows, and lahars; includes hypabyssal plugs and domes
Tm	MESHIK FORMATION (Miocene or Oligocene*)--Basalt flows, volcanic rubble flows, and lahars; minor volcanogenic sedimentary rock

INTRUSIVE ROCKS

Ti	INTRUSIVE ROCKS--Quartz diorite, diorite, and gabbro; medium- to coarse-grained; mainly small plutons
Tgd	GRANODIORITE--Semidi Islands pluton; medium- to coarse-grained; hornblende- and biotite-bearing

* Potassium-argon and fossil data gathered after the publication of the geologic map (Detterman, Miller, Yount, and Wilson, 1979) used as the base for this map indicate that the age of the Meshik Formation is Eocene and Oligocene (Detterman and others, 1981).

ENERGY RESOURCE SYMBOLS

■	Cretaceous coal and (or) lignite and carbonaceous shale
▒	Tertiary coal and (or) lignite and carbonaceous shale
▧	Areas of coal-bearing strata--That meet minimum resource qualifications of a minimum 35.5 cm thick, containing a minimum value of 12,000 Btu, at a maximum depth of 305 m
▨	Areas of potential hydrocarbon accumulation

GEOLOGIC MAP SYMBOLS

- Contact--Dotted where concealed
- Fault--Dashed where approximately located; dotted where concealed; queried where probable. U, upthrown side; D, downthrown side. Arrows indicate relative lateral movement
- Thrust or high-angle reverse fault--Dotted where concealed; sawteeth on upper plate
- Folds--Showing trace of axial plane; dashed where approximately located; dotted where concealed. Arrow indicates direction of plunge
  - Anticline
  - Syncline
- Volcanic crater
- ◆ Volcanic vent or cinder cone
- Hornfels
- Alteration
- Dikes and sills
- ✧ Exploratory drill hole
- Hot spring
- Native Corporation boundary

PURPOSE AND SCOPE

The purpose of this map is twofold: (1) to show areas in which coal-bearing strata are present and to outline or indicate areas considered to have potential for hydrocarbon or geothermal resources; (2) to make a few preliminary interpretations of the energy resource potential.

The geologic investigations conducted in the Chignik and Sutwik Island quadrangles were under the auspices of the Alaska Mineral Resource Assessment Program, and the data and sample collections were clearly oriented towards assessing the mineral resource potential. Modest amounts of data were obtained on the occurrence and thickness of coal beds, and a few samples were taken for maturation, organic carbon, porosity, and permeability. The data presented here can only be considered as a preliminary assessment of the energy resources.

COAL RESOURCES

The presence of coal in the Chignik area has been known for many years (Stone, 1905; Atwood, 1909, 1911; and Knappen, 1929). Generalized maps showing the occurrence of coal in this part of Alaska are by Barnes (1967), Holloway (1977), and Conwell and Triplehorn (1978). The study by Conwell and Triplehorn was prompted by the renewed interest in coal after the substantial increase in the price of oil in 1973 and contains the first modern analysis of coal in the Chignik area; that study considered only coal in the Chignik Formation (Late Cretaceous), however. By adding Tertiary coal-bearing strata, the aerial extent of these beds in the quadrangles is nearly doubled.

Coal mining in the Chignik area started in 1893 (Atwood, 1911, p. 20) when the Alaska Packers Association opened a mine on the Chignik River. An undetermined amount of coal was taken from this mine for use in the cannery. The mine was still open when visited in 1977 during the course of the present field investigation, but has not been in operation for many years. Atwood (1911) reported that tunnels were opened also in coal seams in Whalers Creek, Thompson Valley, and at the head of Hook Bay, but no evidence of these tunnels was found. Rusting equipment and remnants of the wagon road were found at the head of Hook Bay, however.

Coal, lignite, and carbonaceous shale are present at many localities in nonmarine strata of the Chignik Formation (Late Cretaceous) and Tolstoi Formation of Burk (1965) (Paleocene and early Eocene) in the Chignik and Sutwik Island quadrangles. Thin seams 1-5 cm thick (0.5 to 2 in.) of coal and lignite are also present in the Bear Lake Formation and Milky River Formation of Galloway (1974). All areas in which coal and (or) lignite and carbonaceous shale were noted in surface exposures are shown on the map; this includes areas in which observations were in close proximity to each other and the bedrock structure is such that coal is reasonably assumed to be present throughout.

The reconnaissance nature of the investigation and absence of drill-hole data prevent us from numerically estimating coal resources for the quadrangles. However, we consider that areas shown on the map by the northwest-southeast diagonal line pattern meet the minimum resource qualifications of a 35.5-cm (14-in.) thickness of coal containing a minimum value of 12,000 Btu at a maximum depth of 305 m (1,000 ft), based on the U.S. Bureau of Mines and U.S. Geological Survey coal classification system (U.S. Geological Survey, 1976; Bass and others, 1970). The cumulative area meeting these specifications is about 23,296 hectares (58,240 acres). Structural complications or the pinching out of coal seams could reduce this area substantially.

The Chignik Formation is a cyclic marine-nonmarine sequence about 420-490 m (1,375-1,600 ft) thick (Detterman, 1977; Fairchild, 1977). Coal-bearing strata are found in flood-plain and swamp deposits associated with meandering and braided stream complexes in the nonmarine parts of the cycles. Four depositional cycles are present at the type locality, but due to postdepositional erosion other areas contain fewer cycles. Two to three coal seams a few centimeters to 2 m (1 in. to 6 ft) thick occur in each cycle and locally contain bone coal and shale partings. Analyses of coal from two localities, Chignik River and Thompson Valley, by Conwell and Triplehorn (1978) indicate that the coal of the Chignik Formation is high-volatile B bituminous and has a high ash content (about 20 percent) and a value of 12,000 Btu. They determined that the ash content could be reduced to less than 10 percent by washing the coal. The sulfur content ranges between 0.55 and 2.75 percent.

The Tolstoi Formation is the only other stratigraphic unit containing coal of potential economic value. These coals are untested, but in general we believed they are similar to coal in the Chignik Formation. The coal-bearing sequences are restricted to fluvial and swamp deposits in the upper part of the formation; four to six beds, 30 to 60 cm (1 to 2 ft) thick, are generally present at most localities.

Nearly all the coal in the Chignik-Sutwik area lies within a few kilometers of tidewater; ample fresh water is available for beneficiation by washing to reduce ash content, thus increasing Btu values and making the coal more attractive for development.

There are approximately 1,045,071 t (1,152,000 short tons) of bituminous coal per 30.5 cm (1 ft) of bed thickness per 2.59 km^2 (1 sq mi). Four areas should have potential for coal: (1) Chignik River-upper Chignik Lagoon; (2) northern Chignik Lagoon-Anchorage Bay area; (3) Thompson Valley-Hook Bay area; (4) Nakalilok Bay area.

Table 1.--Estimated original resource of coal and lignite

Area	Size (km^2)	Number of beds	Thickness (m)	Inferred resource (10^6t)
1 Chignik River-upper Chignik Lagoon	23.3	2	2.0	56.4
2 Northern Chignik Lagoon-Anchorage Bay	38.8	4	1.2	62.6
3 Thompson Valley-Hook Bay	15.5	3	2.4	49.9
4 Nakalilok Bay	25.9	3	2.1	73.1
Total	---	---	---	242.0

The estimated amount of coal available can be considered at best an inferred resource. An inferred resource is one for which quantitative estimates are based on broad knowledge of the geologic character of the bed or region and for which few measurements of bed thickness are available. Very little information is available on the continuity of beds between our points of observation, and numerous faults are known to cut some of the area, which could further reduce recovery. Nonetheless, if our estimate of inferred resource is reasonable, and if we assume a 60 percent recovery factor, approximately 150 to 160 million tons of coal could be mined in the Chignik and Sutwik Island quadrangles. In much of the area the coal seams are close to the surface and suitable for strip mining, which could substantially increase the amount of recoverable coal (Averitt, 1961, p. 25). However, the coal beds dip 20°-40°, which would reduce their potential for strip mining.

OIL AND GAS RESOURCES

The Chignik and Sutwik Island quadrangles have been of considerable interest as a potential oil and gas province for many years (Atwood, 1911, p. 120-124; Knappen, 1929, p. F212-F221; Martin, 1905, p. 135-139; 1921, p. 209-213; Smith and Baker, 1924, p. D205-D211). Many lease applications were filed in the first quarter of this century after the enactment of the oil-leasing law. No wells were drilled, and all activity stopped when wells drilled on Bear Creek anticline and Pearl Creek Dome in the Kanatuk district (80 km [48 mi] north of the map area) failed to produce commercial quantities of petroleum. Interest was revived after Keller and Cass (1956) reported oil-saturated sandstone in the Chignik Formation at Chignik Lagoon. The many excellent exposures of Mesozoic and Tertiary rocks attracted geologists from numerous oil companies, particularly after Burk (1965) published the first modern geologic map of the Alaska Peninsula showing structural features.

Two wells were drilled on the Bristol Bay Lowland adjacent to Bristol Bay by the Gulf Oil Corporation, No. 1 Port Heiden and No. 1 Sandy River. A third well, Chevron-Koniag No. 1, was drilled by Chevron USA in 1981 on the Pacific side of the peninsula near Yantarni Bay.

The Port Heiden well, drilled in 1972 to a depth of 4,577.5 m (15,017 ft) (Alaska Geologic Society, 1975), penetrated 2,812 m (9,225 ft) of clastic sedimentary rocks of the Milky River and Bear Lake Formations and 1,764 m (5,787 ft) of mainly volcanic breccia, flows, and tuffs of the Meshik Formation and bottomed in quartz diorite of the Alaska-Aleutian Range batholith. No oil or gas shows were found in this well, which was plugged and abandoned.

The Sandy River well, drilled in 1963 on the Bristol Bay coastal plain to a depth of 3,983 m (13,067 ft), encountered numerous shows of both oil and gas below 3,048 m (10,000 ft) and several strong shows of methane associated with coal between 1,515 and 1,768 m (4,970 and 5,800 ft) (Alaska Geologic Society, 1975). The well is plugged and abandoned.

Data for the Chevron-Koniag No. 1 well drilled in 1981 have not been released, but, based on field evidence, the well (total depth 3,325 m (10,908 ft)) probably was drilled entirely within the Mesozoic. It started in the Upper Jurassic Naknek Formation and may possibly have reached the Upper Triassic, but more likely was drilled entirely in Jurassic rocks.

An assessment of the petroleum potential of any area requires considerable information about the lithology, structure, stratigraphy, and certain specific characteristics of the rocks relevant to the formation of hydrocarbons. Lithologic sections of all the stratigraphic units exposed in the Chignik and Sutwik Island quadrangles were presented by Detterman, Yount, and Case (1981). Some details on the lithologic characteristics and organic content of each stratigraphic unit are shown in table 2 (sheet 2). This table includes data on environment of deposition, sand-shale and clastic ratios, characteristics of potential reservoir rocks, including porosity and permeability, and a minor amount of data on organic carbon content and degree of thermal maturation. More detailed data are available in McLean (1977) for wells just beyond both north and south boundaries of the quadrangles; those wells penetrate the same stratigraphic units that are present in the map area and are in similar structural positions. Data on the Kialagvik Formation and the unnamed Upper Triassic and Lower Jurassic rocks, which are not exposed in the map area, are from fieldwork by the authors in the Ugashik and Karluk quadrangles and by L. B. Magoon (written commun., 1980).

To be considered potentially capable of producing oil and gas, source rocks must contain at least 0.5 percent organic carbon (Claypool and Reed, 1976; Tissot and Welte, 1978). In addition, they must have reached a state of thermal maturity that will give a vitrinite reflectance (R_o) of 0.5 percent and a thermal alteration index (TAI) of 2 (Tissot and Welte, 1978; Heroux and others, 1979). Using the limited data that we obtained in conjunction with data from nearby wells (McLean, 1977) and the correlation chart of Heroux, Chagnan, and Bertrand (1979, p. 2130-2131), we conclude that the Tertiary rocks are immature except for the Tolstoi Formation, which is marginally mature. The Cretaceous rocks are all mature, as are the Jurassic Naknek and Shelikof Formations. Most of these rocks contain sufficient organic carbon to be potentially productive. The Kialagvik Formation and unnamed Lower Jurassic and Upper Triassic beds are reaching supramaturity.

We were looking specifically for areas that had the greatest concentration of potential sandstone reservoir beds containing porosity; this basically restricted the search to areas of upper Tertiary clastic rocks over a structural trap. Additionally, the thick sandstone unit in the lower part of the Naknek Formation was considered to have potential even though porosity values are generally low. Organic carbon is present in most of the rocks underlying the quadrangles, mainly in the form of herbaceous and coaly material. We have little data on maturation, but that data suggest all but the youngest rocks are mature and can be considered source beds.

Late Tertiary deformation, possibly as late as Pliocene, formed the geologic structures in the Chignik and Sutwik Island quadrangles. Thus, the formation of structural traps for hydrocarbons postdates maturation of the organic carbon in the rocks.

The Chignik anticline is the main structure in the map area; it extends for about 75 km (47 mi) along the Pacific Ocean side of the peninsula. Many faults cut the anticline, and a high-angle reverse fault along the axis exposes rocks as old as Middle Jurassic (Shelikof Formation). We do not consider the Chignik anticline prospective for the following reasons: (1) potential reservoir beds are breached over the high point of the structure; (2) no information is available on the lithology of the underlying rocks, and the nearest exposures are about 100 km (62 mi) to the northeast, where they show rapid facies change; (3) several intrusive bodies are exposed along the anticline and the aeromagnetic map (Case and others, 1981a) suggests several more are in the subsurface; (4) as much as 1,000 m (3,280 ft) of volcanic rocks cap the northeast end of the structure. A detailed seismic survey across the anticline may reveal features, not apparent from our data, that would make the structure prospective.

Inasmuch as most geologic structures were formed in late Tertiary time and postdate possible generation of hydrocarbons, the main trapping mechanism will be unconformities. The two major unconformities predate both the Chignik Formation (Late Cretaceous) and the Tolstoi Formation (early Tertiary). The Chignik overlies either the Herendeen Limestone, Staniukovich, or Naknek Formations. The Tolstoi unconformably overlies either the Hoodoo, Chignik, Herendeen, Staniukovich, or Naknek Formations. Impervious shale units overlying sandstone in both the Chignik and Tolstoi Formations could form caprocks for entrapment of hydrocarbons.

On the Bristol Bay side of the peninsula, three areas totalling about 1,050 km^2 (405 mi^2) are outlined on the map. We consider these to have the greatest potential for hydrocarbon accumulations in the Chignik and Sutwik Island quadrangles. A fourth area on the Pacific side, between Yantarni and Nakalilok Bays, may possibly be prospective. An estimate of the potential volume of oil and gas in areas 1-3 is given in table 3 (sheet 2). The data for this estimate were obtained by calculating the thickness of potential sandstone reservoir beds that could be expected to be found in the subsurface, considering facies changes from the nearest outcrops. Additionally, an estimated amount of porosity, permeability, and organic carbon, along with the total area on structure, were used to make an *estimate of potential* hydrocarbons.

The nature of the kerogen composing the organic carbon in a rock unit determines the type of hydrocarbons produced (Tissot and Welte, 1978). Amorphous sapropel (Kerogen Type II) will yield mainly oil and minor gas. Kerogen Type III, consisting mainly of woody, herbaceous, and coaly material, yields mostly gas and condensate. Most of the obvious organic carbon, particularly in the Bear Lake, Tolstoi, Chignik, and Staniukovich Formations and in the lower part of the Naknek Formation, is the woody, herbaceous, and coaly type; thus these units would be expected to produce mainly gas with minor amounts of liquid hydrocarbons. The Hoodoo Formation and the upper part of the Naknek Formation, along with the Shelikof Formation and underlying units, contain considerable amorphous sapropel and are more likely to yield mainly oil.

Thin sections of the major sandstone beds were studied, including point-counting of grains, in order to determine suitable potential reservoirs. Histograms (sheet 2) for the major sandstone-bearing units show some of the more important parameters. Ternary diagrams (sheet 2) show sandstone classifications and relative percent of coarse clastic rocks (sandstone and conglomerate), fine clastic rocks (siltstone and shale), and nonclastic rocks (limestone and volcanic flows, tuffs, and breccia).

Not all the characteristics of sandstone petrography are apparent in the ternary diagrams and histograms. The almost complete absence of pore space in most outcrop samples is of prime importance. Calcite, siderite, clay minerals, and rarely quartz fill most available pore space in the sandstones of the Jurassic and Cretaceous rocks. Pressure solution and recementing by quartz is common in the Naknek Formation. Diagenesis of the pervasive volcanic detritus in the Tolstoi Formation results in clay minerals and zeolites filling most pore space. The few sections of the Bear Lake Formation studied showed moderate primary porosity. In the older rocks the porosity will be mainly secondary.

In addition to three major Quaternary volcanic centers whose extrusive deposits cover about 20 percent of the area, numerous middle and late Tertiary (Oligocene to Pliocene) volcanic and hypabyssal intrusive rocks are in the map area. Small hypabyssal plugs, some of which were probably cores of former volcanoes, intrude all exposed rock units. The aeromagnetic map (Case and others, 1981a) suggests that many more are buried beneath the surface; several probably intrude the Chignik anticline as well as some of the other anticlines. The presence of numerous exposed intrusive plugs and the presumed occurrence of many more in the subsurface substantially reduces the potential for a major petroleum province in the quadrangles. Some hydrocarbons are probably formed near the intrusives due to proximity of a high heat source.

Seismic data were not available to aid in evaluating the petroleum potential. Consequently, aeromagnetic and gravity data (Case and others, 1981a, b) and field observation of surface exposures (Dettterman and others, 1979, 1981) were used to evaluate potentially productive areas.

Area 1, in the southwest corner of the Chignik quadrangle south of Cape Seniavin, has been drilled; Gulf Oil Corporation Sandy River Federal No. 1 was drilled to a depth of 3,983 m (13,067 ft) and abandoned in 1963. Several shows of oil and gas were found below 3,048 m (10,000 ft), and methane was present between 1,515 and 1,768 m (4,970 and 5,800 ft). The methane occurred in a coaly sequence and was probably of biogenic origin. The methane came from a thick, nonmarine, coal-bearing sandstone sequence in the Bear Lake Formation. Sandstones in this interval are highly porous, ranging between 33 and 36.5 percent, and have a permeability ranging between 48 and 254 millidarcies (mD). Gas shows were concentrated between 3,100 and 3,500 m (10,170 and 11,480 ft) (Alaska Geologic Society, 1975) in sandstone of the Bear Lake Formation; three drill-stem tests recovered 120-330 m (394-1,082 ft) of slight gas-cut and saltwater-cut mud. Slight oil shows were reported (Alaska Geologic Society, 1975) below 3,560 m (11,680 ft) and continued intermittently to the total depth (3,983 m, 13,067 ft). The oil shows were mainly in the lower part of the Bear Lake Formation and continued into the underlying Tolstoi(?) Formation. Some disagreement exists on the stratigraphic terminology for the lower part of the well section. The Alaska Geologic Society (1975) placed the contact between the Bear Lake and Stepovak Formations at 3,231 m (10,600 ft); McLean (1977) placed the contact at 3,818 m (12,526 ft), based on a change in lithology and a 30° change in dip. We essentially agree with McLean, but believe the "white granite wash sandstone" reported on the well log is the Tolstoi Formation rather than the Stepovak Formation of Burk (1965).

The presence of good porosity and permeability (29.5 percent and 263 mD average in subsurface) in the Bear Lake Formation along with numerous shows of oil and gas make this area attractive for drilling. Specific recommendations cannot be made without seismic data because we do not know the size or orientation of the structure, but a general location near the coast between Cape Seniavin and Cape Kutuzof is suggested by the aeromagnetic and gravity data (Case and others, 1981a, b). This is a part of a much larger area that extends offshore. This would be a Tertiary prospect with the hydrocarbons originating in the Mesozoic. The Tertiary rocks are not buried sufficiently deep to produce oil or gas. An analog for this area would be the Cook Inlet basin where the oil was probably derived from Jurassic rocks, but it is trapped in unconformably overlying Tertiary rocks (Magoon and Claypool, 1979).

Area 2 between the Seal Islands and Black Lake also is suggested by the aeromagnetic and gravity data. The area is covered by surficial materials and lacks bedrock outcrops to indicate subsurface structure. However, considering the northeast structural trend of the Alaska Peninsula, the anticline in area 3 may extend in the subsurface to beneath area 2. A well drilled in this area should penetrate at least 3 km (1.8 mi) of Tertiary sediments and, as in area 1, would be primarily a Tertiary prospect. Any production would be from reservoirs in the Tolstoi Formation of hydrocarbons produced by the underlying Mesozoic rocks. Ideally, the thick volcanic sequence of the Meshik Formation would be thinner or missing in this area as the formation thins rapidly in a southwest direction from its type area on the upper Meshik River.

Area 3 is located on the southwest plunge of a small anticline crossing Plenty Bear Creek just south of Aniakchak Volcano. Several unconformities are present to form traps in the Mesozoic rocks as well as between the Mesozoic and Tertiary. Heat from the volcano could have generated considerable oil and gas in these rocks, but it could have taken the rocks beyond the oil generating point if the rocks were too close to the heat source. A well drilled in such rocks would produce only dry gas.

Area 4 between Yantarni and Nakalilok Bays also would have oil traps in the Mesozoic, primarily the lower Mesozoic. The Chevron-Koniag No. 1 well was drilled in this area in 1981; it started in the upper part of the Naknek Formation and possibly bottomed in Triassic rocks, but data on the well have not been released. These rocks are all mature to supramature, and good reservoir rocks are present in the lower part of the Naknek Formation. Channel sandstones and conglomerates in the deep-water Shelikof Formation and Kialagvik Formation also may be potential reservoirs, but generally they are dirty and have low porosity. Numerous small intrusive bodies, both onshore and offshore, may substantially reduce the potential for this area. This report does not include an evaluation of this area.

GEOTHERMAL RESOURCES

The Chignik and Sutwik Island quadrangles have potential for geothermal energy resources. The Aleutian volcanic arc of active, intermediate to silicic volcanoes crosses the quadrangles, and three large composite volcanoes, Mount Veniaminof, Black Peak, and Aniakchak Crater, lie entirely within the quadrangles. Two other smaller volcanoes, Kupreanof to the south and Yantarni to the north, are partly within the quadrangles. These large young caldera systems indicate a near-surface heat reservoir possibly containing as much as 256×10^{18} calories (Smith and Shaw, 1975).

In addition to the obvious large volcanic centers, numerous small, young (1.8 to 7.7 m.y., Wilson and others, 1981) intrusive stocks and plugs are present that probably still contain a large reservoir of heat even though the surface exposures are at ambient temperature. These small stocks and plugs have a characteristic aeromagnetic signature consisting of small ovoid highs. Many such highs are present on the aeromagnetic map (Case and others, 1981a) in areas where intrusive rocks are not exposed. These may represent small bodies, buried 1-2 km (0.6-1.2 mi) below the surface, that might still retain considerable heat; some still may be partly molten and, thus, represent a potential source of geothermal energy.

In general, only areas of acidic volcanism and related subvolcanic intrusive rocks are considered as promising source areas for geothermal energy, because acidic magma is believed to accumulate in large epithermal storage chambers in the upper 10 km (6 mi) of the crust. Basic magma, on the other hand, originates in the mantle or lower crust and rises through narrow pipes that do not supply a large heat source (Smith and Shaw, 1973, 1975).

Many factors affect the geothermal potential of any area, and some are poorly understood. Smith and Shaw (1975) describe some of the key criteria essential to any evaluation. Briefly, a few of the critical elements are the following: date of the youngest eruption; size and volume of the magma chamber; depth of the magma chamber; type and extent of hydrothermal circulation; character of the magma-chamber roof rock; and the rate of the supply of magma to the chamber from deep crustal sources.

The areas comprising Mount Veniaminof and Aniakchak volcanoes are considered by Smith and Shaw (1975) to have significant geothermal potential. Both are large composite stratovolcanoes that had caldera-forming eruptions 3,300 to 3,700 radiocarbon years B.P. (Miller and Smith, 1979), and both are considered active; Aniakchak erupted in 1933, and Veniaminof entered an eruptive cycle in June 1983 from a vent inside the summit caldera. Both volcanoes have similar eruptive histories, starting with leucobasalt and andesite and progressing to more silicic dacite, suggesting growth in both magma-chamber size and heat-storage capacity and a continuing supply of magma from the deep crust and (or) upper mantle.

Smith and Shaw (1975) calculated a geothermal potential of 115×10^{18} calories for the crater area of Veniaminof. Aniakchak volcano has a calculated 129×10^{18} calories of geothermal potential in the caldera area (Smith and Shaw, 1975), but is a National Monument and will not be available for development.

Black Peak is an acidic (dacite) system and has a calculated geothermal potential of 12×10^{18} calories (Smith and Shaw, 1975). The age of the youngest and (or) caldera-forming eruptions are not known, but field relations between ash and debris flows and glacial moraine suggest the caldera-forming eruption was less than 10^4-12^4 years B.P.

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1984

Interior—Geological Survey, Reston, Va.— 1984

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