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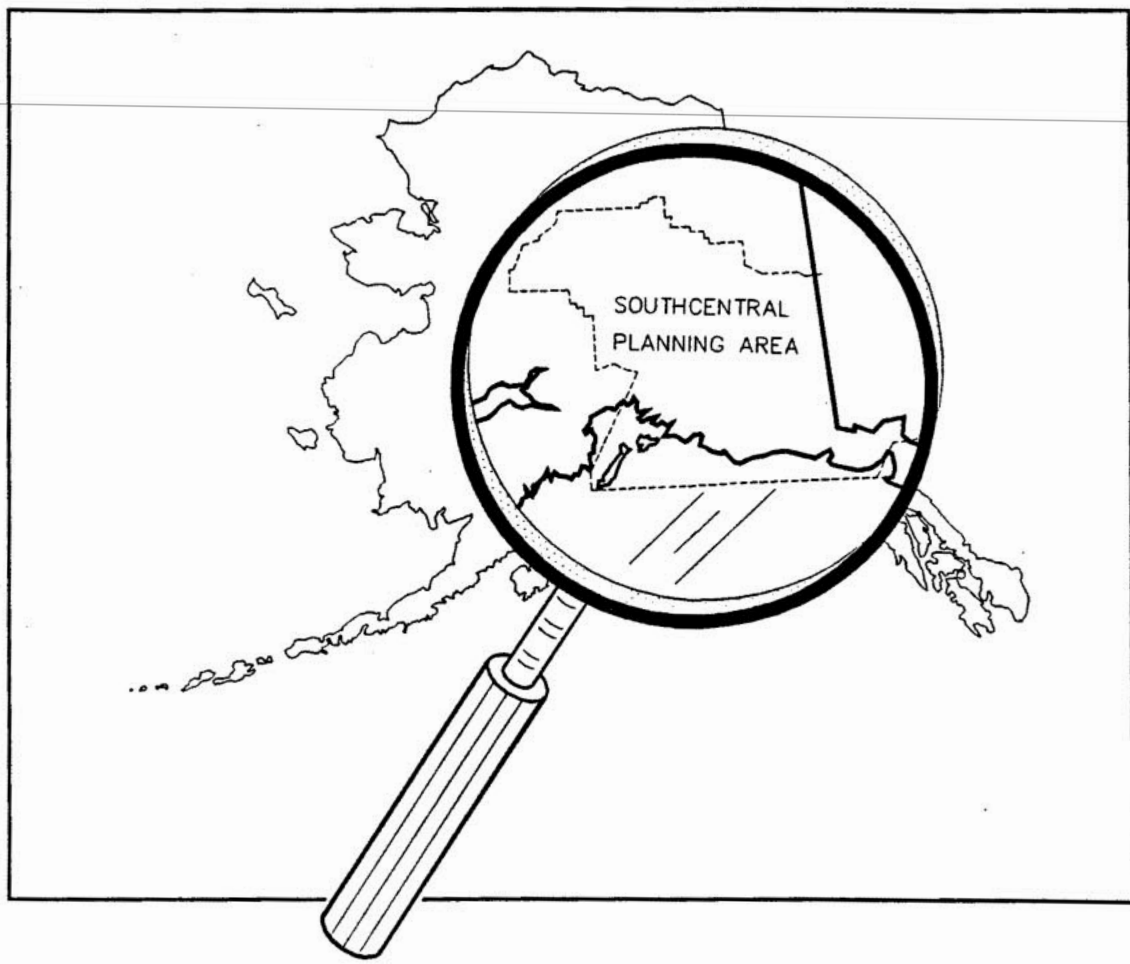
Leasable Mineral Resource Assessment of the Southcentral Planning Area, Alaska

William R. Diel



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Author

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Leasable Mineral Resource Assessment of the Southcentral Planning Area, Alaska

SUMMARY

This leasable mineral resource assessment was prepared in conjunction with the land-use planning effort undertaken by BLM in the development of a Resource Management Plan (RMP) for the Southcentral Planning Area (SPA).

Three basins within the SPA have High potential for the accumulation of oil and gas. They are the Gulf of Alaska Onshore basin, the Copper River basin, and the Susitna basin. The remaining acreage has Low potential for this resource.

Coal occurs in widely scattered areas of the SPA. Eleven areas are identified as having High potential for coal resources. The remainder of the Southcentral Planning Area has Low potential for this resource.

The distribution and extent of potential geothermal resources within the Southcentral Planning Area is centered around the Mt. Wrangell volcanic pile. This area has High potential as a geothermal resource. The remainder of the SPA has No potential.

Solid leasable mineral potential within the SPA was not determined (ND) due to the lack of useful data in the literature.

1. Introduction

The assessment of mineral resources is an important aspect of the Bureau of Land Management's (BLM) land-use decision process. The Bureau's policy regarding multiple use management of public lands requires "an understanding of the potential occurrence and distribution of mineral resources." This is accomplished by a comprehensive mineral investigation of the public lands in question.

This report presents an evaluation of the leasable mineral resource potential of the Southcentral Planning Area (SPA). Conclusions drawn

The report is based on a review of available published literature on the geology, structure, economic geology, and mineral occurrences of the planning area. The principle sources of data are publications by the Alaska Division of Geological and Geophysical Surveys, U.S. Geological Survey, U.S. Bureau of Mines, and the American Association of Petroleum Geologists.

Appendix A and B describe BLM's mineral potential classification system and refer to the potential for the presence of one or more leasable mineral resources. <u>It does not, however, imply that the potential concentration of these resources can be extracted at a profit.</u>

2. Location and Physiography

The Southcentral Planning Area consists of about 30 million acres or about 47,000 square miles *(Figure 1)*. It extends roughly from the crest of the Alaska Range, south to Montague Island in Prince William Sound, and from the U.S.-Canada border, west to the Parks Highway.

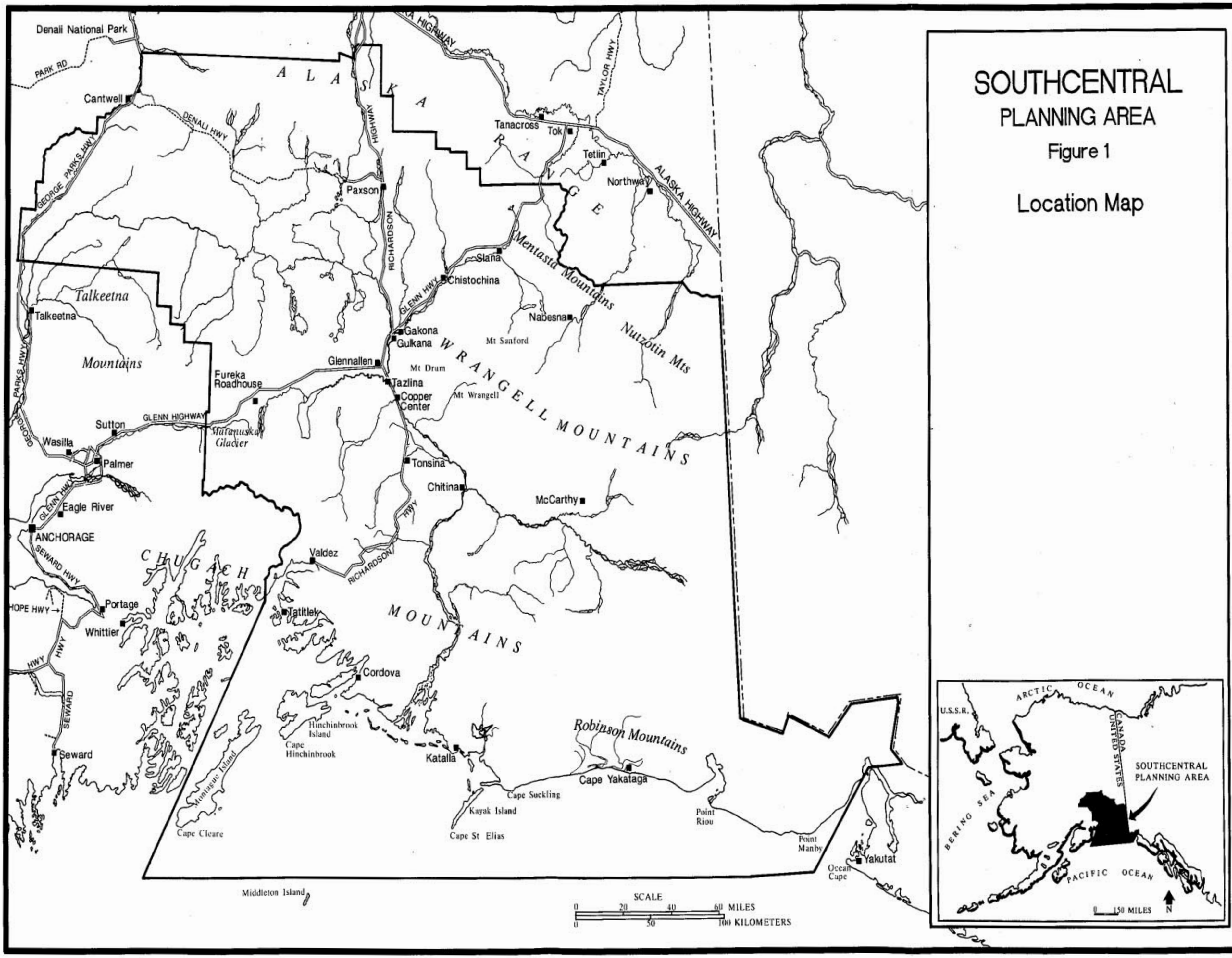
The SPA lies entirely within the Pacific Mountain System, an arcuate belt of high mountains that borders the Pacific Ocean (Wahrhaftig, 1965). The system generally consists of two ranges of mountains with an intervening belt of lowlands. Relief in the SPA is extreme, ranging from sea level in the plains and lowlands of the Gulf of Alaska coast to over 13,000 feet in the high, rugged peaks of the Alaska Range *(Figure 2)*.

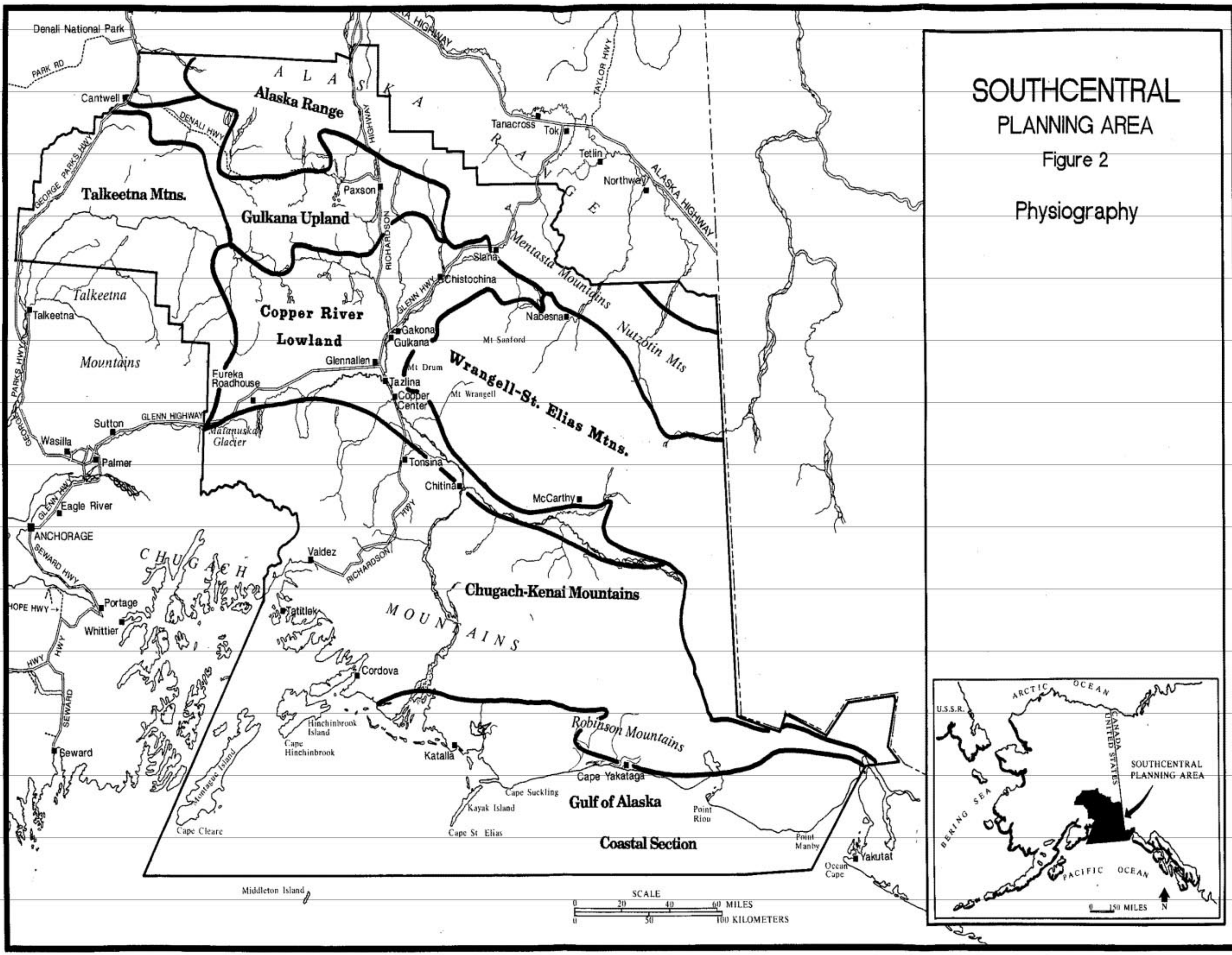
3. Tectonic Development

Geologic investigations over the last decade show that Alaska is made up of about fifty major crustal fragments referred to as terranes (Jones and others, 1983). About 200 million years ago the first of these terranes, the Yukon-Tanana terrane, collided with the northwestern-most margin of the North American craton. By late Mesozoic time (about 70 million years ago) most of these colossal crustal blocks, which represent diverse geologic environments, had assembled in Alaska *(Figure 3)*.

A collage of terranes, decreasing in age southward, occupy south-central Alaska. *Figure 4* represents a simplified tectonostratigraphic terrane map with respect to the Southcentral Planning area.

The highly deformed and thrust faulted Cretaceous and Jurassic


SOUTHCENTRAL
PLANNING AREA
Figure 1
Location Map
Denali National Park
PARK RD
Cantwell
DENALI HWY
GEORGE PARKS HWY
ALASKA RANGE
ALASKA HIGHWAY
TAYLOR HWY
Tanacross
Tok
Tetlin
Northway
Paxson
RICHARDSON HIGHWAY
Slana
Mentasta Mountains
Chistochina
GLENN HWY
Talkeetna
Talkeetna Mountains
Nabesna
Gakona
Gulkana
Mt Sanford
Nutzotin Mts
Glennallen
Mt Drum
WRANGELL MOUNTAINS
Eureka Roadhouse
Tazlina
Copper Center
Mt Wrangell
Sutton
GLENN HIGHWAY
Matanuska Glacier
Wasilla
Palmer
Tonsina
Chitina
McCarthy
Eagle River
ANCHORAGE
SEWARD HWY
CHUGACH MOUNTAINS
Valdez
RICHARDSON HWY
HOPE HWY
Portage
Whittier
Tatitlek
Cordova
Hinchinbrook Island
Cape Hinchinbrook
Katalla
Robinson Mountains
Cape Yakataga
Cape Suckling
Kayak Island
Cape St Elias
Point Riou
Point Manby
Yakutat
Ocean Cape
Seward
Montague Island
Cape Cleare
Middleton Island
SCALE
0 20 40 60 MILES
0 50 100 KILOMETERS
ARCTIC OCEAN
U.S.S.R.
CANADA
UNITED STATES
BERING SEA
SOUTHCENTRAL PLANNING AREA
PACIFIC OCEAN
0 150 MILES
N



Simplified physiography of the Southcentral Planning Area.
(after Wahrhaftig, 1965)

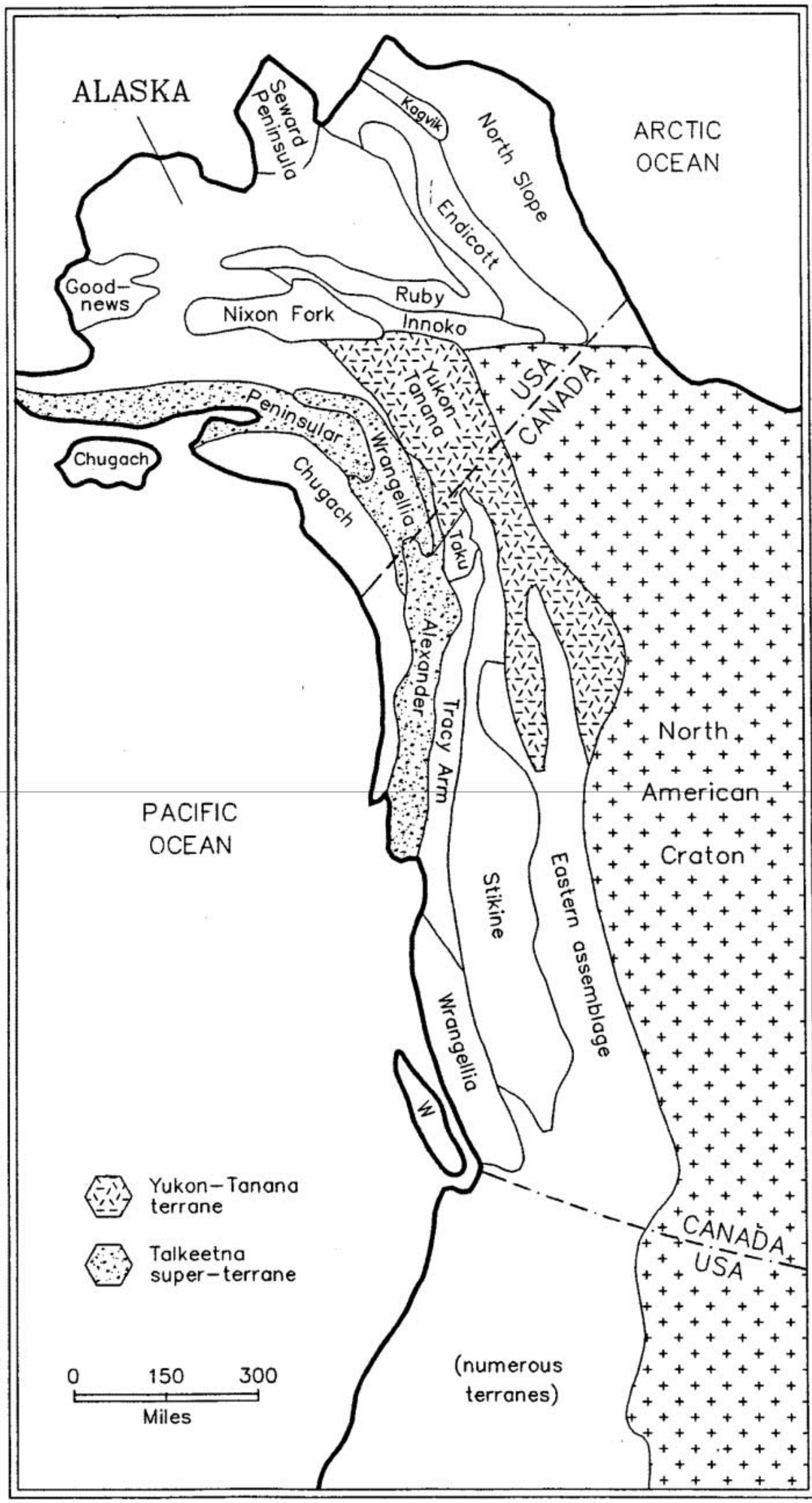
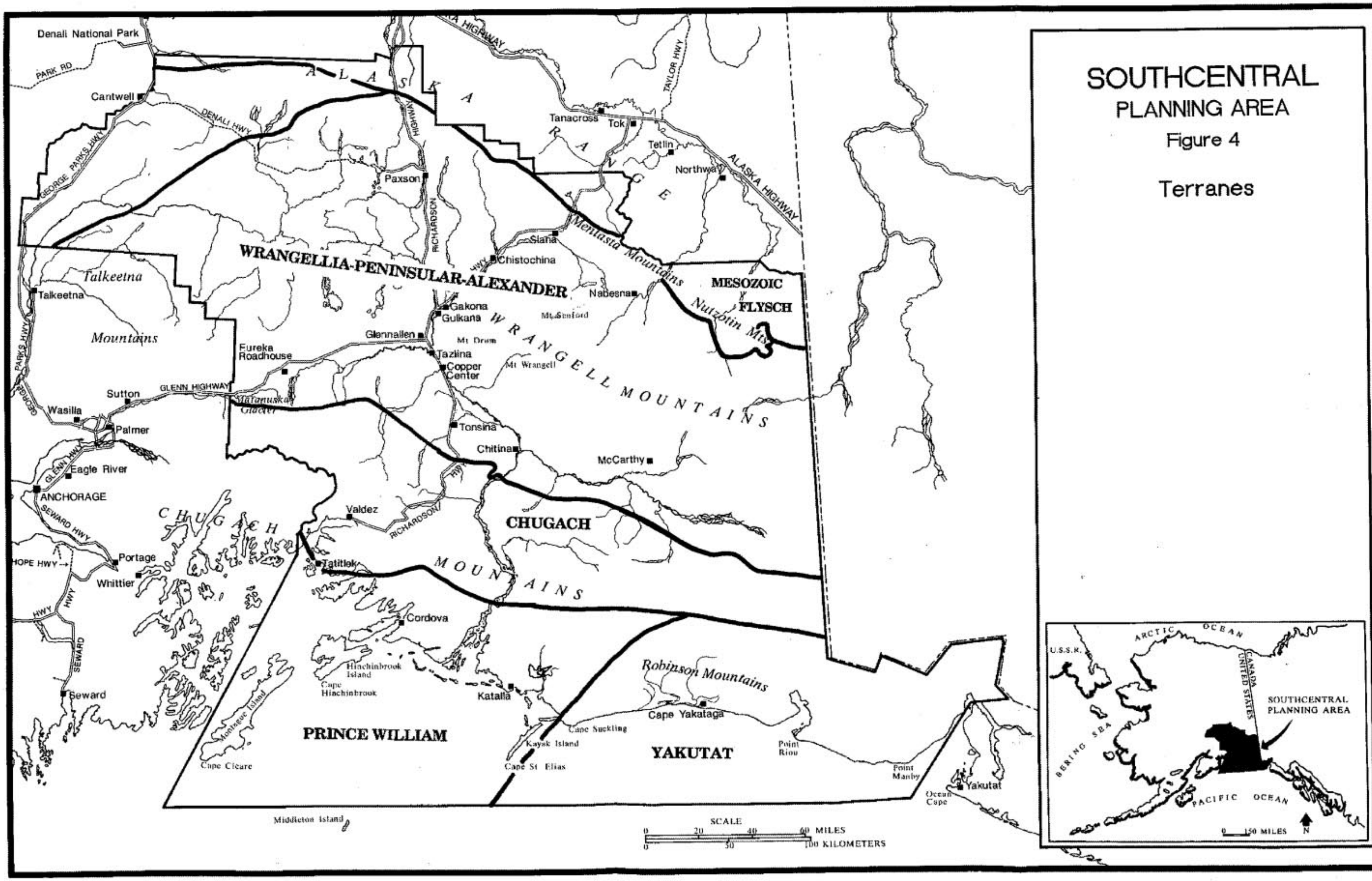


Figure 3. Generalized distribution of selected terranes throughout the cordillera of western North America.
(after Jones and others, 1983; Coney and others, 1980)



Simplified tectonostratigraphic terranes within the Southcentral Planning Area.
(after Stanley and others, 1990)

flysch terrane, located near the northern border of the SPA, was deposited between about 100 to 160 million years ago in the narrowing oceanic basin between the Talkeetna superterrane and ancestral Alaska (Stanley and others, 1990).

The Talkeetna superterrane formed through the amalgamation of the Wrangellia, Peninsular, and Alexander terranes prior to its docking with Alaska. Wrangellia consists primarily of an upper Paleozoic island-arc sequence of volcanic and sedimentary rocks and a sequence of rift basalts of Upper Triassic age. The Peninsular terrane, also interpreted to have formed in an island-arc setting, consists mainly of Jurassic sedimentary, volcanic, and granitic rocks.

The Wrangellia and Peninsular terranes are adjoined on the south by the Alexander terrane, composed of upper Precambrian to Triassic metabasalts, limestones, schist and gneiss (Stanley and others, 1990; Wilson and others, 1985; Nokleberg and others, 1985).

The Chugach terrane, bounded on the north by the Border Ranges fault system and on the south by the Contact/Chugach-St. Elias fault systems, consists of two metamorphic rock units, the McHugh Complex and the Valdez Group (Plafker and others, 1977; Clark, 1972, 1973). The McHugh Complex, of Late Paleozoic to Middle Cretaceous age, is a landward melange composed primarily of chaotically-mixed, mafic meta-volcanics and metaclasitc rocks (Clark, 1973). The Valdez Group is a highly-deformed and widely-distributed flysch sequence that accreted to southern Alaska in Late Cretaceous or early Tertiary time. It consists of interbedded graywacke, siltstone, and argillite and minor, pebble conglomerate. Some areas have retained sedimentary features characteristic of turbidites (Winkler and others, 1981; Clark, 1972).

The last allocthonous terrane to arrive in southern Alaska, the Yakutat block, is bounded by the Chugach-St. Elias thrust- fault system and the Fairweather fault. It is currently colliding with and accreting to Alaska (Bruns, 1983a).

4. Mineral Resources

A. OIL AND GAS

Ehm (1983) delineates three petroleum basins that fall either partially or entirely within the SPA (*Plate I*). These basins, the Gulf of Alaska, Copper River, and Susitna, are considered prospectively valuable for oil and gas resources. The analysis of hydrocarbon-resource occurrence within the SPA is, therefore, focused in and around these basinal boundaries.

The three basinal areas outlined in Plate 1 are classified as having HIGH potential (H/D) for the accumulation of oil and gas resources (*see Appendix A and B* for BLM's mineral potential classification system). Available data provides abundant direct evidence to support the existence of these mineral resources. The remainder of the SPA is classified as having LOW potential (L/A) for oil and gas resources.

Gulf of Alaska Basin

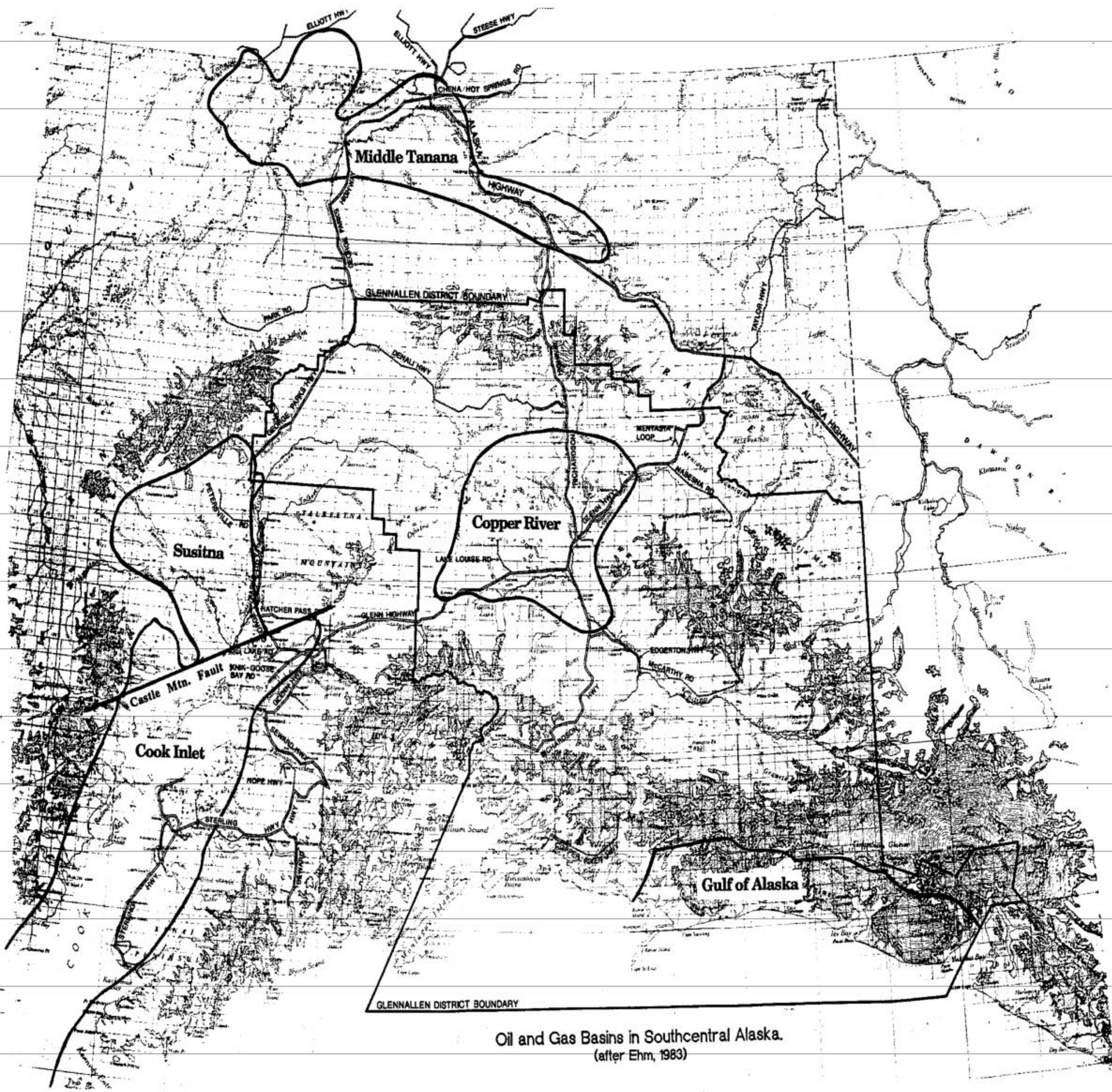
The onshore Gulf of Alaska basin, also referred to as the Gulf of Alaska Tertiary basin or province, is a lowland and foothills belt about 300 miles long and up to 40 miles wide (*Figure 5*). The onshore province lies seaward of the Chugach-Saint Elias and Fairweather faults and is bordered by the Ragged Mountain fault in the west and by Cross Sound in the east.

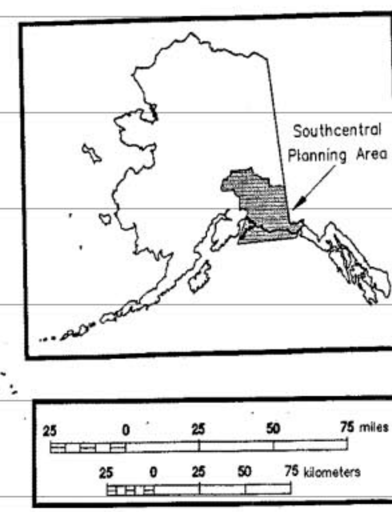
This distinct physiographic and geologic province is underlain by a thick sequence (over 9 miles) of continental and marine sedimentary rocks that decrease in age seaward (Paleocene through Holocene) (Bayer and others, 1977; Bruns and Plafker, 1982). The Tertiary sequence is broadly divisible into two stratigraphic units: (1) a thick lower unit of intensely deformed, well indurated rocks of Paleocene to Eocene age; (2) a less deformed and indurated upper unit of Oligocene to Pliocene age which contains most of the known indications of oil and gas in the province.

The Gulf of Alaska onshore province has numerous oil and gas seeps and anticlinal traps, good organic-carbon content in potential source rocks, and at least some sections with potential reservoir rocks (Bruns, 1988). The absence of successful, large-scale oil and gas discoveries are related primarily to the young age and complexity of the structures, the poor potential of a thick, late Cenozoic covering sequence, and a lack of thermal maturity, as well as reservoir rocks, in

SOUTHCENTRAL
PLANNING AREA
Figure 5

Oil and Gas Basins





Oil and Gas Basins in Southcentral Alaska.
(after Ehm, 1983)

the early Tertiary sections tested by drilling (Bruns, 1988).

Bordering the Tertiary province to the north are Mesozoic-age and older, highly deformed, locally metamorphosed and intruded sedimentary and volcanic rocks of the Chugach-St. Elias Mountains (Plafker, 1971). Pre-Tertiary age rocks, such as these, and onshore Tertiary rocks, of the Orca Group, are considered to have no potential for petroleum resources within this area (Bruns, 1988; Bruns and Plafker, 1982).

Tectonic Setting

The Yakutat terrane has characteristics favorable for the generation and accumulation of hydrocarbon resources. This terrane, currently moving with the Pacific plate, is colliding with and subducting beneath southern Alaska (Bruns, 1988).

The origin of the Yakutat terrane, relative to it's present position, is an important factor in determining the timing of source rock maturation. Maturation of Paleogene source rock within the terrane may be dependant on the timing of the uplift and erosion of the Chugach and Saint Elias mountains and the subsequent deposition of the overlying Yakataga Formation. The earlier the collision, the more time the potential source rocks would have had to generate hydrocarbon (Bruns, 1988).

Stratigraphy

Figure 6 shows a stratigraphic correlation for the Yakutat terrane from the Katalla district in the west to Lituya Bay in the east.

The Gulf of Alaska Tertiary province can be divided into three major subdivisions that correspond to major tectonic and depositional changes since early Tertiary time (Plafker, 1971; Bayer and others, 1977; Bruns and Plafker, 1982; Bruns, 1988). The major subdivisions are:

(1) a lower Tertiary sequence (Paleocene through lower Oligocene) of hard, dense, and intensely deformed and faulted rocks. It is composed of the Orca Group and the Stillwater, lower Tokun, and Kulthieth Formations. The Orca Group is a flysch-like sequence of turbidites and interbedded pillow basalts that probably represents deep-sea fan deposits. Continental to shallow marine coal-bearing clastic rocks of the Stillwater, lower Tokun, and Kulthieth Formations,

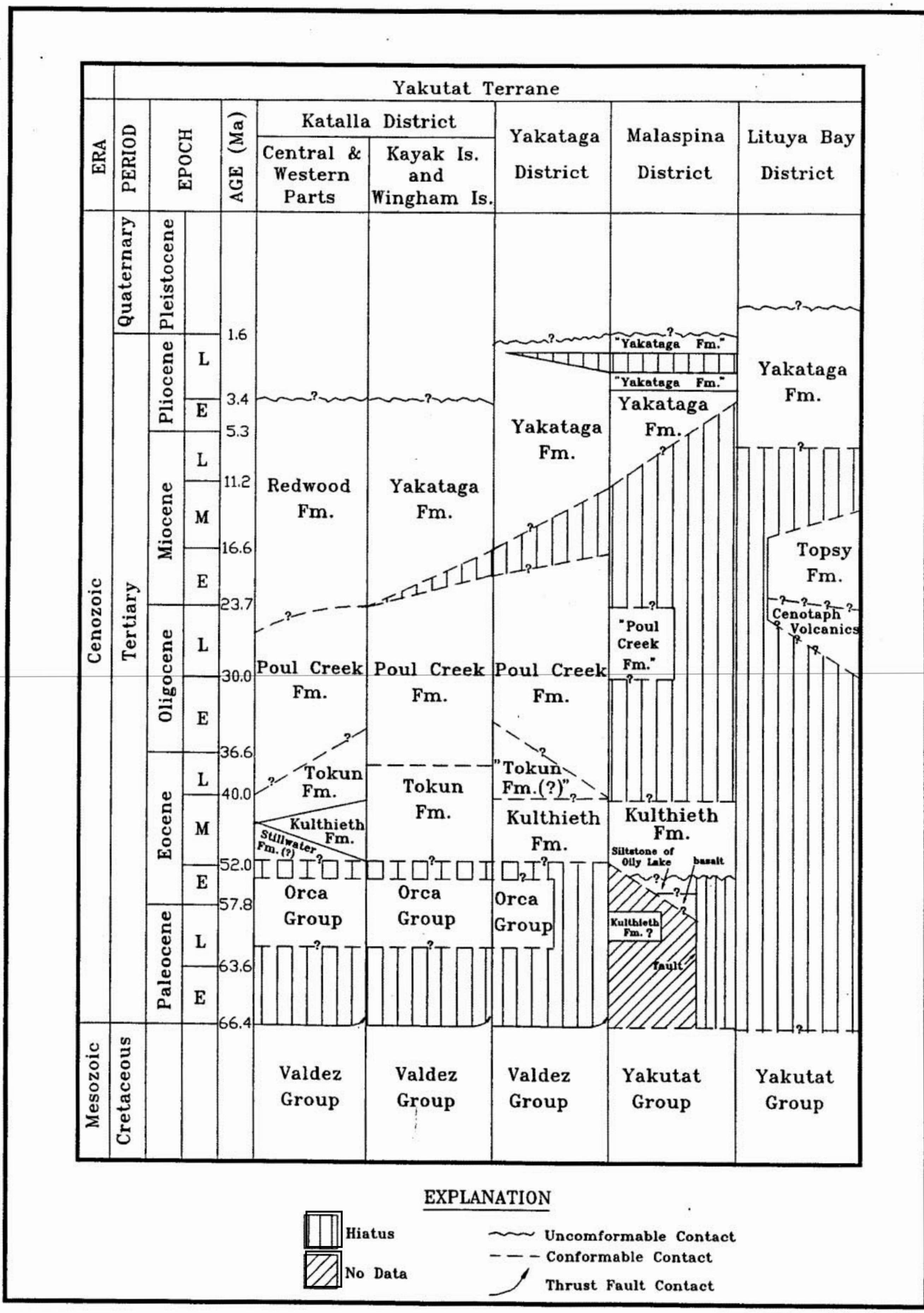


Figure 6. Yakutat terrane stratigraphic correlation chart. (after Brunes, 1988)

overlie the Orca Group In outcrop, the sequence totals about 22,000 feet in the Katalla district, but appears to thin toward Yakutat Bay. Sandstones in the Kulthieth Formation are potential reservoir rocks for oil and gas (Bird and Magoon, 1988).

(2) a middle Tertiary sequence (middle Oligocene through lower Miocene) of richly organic mudstone and siltstone. It unconformably overlies the lower Tertiary strata. This sequence consists of up to 6,000 feet of the Poul Creek Formation (including the Katalla Formation of Miller, 1975), and up to 2,500 feet of Cenotaph Volcanics and the Topsy Formation. In the central part of the Gulf of Alaska Tertiary province, the middle Tertiary sequence contains many petroliferous beds as well as seeps of oil and gas. Thickness of the middle Tertiary sequence in outcrop varies abruptly within short distances. It ranges from a few hundred feet in the Malaspina district to about 9,000 feet in the Katalla district. Marine shales of the Poul Creek Formation are potential source rocks for oil and gas (Bird and Magoon, 1988).

(3) a Miocene through Holocene sequence of about 3,700 feet of nonglacial clastic sediments (conglomerate and sandstone) of the Redwood Formation and up to 18,000 feet of interbedded siltstone, mudstone, sandstone, and conglomeritic sandy mudstone of the Yakataga Formations. These strata are interpreted as marine diamictite with abundant glacial detritus deposited close to tide water by ice rafting. Sandstones in the Yakataga Formation are potential reservoir rocks for oil and gas (Bird and Magoon, 1988).

Geologic History

The geologic history of the Gulf of Alaska is summarized from Bruns and Plafker (1982).

The southern margin of Alaska formed about mid-Cretaceous time, through the accretion of several northward-moving microplates against Precambrian and Paleozoic rocks of Alaska. Underthrusting of the Pacific oceanic crust beneath the continental margin formed a volcanic arc during the late Cretaceous. The Chugach terrane, a volcanogenic flysch and melange sequence, accreted along the continental margin in a continuous belt up to 60 miles wide. A subparallel volcanoplutonic arc developed north of this accretionary belt on continental crust. Subsequent shelf sediments were deposited in an arc-trench gap basin.

During early Tertiary time, a change in plate motions initiated northwestward movement in the Pacific oceanic crust relative to the continental margin of Alaska. Late Paleocene and early Eocene(?) age rocks (Orca Group and related rocks) accreted along the western part of the area as a result of these plate movements.

The retraction of shallow seas at the continental margin during middle to late Eocene time brought about development of a thick coal-bearing lagoon, barrier beach, and delta complex. Bedded rock units include the Stillwater, Kulthieth, and Tokun Formations. Erosion of the now uplifted Cretaceous to early Tertiary accretionary sequences and the granitic plutons emplaced in them supplied sediment for this complex.

During Oligocene and early Miocene time predominantly shaly sediments of the Poul Creek and Cenotaph Formations were laid down in a transgressive environment.

The Chugach-St. Elias range in the northern Gulf of Alaska developed as a result of collision and underthrusting of the Yakutat block, an allochthonous terrane or microplate attached to the Pacific plate (Lull and Plafker, 1985).

A great thickness of clastic sediment comprising the Yakataga, Redwood, and Topsy Formations, and including glacially-derived material, was deposited in a predominantly shallow shelf environment from the middle Miocene to the present (Armentrout, and others, 1979).

Structure

Deformation throughout the Gulf of Alaska onshore basin took place with varying degrees of intensity during the Cenozoic era. The fold-fault pattern and stratigraphy suggest deformation occurred primarily during two mountain building periods, culminating in early and late Cenozoic time.

Observed structures along the Yakataga fold and thrust belt, extending from Icy Bay to Kayak Ialand, show uplift and overthrusting of older, landward formations over younger, seaward formations. Displacement in this region occurs along northward dipping thrust faults where the magnitude of fault displacement and intensity of folding increase from south to north.

The coastal area on the south is characterized by broad synclines and narrow, tightly compressed, asymmetrical, thrust-faulted anticlines.

Structures in the north become more intensely folded and faulted and are of smaller, but nearly equal, amplitude (Bruns, 1988).

In the structurally complex Katalla area, folds are mostly asymmetric, tightly compressed and of small amplitude.

Petroleum Exploration and Development

The discovery of oil and gas seeps east of Katalla in 1896 first directed attention to the petroleum potential of the onshore Gulf of Alaska Tertiary Province. From 1901 to 1933, a total of 44 shallow wells were drilled in the Katalla area; 28 wells at the Katalla field and 16 wells at nearby locations. Most wells had oil shows, some had gas shows, and 18 produced oil commercially (about 154,000 barrels) from fracture porosity in sandstone and siltstone of the Poul Creek Formation at depths ranging from 360 to 1,750 feet.

The Katalla field became the only commercially productive area in the Gulf of Alaska Tertiary province. *Table 1* lists the hydrocarbon production and value by year from the Katalla field. There are no records of gas production from this period. Operation of a small refinery at the field began in 1911, however, production from the Katalla field ended when the refinery burned down in 1933 (Miller and others, 1959; Blasko, 1976; Bruns and Plafker, 1982).

Records show that a test well drilled between 1926-1927 in the Yakataga district had shows of oil and gas.

Exploration for onshore oil and gas deposits within the province continued from 1954 to 1963 when an additional 25 wells and 5 core holes were drilled *(Tables 2a, 2b, 2c)*. Although all were abandoned, records indicate shows of oil and/or gas in nine of the wells (Plafker, 1971). No commercial hydrocarbon field has been discovered in the basin to date.

Source and Reservoir Rocks

The Poul Creek, Stillwater, Kulthieth, and Tokun Formations have favorable hydrocarbon source rock characteristics. Organic matter in these formations is mostly herbaceous with smaller amounts of woody and amorphous kerogen capable of generating both liquid hydrocarbons and gas. The total organic-carbon content ranges from 0.42 to 1.87 percent. (Bruns, 1988).

Year	Oil (bbl)	Value	Year	Oil (bbl)	Value
1904	500	$1,000	1920	10,746	$53,730
1905	–	–	1921	10,280	51,400
1906	–	–	1922	10,047	30,000
1907	1,500	3,000	1923	10,653	26,633
1908	500	1,000	1924	7,299	36,500
1909	–	–	1925	7,963	34,000
1910	500	1,000	1926	7,600	38,000
1911	500	1,000	1927	6,245	32,600
1912	4,057	20,285	1928	5,470	35,000
1913	6,000	30,000	1929	5,226	36,000
1914	6,000	30,000	1930	4,611	27,500
1915	6,500	32,500	1931	4,290	23,000
1916	4,555	22,775	1932	3,410	18,200
1917	7,300	36,500	1933	3,774	20,200
1918	7,543	37,715	Total	153,922	736,501
1919	10,853	56,963			

Table 1. Hydrocarbon production from the Katalla field. (after Blasko, 1976)

Well	Company	Location	Spudded	Total Depth (ft.)	Status
# 110	Alaska Petroleum and Coal	NE 1/4 sec 1, T20S, R5E	1903	1,701	Plugged and abandoned
A	Alaska Steam Coal and Pet	SW 1/4 NE 1/4 sec 36, T19S, R5E	1901	270	Do.
No. 1	Do.	NE 1/4 sec 36, T19S, R5E	1902	550	Oil well discovery (abandoned 1933)
No. 2	Do.	Do.	1903	1,000	Oil well (abandoned, 1933)
No. 3	Do.	Do.	1904	900	Plugged and abandoned
B	Do.	Do.	1904	unrecorded	Do.
C	Do.	Do.	1904	unrecorded	Do.
No. 4	Amalgamated Development Co.	Do.	1912	690	Oil well (abandoned, 1933)
No. 5	Do.	Do.	1912	1,000	Do.
No. 6	Do.	Do.	1912	100	Plugged and abandoned
No. 7	Do.	NE 1/4 sec 36, T19S, R5E	1912	645	Oil well (abandoned, 1933)
No. 8	Do.	Do.	1913	1,100	Oil well (abandoned, 1918)
No. 16	Chilkat Oil Co.	Sec 36, T19S, R5E	1920	740	Oil well (abandoned, 1933)
No. 17	Do.	Do.	1920	903	Do.
No. 18	Do.	Do.	1921	1,000	Do.
No. 19	Do.	Do.	1922	1,465	Do.
No. 20	Do.	Do.	1922	1,202	Do.
No. 21	Do.	Do.	1922	1,750	Do.
No. 22	Do.	Do.	1923	1,280	Do.
No. 23	Do.	Do.	1925	1,160	Plugged and abandoned
No. 24	Do.	Do.	1925	2,350	Do.
No. 25	Do.	Do.	1931	2,005	Do.
No. 9	Do.	Do.	1917	1,810	Do.
109	St. Elias Oil Co.	NW 1/4 sec 31, T19S, R6E	1917	1,613	Do.
No. 11	Do.	Sec. 36, T19S, R5E	1918	1,130	Oil well (abandoned, 1933)
No. 12	Do.	Do.	1918	903	Do.
No. 13	Do.	Do.	1918	900	Do.
No. 14	Do.	Do.	1919	2,265	Plugged and abandoned

Table 2a. Onshore Gulf of Alaska wells. (after Blasko, 1976)

Well	Company	Location	Spudded	Total Depth (ft)	Status
115	Alaska Coal Co.	Sec 11, T19S, R4E	1911	1,024	Plugged and abandoned
116	Do.	Do.	1911	272	Do.
No. 3	Do.	Do.	1911	250	Do.
118	Alaska Gulf Syndicate	NW 1/4 sec 4, T19S, R8E	1930	190	Do.
111	Alaska Petroleum and Coal	SE 1/4 sec 22, T19S, R5E	1903	280	Do.
112	Do.	Do.	1904	1,500	Do.
113	Do.	Do.	1905	1,500	Do.
114	Do.	SE 1/4 sec 26, T19S, R5E	1907	1,600	Do.
No. 103	Alaska Steam Coal and Pet	Sec 30, T19S, R7E	1904	400	Do.
No. 104	Do.	Do.	1904	650	Do.
No. 105	Do.	Do.	1904	800	Do.
No. 108	Do.	Do.	1904	1,000	Do.
106	Clarence Cunningham	Sec 5, T20S, R6E	1904	unrecorded	Do.
107	Do.	Do.	1904	903	Do.
101	Rathbun	NW 1/4 sec 15, T18S, R6E	1905	1,000	Do.
No. 102	Unknown	Sec 16, T19S, R7E	1903	1,465	Do.
Duktoth Rv Unit No. 1	Atlantic Richfield Co.	SE 1/4 sec 24, T20S, R15E	1961	10,390	Do.
White Rv No 1	Do.	NW 1/4 SW 1/4 sec 10, T21S, R18E	1961	7,892	Do.
Bering Rv Unit No. 1	Do.	SW 1/4 sec 32, T18S, R7E	1961	6,175	Do.
Bering Rv Unit No. 2	Do.	Sw 1/4 sec 22, T19S R7E	1961	6,019	Do.
White Rv Unit No. 1	Do.	NW 1/4 NE 1/4 sec 27, T21S, R19E	1962	12,417	Do.
White Rv Unit No. 3	British Petroleum Exploration Co. (ALASKA) Inc.	SE 1/4 sec 29, T21S, R19E	1963	6,984	Do.
Yakutat No. 1	Colorado Oil and Gas Corp	SW1/4 sec 33, T27S, R34E	1957	9,314	Do.
Yakutat No. 2	Do.	SW 1/4 sec 2, T28S, R34E	1957	11,765	Do.
Yakutat No. 3	Do.	NE 1/4 sec 3, T28S, R34E	1958	10,848	Do.
Dangerous Rv. No. 1	Do.	NE 1/4 sec 17, T29S, R37E	1960	8,634	Do.
Yakutat Core Hole 1	Do.	NE 1/4 sec 20, T27S, R35E	1961	3,230	Do.
Yakutat Core Hole 2	Do.	SE 1/4 sec 28, T29S, R36E	1961	5,690	Do.

Table 2b. Onshore Gulf of Alaska wells. (after Blasko, 1976)

Well	Company	Location	Spudded	Total Depth (ft.)	Status
Yakutat Core Hole 3	Colorado Oil and Gas Corp.	SW 1/4 sec 6, T31S, R39E	1961	5,484	Plugged and abandoned
Yakutat Core Hole 4	Do.	SE 1/4 sec 27, T32S, R41E	1961	5,326	Do.
Malaspina Unit No. 1	Do.	Sec 31, T24S, R32E	1962	1,802	Do.
Malaspina Unit No. 1A	Do.	NW 1/4 sec 31, T24S, R32E	1962	13,823	Do.
Sullivan No. 1	General Petroleum Co.	SE 1/4 sec 4, T22S, R20E	1926	2,005	Do.
Katalla State No. 1	Panoil-Arabian Shield	NE 1/4 sec 33, T19S, R5E	1969	421	Do.
Sullivan Strat No. 1	Phillips Petroleum Co.	NW 1/4 NE 1/4 sec 20, T22S, R22E	1954	4,837	Do.
Sullivan No. 1	Do.	S 1/2 NW 1/4 sec 10, T22S, R21E	1954	10,013	Do.
Sullivan No. 2	Do.	NE 1/4 sec 9, T22S, R21E	1956	12,054	Do.
Kaliakh Rv Unit No. 1	Richfield Oil Corp.	SW 1/4 sec 34, T20S, R14E	1959	14,699	Do.
Kaliakh Rv Unit No 2	Do.	NE 1/4 sec 28, T20S, R14E	1960	9,575	Do.
Kaliakh Rv Unit 2 (RD)	Do.	NE 1/4 sec 28, T20S, R14E	1960	12,135	Do.
Chaix Hills Unit No. 1	Standard Oil of California	SW corner sec 4, T22S, R25E	1961	10,017	Do.
Chaix Hills Unit No. 1A	Do.	SW corner sec 4, T22S, R25E	1961	10,121	Do.
Riou Bay No. 1	Do.	NE corner sec 26, T23S, R23E	1962	14,107	Do.

Table 2c. Onshore Gulf of Alaska wells. (after Blasko, 1976)

Potential reservoir rocks are found in the Paleogene Kulthieth, Tokun, and Poul Creek Formations and in the Yakataga and Redwood Formations. Paleogene sandstones were strongly deformed during burial and diagenesis resulting in further reduction of porosity and permeability and a reduction in pore space. The approximate percentage of sandstone, thickness, porosity, and permeability for these major onshore units are as follows (Winkler and others, 1976; Lyle and Palmer, 1976):

Formation	Percent Sandstone	Thickness (m)	Porosity (%)	Permeability (md)
Kulthieth, Tokun	60	15-600	1.8-22.7	0-43
Poul Creek	1-30	15-350	2.2-19.2	0-12
Yakataga, Redwood	9-53	15-490	1.2-32.2	0-597

Thermal Maturation and Traps

Thermal maturity indicators show that onshore Eocene rocks are immature to marginally mature from Icy Bay to Yakutat Bay and mature or overmature west of Icy Bay.

Large anticlinal structures of the fold and thrust belt of the western Yakutat terrane are considered primary hydrocarbon traps within the province. In addition, stratigraphic and fault traps, which may exist within the fold belt, are potential trapping mechanisms which can be filled by hydrocarbons (Bruns, 1988).

Identified Plays - USGS

The USGS has identified five hydrocarbon plays (three lying partially or entirely within the boundary of the SPA) within the Gulf of Alaska onshore province *(Figure 7)* (Bruns, 1988).

(1) Yagataga Fold and Thrust Belt: Extends from the Ragged Mountain fault-Kayak zone to Icy Bay.

(2) Yakutat Foreland Play: Lies between Icy Bay and Cape Fairweather.

(3) Middleton Island Play: Includes Middleton Island and the

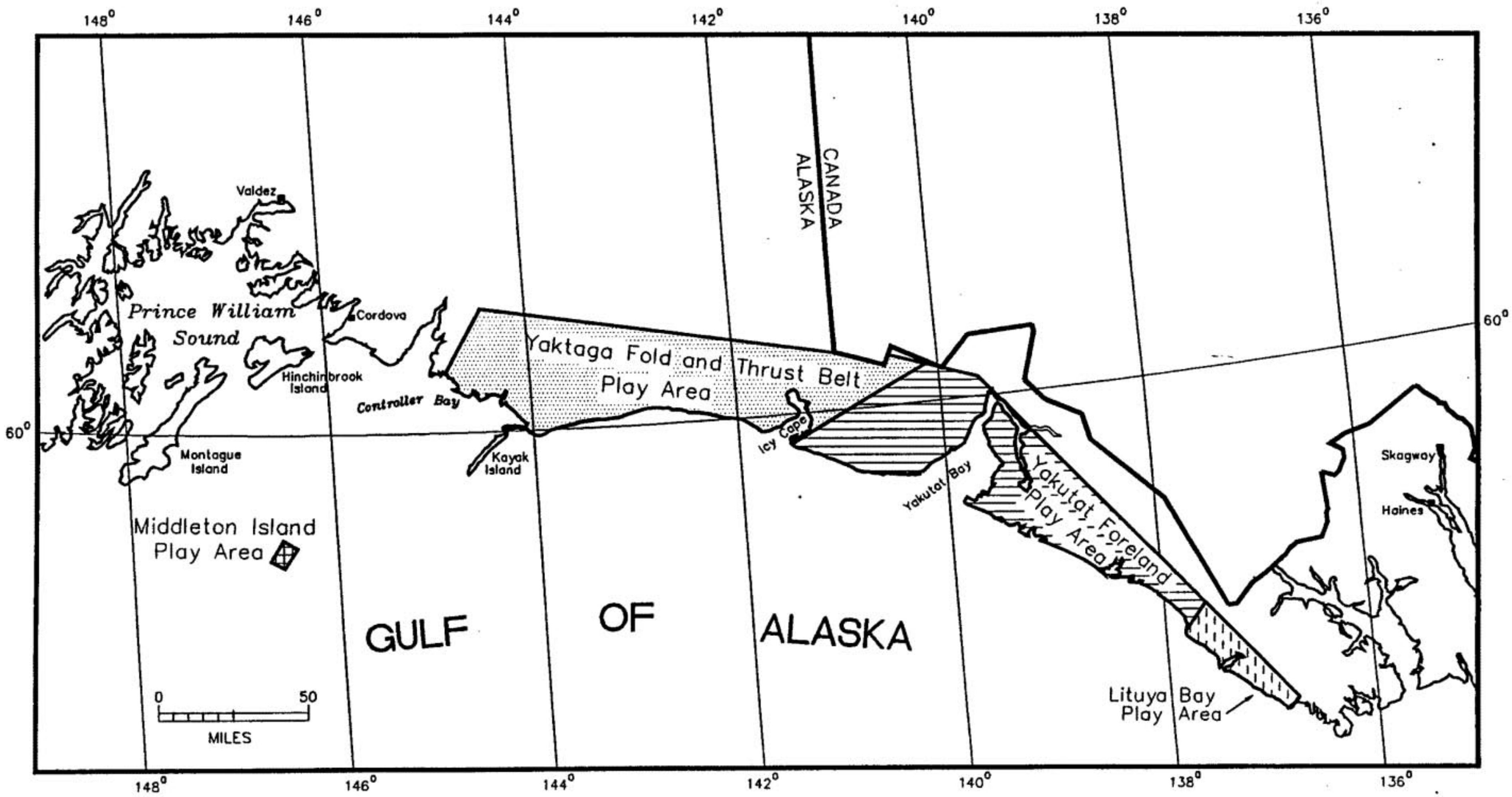


Figure 7. USGS hydrocarbon play areas for the Gulf of Alaska Onshore Province. (after Bruns, 1988)

contiguous state lands.

(4) Subducting Plate Play: This play assumes that rocks of the Yakutat terrane are subducting beneath southern Alaska along the Kayak zone and the Chugach-Saint Elias fault system. Because the play is highly speculative, boundary limits have not been established.

(5) Lituya Bay Play: Extends from Icy Point to Cape Fairweather.

Copper River Basin

The Copper River basin, a 6,000 square mile topographic depression drained primarily by the Copper River *(Figure 5)*, ranges from 1,000 to 3,000 feet in elevation and is bounded by the Alaska Range, Wrangell, Chugach, and Talkeetna mountains.

The Copper River basin represents a Cenozoic nonmarine basin found mostly in interior Alaska. These basinal areas generally consist of thick, nonmarine fluvial and coal-bearing sedimentary rocks deposited in numerous fining-upward sequences. Little subsurface data is available for these interior basins and consequently, they are not well understood. Gas is the expected hydrocarbon resource for most Cenozoic nonmarine basins in Alaska (Bird and Magoon, 1988).

Stratigraphy

Up to 500 feet of Quaternary-age, glacial, fluvial, and lacustrine deposits conceal a complex assemblage of lower Jurassic to Tertiary-age strata within the Copper River basin (Magoon and Kirschner, 1990; Connor, 1984). Subsurface stratigraphic correlation sections compiled by Church and others (1970a, 1970b) using log data from several wells drilled in the Copper River basin, show sedimentary sequences through the Talkeetna Formation of Lower Jurassic age *(Figure 8)*.

The Talkeetna Formation consists of several thousand feet of sandstone and argillite interbedded with volcanic flows and pyroclastic rocks. The upper section contains marine sandstone and siltstone becoming more tuffaceous downward. Nonmarine and marine volcanics and sedimentary rocks represent the lower section (Grantz, 1965).

Overlying these rocks are three distinct stratigraphic sequences separated by regional unconformities:

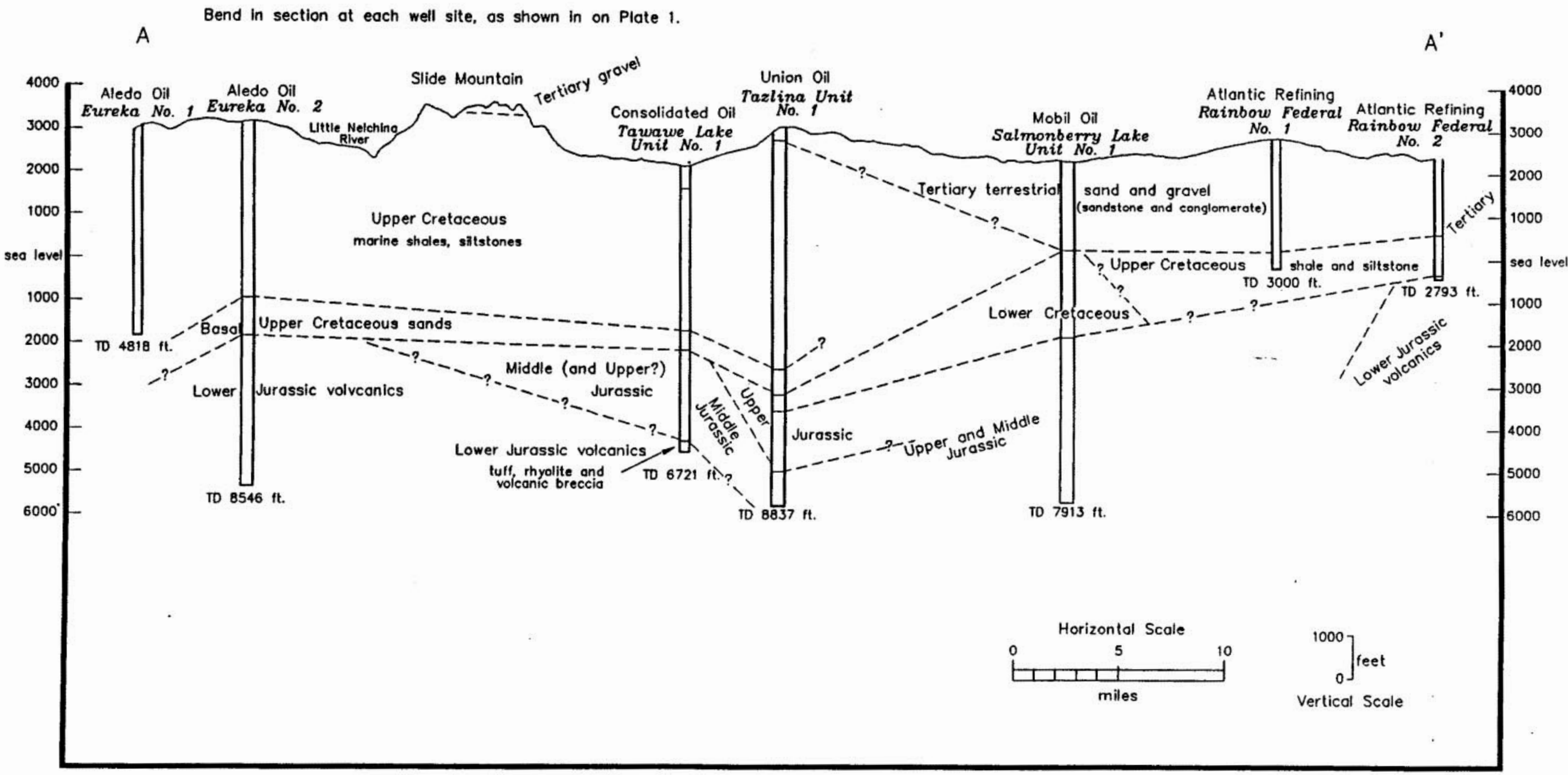


Figure 8. Cross Section AA' across southwestern part of the Copper River Basin, Alaska. (modified from Williams, 1985)

(1) a Middle Jurassic through Early Cretaceous sequence representing about 8,000 feet of marine sandstone, shale, siltstone and conglomerate of the Tuxedni Group, the Chinitna and Naknek Formations, and the Nelchina Limestone.

(2) an Early and Late Cretaceous sequence over 10,000 feet thick of marine sandstones, siltstones, conglomerates, and thin coal-bearing claystones of the Matanuska Formation.

(3) a Tertiary sequence about 4,000 feet thick of nonmarine conglomerate, sandstone, siltstone, and local thin beds of lignite coal, in part equivalent to the Chickaloon Formation and the Kenai Group of the Cook Inlet basin (Magoon and Kirschner, 1990;

Structure

Limited subsurface structural data inferred from limited, poor quality seismic records and outcrop data, appears to be similar in style to that suggested by outcrop data west of the basin (Magoon and Kirschner, 1990). Small amplitude folds trend in a northeasterly direction, major thrust faults, normal and reverse strike and cross faults as well as horst and graben structural blocks are common within the basin.

Petroleum Exploration

Investigations of saline water springs and associated gases in the south-central part of the Copper River basin were first conducted in the early 1960's (Nichols and Yehle, 1961a, 1961b; Grantz and others, 1962). Data gathered on the origin and distribution of these waters, which are basically similar in composition to one type of connate water found in oil field brines, could aid in determining the petroleum potential of the southeastern Copper River lowland.

Saline waters that issue from craters in smallmounds of mud west of the Copper River discharge methane gas. At this location, marine sedimentary rocks of Cretaceous age and semiconsolidated sandstone, conglomerate, and a few thin lignitic beds of Tertiary age, are overlain by Pleistocene deposits (Nichols and Yehle, 1961a; Miller and others, 1959). Reitsema (1979) concludes that the Nelchina Formation bituminous coal beds of Cretaceous age are a more likely source of the methane gas than the lignitic coals of the Upper Cretaceous Matanuska Formation and overlying Tertiary sandstones and conglomerates.

This is supported by the presence of Cretaceous age fossils in mud volcanoes west of the Copper River (Grantz and others, 1962). The water and gas have migrated from bedrock upward through the unconsolidated deposits to either be discharged from springs and mud volcanoes or to become trapped beneath impermeable strata in unconsolidated deposits such as lacustrine silt (Williams, 1985).

Eleven exploratory wells have been drilled in the Copper River basin since the late 1950's (*Table 3*). Although all eleven wells were abandoned as dry holes, significant shows of methane gas in association with saline water were encountered in lower Cretaceous beds of the Matanuska Formation at two well sites, the Ahtna No. 1 and No. A-1. No significant oil shows have been reported from any wells drilled to date (Magoon and Kirschner, 1990; Williams, 1985).

Identified Plays—USGS

Anticlinal traps within Cretaceous and Jurassic age flysch deposits are identified by the U.S. Geological Survey (USGS) (Magoon and Kirschner, 1990) as a speculative play involving Jurassic and younger rocks. Source rocks of the Copper River basin are Jurassic and Cretaceous shales that should have generated hydrocarbons by the early Tertiary. These hydrocarbons would have migrated into poor quality, fractured sandstone reservoirs probably sealed with shale at depths ranging from 3,000 to 10,000 feet.

Susitna Basin

The Susitna basin, about 8,000 square miles in area, is bounded by the arcuate Alaska Range on the north and west, the Talkeetna Mountains on the east, and Cook Inlet on the south *(Figure 5)*. Elevations range from sea level to about 1,000 feet near the northern boundary, however, isolated mountains rise above the surrounding lowland by as much as 4,000 (Merritt and others, 1982).

The Susitna basin is considered, by some, to be the northwest extension of the Cook Inlet Tertiary basin (Miller and others, 1959). The northeast-trending Castle Mountain fault creates a break in the subsurface between the Cook Inlet basin to the south and the Susitna basin in the north. Currently, oil and gas production and most subsurface stratigraphic information occur south of the fault in the Cook Inlet basin.

Well	Company	Location	Spudded	Total Depth (ft.)	Status
Eureka No. 1	Aledo Oil Co.	Sec 9, T21N, R12E	1956	4,818	Plugged and abandoned
Eureka No. 2	Do.	Sec 18, T2N, R10W	1963	8,546	Do.
Ahtna No. 1	Amoco Production Co.	Sec 18, T6N, R1W	1980	7,928	Do.
Ahtna No. A-1	Do.	Sec 28, T5N, R1W	1980	5,677	Do.
Rainbow No. 1	Atlantic Refining Co.	Sec 31, T8N, R5W	1965	3,000	Do.
Rainbow No. 2	Do.	Sec 1, T8N, R5W	1965	2,795	Do.
Tawawe Lake Unit No. 1	Consolidated Allied and Embassy, Miami	Sec 24, T4N, R8W	1969	6,721	Do.
Alicia No. 1	Copper Valley Machine Works	Sec 23, T4N, R4W	1982	1,050	Do.
Salmonberry Lake No. 1	Mobile Oil Co.	Sec 24, T6N, R6W	1963	7,913	Do.
Moose Creek No. 1	Pan American Oil Corp.	Sec 29, T4N, R3W	1963	7,869	Do.
Tazlina No. 1	Union Oil Co. of California	Sec 10, T4N, R7W	1962	8,837	Do.

Table 3. Copper River Basin well data. (after Dibona and Kirschner, 1984)

Stratigraphy

Rocks in the Cook Inlet basin-Kenai Peninsula area range in age from Pennsylvanian to Recent (Kremer and Stadnicky, 1985).

Paleozoic-age rock exposures in the surrounding Cook Inlet region are few, but can be found in the Talkeetna Mountains, the Alaska Peninsula, and in the Alaska-Aleutian Range (Moore and Connelly, 1979; Detterman and others, 1979).

Mesozoic-age outcrops include metasedimentary and metavolcanic rocks out of the Alaska Range and Talkeetna Mountains, metavolcanics of the Kenai-Chugach Mountains, and marine sedimentary rocks that subcrop beneath Tertiary-age strata in central or axial parts of the basin (Kirschner and Lyon, 1973).

The following lithologic descriptions begin with the Lower Jurassic Talkeetna Formation which represents the economic basement for the Cook Inlet petroleum province (Magoon and Kirschner, 1990; Boss and others, 1976). Descriptions are modified from Teseneer and others (1986). *Figure 9* shows the stratigraphic column of the Cook Inlet basin.

Lower Jurassic

The Lower Jurassic Talkeetna Formation is exposed on both sides of Cook Inlet. In the Iniskin-Tuxedni region, it is more than 9,000 feet thick and has three distinct members: 1) the Marsh Creek Breccia, massive dark green volcanic breccia and argillite; 2) the Portage Creek Member, consisting of massive red and pink conglomerates, tuff breccias, and argillites; and 3) the Horn Mountain Member, a thinly bedded to massive tuffaceous sandstones (Detterman and Hartsock, 1966). Near Port Graham, at the southern end of the Kenai Peninsula, the Talkeetna Formation consists of over 4,500 feet of massive volcanic conglomerates, tuffs, and sandstones (Boss and others, 1976).

Middle Jurassic

The Middle Jurassic Tuxedni Group unconformably overlies the Lower Jurassic Talkeetna Formation. Up to 10,000 feet of Tuxedni Group rocks are known to exist. Marine sandstone, conglomerate, siltstone, and shale are the major rock types of the Tuxedni Group. A few wells on the Kenai Peninsula have penetrated Tuxedni Group rocks, and some have had shows of oil from this Group.

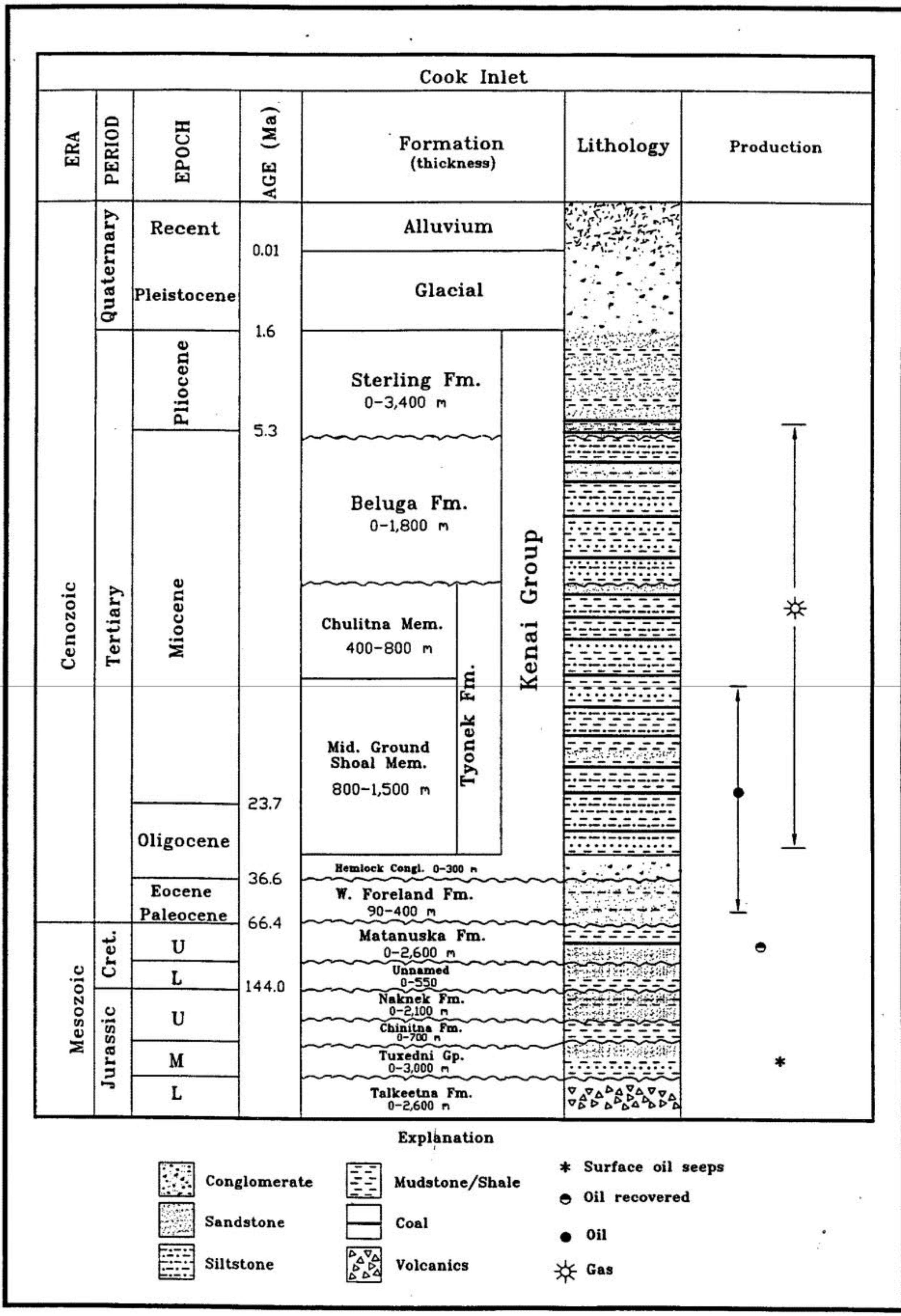


Figure 9. Generalized stratigraphic column for Cook Inlet. (after Magoon and Kirschner, 1990)

The Middle Jurassic Chinitna Formation unconformably overlies the Middle Jurassic Tuxedni Group (Boss and others, 1976). The Chinitna Formation is composed of up to 2,000 feet (600 m) of dark gray fossiliferous marine siltstones (Detterman and Hartsock, 1966).

Upper Jurassic

The Upper Jurassic Naknek Formation unconformably overlies the Upper Jurassic Chinitna Formation. The Naknek Formation extends laterally from the Talkeetna Mountains to the Black Hills near Cold Bay, Alaska (Wilson, Detterman, and Case, 1985). The Naknek Formation ranges from 5,000 feet thick in the Iniskin-Tuxedni area to as much as 10,000 feet in more complete exposures in the Alaska Peninsula (Boss and others, 1976). In outcrop, the Naknek is composed of boulder conglomerates and interbedded coarse-grained sandstones, but well-site samples are described as fine grained, with fine-grained sandstones and shales probably predominating (Boss and others, 1976). The Naknek Formation may record the unroofing of the Alaska-Aleutian Range batholith (Magoon and others, 1976a).

Lower Cretaceous

On the Kenai Peninsula, the Lower Cretaceous Herendeen Limestone unconformably overlies the Upper Jurassic Naknek Formation. The Herendeen Limestone apparently has a wide lateral extent, although it is exposed in few locations. The Herendeen Limestone is a calcarenite that contains abundant Inoceramus prisms (locally up to 50 percent). Grantz and others (1966) and Bergquist (1961) correlate the Herendeen Limestone with the Nelchina Limestone of the eastern Matanuska Valley and of the southwestern Wrangell Mountains. Jones and Detterman (1966) correlate it with a lithologically similar unit in the Kamishak Hills. The Herendeen Limestone is about 13,000 feet thick near Anchor Point and has not been penetrated by any wells north of there.

Upper Cretaceous

The Upper Cretaceous Matanuska/Kaguyak Formation (Grantz and Jones, 1960) is angularly unconformable with the underlying Lower Cretaceous Herendeen Limestone (where present) and the Upper Jurassic Naknek Formation. The Matanuska/Kaguyak Formation consists of up to 4,500 feet of marine sandstone, bioturbated siltstone and shale, and turbiditic sandstone and siltstone.

Tertiary

Paleocene-Eocene

The West Foreland Formation is composed of conglomerates that contain pebbles of volcanic rocks, volcaniclastic sandstones and siltstones, tuffs, and thin coal beds. Kirschner and Lyon (1973) describe the depositional environment of the West Foreland sediments as fluvial, non-marine. The formation is from 0 to 1,700 feet thick and is 890 feet thick in the Pan American West Foreland Well No. 1 (Sec. 21, T. 8 N., R. 14 W., SM), where it was first described by Calderwood and Fackler (1972). The West Foreland Formation contains up to 50 percent sandstone.

Four formations comprise the Tertiary Kenai Group; from oldest to youngest, they are the Hemlock Comglomerate, the Tyonek Formation, the Beluga Formation, and the Sterling Formation (Kremer amd Stadnicky, 1985). The Kenai Group consists predominantly of sandstone, siltstone, claystones, conglomerates, and coals and reaches a maximum thickness of about 25,000 feet under Cook Inlet. However, the Kenai Group is generally less than 10,000 feet thick in northern Cook Inlet, but may range up to 16,000 feet thick (Merritt and others, 1982; Calderwood and Fackler, 1972). The Kenai Group unconformably overlies the West Foreland Formation.

Oligocene

The Oligocene Hemlock Conglomerate, exposed along the western margin of Cook Inlet, unconformably overlies the Eocene West Foreland Formation. The Hemlock Conglomerate contains from 0 to 800 feet of massive sandstone, pebbly sandstone, and conglomerate with minor interbeds of shale and coal, and is lithologically similar to the overlying Tyonek Formation (Kremer and Stadnicky, 1985). In the Atlantic Richfield Swanson River Well No. 1 (34-10) (Sec. 10, T. 8 N., R. 9 W., SM), where it was first described by Calderwood and Fackler (1972), it is 570 feet thick. Kirschner and Lyon (1973), Boss and others (1976), and Hite (1976) have described the depositional environment for the Hemlock Conglomerate as braided and/or meandering fluvial to deltaic to estuarine.

Upper Oligocene to Middle Miocene

The Upper Oligocene to Middle Miocene Tyonek Formation conformably overlies (gradationally) the Oligocene Hemlock Conglomerate. Calderwood and Fackler (1972) first described the Tyonek Formation in the Pan American Tyonek State Well No. 2 (Sec. 30, T. 11 N., R. 11 W., SM), where it is 7,695 feet of massively bedded sandstones, commonly conglomeritic, with interbedded shale and relatively thick subbituminous to bituminous coal beds (Merritt and others, 1982; Kremer and Stadnicky, 1985). The Tyonek Formation reaches a maximum thickness of over 9,000 feet and contains 25 to 50 percent sandstone. Kirschner and Lyon (1973) and Hite (1976) suggest that the Tyonek Formation was deposited in a fluvial deltaic and estuarine environment. Hite (1976) considers the "poorly drained alluvial basin" of the Susitna Flat to be a modern analog.

Miocene

The Miocene Beluga Formation unconformably overlies the upper Oligocene to Middle Miocene Tyonek Formation. The Beluga Formation is over 3,000 feet thick in exposures near Homer (Adkison and others, 1975), and 4,150 feet thick in the Standard Oil (Chevron) Beluga River Well No. 1 (Sec. 35, T. 13 N., R. 10 W., SM) where it was first described by Calderwood and Fackler (1972). The Beluga River Formation consists of interbedded sandstones, siltstones, and claystones, with thin beds (less than 6 feet) of lignitic to subbituminous coal. Thick conglomeratic sandstones (fanglomerates) occur locally. The sandstones are generally laterally continuous. Sedimentary structures within the sandstones suggest a variable flow regime indicative of a braided stream environment with coalescing alluvial fans (Kirschner and Lyon, 1973; Hayes and others, 1976). Heavy mineral suites from the sandstones indicate that the Kenai Chugach Mountains are the source of the Beluga sediments (Hayes and others, 1976).

Pliocene

The Sterling Formation unconformably overlies the Miocene Beluga Formation. The Sterling Formation is characterized by fining upward sequences of conglomerates (rare), conglomeratic sandstones and massive coarse- to fine-grained sandstones. These sequences are commonly 30 to 90 feet thick and are overlain by siltstones, claystones, tuffs, and thin coals. The fining upward sequences are repetitive and can be traced laterally over large distances. They are indicative of meandering point bar sequences (Hayes and others, 1976). The Sterling Formation reaches a maximum thickness of about 11,000 feet on the

Kenai Peninsula and is 4,490 feet thick in the Union Oil Sterling Unit Well No. 23-15 (Sec. 15, T. 5 N., R. 10 W., SM) where it was first described by Calderwood and Fackler (1972). The sandstone composition of the Sterling Formation indicates that its primary source was the Alaska-Aleutian Range batholith (Hayes and others, 1976; Hite, 1976).

Quaternary and Recent

Pleistocene and Holocene glacial sediments and alluvium unconformably overlie the Tertiary Sterling Formation (Adkinson and others, 1975).

Structure

Structural features within the Cook Inlet region include the Cook Inlet basin and three fault systems: the Castle Mountain-Lake Clark, Bruin Bay, and Border Ranges fault systems. Data are lacking relating these fault systems to one another, to the basin, and to the major strike-slip movments in this region (Kelley, 1985). However, Kelley states that "the position of the fault systems relative to the basin depocenter strongly suggests the faults had a role in the development of the Tertiary basin."

The Cook Inlet basin, an asymmetric intermountain graben or half-graben, is characterized by a steeper, more complex northwest flank in the north and by Tertiary-age sedimentary beds deformed into a parallel series of anticlines of varying structural amplitude. The general trend of the basin is north east and is subparallel with the surrounding mountain borders. Most anticlines in the basin are asymmetric structures with steeper west flanks that are commonly faulted on the high relief parts of the major folds (Kirschner and Lyon, 1973). Pre-Tertiary strata are present in the cores of nearly all folds in the basin.

The Castle Mountain-Lake Clark fault zone, which borders the northwest margin of Cook Inlet, starts as single major fault zone in the Susitna River flats and is believed to fan out into a series of smaller, southwest-splaying faults on the the west side of Cook Inlet (Kelley, 1985).

The Bruin Bay fault system extends 250 miles to the southwest, from its intersection with the Castle Mountain fault west of Anchorage to Becharof Lake along the Alaska Peninsula. It comprises a family of faults up to five miles wide and juxtaposes volcanic, plutonic, and metamorphic rocks beneath the Alaska Range with clasitc rocks along the margin of Cook Inlet basin. (Detterman and Hartsock, 1966; Detterman and Reed,1980)

The Border Ranges fault zone is considered a major tectonic boundary in south-central Alaska and is believed to mark the latest Mesozoic or early Tertiary plate boundary between continental Alaska and a subduction complex. The fault zone extends 620 miles from Kodiak Island to the eastern Gulf of Alaska and forms the southeast margin of the Cook Inlet basin (MacKevett and Plafker, 1974).

Geologic History

Three Mesozoic marine sedimentation cycles with a cumulative total of 40,000 feet and two Tertiary estuarine to nonmarine cycles up to 30,000 feet characterize the historical (stratigraphic and tectonic) development of the basin. Each cycle ended with an mountain building episode accompanied by a geographic shift in the depocenter for subsequent cycles. Each cycle also saw an increase in land area and a more restrictive basin for deposition (Kirschner and Lyon, 1973).

Mesozoic Cycle

Two phases (early and late) of eugeosynclinal deposition during Early Mesozoic time are recognized by Kirschner and Lyon (1973). The early phase rocks, the oldest known in this region, include sediments of Permo-Triassic to Early Jurassic time. They are pre-flysch and associated volcanic-arc sediments many thousands of feet thick and crop out in southern Cook Inlet (Detterman and Hartsock, 1966). These rocks formed a segment of a volcanic archipelago and trench that subsequently accreted to the continent. The early phase ended with the advent of the Alaska Range orogeny (Detterman and others, 1965).

The late phase, a regressive phase consisting of at least 13,000 feet of clasitc rocks of Early to Late Jurassic age, probably was deposited in a marine trough in front of the rising Alaska Range.

Late Mesozoic time is represented by; 1) the Early Cretaceous cycle, consisting of a marine continental-shelf facies and coeval, turbidite sediment suit, and 2) the Late Cretaceous cycle, 10,000 feet of marine siltstone with thin basal transgressive and upper regressive sandstone members deposited in the Matanuska geosyncline. The Late Cretaceous cycle ended with the beginning of the Laramide orogeny which compressed the youngest (Upper Cretaceous) sedimentary beds into tight folds and accreted the older rocks (Lower Cretaceous) to the continent.

Tertiary Cycle

The transformation from marine shelf deposits to nonmarine forearc basin deposits marked an abrupt change in the Cook Inlet basin during Cenozoic time. Up to 30,000 feet of Tertiary-age sediments unconformably overlie the Mesozoic rocks. Tertiary-age sediments were deposited between the Kenai-Chugach Mountains and the southern Alaska Range, in a broad, liner intermontane trough or troughs. Sediment source during the early Tertiary originated in the northeastern Interior province while later sources were out of nearby highlands. Trough deposition is represented by an early cycle of sedimentation, whose depocenter was northeast of the present Cook Inlet, and by a late cycle of sedimentation where the depocenter was in the present upper Cook Inlet. The Early Tertiary cycle (Paleocene and Eocene Epochs) accumulated several thousand feet of nonmarine to estuarine sediment.

The Chickaloon Formation is the thickest sediment deposit in the trough and was probably derived from a northeastern source consisting of a high-grade meta terrane. Uplift, folding and erosion terminated this cycle. A hiatus during the Oligocene orogenic episode resulted in a regional unconformity between the Chickaloon Formation and overlying deposits, and also brought about an abrupt change in the prevailing sedimentary regime.

The Late Tertiary cycle within the Cook Inlet basin is represented by 25,000 feet of estuarine and nonmarine calstic sedimentary rocks of the West Foreland Formation and the Kenai Group. The cycle is divided into three phases: 1) A transgressive phase during Oligocene-Miocene time deposited sediments of the West Foreland Formation, Hemlock Conglomerate, and the lower Tyonek Formation; 2) During Late Miocene time a short transitional period of low energy sedimentation took place. Sediments from this period are believe to be represented by the upper part of the Tyonek Formation and the lower part of Beluga Formation. Concurrent orogenic uplift of the Alaska Range and the Kenai-Chugach Mountains initiated the final phase; 3) The Pliocene regression includes an accumulation of about 12,000 feet of conglomerate, sandstone, and siltstone of the Beluga and Sterling Formations. The Kenai-Chugach terrane was the dominant source terrane for these formations.

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Petroleum Exploration and Development

Oil and gas seeps were discovered by Russians in 1853 along the Iniskin Peninsula on the west side of Cook Inlet. Several unsuccessful shallow wells were drilled around the turn of the century and the exploration venture ended in 1904.

Petroleum exploration of the Cook Inlet area revived by the 1920's. Anchorage Oil and Development Co. drilled a 300 foot well in Anchorage during 1920-21. The well was abandoned before reaching bedrock. A Matanuska Valley site, 2 miles west of Chickaloon, received intermittent drilling between 1920 and 1930.

From 1940 through 1955 at least 23 test wells, some with shows of oil and gas, were drilled in the Alaska Peninsula - Cook Inlet region. Commercial oil production within the Cook Inlet region began in 1957 with the discovery of the Swanson River field in the northern part of the Kenai lowlands. Since 1957, 6 more oil fields and 22 gas fields have been discovered with total production of about 1.1 billion barrels of oil and about 3.1 trillion cubic feet of natural gas (Alaska Division of Oil and Gas, 1987; Stickney, 1985).

All oil and gas production in the Cook Inlet basin is from the Tertiary-age Kenai Group and West Foreland Formation (*Table 4*). They consist predominantly of sandstones, siltstones, claystones, conglomerates, and coals (Kremer and Stadnicky, 1985). Tertiary strata north of the Castle Mountain fault are generally less than 2,000 feet thick and overlie granitic rocks (Merritt and others, 1982). This is compared to the central part of the Cook Inlet basin where the Kenai Group is over 26,000 feet thick (Calderwood and Fackler, 1972).

Eighty percent of the oil production in the Cook Inlet basin is from the Hemlock Conglomerate, 18 percent comes from the Tyonek Formation and 2 percent is from the West Foreland Formation (Magoon and Claypool, 1979, 1981). Gas production comes from the Sterling Formation, the major gas reservoir in the basin, and from the Tyonek and Beluga Formations (Teseneer and others, 1986).

Mesozoic-age rocks penetrated within the Cook Inlet subsurface have not proved significant for oil potential (Kirschner and Lyon, 1973). Magoon and Claypool (1979, 1981) suggest that Middle Jurassic rocks of the Cook Inlet basin are a possible source of all commercially important oil in the basin. These rocks contain thermally mature, oil-prone organic matter and extractable hydrocarbons that are chemically and physically similar to Cook Inlet oil. Nonmarine Tertiary rocks and

AGE	PERIOD	TERTIARY					
ROCK UNIT	GROUP	KENAI GROUP					
	FORMATION	STERLING FORMATION	BELUGA FORMATION	TYONEK FORMATION		HEMLOCK CONGLOMERATE	WEST FORELAND FORMATION
	MEMBER			CHUITNA MEMBER	MIDDLE GROUND SHOAL MEMBER		
Oil Fields	Beaver Creek				0		
	Granite Point				0	0	
	McArthur River				0	0	0
	Middle Ground Shoal				0	0	
	Redoubt Shoal					0	
	Swanson River					0	
	Trading Bay				0	0	
Gas Fields	Albert Kaloa			X			
	Beaver Creek	X	X				
	Beluga River	X	X				
	Birch Hill				X		
	Falls Creek				X		
	Ivan River			X			
	Kenai	X	X				
	Lewis River		X				
	McArthur River			X	X		
	Middle Ground Shoal				X		
	Moquawkie			X	X		
	Nicolai Creek		X	X			
	North Cook Inlet	X	X		X		
	North Fork				X		
	North Middle Ground Shoal				X		
	Sterling	X					
	Stump Lake		X				
	Swanson River	X			X		
	Theodore River		X				
	Trading Bay				X		
	West Foreland				X		
	West Fork	X					

Table 4. Productive horizons, by field, in the Cook Inlet basin. (from AOGCC, 1985)

Cretaceous rocks are tentatively eliminated as possible source rocks because of thermal immaturity. In addition, Tertiary rock samples contained a coaly type of organic matter that did not yield liquid hydrocarbons efficiently upon heating and the Cretaceous rocks contain inadequate organic material (Magoon and Claypool, 1979, 1981).

B. COAL

Coal resources within the Southcentral Planning Area are identified by province, basin, field, district, and occurrence (Merritt and Hawley, 1986) *(Plate II)*. Each of these divisions indicate HIGH potential (H/*) for the accumulation of coal resources, however, the level of certainty may change at each location identified *(Table 5)*. The remainder of the SPA is classified as having LOW potential (L/A) for the occurrence of coal. The level of certainty reflects the insufficient data base available to support the possible existence of coal resources within this area.

Exploration and Production History

Considering Alaska's vast coal resources (about half of the total coal resources of the U.S.), past production has been minimal due, in part, to the lack of an available market and the remote location of its coal deposits (Merritt and others, 1982).

The first commercial coal mine in Alaska was opened by the Russian-American Company near Port Graham on the Kenai Peninsula in 1855 (Merritt, 1986b).

Tertiary-age, coal-bearing rocks exposed along the eastern shore of Cook Inlet and in the Matanuska Valley attracted pre-1950 exploration interest. In recent years industrial activity has focused on two coal fields in this region: the Beluga and Matanuska coal fields. These areas are accessible by water, railroad, and highway transportation systems.

The Matanuska field began its first commercial production in 1916 and eventually produced 7.5 million tons of coal for use by U.S. Navy ships, local communities, and the Alaska Railroad (Merritt, 1986b). Production ended with the availability of Cook Inlet gas in 1967. In 1988 a major drilling program, which consisted of geophysical logging, and seismic surveys on eight coal leases, took place (Green and others, 1989).

Area	Rank	Thickness	Formation/Group	Age	BLM Potential
Susitna Basin................	subbituminous	unknown	Kenai Gp.	Tertiary	H/C
Broad Pass Field.............	lignite	5 to 10 ft.	continental rocks	Do.	H/D
Bering River Field............	bituminous/ anthracite	up to 30 in.	Kushtaka Fm.	Do.	H/D
Duktoth River District	bituminous	up to 6 ft.	Kulthieth Fm.	Do.	H/D
Malaspina District............	bituminous	1 to 8 ft.	Kulthieth Fm.	Do.	H/D
Jarvis Creek Field............	subbituminous	1 to 10 ft.	Healy/Lignite Fms.	Do.	H/D
Copper River Field	lignite	unknown	Gakona/Matanuska Fms.	Tertiary/Cretaceous	H/C
Wrangell District..............	lignite	less than 0.2 ft.	Frederika Fm.	Tertiary	H/D
Summit District...............	lignite	unknown	Gakona Fm.	Do.	H/D
Watana District...............	lignite/ subbituminous	unknown	continental rocks	Do.	H/D
Matanuska Field..............	subbituminous	unknown	continental rocks	Do.	H/D

Table 5. Southcentral Planning Area coal summary.

The Beluga and Yentna coal fields contain sites of only minor coal extraction and no production history is available (Merritt, 1986b). However, since 1985 Placer Dome U.S., Incorporated and Diamond Alaska Coal Company have conducted exploratory drilling in the Beluga field to help identify new coal seams and determine reserve estimates (Green and others, 1989; Bundtzen and others, 1988; Bundtzen and others, 1987).

Most coal resources in Alaska occur in regions defined as geological or geographical provinces (Merritt and Hawley, 1986). A province is an extensive area that contains similar coal-bearing rocks. Further divisions include:

(1) basin: an area that contains one or more coal fields or that forms a distinct part of a coal province.

(2) field: an area that has high resource potential and contains one or more known coal beds of minable thickness and quality.

(3) district: an area that forms part of a coal field or an isolated area that has less probable resource potential than a coal field.

(4) occurence: a site where one or more typically thin, discontinuous coal beds crop out.

Susitna Basin

The Cook Inlet-Susitna coal province *(Figure 10)* contains Alaska's most accessible and second largest coal resource base (Merritt and Hawley, 1986). Identified resources are measured at over 11 billion short tons, second only to the 150 billion short tons of the Northern Alaska province.

The Beluga, Yentna, and Susitna fields north and east of Anchorage contain substantial reserves of very low sulfur, subbituminous and lignite coals of the Tertiary Kenai Group (Merritt and others, 1982).

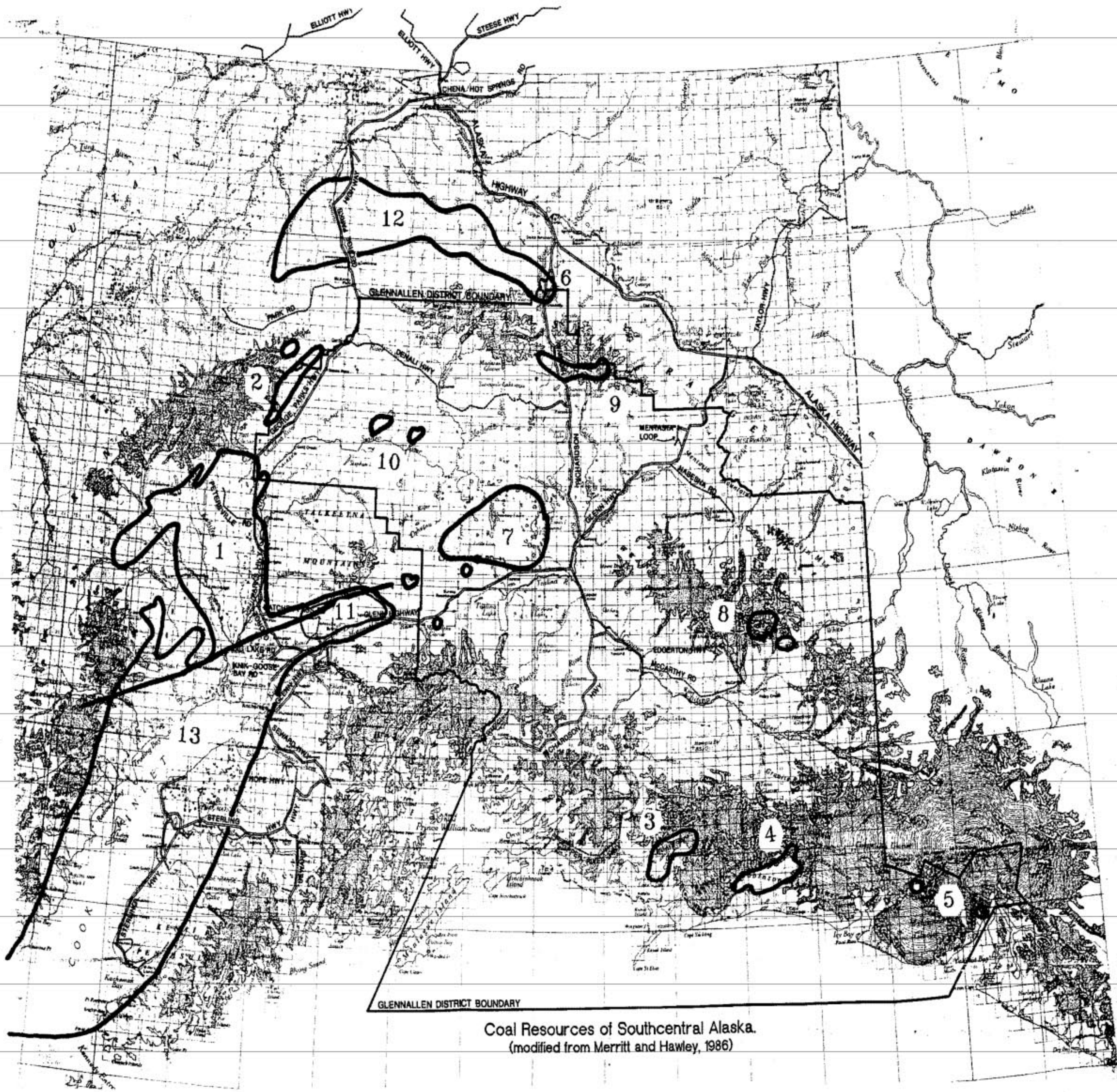
Coal-bearing outcrops in the Beluga-Yentna region are scattered over a 6,000 square-mile area. Most of the seams considered mineable (over 20 ft. thick) are within the Tyonek Formation. Thinner, subbituminous and lignite coal beds occur in the younger Sterling and Beluga Formations (Merritt and others, 1982; Merritt and Hawley, 1986)..

SOUTHCENTRAL PLANNING AREA

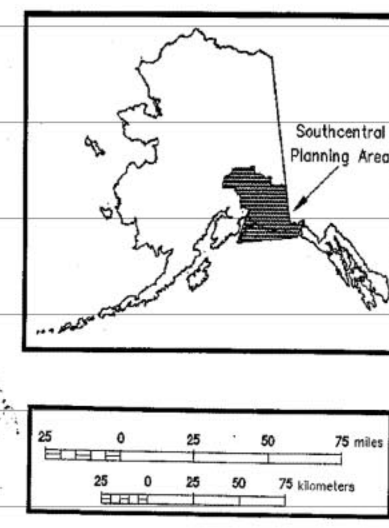
Figure 10

Coal Resources

1. Susitna Basin
2. Broad Pass Field
3. Bering River Field
4. Duktoth River District
5. Malaspina District
6. Jarvis Creek Field
7. Copper River Field
8. Wrangell District
9. Summit District
10. Watana District
11. Matanuska Coal Field
12. Nenana Basin
13. Cook Inlet Basin



Coal Resources of Southcentral Alaska.
(modified from Merritt and Hawley, 1986)



Subbituminous coal deposits of the Kenai Group occur in the Susitna field in the Talkeetna quadrangle (Reed and others, 1978; Hackett, 1977). The Susitna field's northernmost boundary, established by Merritt and others (1982), extends into the SPA. In addition, Reed and others (1978) report woody, coal float and possible beds of coal near Troublesome Creek.

Broad Pass Field

The Broad Pass field, located about 160 miles south of Fairbanks along the Parks Highway, is considered a northeastern extension of the Cook Inlet/Susitna basin (Merritt, 1986a). The Tertiary coal-bearing sequence occupies a narrow graben about 36 square miles in area and contains lignite seams 5 to 10 feet thick that dip between 2 and 9 degrees. Identified resources are estimated at 50 million short tons (Merritt and Hawley, 1986; McGee and O'Connor, 1975a; Barnes, 1967; Hopkins, 1951;).

Bering River Field

The Bering River coal field, located within Chugach National Forest near the Gulf of Alaska, is about 20 miles long and 2 to 5 miles wide (Smith and Rao, 1987). The coal-bearing rocks are exposed in a belt running northeast from the eastern shore of Bering Lake. The field is bordered by the Martin River Glacier on the northwest and by the Bering Glacier on the southwest.

The Bering River field contains four formations of Tertiary age; the Tokun, Kushtaka, Stillwater, and Poul Creek Formations. The exact relationship of these formations to one another is not known due to the lack of contacts. The middle part of the Kushtaka Formation is the primary coal-bearing strata in the field (Smith and Rao, 1987). It contains bituminous, semianthracite, and anthracite coal with a total resource potential of 59 million tons. Past production has been less than 100,000 tons (Merritt, 1986a).

The structure of the coal field is characterized by complex folding including isoclinal recumbent and overturned folds as well as northwest trending major faults and minor faults that run northeast. This structural deformation has resulted in thickness variations within short distances (a few inches to 60 feet), however, drilling data shows that continuity exists from outcrop to their subsurface extensions (Smith and Rao, 1987).

Duktoth River District

The coal-bearing rocks of the Tertiary Kulthieth Formation in the Bering River area correlates with the coal-bearing rocks of the Kulthieth Formation in adjacent Bering Glacier, Yakutat, and Mount Saint Elias quadrangles to the east (Winkler and Plafker, 1981). The Duktoth River district, located in the Robinson Mountain area, contains bituminous coal beds up to 6 feet thick (Merritt and Hawley, 1986).

Malaspina District

Numerous coal beds occur throughout the Kulthieth Formation in the Samovar Hills and Yakutat Bay areas. Samovar Hills coal beds range from 1 to 8 feet in thickness and average 3 feet thick in a measured stratigraphic interval of 2,700 feet (Plafker and Miller, 1957).

The exposed coal-bearing strata near Esker stream on the west side of Yakutat Bay totals 505 feet in thickness and contains nine coal beds ranging from 6 to 18 inches thick. According to Russell (1891), claims were filed and exploratory shafts were sunk, but the properties were subsequently abandoned (Plafker and Miller, 1957; Tarr and Butler, 1909).

Jarvis Creek Field

The Jarvis Creek field, an easternmost, isolated subfield of the Nenana coal province, is located about 30 miles south of Delta Junction in east-central Alaska. The coal field covers about 16 square miles and is underlain by lower Paleozoic schist and coal-bearing Tertiary age rocks. The coal-bearing formation at Jarvis Creek, tentatively correlated with the Healy Creek and Lignite Creek Formations in the Nenana coal field 100 miles to the west, is about 2,000 feet thick and contains at least 30 coal beds of subbituminous rank, most of which are thin (1 to 10 feet) and discontinuous. Estimates of inferred reserves are reported as 100 million tons. (Wahrhafitg and Hickcox, 1955; Wahrhaftig and others, 1969; Belowich, 1987).

The Tertiary rocks can be divided into three distinct units. The lower unit, composed of quartz conglomerate with minor amounts of sandstone, siltstone, and carbonaceous shale, is best exposed in the southeastern part of the field and contains one major lenticular eight foot coalbed. The middle unit is composed primarily of feldspar-rich sandstone and minor amounts of siltstone, and claystone. A major coal zone is located at the base of this unit. The upper unit contains beds of sandstone, siltstone, and claystone and numerous coal seams, four of which are more than 6 feet thick (Belowich, 1987).

Copper River Field

According to Merritt and Hawley (1986) the coal-bearing Gakona Formation crops out at several locations within the Copper River field. The Tertiary age Gakona Formation contains lignite coal beds of unknown thickness. Sparse coal also occurs in upper Cretaceous sandstone along the Nelchina River (Williams, 1985)

Subsurface data gathered from exploratory oil wells and water wells drilled in the Copper River basin show several thin lignitic coal beds in Tertiary age rocks unconformably overlying the Cretaceous Matanuska Formation. A 5 foot thick coal bed was recorded in a drill hole south of Lake Louise at depths ranging from 126 to 167 feet (Williams, 1985).

Merritt (1986a) reports that coals of the Copper River field occur in the Frederika Formation of Tertiary age. Numerous beds up to 18 feet thick are found in isolated fault blocks, prisms, and erosional remnants.

Wrangell District

Sparse, thin seams of lignite coal, generally less than 6 inches thick, occur in the Tertiary, continental sediments of the Frederika Formation. The best exposures are found in Townships 2 and 3 South, Range 19, 20 East of the Copper River Meridian (McCarthy quadrangle) (MacKevett, 1978). Deposited primarily in intermontane basins, the Frederika Formation is as much as 2,100 feet thick and preceded or accompanied early stages of the Wrangell Lava volcanism (MacKevett, 1978, 1976a, 1976b, 1972, 1970a, 1970b, 1970c).

Summit District

The Summit district, located about 12 miles north of Paxson along the Richardson highway, consists of scattered outcrops of thin lignite coal layers of the Gakona Formation (Merritt and Hawley, 1986; Nokleberg and others, 1982). The lignite coals occur in Pliocene sandstone and Eocene to Oligocene conglomerate with lesser sandstone layers. Thickness of these sediments is estimated to be several hundred meters, however, the total number of individual coal layers and their thickness are unknown.

Watana District

Coal-bearing continental rocks of Pliocene age crop out along Watana Creek in the northern Talkeetna Mountains about 40 miles southeast of Broad Pass. The coal is reported as both subbituminous (Merritt and Hawley, 1986) and lignite (Csejtey and others, 1978), however its thickness and extent is not known.

Matanuska Field

Coal-bearing outcrops of the Tertiary-age Chickaloon Formation in the Matanuska field are scattered over 700 square miles, the majority of which, lies outside the SPA boundary. The Matanuska field contains more than 30 coal beds, some beds up to 40 feet thick, in the upper 1,200-1,500 feet of the 5,000 foot thick formation (Merritt and others, 1982; Merritt and Hawley, 1986; Goff, 1986). Coal bed thickness ranges from 2 to 40 feet in this region.

Several coal-bearing rocks of Eocene age are exposed near Caribou Creek and along the East Fork of the Matanuska River near the southwestern border of the SPA (Conwell, and others, 1982; Grantz, 1961a, 1961b). The thickness, extent, and number of subbituminous coal beds at these isolated occurrences is unknown.

C. GEOTHERMAL

Background

Geothermal energy consists of heat stored in rocks, and to a lesser extent, in water or steam-filling pores and fractures. Water and steam transfer geothermal heat, by convection, to shallow depths within the earth's crust which may then be tapped by drilling. Geothermal heat may also escape at the surface in geysers, thermal springs, mud volcanoes, and fumaroles (a vent, usually volcanic).

Concentrations of extractable heat are known as geothermal reservoirs *(Figure 11)*. Reservoirs are found in regions of recent volcanism and mountain-building and in deep parts of many sedimentary basins. Identification of potential geothermal areas can be inferred from the distribution of hot springs and young volcanic rocks (Godwin and others, 1971).

The distribution and extent of potential geothermal resources within the Southcentral Planning Area is centered around the Mt. Wrangell volcanic pile (ADGGS, 1984) (*Plate III & Figure 13*). This area has HIGH potential (H/D) for geothermal resources. The remainder of the SPA has NO potential (O/D) for this resource.

The type of geothermal system identified in the Mt. Wrangell area consists of two major groups:

1) Volcanic; where the magma chamber is still molten orpartly molten.

(2) Hot, Dry Rock; located on the margins of molten magma chambers where the magma is no longer molten (*Figure 12*).

Volcanic Group

Quaternary volcanic rocks comprise the bulk of the Mt. Wrangell massif. Geothermal resource targets are more likely to be associated with young silicic volcanic areas where magmas may still remain in the subsurface conduit and reservoir system (Forbes, 1975). Mt. Wrangell (14,163 feet), a large glacier-covered, shield volcano, is capped by an ice-filled, but geothermally active summit caldera. The high heat flow, observed along the caldera rim (Motyka and others, 1978), is thought to originate from a shallow-lying magma chamber under the caldera (Motyka, 1984; Motyka and Benson, 1982; Motyka and others, 1980).

Estimated thermal energy (in quadrillion Btu) still remaining within the Mt. Wrangell massif are given by Smith and others (1978) for three volcanic systems: 1) Mount Drum (840), 2) Mt. Wrangell (120), and 3) White River (190). Each system is thought to have a magma chamber within about six miles of the surface (Smith and Shaw, 1979).

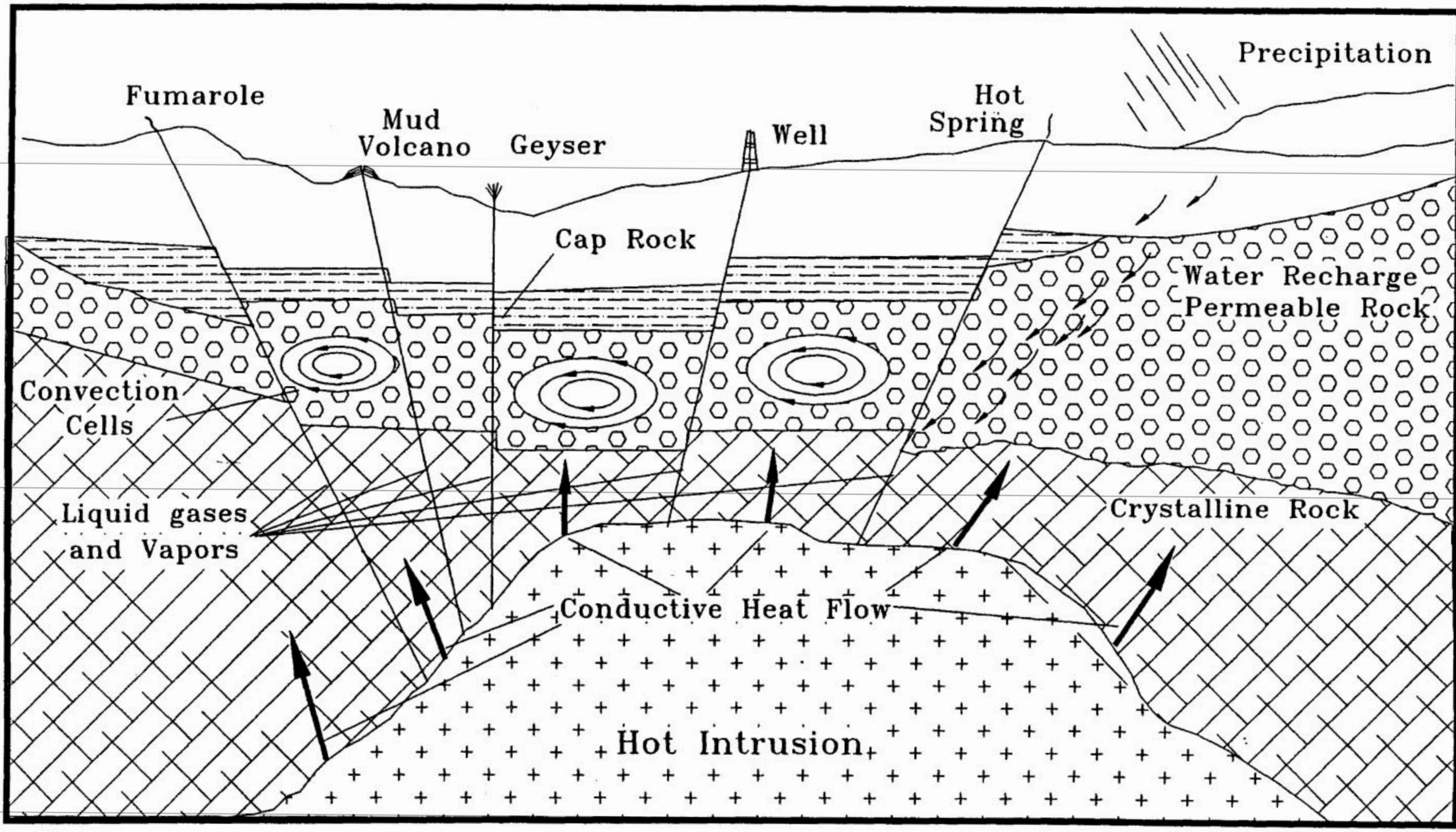


Figure 11. Hydrothermal geothermal reservoir. (modified from Chilingar and others, 1982)

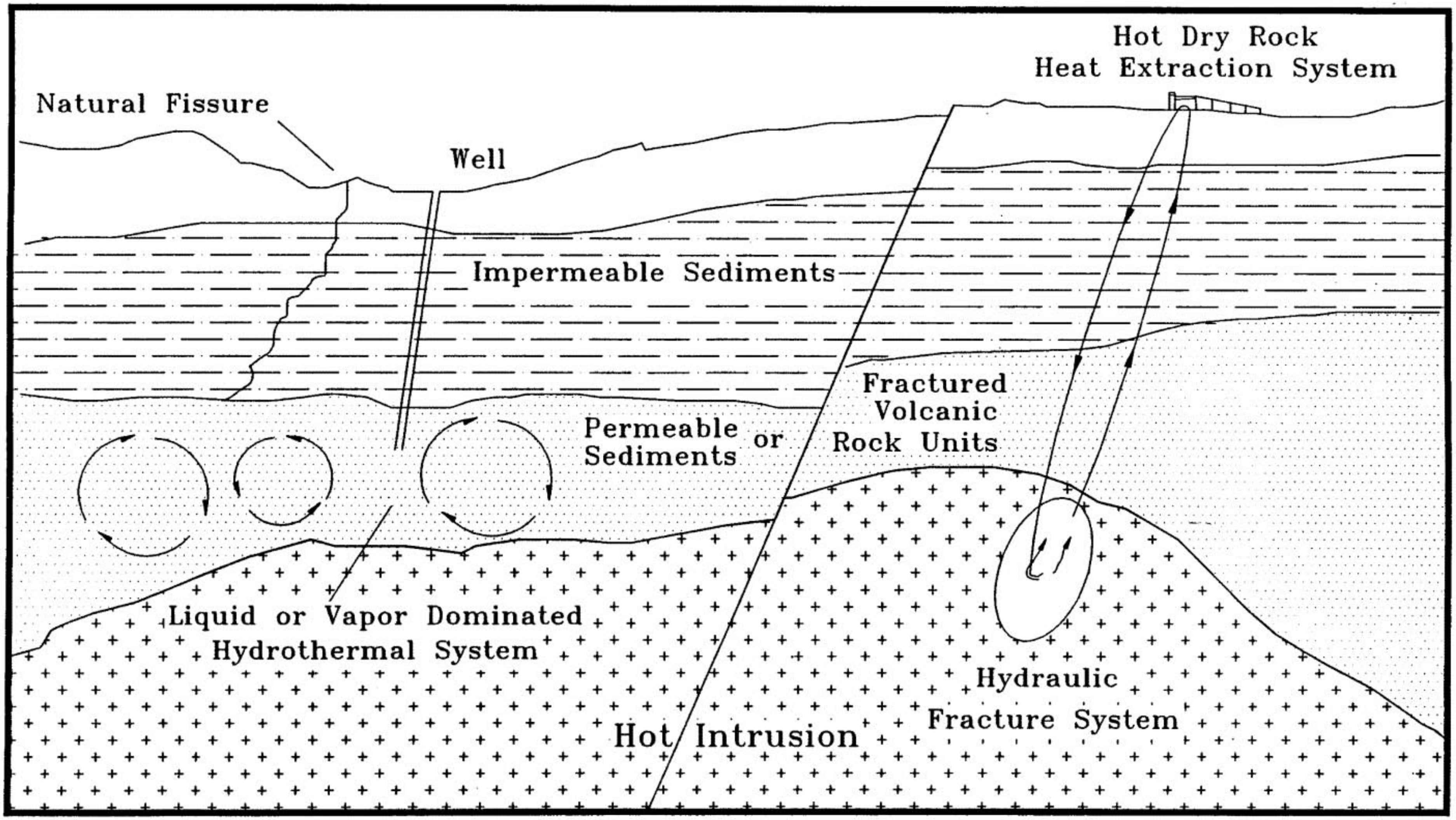
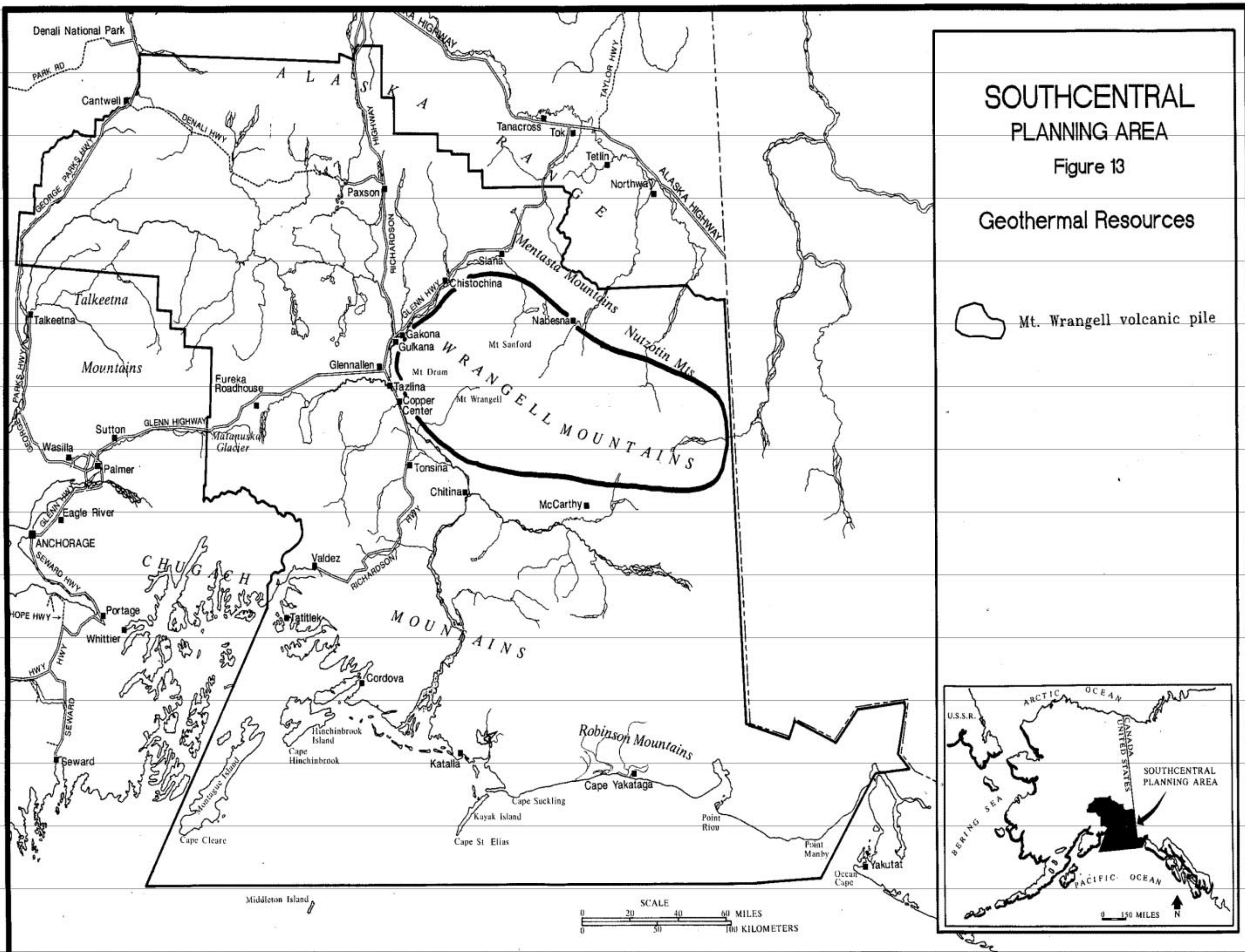


Figure 12. Hot, Dry Rock geothermal system. (after Chilingar and others, 1982)



Geothermal Resources of the Southcentral Planning Area.
(ADGGS. 1984)

Hot, Dry Rock

Regional aeromagnetic surveys (Andreasen and others, 1958, 1964) suggest that the mud volcanoes in the Mt. Wrangell massif are underlain by extensive andesitic lavas at relatively shallow depths (Basescu and others, 1980).

The Klawasi Group mud volcanoes, located near the base of Mount Drum at the western end of the Wrangell Mountains *(Figure 14)*, may be evidence for the existence of a warm and possibly a hot water hydrothermal system in the Copper River basin (Liss and others, 1987; Reeder and others, 1980). Water temperatures measure as high as 86.5 degrees F (*Figure 15*) for this group. However, geothermometer readings are inconclusive: some suggest a cold water source, while others indicate a source greater than 150 degrees C (Wescott, and Turner, 1983; Nichols and Yehle, 1961, 1969). University of Alaska researchers found gravity, magnetic, self-potential, and helium anomalies at the Klawasi group which support speculations that a geothermal reservoir may underlie this group of mud volcanoes (Wescott, and Turner, 1983, 1985).

The Tolsona group mud volcanoes, located about 15 miles west of Glennallen *(Figure 14)*, are believed to be driven by an overpressured zone located about 5,500 feet from the surface. This zone, discovered during the drilling of the Pan American Moose Creek #1 oil exploration well, produced methane which is the principal gas emitted by the Tolsona group. Wescott and Turner (1983) conclude that this group of mud volcanoes does not require a geothermal heat source to drive them.

D. SOLID LEASABLES

Solid leasable mineral potential within the Southcentral Planning area was not determined (ND) due to the lack of useful data in the literature. This includes information on the geologic environment, the inferred geologic processes, reported mineral occurrences, and valid geochemical and geophysical anomalies. Solid leasable minerals include phosphate and gilsonite, and the chlorides, sulphates, carbonates, borates, silicates or nitrates of potassium or sodium.

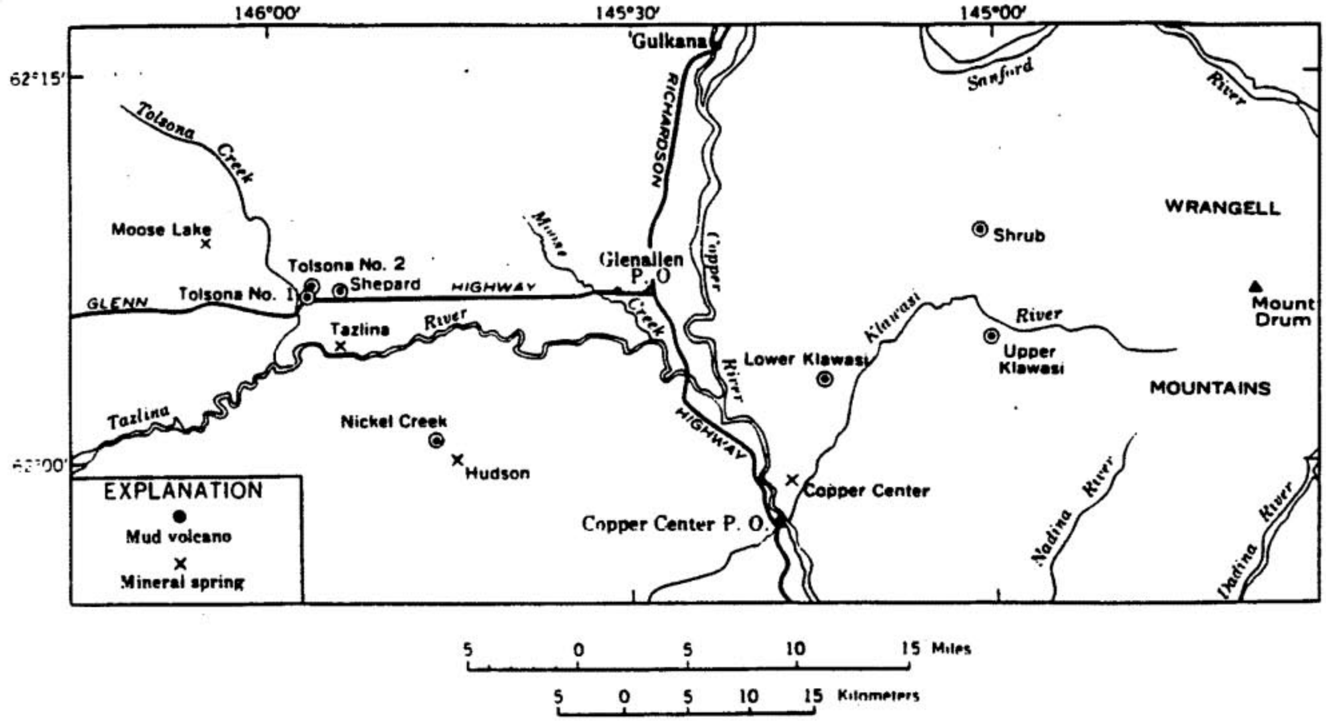


Figure 14. Location of principle mud volcanoes and mineral springs, Copper River Basin, Alaska. (after Nichols and Yehle, 1961a)

	Mud Volcano	Diagrammatic cross-section N S	Approximate dimension * of cone Base	Hgt.	Alt. * of crest	Approx. * diam. of "crater"	Surf. water temp., °F.	Est. water disch., gpm.
Drum Group	Shrub		3600 4200	310	2950	120	54	< ¼
	Upper Klawasi		4200 6700	300	3017	150	86.5	2-5
	Lower Klawasi		6000 8200	150	1875	175	82	5-10
Tolsona Group	Nickel Creek		800 1000	60	2025	150	cold	< ¼
	Shepard		1300 1600	25	2172	15	—	—
	Tolsona No. 1		600 900	25	2045	30	38-55	< ¼
	Tolsona No. 2		2000 2300	40	2085	150	40-60	< ¼

* =in feet, • = active spring, • =inactive spring.

Figure 15. Physical characteristics of mud volcanoes, Copper River Basin, Alaska. (after Nichols and Yehle, 1961b)

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APPENDIX A

BLM's Mineral Potential Classification System
(from BLM Manual, Chapter 3031)

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 accumualtion 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 or 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 a 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 evidenceto 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 onclude, 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.

APPENDIX B

Planning For Fluid Mineral Resources
(from BLM Handbook H-1624-1)

(1) Oil and Gas. Due to the nearly ubiquitous presence of hydrocarbons in sedimentary rocks, use the following for classifying oil and gas potential:

HIGH. Inclusion in an oil and gas play as defined by the USGS national assessment, or, in the absence of a play designation by USGS, the demonstrated existence of: source rock, thermal maturation, and reservoir strata possessing permeability and/or porosity, and traps. Demonstrated existence is defined by physical evidence or documentation in the literature. (Note that reasonable adjustments to any USGS play areas and boundaries may be made if it is apparent that a particular boundary was set up based on administrative convenience rather than a definable change in geological character.)

MEDIUM. Geophysical or geological indications that the following may be present: Sources rock, thermal maturation, and reservoir strata possessing permeability and/or porosity and traps. Geologic indication is defined by geological inference based on indirect evidence.

LOW Specific indications that one or more of the following may not be present: source rock, thermal maturation, or reservoir strata possessing permeability and/or porosity, and traps.

NONE. Demonstrated absence of (1) source rock, (2) thermal maturation, or (3) reservoir rock that precludes the occurrence of oil and/or gas. Demonstrated absence is defined by physical evidence or documentation in the literature.

(2) Geothermal. Use the following for classifying geothermal potential.

HIGH. Inclusion in a KGRA; or the existence of a hydrothermal convection system demonstrated by geological evidence of: a structural fault/fracture system and related thermal spring activity or other thermal features (i.e., geysers, fumaroles, mud volcanoes, vents, etc.); and high subsurface temperatures measured in wells and/or estimated from geochemical temperature indicators. Demonstrated existence is defined by physical evidence or documentation in the literature.

MEDIUM. Existence of a hot igneous system demonstrated by geologic evidence of Late Tertiary or Quaternary volcanism and higher than normal geothermal gradient as documented in existing literature.

LOW. Existence of a conduction-dominated area demonstrated by geologic evidence of radiogenic heat production or geopressured environment and higher than normal geothermal gradient as documented in existing literature.

NONE. Demonstrated absence of evidence indicating the existence of hydrothermal convection systems, hot igneous systems, and higher than normal geothermal gradient. Demonstrated absence is defined by physical evidence or documentation in the literature.