Appendix G

Mineral Potential Report

MINERAL POTENTIAL REPORT

RING OF FIRE PLANNING AREA, ALASKA

Prepared for

BUREAU OF LAND MANAGEMENT

ANCHORAGE FIELD OFFICE

Prepared by

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ANCHORAGE, ALASKA

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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
ADN	Anchorage Daily News
ADNR	Alaska Department of Natural Resources
AEIDC	Arctic Environmental Information Data Center
AFO	Anchorage Field Office
AGI	American Geological Institute
AMIS	Alaska Minerals Information Service
AMRAP	Alaska Mineral Resource Appraisal Program
ANCSA	Alaska Native Claims Settlement Act
ANILCA	Alaska National Interest Lands Conservation Act
AOGCC	Alaska Oil and Gas Conservation Commission
ARDF	Alaska Resource Data File
ASTM	American Society of Testing and Materials
AVO	Alaska Volcano Observatory
BLM	Bureau of Land Management
Btu/lb	British thermal unit per pound
CBNG	coalbed natural gas
CFR	Code of Federal Regulations
CNF	Chugach National Forest
DGGS	Division of Geological & Geophysical Surveys
FEIS	Final Environmental Impact Statement
ft	foot/feet
KGRA	known geothermal resource area
KMDA	Known Mineral Deposit Area
lb	pound
MAS/MILS	Mineral Availability System/Mineral Industry Location System
MEA	Matanuska Electric Association
MEP	Mineral Exploration Potential
MMBO	million barrels of oil
MMS	Minerals Management Service
MW	megawatt
NEPA	National Environmental Policy Act
NPS	National Park Service
NURE	National Uranium Resource Evaluation
NWR	National Wildlife Refuge
PGE	platinum group metals
PRMP	Proposed Resource Management Plan
PWS	Prince William Sound
RASS	Rock Analysis Storage System
RDI	Resource Data Center, Inc.
REE	rare earth elements
RFD	Reasonable Foreseeable Development
scf	standard cubic feet
S-P	self-potential
TCFG	trillion cubic feet of gas
TNF	Tongass National Forest

ACRONYMS AND ABBREVIATIONS

URS	URS Corporation
U.S.	United States
USBOM	U.S. Bureau of Mines
USDOE	U.S. Department of Energy
USDOI	U.S. Department of the Interior
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VMS	volcanic massive sulfide

1.0 INTRODUCTION

Presented in this document are the results of a Mineral Potential Assessment conducted for the United States (U.S.) Department of Interior (USDOI), Bureau of Land Management (BLM) for the Ring of Fire planning area in southern Alaska. This document has been prepared by URS Corporation (URS) as part of BLM Contract No. GS.10F.0105K for completion of the Proposed Resource Management Plan (PRMP) and Final Environmental Impact Statement (FEIS) for the Ring of Fire planning area.

The Ring of Fire planning area spans a linear distance of 2,500 miles extending from the Aleutian Islands at the southwestern tip of Alaska, through the Alaska Peninsula, parts of southcentral Alaska, and through the southeast panhandle of Alaska (Figure G-1). The planning area is divided into four geographic regions: 1) Alaska Peninsula/Aleutian Chain, 2) Kodiak, 3) southcentral, and 4) southeast regions. The southcentral region includes the Cook Inlet area, Matanuska-Susitna Valley, and Kenai Peninsula, but excludes the eastern Prince William Sound (PWS) area and the Wrangell Mountains to the east. The southeast region extends from Yakutat Bay to the southeastern tip of Alaska.

1.1 Lands Involved and Land Status

BLM-managed surface lands within the Ring of Fire planning area include lands held by BLM, as well as lands selected by the State of Alaska and Native corporations that have not yet been conveyed, referred to as state-selected and Native-selected lands. State lands in Alaska came about through the Alaska Statehood Act of 1959, which gave the new state selection rights to federal land to foster development and state independence, a process that was supposed to end in 1984. Native lands were designated as a result of the Alaska Native Claims Settlement Act (ANCSA) of 1971, which superceded the Statehood Act and provided for Native claims to traditional lands. ANCSA and the Alaska National Interest Lands Conservation Act (ANILCA) of 1980 froze state selection rights to previously open federal lands. ANILCA granted a ten-year extension to complete the state-selection process by 1994. Most areas of known high mineral potential within the Ring of Fire planning area were selected and conveyed as a result of these actions.

During the land-selection process, both the state and Native organizations were allowed to overselect beyond their legal entitlement. Selections are being relinquished regularly. Thus, not all of the selected lands in the Ring of Fire planning area will be conveyed over the next 10 to 15 years. Some will be retained by BLM.

ANCSA authorized the withdrawal of federal lands from development in order to protect the public interest and create potential conservation units such as national parks, forests, and wildlife refuges (referred to as D-1 and D-2 lands). D-2 land withdrawals resulted in the introduction of ANILCA, under which many of the conservation units were established. Land withdrawals are still in effect for all remaining BLM-managed surface lands within the Ring of Fire planning area, which have restricted mining development since the early 1970s. Under the Ring of Fire PRMP/FEIS, land withdrawals may be revoked or modified based on studies that will determine their proper classification. Thus, all BLM lands are addressed in this report regardless of land withdrawal status.

BLM is responsible for administering subsurface minerals on BLM surface lands, as well as on split estate lands in which BLM owns the subsurface mineral rights, but the surface is owned by another government agency or is privately held. Federal split estate lands within the Ring of Fire planning area include U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), National Park Service (NPS), and Department of Defense (military) lands. Mineral development and surface activities on federal split estate lands are managed by the appropriate surface agency, but BLM is responsible for administrative functions such as mining claim filings, adjudications, and record keeping (Cody 1995; Nichols 1999; Persson 2004).

Land status within the Ring of Fire planning area is depicted on Figures G-2 through G-5. BLM-managed surface lands greater than 320 acres or one-half of a section are shown. Those less than 320 acres are not shown and are unavailable at this time. There are thousands of unknown BLM-managed surface parcels scattered throughout the planning area.

1.2 Minerals Addressed

Mineral resources on BLM-managed surface and subsurface lands are divided into three categories based on provisions of various mining laws. These are referred to as “leasable,” “locatable,” and “salable” minerals, which are each addressed in Chapters 3 and 4 of this report.

In the late 1800s, the USDOI began to define hardrock minerals as “locatable” if they could be found on public lands in quantity and quality sufficient to make the land more valuable by their existence (BLM 2004d; ENSR *et al.* 2003). The General Mining Law of 1872 established the authority for locatable mineral mining claims, and provided the basis for subsequent mining laws that, over time, substantially reduced the number of minerals considered locatable. Two primary laws, the Mineral Leasing Act of 1920 and the Materials Act of 1947, excluded certain mineral types that could only be acquired through a federal leasing program or disposed of by sale. Leasable minerals include oil and gas, coalbed natural gas (CBNG), geothermal fluids, and certain solid minerals such as potassium, sodium, phosphate, and oil shale. Salable minerals include common varieties of mineral materials such as construction aggregate (sand and gravel), building stone, pumice, clay, and limestone. Mineral types remaining in the locatable category following these modifications include metallic and certain nonmetallic industrial minerals generally found in lode or placer deposits (BLM 2004d; ENSR *et al.* 2003; Nichols 1999). Under certain circumstances, mineral materials can be considered locatable minerals.

1.3 Scope and Objectives

The objective of the Mineral Potential Assessment is to evaluate mineral potential within the Ring of Fire planning area at an intermediate level of detail as specified in BLM Manual 3031 (BLM 1985), for the purpose of making planning decisions in the PRMP/FEIS. BLM actions that require an intermediate level of detail include those that restrict mineral exploration and development, or that withdraw lands from mineral entry or leasing. Consequently, this report has been prepared as a preliminary mineral assessment, and is intended for use in preparation of the FEIS as required by the National Environmental Policy Act (NEPA) of 1969, and for use in the development of the PRMP for the BLM Anchorage Field Office (AFO). It is intended to be broad enough to apply to both known and unknown lands under BLM jurisdiction, but is not intended to be a comprehensive analysis of mineral potential for individual land parcels within the Ring of Fire planning area.

1.4 Occurrence and Development Potential

Mineral potential assessment requires understanding of two components, the potential for mineral occurrence and the potential for their economic development. The potential for mineral occurrence is a prediction of the likelihood of the presence of these resources. Occurrence potential does not necessarily imply that the mineral can be economically exploitable, or that the quality and quantity of the resource is known. Whenever known, however, the current and projected development potential is part of the mineral resource assessment. Development potential describes whether or not a mineral occurrence is likely to be explored or developed within the next 10 to 15 years under given geologic and nongeologic assumptions and conditions (BLM 1985).

Occurrence and development potential of each mineral resource category are discussed in Chapters 3 and 4 of this report, respectively. Development potential requires the projection of Reasonable Foreseeable Development (RFD) per BLM guidance (BLM 1990). RFD scenarios have been prepared by BLM geologists, and are provided in Attachments A and B and summarized in Chapter 4 of this Appendix. While development potential for leasables applies to both BLM-managed surface and split estate lands, BLM does not actively manage locatable or salable minerals on split estate lands. For example, on USFS land, locatables are managed by the USFS and BLM maintains records only. Thus, the description of development potential for locatables and salables in Chapter 4 is intended to apply only to BLM-managed surface lands.

1.5 Report Organization

The main body of this document is divided into three chapters. Chapter 2 provides a description of the geologic setting of each region in the Ring of Fire planning area, including rock units, structural geology, and other data that are available to provide an understanding of the resource. Chapter 3 describes known or suspected mineral deposits within each mineral category, history of past production, and criteria used in the development of occurrence potential maps. Chapter 4 provides discussion of development potential for each mineral category. Recommendations and references are provided in Chapters 5 and 6, respectively.

2.0 DESCRIPTION OF GEOLOGY

2.1 Physiography

2.1.1 Alaska Peninsula/Aleutian Chain Region

The Alaska Peninsula/Aleutian Chain region of the Ring of Fire planning area encompasses the extreme southwest portion of the state (Figures G-2 and G-3). Bounded by the North Pacific Ocean to the south and the Bering Sea to the north, the Aleutian Chain portion of the region extends in an east-west arc for over 1,000 miles from the Kamchatka Peninsula of Russia to the Alaska Peninsula. The Aleutian Chain consists of many islands ranging from 20 to 60 miles wide, which represent volcanic summits of a submarine ridge. One of the most seismically and volcanically active areas in the world, the region contains 57 volcanoes, of which 27 are reportedly active, and rise to elevations between 2,000 and 9,400 feet (ft) above sea level. The topography features glaciated and rubble-strewn volcanic cones, indented with fjords and bordered by sea cliffs or wave-beaten platforms (USFWS 1988; Nowacki *et al.* 2002; Selkregg 1974b).

The Alaska Peninsula divides Bristol Bay from the North Pacific Ocean. The peninsula extends for approximately 400 miles from Bechevin Bay at the beginning of the Aleutian Islands arc to the base of the peninsula near Mount Katmai (USFWS 1985). The Aleutian Range, which forms the backbone of the peninsula, reaches elevations of 4,500 to 8,500 ft, and is mantled on its northwest side by the Nushagak-Bristol Bay Lowland (Selkregg 1974b; Warhaftig 1965). The Alaska Peninsula is about 100 miles wide at its base, and narrows progressively toward the southwest as the range becomes increasingly submerged. The peninsula is characterized by rugged mountain terrain, lake-dotted tundra, and many rivers. Pleistocene glaciation has produced topographies that range from smooth glacial moraines and colluvial shields on the north side of the peninsula, to deeply cut fjords on the south side (Nowacki *et al.* 2002; Selkregg 1974b).

2.1.2 Kodiak Region

The Kodiak region of the Ring of Fire planning area includes Kodiak Island and all surrounding islands that lie across Shelikof Strait from the Alaska Peninsula (Figure G-3). The Kodiak archipelago is approximately 180 miles long by 70 miles wide. Kodiak Island is mountainous and intensely scoured and eroded by repeated Pleistocene glaciations. The island is characterized by high peaks with cirque glaciers and low rounded ridges surrounding glacially scoured valleys. The Kodiak Mountains reach elevations of 2,000 to 4,000 ft, and are generally drained by short swift streams. The northern part of Kodiak Island is characterized by rocky, glacially carved fjords, while the southern coastline is relatively smooth with few indentations (Nowacki *et al.* 2002; Selkregg 1974a; USFWS 1987).

2.1.3 Southcentral Region

The southcentral region of the Ring of Fire planning area encompasses a wide variety of land types surrounding the Cook Inlet Basin (Figure G-4). This region includes the eastern slopes of the northern Aleutian Range, the foothills of the southern and central Alaska Range, the Matanuska-Susitna Valley, the western part of the Talkeetna Mountains, the Chugach Mountains located between Anchorage and Valdez, the island fjords of western PWS, and the Kenai Peninsula.

The north end of the Aleutian Range merges imperceptibly with the southern end of the Alaska Range. Several active volcanoes, including Augustine, Illiamna, Redoubt, and Mount Spurr, lie in this area, reaching elevations over 10,000 ft. The northwest corner of the southcentral region is composed of foothills of the central Alaska Range, which are drained by the Yentna and Skwentna Rivers, major tributaries to the Susitna River. The ice-carved Talkeetna Mountains in the northeast corner of the region sustain several glaciers and rise to elevations of 6,000 to 7,000 ft (Selkregg 1974a; Wahrhaftig 1965).

The Cook Inlet-Susitna Lowland extends for over 200 miles through the center of the southcentral region. Together with the Upper Matanuska Valley, these gently-sloping lowlands were buried by ice and flooded by proglacial lakes several times during the Pleistocene. Numerous lakes, ponds, and wetlands associated with glacial tills and outwash deposits exist throughout this area. The lowlands are fed by multiple drainages that originate in the mountains of the Alaska Range and the Talkeetna and Chugach Mountains. Several of these drainages, including the Susitna, Matanuska, and Knik Rivers, are large, glacially fed rivers with heavy sediment loads that course down mountain ravines and braid across valley bottoms and coastal flats (Nowacki *et al.* 2002; Wahrhaftig, 1965).

The Chugach Mountains extend east of Anchorage and across the north side of PWS. Along PWS, these mountains form steep angular peaks with elevations in the range of 12,000 to 13,000 ft, that are surrounded by large icefields, snowfields and glaciers, some of which extend down to tidewater. Western PWS and the southern portion of Kenai Peninsula are characterized by a fjordal coastline, which formed where glacier-carved terrain filled with seawater after deglaciation. Broad U-shaped valleys with deeply incised sidewalls lie at the heads of many of the fjords (Nowacki *et al.* 2002). The Kenai Mountains form the central and eastern portions of the Kenai Peninsula. These moderately high, rugged mountains are covered with icefields, snowfields, and glaciers (Nowacki *et al.* 2002; Wahrhaftig 1965).

2.1.4 Southeast Region

The southeast region of the Ring of Fire planning area encompasses all of southeast Alaska from Yakutat Bay to the southeastern border with Canada (Figure G-5). This island-rich fjordland formed when the glacier-carved landscape filled with seawater after deglaciation. Broad U-shaped valleys with steep sidewalls are common at the heads of fjords. Rounded mountains with rolling till plains occur where continental and piedmont glaciers overrode the land. High, steep-sided, angular mountains exist above the upper reaches of the glaciers. The St. Elias Mountains east of Yakutat Bay reach elevations of 14,000 to 19,000 ft. South of the St. Elias Mountains, the Boundary Ranges, which form the eastern border with Canada comprise a glacier-covered upland between 5,000 and 10,000 ft (Nowacki *et al.* 2002; Selkregg 1974c).

Lush temperate rain forests blanket the shorelines and mountain slopes of this region. Open and forested wetlands occur on poorly drained soils, especially where they overly compact glacial tills, marine terraces, and gentle slopes. A narrow coastal plain lies along the Gulf of Alaska coast between Yakutat Bay and Chichagof Island (Nowacki *et al.* 2002; Wahrhaftig 1965).

2.2 Structural Geology and Tectonics

The Ring of Fire planning area spans one of the most tectonically active areas of the world. Major fault systems along the southern edge of the Ring of Fire planning area form the boundary between the North American Plate to the north and east, and the Pacific Plate to the south. The entire region has been dominated by large-scale plate convergence or oblique convergence since the Late Triassic. Manifestations of this plate interaction include development of the Aleutian volcanic arc and oceanic trench, the major right-lateral Fairweather fault system of the southeast region, extreme uplift and topographic relief on coastal mountains throughout the Ring of Fire planning area, and some of the most active seismicity and largest earthquakes in the world (Pflafker and Berg 1994).

2.2.1 Alaska Peninsula/Aleutian Chain Region

The Alaska Peninsula/Aleutian Chain region forms an arcuate arrangement of mountain ranges and submerged margins, encompassing two different geologic segments that meet near Unimak Pass off the southwestern tip of the Alaska Peninsula (Figures G-6 and G-7). The Aleutian Ridge segment lies west of Unimak Pass and is geologically younger than the Alaska Peninsula, having no pre-Eocene rocks (Vallier *et al.* 1994). The Aleutian Ridge is a mostly submerged mountain range that formed by the subduction of the Pacific Plate underneath the North American Plate along the Aleutian Megathrust. This major south-dipping decollement fault system surfaces near the bottom of the Aleutian Trench in the Pacific Ocean about 100 miles south of the islands. The average depth of megathrust earthquakes beneath the Aleutian Chain is on the order of 60 miles (Plafker *et al.* 1993).

The Alaska Peninsula segment lies east of Unimak Pass and consists of the peninsula, its adjacent islands, and submerged margin. The Aleutian Megathrust is responsible for active seismicity beneath the peninsula at depths ranging from 45 to 100 miles. A number of northeast-trending surface faults occur along the southeast coast of the peninsula, including the suspected active Chignik and Hallo Creek Faults in the vicinity of Chignik Bay and Mount Katmai, respectively. Additionally, the suspected active Bruin Bay Fault trends northeasterly through the center of the northern peninsula, separating Cenozoic deposits to the northwest from older rocks of the Peninsular Terrane to the southeast (Plafker *et al.* 1993; Siberling *et al.* 1994).

2.2.2 Kodiak Region

The Kodiak region is composed primarily of Chugach terrane rocks that are bounded on both sides by major northeast-trending and northwest-dipping thrust fault systems. Geologically, the Kodiak area is an extension of Kenai Peninsula, as they share the same rocks and structures (Figure G-7) (Beikman 1980; USFWS 1988). The Border Ranges Fault along the northwest coast of Kodiak Island separates Chugach terrane from Peninsular terrane rocks to the northwest. The Contact Fault lies along the southeast coast of Kodiak, is suspected to be active, and separates Chugach terrane rocks from younger slivers of Ghost Rocks terrane and Prince William terrane (Plafker *et al.* 1994; Siberling *et al.* 1994).

The Aleutian Megathrust lies beneath the Kodiak region at depths of about 20 to 25 miles, and surfaces in the Aleutian Trench about 70 miles southeast of Kodiak. Additional known active surface faults occur along Kodiak Shelf between the island and trench. The Kodiak region lies within the rupture zone of the 1964 Alaska earthquake, which originated along the megathrust approximately 250 miles to the northeast. Kodiak Island experienced approximately 1 to 5 ft of subsidence during this event (Plafker *et al.*1994).

2.2.3 Southcentral Region

The structural geology of the southcentral region is composed of a complex series of subparallel strike-slip and/or thrust fault systems and intervening arcuate-shaped rock terranes of various ages. Mesozoic Peninsular terrane rocks underlie the northeast part of the Alaska Peninsula, the southwest coast of Cook Inlet, and the Talkeetna Mountains. These rocks, overlain by Cenozoic strata of Cook Inlet Basin and the Susitna Valley, are bounded to the southeast by the regionally extensive, arcuate Border Ranges fault system. This fault system extends from Kodiak through the southcentral region, where it curves around to the east and eventually arcs towards the southeast region (Plafker *et al.* 1994).

The Border Ranges fault system separates Peninsular terrane from Chugach terrane rocks of Kenai Peninsula and the Chugach Mountains (Siberling *et al.* 1994). Chugach terrane rocks are separated from younger slivers of Prince William and Ghost Rocks terranes along eastern Kenai Peninsula and northern PWS by the regionally extensive Contact Fault (Plafker *et al.* 1994; Siberling *et al.* 1994).

In the Susitna Valley area, the active Castle Mountain Fault generally separates Peninsular terrane and Cook Inlet Basin strata from Kahiltna and Wrangellia terranes to the northwest. The Castle Mountain Fault merges with the Bruin Bay Fault along western Cook Inlet, which extends into northern Alaska Peninsula (Plafker and Berg 1993; Nokleberg *et al.* 1994; Siberling *et al.* 1994).

Much of the southcentral region lies within the rupture zone of the 1964 Alaska earthquake, experiencing subsidence and uplift ranging from -6 ft along eastern Kenai Peninsula to +10 ft in southwestern PWS (Plafker and Berg 1994). Active seismicity along the megathrust lies at depths of approximately 20 to 30 miles beneath Kenai Peninsula, the Matanuska-Susitna Valley, and Chugach Mountains; and is up to 60 miles deep along the west side of Cook Inlet.

Folding and reverse faulting of Cenozoic strata is suspected to be actively occurring throughout Cook Inlet Basin as a result of the oblique convergent tectonics of the region (Haeussler *et al.* 2000). Many of these features form traps for oil and gas fields in the Cook Inlet Basin (Section 3.1.1).

2.2.4 Southeast Region

The rocks of the southeast region were emplaced in the Alexander Archipelago during a series of subductions and accretions by tectonic plates obliquely colliding with the ancient continental margin of western North America from Jurassic to early Tertiary time (Gehrels and Berg 1992 and 1994). The region is dominated by a series of north-northwest-trending, active or suspected active, right-lateral fault systems that separate subcontinental blocks of accreted terranes, and intervening shorter northwest-trending faults within terranes (Figure G-9). Many of these faults have provided preferential pathways for glaciation, which has formed deeply carved valleys and fjords throughout the southeast region. Deformation during successive accretions also resulted in regional metamorphism (Gehrels and Berg 1992; Baichtal and Swanston 1996), providing a rich setting for metalliferous minerals (Section 3.2.3.4).

The active Fairweather Fault lies offshore of most of the southeast region, trending onshore at Icy Cape and east of Yakutat, where it merges with the Contact fault system of the southcentral region. The Fairweather Fault separates Yakutat terrane at the northeast apex of the Pacific Plate, from older Chugach terrane rocks along the west edge of the North American Plate. The Yakutat terrane is currently moving with the Pacific Plate, and is colliding with the North American Plate along the Fairweather Fault (Bruns 1996a, Bruns 1996b). Earthquakes greater than magnitude 7.0 occurred along the Fairweather Fault in 1949, 1958, and 1972. Two short faults east of Yakutat that are subparallel to the Fairweather Fault are the suspected source of the Yakutat Bay Earthquakes of 1899 (Plafker *et al.* 1993).

Paleozoic and Mesozoic-aged Alexander terrane rocks lie along the eastern boundary of the Chugach terrane throughout the southeast region (Siberling *et al.* 1994). The boundary between the two terranes is marked by inactive faults to the north, and the suspected active Peril Strait and Chatham Strait Faults to the south. The Chatham Fault extends north-northwesterly through Alexander Terrane into the northeast corner of the southeast region, where it is continuous with the active Denali Fault of interior Alaska (Gehrels and Berg 1992 and 1994; Plafker *et al.* 1993). The Denali Fault was the epicenter of the magnitude 7.9 Denali Earthquake of 2002.

Slivers of Wrangellia terrane and Gravina-Nutzotin belt rocks occur along the west and east sides of the Alexander terrane, respectively. Taku terrane rocks lies east of both the Alexander terrane and Gravina belt, separated by the Denali Fault at the north end of the region, and by numerous northwest-trending inactive faults throughout central and southern the southeast region (Gehrels and Berg 1992 and 1994; Siberling *et al.* 1994; Plafker *et al.* 1993). Post-accretionary plutonic rocks intrude both Taku and Stikinia terrane strata along the eastern border of the southeast region with Canada, and are separated from Taku terrane rocks by the Coast Range megalineament (Gehrels and Berg 1992).

2.3 Historical Geology and Rock Units

2.3.1 Alaska Peninsula/Aleutian Chain Region

Aleutian Chain. The Aleutian Chain, geologically the youngest region in Alaska, is dominated by Tertiary and Quaternary volcanic rocks that form the crests of a submarine volcanic arc (Beikman 1980; USFWS 1988) (Figures G-2 and G-6). The Aleutian arc formed since Eocene time along zones of convergence between the North American Plate and various oceanic plates, including the modern day Pacific Plate and the extinct Kula Plate. The first major growth of the Aleutian Ridge occurred after a rotational change in the Kula Plate during the Eocene. The ridge was subsequently eroded and experienced renewed volcanism since the Oligocene (Vallier *et al.* 1994).

Figure G-10 presents a stratigraphic column of sedimentary and volcanic formation names of the Aleutian Chain. Most of the islands are underlain by Cretaceous or Lower Tertiary basement rocks consisting of basalt and andesite lava flows and tuffs (Selkregg 1974b; Vallier *et al.* 1994). Metamorphosed mafic plutonic rocks comprise a portion of the Eocene basement rocks on Attu, and younger intrusive rocks of felsic to intermediate composition outcrop in the central and eastern Aleutians. Lower to Middle Tertiary marine interbedded sedimentary and volcanogenic strata have been identified in the vicinity of Attu and Amchitka Islands in the western Aleutians, and on Unalaska Island in the eastern Aleutians. These units include primarily volcaniclastic debris flows, turbidites, and sandstone (Vallier *et al.* 1994).

Most of the active volcanoes of the Aleutian arc are stratovolcanoes or composite cones, which are characterized by steep slopes, dike swarms radiating from the center, and parasitic cones and vents on the flanks of the main volcano (USFWS 1988; Wohletz and Heiken 1992). Older volcanoes of the Aleutians include both stratovolcanoes and shield volcanoes, characterized by thin flows and gentle slopes. Many of the Aleutian volcanoes also contain calderas of former collapsed volcanoes (USFWS 1988).

Unconsolidated surficial deposits of the Aleutian Chain include volcanic ash, pumice, cinders, and alluvium, as well as deposits of glacial origin. Glaciation is responsible for the presence of till, meltwater outwash, and loess (USFWS 1988).

Alaska Peninsula. Since the early Eocene, the entire Aleutian arc, including the Alaska Peninsula, has shared a similar geologic history. Prior to the Eocene, however, the evolution of the Alaska Peninsula was different from the rest of the Aleutian arc. Parts of the Alaska Peninsula may have originated as an island arc far to the south of their present position, and were accreted onto the rest of Alaska during Late Cretaceous and earliest Tertiary time. The Aleutian-Alaska Range batholith, which forms the backbone of the Alaska Peninsula, was emplaced in the Jurassic prior to accretion. Late Cretaceous strata of the Alaska Peninsula (Figure G-7) were formed from detritus of the eroded batholith and earlier Mesozoic formations. Volcanism and magmatism occurred over several episodes along the peninsula during the Tertiary, and sedimentary rocks of this period contain many volcaniclastic sequences. Folding and development of en echelon anticlines occurred in the central Alaska Peninsula during the middle Tertiary (Nokleberg *et al.* 1994; Vallier *et al.* 1994). Tertiary strata of the northwest side of the peninsula are gently deformed and rest on Jurassic basement (Molenaar 1996a, Molenaar 1996b). Numerous late Tertiary granitic stocks intrude the sedimentary section, and volcanism during the Quaternary resulted in a chain of stratocones along the peninsula (Miller and Richter 1994; Molenaar 1996a; Molenaar 1996b).

The present day configuration of rock units on the peninsula can be divided into two distinct areas that are split down the center of the peninsula by the inferred extension of the Bruin Bay Fault (Section 2.2.1, Figure G-7): 1) the mountainous southeastern half consists of folded Mesozoic to Tertiary sedimentary rocks and Quaternary volcanoes; and 2) the alluvial-covered lowland of the northwest half is underlain by Tertiary sedimentary rocks that thicken to the northwest under Bristol Bay. Mesozoic strata on the southeast side of the peninsula include Triassic limestone and shale; and a number of marine and nonmarine graywacke, sandstone, and shale formations of Jurassic and Upper Cretaceous age, including the coal-bearing Chignik Formation (Figure G-10) (Burk 1965; Merritt and Hawley 1986). Limestones of the Upper Triassic Kamishak Formation have been the focus of oil exploration activities in this area (Molenaar 1996a; Molenaar 1996b) (Section 3.1.1.1). Early Tertiary strata of the Alaska Peninsula include volcaniclastic siltstone, sandstone, and conglomerate of the Tolstoi and Belkoski Formations. Middle Tertiary rocks consist primarily of mudstones, siltstones, and sandstones with intercalated coals, which were laid down in swampy to marine environments (Stepovak, Meshik, and Bear Lake Formations). Marine sandstone and conglomerate comprise the Pliocene Tachilni Formation (USFWS 1985).

Surficial deposits on the Alaska Peninsula are mostly of glacial, fluvial, and volcanic origin. The eastern slopes of the Aleutian Range are generally free of surficial cover, while the gentler northwest slopes and Bristol Bay lowlands contain a thick blanket of unconsolidated material, including volcanic ash, pumice, cinders, glacial till, morainal deposits, outwash, and alluvium. Sand, silt, and gravel are found on beds and terraces of modern floodplains and meltwater streams. Fine-grained glaciolacustrine deposits occur along some of the larger lakes, and slope wash deposits are found at the base of volcanoes (USFWS 1988; Selkregg 1974b).

2.3.2 Kodiak Region

Like the Alaska Peninsula, the Kodiak region evolved along a zone of plate convergence since at least the Jurassic. The various rock terranes of the Kodiak region, including the Peninsular, Chugach, and Prince William Terranes, originated far to the south of their present position, and were accreted during the Late Cretaceous and Lower Tertiary through intermittent subduction-related offscraping of oceanic deposits. The Border Ranges Fault along the northwest side of the Kodiak region was initiated prior to accretion, and forms the boundary between the Peninsular and Chugach terranes (Plafker *et al.* 1994; USFWS 1987; Vallier *et al.* 1994).

Chugach and Prince William terrane rocks are generally younger than those of the Peninsular terrane, and consist largely of fine-grained clastic and volcanic rocks deposited in deep marine settings (e.g., Uyak Complex, Kodiak Formation, Ghost Rocks Formation, and Sitkalidak Formation, Figure G-11). Granitic intrusive rocks invaded the upper Cretaceous Kodiak Formation during Paleocene time. Middle to Upper Tertiary strata along the southeast side of the Kodiak region (e.g., Sitkinak, Narrow Cape, and Tugidak Formations) record progressive tectonic uplift in the region, a decrease in volcaniclastic rocks, and an increase in strata of glaciomarine origin (Vallier *et al.* 1994; Siberling *et al.* 1994).

Three main glaciations that covered Kodiak during the Pleistocene left behind discontinuous surficial deposits consisting of moraines, glacial till, and outwash. A small amount of alluvium occupies the short steep rivers of Kodiak. Volcanic ash from Aleutian Range eruptions forms a relatively continuous surficial layer throughout the Kodiak region (USFWS 1987).

2.3.3 Southcentral Region

Kenai Peninsula and Western PWS. Geologically, Kenai Peninsula is an extension of the same rock terranes found on Kodiak. Like Kodiak, the Chugach and Prince William terranes of Kenai and western PWS are accreted parts; that is, they were scraped off onto bending edges of the northern continental plate as the southern oceanic plate was underthrust (USFWS 1987). Most rocks of the Chugach and Prince William terranes of eastern Kenai Peninsula and the Chugach Mountains consist of metamorphosed, deep-water flysch deposits such as graywacke and slate; mafic volcanic and igneous rocks such as pillow basalts, greenstone, and gabbro; and ultramafic assemblages (e.g., McHugh Complex and Valdez group, Figure G-11) (Tysdal and Case 1979; Plafker *et al.* 1994; Siberling *et al.* 1994).

Aleutian-Alaska Range and Talkeetna Mountains. Geologically, the northern part of the Aleutian Range along the west side of Cook Inlet is an extension of the Alaska Peninsula. Jurassic intrusive rocks of the Aleutian-Alaska Range batholith form the backbone of the mountains in this area (Beikman 1980). A narrow band of Jurassic and Tertiary Peninsular terrane strata are juxtaposed against the intrusive rocks by the Bruin Bay fault (Figures G-8 and G-12). Quaternary volcanic rocks, including andesite flows and pyroclastic deposits, form the active stratovolcanoes of Augustine, Illiamna, Redoubt, and Mount Spurr (Alaska Volcano Observatory [AVO] 2004; Miller and Richter 1994).

Late Jurassic to Early Cretaceous strata of the Kahiltna assemblage overlies basement rocks of the Alaska Range and western Talkeetna Mountains in the northwest part of the southcentral region. These rocks consist of complexly deformed volcaniclastic turbidites, conglomerates, sandstone, graywacke, and phyllite deposited in slope and fan environments of a marine flysch basin, that later collapsed as a result of compressional tectonics (Nokleberg *et al.* 1994) (Figure G-12). Tertiary granitic rocks intrude these strata in the vicinity of Mount Spurr and on the south side of the Alaska Range (Figure G-8).

Peninsular and Kahiltna terrane rocks extend into the northeastern corner of the southcentral region, with Wrangellia terrane rocks sandwiched in between the two (Siberling *et al.* 1994). A major thrust fault, the Talkeetna thrust, places Wrangellia and Peninsular terrane rocks over the Kahiltna assemblage to the north. Together, these three terranes form the complexly deformed and metamorphosed Talkeetna Mountains. Within the planning region, Wrangellia terrane rocks consist primarily of Pennsylvanian and Permian marine volcanic rocks and shallow water limestone, and are interpreted to be the stratigraphic basement for Mesozoic Peninsular terrane rocks (Nokleberg *et al.* 1994). A large granite batholith of both Mesozoic and Tertiary age intrudes all three sedimentary terranes in this area, and flat-lying Tertiary basalt caps both the metasedimentary and plutonic rocks of the area (Beikman 1980; Selkregg 1974a) (Figure G-8).

Cook Inlet-Susitna Basin. Cook Inlet-Susitna Basin is an elongate, northeast-trending, fault-bounded basin that is bordered to the west and north by the Aleutian-Alaska Range and Talkeetna Mountains, and to the southeast by the Chugach and Kenai Mountains. The basin contains up to 25,000 ft of Tertiary strata overlying a 30,000-ft thick sequence of Mesozoic sedimentary rocks belonging to the Peninsular terrane (Selkregg 1974a; Swenson 1997). Together these deposits form important oil and gas, coal, and CBNG resources in the Ring of Fire planning area.

Stratigraphic columns for the Cook Inlet-Susitna Basin are provided on Figure G-13. Volcaniclastic rocks of the Lower Jurassic Talkeetna Formation form the effective basement of the basin. The overlying Middle to Upper Jurassic Tuxedni Group and Chinitna Formation contain rich marine-shale source rocks for all of the oil and some natural gas in the region. Along with the Cretaceous Matanuska Formation, these rocks were deposited in coastal to deep marine environments, and unconformably underlie the mostly nonmarine petroleum-bearing Cenozoic rocks (Magoon 1994 and 1996a).

The Cenozoic strata of Cook Inlet Basin overlap the Alaska Range batholith to the northwest and the Border Ranges Fault to the southeast (Beikman 1980; Magoon 1994) (Figure G-8). Primary stratigraphic units within the Tertiary section beneath Cook Inlet and Kenai Peninsula include the West Foreland, Hemlock, Tyonek, Beluga, and Sterling Formations. These units were deposited in a terrestrial fore-arc basin setting, and each contains reservoir rocks for oil or gas somewhere in the basin (Figure G-13a). In addition, numerous coal deposits were laid down and preserved throughout the Tertiary section, providing the primary source of natural gas in the Cook Inlet basin. The coal-bearing Paleocene Chickaloon Formation lies at the base of the Tertiary section in the Matanuska Valley area, but is absent beneath Cook Inlet and Kenai Peninsula (Figure G-13b) (Barnes and Payne 1956; Barnes 1962; Wahraftig *et al.* 1994). The Tyonek, Beluga, and Sterling Formations contain large coal deposits elsewhere in the basin, forming the Beluga, Kenai, Susitna, and Yentna coal fields (Merritt and Hawley 1986).

Surficial Deposits. Unconsolidated surficial deposits of the southcentral region consist chiefly of glaciofluvial sediments related to a succession of repeated Pleistocene glaciations, and the development of drainage systems from several large mountain ranges (Reger and Pinney 1997; Selkregg 1974a). As glaciers advanced and retreated, they left behind a complex series of deposits produced by the interplay between glacial ice, flowing streams, lakes, and estuaries. Moraines, till, and fine-grained glaciolacustrine deposits are common throughout the Kenai Peninsula, the Anchorage Bowl, and Susitna Valley. Fluvial deposits consisting of modified glacial outwash, alluvial fans, and floodplain and terrace deposits are present throughout the river systems of the southcentral region. Wind-blown silt and sand deposits occur in the Susitna delta area. Coastal beaches and spit deposits are common around Cook Inlet, particularly on the west side of Upper Cook Inlet (Selkregg 1974a).

2.3.4 Southeast Region

As described in Section 2.2.4, the rocks of the southeast region were emplaced during a series of subductions and accretions by colliding tectonic plates during Jurassic to early Tertiary time (Gehrels and Berg 1992 and 1994). Thus, the current geologic configuration of the area consists of a series of linear, northwest-trending terranes or lithic assemblages, each with a unique provenance and history prior to accretion. Stratigraphic columns for the rock terranes of the southeast region are depicted on Figures G-11 and G-14, and described below from northwest to southeast.

Yakutat, Chugach, and Wrangellia Terranes. Together these three terranes form the northwest margin of the southeast region from Yakutat Bay to the southern tip of Baranof Island. Yakutat Terrane rocks lie on the west side of the Boundary-Fairweather Fault from Yakutat Bay to the Lituya Bay area (Figure G-9), and extend northwest out of the Ring of Fire planning area towards PWS. Yakutat terrane rocks in the Ring of Fire planning area include the Jurassic- to Cretaceous-age Yakutat Group, composed of highly deformed marine sedimentary and volcanic rocks deposited in a submarine fan environment, which is overlain by mostly nonmarine Tertiary formations that thicken rapidly to the west (Gehrels and Berg 1994). Sandstones within the Tertiary formations have been the focus of oil and gas exploration in this area (Bruns 1996) (Section 3.1.1.1). From oldest to youngest, the Tertiary sequence includes siltstone and sandstone of the Stillwater Formation, coal-bearing terrestrial deposits of the Kulthieth Formation, deltaic and shallow marine deposits of the Tokun Formation, organic-rich marine shales of the Poul Creek Formation, and siltstone and sandstone of the Yakataga Formation (Figure G-11).

Chugach terrane rocks lie east of the Fairweather Fault, and extend from the head of Yakutat Bay south to the south end of Baranof Island. Chugach terrane rocks were emplaced during the Cretaceous as a result of plate convergence along the older Alexander and Wrangellia terranes, and are part of the same sequence of rocks that arc northwest towards Kenai Peninsula and the Kodiak region (Sections 2.3.2 and 2.3.3). These rocks consist of strongly deformed Mesozoic graywacke and slate, as well as a mélange of basalt, ultramafic, plutonic rocks, and argillite. Greenschist metamorphism overprints the inboard (eastern) side of these rocks (Gehrels and Berg 1994). Cretaceous to Tertiary-age granitic rocks intrude the older sequence and are exposed at the surface in isolated patches (Figure G-9).

Wrangellia Terrane contains the oldest rocks of the three terranes in this group, and is exposed on the east side of the Chugach terrane on northwest Chichagof Island. This block is interpreted to be an extension of the Wrangellia Terrane that arcs towards Interior Alaska and into the Talkeetna Mountains (Siberling *et al.* 1994) (Section 2.3.3). On Chichagof, these rocks consist of Mesozoic basalt, limestone, and deep-marine sedimentary rocks, overlying upper Paleozoic metavolcanics, metasedimentary rocks, and marble (Gehrels and Berg 1994).

Alexander Terrane and Gravinia Belt. The Alexander terrane occupies the largest area of the southeast region, and contains some of the oldest rocks in Alaska. It comprises a variety of sedimentary, metamorphic, and plutonic rocks of Late Precambrian to Middle Jurassic age. Alexander terrane rocks are found in the Glacier Bay area, on the west side of Lynn Canal and Chatham Strait, and on the northeast half of Chichagof Island. They also cover most of Admiralty and Kuiu Islands, lie within central sections of Kupreanof and Zarambo Islands, and are exposed throughout Prince of Wales Island and adjacent smaller islands to the west (Figure G-9).

Much of the Alexander Terrane formed near a paleoequator in an oceanic and volcanic island arc environment, prior to northward rafting that resulted in the current structural setting. Precambrian volcanogenic greenschist and marble are located in the southwest corner of the terrane. Lower to middle Paleozoic strata (Ordovician, Silurian, Devonian ages) are the most widespread geologic units within the Alexander Terrane, and consist of turbidites, shallow marine carbonates, and conglomerate (Gehrels and Berg 1994; Beikman 1980). Upper Paleozoic rock units consist primarily of shallow marine carbonates and clastic sedimentary rocks, as well as mafic to intermediate volcanic rocks. Mesozoic strata overlie the older rocks on a regional unconformity, and include basal conglomerate, tuff, limestone, argillite, and pillow basalts that may have formed in a rift environment (Gehrels and Berg 1994). Cretaceous granitic intrusive rocks on southern Prince of Wales Island formed as the youngest component of the Alexander Terrane prior to accretion.

Gravinia Belt rocks occur in narrow strips along the southeast side of the Alexander Terrane along the eastern coasts of Admiralty and Kupreanof Islands. These rocks consist of Jurassic to Cretaceous marine slate and graywacke, and interbedded andesitic to basaltic volcanic rocks, with lesser amounts of conglomerate and intrusives (Beikman 1980; Gehrels and Berg 1994). These rocks record a transition in metamorphism from low grade on the west to higher grade on the flanks of the Coast Mountains to the east.

Taku Terrane and Coast Mountains Batholith. Taku terrane rocks lie along the east side of the Alexander and Gravinia rocks, and consist mostly of poorly understood Paleozoic and Mesozoic rocks characterized by strong deformation and high-grade metamorphism. Recognizable rock types within the sequence are similar to Gravinia Belt rocks, and include basalt, fine-grained marine sedimentary rocks, tuffs, carbonates, and metaconglomerates (Gehrels and Berg 1994; Siberling *et al.* 1994).

The Coast Mountains Batholith consists mostly of Cretaceous to Tertiary plutonic rocks of intermediate to felsic composition (Beikman 1980) (Figure G-9). These rocks were intruded during the later stages of regional metamorphism and deformation of adjacent terranes beginning in the Cretaceous, and become progressively younger (Eocene-aged) towards the east and south (Moll-Stalcup *et al.* 1994). These rocks are interpreted to have originated in Andean-type continental margin arc in response to subduction, or as partial melting of older metamorphic rocks during regional metamorphism (Gehrels and Berg 1994).

Surficial Deposits. Unconsolidated deposits cover most of the lowlands of the southeast region, but are thin or absent in the uplands. Much of the surficial material is of glacial origin deposited during multiple Pleistocene advances. Glacial retreats left behind deposits of moraines, outwash plains, a ubiquitous thin veneer of compact till, glaciofluvial material, and fine-grained glaciolacustrine deposits at the heads of ice-dammed valleys. Stream deposits of silt, sand, and gravel are common along most streams (Selkregg 1974c). Beach gravel deposits occur along many shorelines. A narrow coastal plain characterized by glacial outwash and longitudinal beach ridges lies along the coast in the Yakutat area (Nowacki *et al.* 2002; Wahrhaftig 1965).

2.4 Geophysics/Geochemistry

The following discussion provides an overview of geophysical and geochemical data available for the Ring of Fire planning area that are typically used in the identification and interpretation of mineral resources.

2.4.1 Geophysical Data

Aeromagnetic Surveys. The presence of magnetic minerals in rocks causes distortions or anomalies in the earth's magnetic field that, when interpreted alongside geologic data, can provide evidence of mineralized areas. Predictive models are developed from aeromagnetic data for specific geologic units, and, in combination with geochemical analyses of stream sediment, can be extrapolated to improve upon existing geologic maps and predict mineral potential.

Aeromagnetic data collected in the Ring of Fire planning area from the 1960s through the 1980s were first compiled into a regional contour map by Godson (1984 and 1991). More recently, digital magnetic surveys have been completed by the Alaska Division of Geological & Geophysical Surveys (DGGS), BLM, U.S. Geological Survey (USGS), and contracted scientists for targeted areas of Alaska, in an effort to provide additional tools for exploration of new mineral resources (DGGS 2004; Saltus and Simmons 1997; Saltus *et al.* 1999a). Electromagnetic and apparent resistivity data were also derived from these surveys.

Within the southcentral region, digital aeromagnetic surveys have been completed for the Tyonek, Anchorage, Petersville, and Talkeetna areas (Alstatt *et al.* 2002; DGGS 2004; USGS 2002). Surveys have been completed for the Stikine and Ketchikan mining districts, within the southeast region (DGGS 2004; Still *et al.* 2002; Wynn *et al.* 2001). The results of recent surveys conducted in the Stikine area, for example, have shown promising correlations between magnetic signatures and volcanic massive sulfide (VMS) mineral occurrences (Still *et al.* 2002; Wynn *et al.* 2001). A number of additional mineral terranes within the Ring of Fire planning area being considered for future aeromagnetic surveys depending on state funding levels. These include the west side of lower Cook Inlet near Lake Illiamna; the Yentna, Skentna, Willow Creek, King Mountain, and Yenlo Hills areas of the southcentral region; and Chichagof Island, southeast Prince of Wales Island, and the Haines/Klukwan area of the southeast region (DGGS 2004; Burns 2004).

Gravity Data. Isostatic gravity data was collected for portions of the Ring of Fire planning area in the 1970s and 1980s. These surveys were compiled in a comprehensive map by Barnes *et al.* (1994). Gravity data are sensitive to lateral rock density variations in the earth's upper crust. In the Ring of Fire planning area, gravity data depict major lows caused by low-density sediments in the upper Cook Inlet-Susitna basin as well as the coastal Yakutat area. Arcuate highs exist along the Alaska Peninsula, western PWS, the Chugach and Talkeetna Mountains, and in the northwestern corner of the southeast region, which probably reflect the presence of mafic and ultramafic rocks in these regions (Barnes *et al.* 1994; Patton *et al.* 1994; Saltus *et al.* 1999a; Saltus *et al.* 1999b).

Aeroradiometric Data. Airborne gamma-ray spectrometry surveys were conducted in some regions of the Ring of Fire planning area between 1975 and 1980 as part of the National Uranium Resource Evaluation (NURE) program. This program was initiated by the U.S. Atomic Energy Commission in the 1970s with the primary goal of identifying uranium resources in the U.S. (Smith 1997). Gamma-ray surveys measure radioactive decay of the naturally occurring elements potassium, uranium, and thorium. In addition to directly sensing these elements, radiometric data can be used to locate intrusive rocks or map rock units with distinctive radiometric signatures, such as metamorphic rocks with uranium-bearing minerals. Thus, the data can be used to differentiate different types of rocks and soils, and to aid in mineral exploration (Duval 2001; Saltus *et al.* 1999b). Within the Ring of Fire planning area, radiometric surveys have been completed for the northwest corner of the Alaska Peninsula, most of the southcentral region, and all of the southeast region.

Seismic Reflection and Electric Log Data. Geophysical data such as seismic reflection data and downhole logging methods are commonly used in the oil and gas industry to identify exploration prospects and maximize well production. Seismic data related to oil and gas exploration are largely company-confidential and were not reviewed for this analysis. Electric logs for wells in developed fields and older exploration wells are typically available at the Alaska Oil and Gas Conservation Commission (AOGCC) and the Alaska Department of Natural Resources (ADNR) Division of Oil & Gas (2004c).

Geophysical Methods in Geothermal Exploration. Self-potential (S-P) resistivity surveys and refraction seismic methods were used to conduct geothermal exploration and siting investigations in the Aleutians in the 1980s (e.g., DGGS 1986; Motyka *et al.* 1985; Republic Geothermal, Inc. 1985). S-P anomalies from fluxes of water and heat through the subsurface can generate measurable natural electrical fields or S-Ps (Hoover *et al.* 1995). In the Aleutians, S-P surveys have been used to identify the location of reservoirs containing superheated saline groundwater adjacent to volcanoes. Seismic refraction data have been used in conjunction with borehole stratigraphy to identify cross-hole structural and stratigraphic changes (DGGS 1986).

2.4.2 Geochemical Data

Petrologic and Elemental Data. Numerous studies are available documenting the petrology and chemical composition of various rock types in southern Alaska. Moll-Stalcup *et al.* (1994) provide a summary of petrologic and chemical data for the volcanic and intrusive rocks of southern Alaska. Various researchers have conducted geochemical analyses of specific regions; for example, Kay and Kay (1994) provide representative analyses of Aleutian andesitic magmas. Dusel-Bacon (1994) gives a comprehensive interpretation of the metamorphic facies composition for all of Alaska. Barker *et al.* (1994), and Miller and Richter (1994) summarize elemental concentrations of some of the Quaternary and older accreted volcanic rocks within the Ring of Fire planning area. Nokleberg *et al.* (1987 and 1994) summarize metalliferous concentrations of significant lode and placer deposits in Alaska from geochemical analyses. Geochemical analyses have also been compiled for rocks of specific mining districts in southern Alaska by the former U.S. Bureau of Mines (USBOM) and BLM (e.g., Bittenbender *et al.* 1999; Jansons *et al.* 1984; Maas *et al.* 1995; Still *et al.* 2002).

Several online databases provide the results of elemental geochemical analyses from stream sediment samples within the Ring of Fire planning area. An extensive Hydrogeochemical and Stream Sediment Reconnaissance program was conducted as part of NURE (Section 2.4.1), resulting in the collection of thousands of stream sediment, soils, lake sediment, and well water samples across Alaska and the contiguous U.S. These data include elemental uranium concentrations, as well as a number of other elements (Grossman 1998; USGS 2004c), and are available on a quadrangle basis for selected areas of the Ring of Fire planning area (e.g., Wiltse 1991a and 1991b). Similarly, the USGS' Rock Analysis Storage System (RASS) provides elemental geochemical data from stream sediments, soils, waters, and organic material that can be downloaded on a quadrangle basis. RASS is intended as a reconnaissance tool for identifying the regional geochemical signature of an area for mineral exploration or environmental baseline purposes (Bailey 2004). Stream sediments were chosen as the principle sample medium for these programs because they integrate many rock sources within a drainage basin and allow for lower sample density. Approximately 28,000 sample results are available from RASS for the Ring of Fire planning area (Bailey *et al.* 2000 and 2004). Additional stream sediment samples have been collected by BLM as part of specific mineral assessment studies in the Ring of Fire planning area (e.g., Bittenbender *et al.* 2001; Maas *et al.* 1995).

The USGS conducted a multidisciplinary resource assessment program in the early 1970s through early 1990s that included geologic mapping, geochemical sampling, and airborne geophysics (Bailey 2004). These efforts, called the Alaska Mineral Resource Appraisal Program (AMRAP) were synthesized on a quadrangle basis for selected areas of Alaska (e.g., Liss and Wiltse 1993a and 1993b). PLUTO is a USGS database that provides the results of geochemical analyses on plutonic and volcanic igneous rock samples. Approximately 2,800 samples are available on PLUTO database for the Ring of Fire planning area, including samples from the Aleutians, Alaska Peninsula, Kodiak, Kenai Peninsula, Susitna Basin, and the southeast region (USGS 2004c).

Petroleum Geochemistry. The geochemistry of petroleum systems in Cook Inlet has been summarized by Magoon (1994). These data include oil gravity, sulfur content, pristane/phytane ratios, carbon isotope values, gas specific gravity, percent methane, and gas heating values for each field and stratigraphic/production unit. Selected geochemical data, as well as information related to reservoir characteristics and production, are provided in Table G-2 for the onshore oil and gas fields within the Cook Inlet Basin. Chemical markers from the Cook Inlet oil fields indicate that the oil originates from marine-shale source rock. Chemical data for Cook Inlet natural gas provide an indication of its origin as part biogenic and part thermal (Magoon 1994).

Magoon (1994) also summarizes the petroleum geochemistry of the Gulf of Alaska Basin, the southeast corner of which extends into the southeast region of the Ring of Fire planning area. Geochemical analyses of potential source rocks across the basin suggest that, while source rocks are mature enough to generate oil in the Katalla Field to the northwest near Cordova, they decrease in thermal maturity to the southeast. Oils in the southeast portion of the basin generally have lower gravities (13^{o} to 37^{o} American Petroleum Institute), higher sulfur contents, and are lacking in normal alkanes compared to oils in the northwest part of the basin, indicating that they may be biodegraded.

Molenaar (1996a; 1996b) describes general geochemical characteristics of speculative Mesozoic and Tertiary oil and gas plays on the Alaska Peninsula. In general, the thermal maturity of source rocks on the northwest side of the peninsula (Tertiary play area) is expected to be less than that of the southeast side of the peninsula (Mesozoic play area).

Coal Geochemistry. Merritt and Hawley (1986) summarize the geochemistry of coalfields and coal districts of Alaska. The classification of coal by rank is generally a measure of the metamorphism it has undergone since burial. Coal ranks are divided into four classes: in decreasing order of carbon content and heat value, these are anthracite, bituminous coal, subbituminous coal, and lignite (American Society of Testing and Materials [ASTM] 1999; Wahrhaftig *et al.* 1994; Wood *et al.* 2003). Within the bituminous class, coals are further subdivided into five groups based on the amount of volatile matter present and heat value (low volatile, medium volatile, and high volatile A, B, and C) (U.S. Department of Energy [USDOE] 2004b; Wood *et al.* 2003).

Within the Ring of Fire planning area, high rank anthracite coals are known to occur only in the northeast portion of the Matanuska Field, changing to bituminous coal towards the southwest. Overall, Matanuska Field coals have heating values in the range of 10,000 to 14,000 British thermal units per pound (Btu/lb). Merritt and Hawley (1986) and DGGS (1993a) list the geochemical characteristics of Matanuska coals, including percent carbon, volatiles, sulfur, and ash content; the major oxides and trace element composition of the ash; vitrinite reflectance; and a breakdown of organic constituents (maceral composition). Other coal fields of the Cook Inlet-Susitna basin (Beluga, Kenai, Susitna, and Yentna Fields) contain lower rank subbituminous coals, with heating values in the range of 5,400 to 9,500 Btu/lb (Merritt and Hawley 1986).

On the Alaska Peninsula, the Chignik Field and Ugashik District contain high-rank bituminous coals, while those of the Herendeen Bay Field are partly bituminous on the northwest side of the field, changing to lignite to the southeast. The coal district on Unga Island is composed of low-rank lignite. A complete geochemical breakdown of the Chignik and Herendeen Fields is provided by DGGS (1993a).

In the southeast region, the Admiralty and Angoon coal districts located on Admiralty Island are considered bituminous. Several small outcroppings that comprise the Kuiu District on Kuiu Island contain lignite (Merritt and Hawley 1986).

CBNG Geochemistry. CBNG is a methane-rich natural gas that is generated during the conversion of plant material to coal, and is stored in the micropores of coal layers. CBNG is mainly composed of methane, with small quantities of other hydrocarbons such as ethane and propane. It typically contains few impurities, such as hydrogen sulfide and carbon dioxide normally found in natural gas. CBNG is comparable in heating value to conventional natural gas (about 1,000 Btu/standard cubic ft [scf]) (Clough 2001).

The presence and productivity of CBNG is dependent on thermal maturity and other non-geochemical factors (Section 3.1.3.1). High volatile B bituminous coals with vitrinite reflectance (Ro) between 0.6 and 1.0 percent are the minimum threshold of thermal maturity required for the generation of significant amounts of thermogenic gas (Dolan 2002; Tyler *et al.* 2000).

Geochemical analyses of CBNG from a test well in the Cook Inlet-Susitna basin of the southcentral region are summarized by Smith (1995). Coal seams sampled for CBNG between depths of approximately 500 to 1,200 ft indicate gas contents in the range of 63 to 245 scf/ton, vitrinite reflectances increasing with depth up to a maximum of 0.58 percent, and low moisture contents in the range of 4.82 to 9.02 percent. Gas composition was 98 percent methane with minor amounts of carbon dioxide and nitrogen. Carbon isotope analyses indicated that CBNG has both thermogenic and biogenic sources in this area, and that the ratio of thermogenic to biogenic gas increases with depth.

Although CBNG geochemical data are not available for the Alaska Peninsula, Molenaar (1996) indicates that the thermal maturity of conventional oil and gas source rocks on the northwest side of the peninsula is generally less than that of the southeast side of the peninsula, and that the northwest side may be favorable for biogenic gas. Tyler *et al.* (2000) summarize coal geochemical data relevant to CBNG from the Chignik coal field on the southwest side of the peninsula. Vitrinite reflectance values of surface coals (averages of 0.64 to 0.76 percent) indicate that most of the subsurface coals in the area have probably reached, or are approaching, the threshold required for thermogenic methane generation. Maceral composition analyses of coals from the Chignik, Herendeen Bay, and Unga Island fields on the southeast side of the peninsula suggest that the coals generally have good gas-generating potential.

Geochemical data for thermal springs within the Ring of Fire planning area have been summarized in a number of DGGS publications (e.g., Motyka *et al.* 1983 and 1993; Motyka and Moorman 1987). Measurements of temperature, pH, and total dissolved solids are provided for numerous fumeroles and hot springs in the Aleutians and Alaska Peninsula, for summit fumeroles in the four large volcanoes along the west side of Cook Inlet, for an exploratory well in the Susitna basin, and for about 20 hot springs in the southeast region. These publications also describe the use of chemical geothermometry data to estimate subsurface reservoir temperature (Section 3.1.4.1).

3.0 DESCRIPTION OF MINERAL RESOURCES AND OCCURRENCE POTENTIAL

As indicated in Section 1.2, mineral resources on BLM-managed surface and subsurface lands are divided into leasable, locatable, and salable categories based on provisions of various mining laws. The following discussion of known and potential resources within the Ring of Fire planning area is broken down into three sections according to these categories.

3.1 Leasable Minerals

Leasable minerals present in the Ring of Fire planning area include oil and gas, coal, CBNG, geothermal resources, and certain solid minerals. The known resources and occurrence potential of each leasable mineral type are discussed in Sections 3.1.1 through 3.1.5.

3.1.1 Oil and Gas

3.1.1.1 Basins, Fields, Plays, and Production History

Known sedimentary basins with oil and gas potential are located within the Ring of Fire planning area in the following areas: the Alaska Peninsula, the Cook Inlet-Susitna Basin in the southcentral region, and the western edge of the Copper River Basin, and the Yakutat area of the southeast region (Ehm 1983; Kirschner 1992; Magoon *et al.* 1996). Figures G-15 through G-18 depict the location of sedimentary basins mapped by Ehm (1983), exploration wells from ADNR Division of Oil and Gas (2004e), existing state and federal leases (ADNR Division of Oil and Gas 2004b), federal and state unit boundaries for existing fields (ADNR Division of Oil and Gas 2004b), USGS oil and gas assessment play areas (USGS 1995; Beeman *et al.* 1996), and occurrence potential (described in Section 3.1.1.2). These data, as well as the production history of existing oil and gas fields in the planning area, are summarized below by geographic region.

The USGS conducts estimates of conventional oil and gas resources in the U.S. based on the concept of a “play,” which is defined as a set of discovered or undiscovered oil and/or gas accumulations sharing similar geographic boundaries and geologic attributes, such as source rock, reservoir type, and trap. Periodic National Assessments have been conducted by USGS since the early 1900s, in which known or postulated plays were refined in each successive study based on new data and techniques. Joint assessments by USGS for onshore resources and by Minerals Management Service (MMS) for offshore resources have been conducted since the 1980s. The most recent National Assessment was conducted in 1995 (USGS 1995; MMS 1996).

BLM (1990) guidance directs that the evaluation of fluid mineral potential on BLM-managed lands be based on USGS resource estimates. Thus, the evaluation of oil and gas resources in the following paragraphs is derived largely from 1995 USGS play analyses and reserves modeling (USGS 1995; Beeman *et al.* 1996; Gautier *et al.* 1996).

<u>Alaska Peninsula/Aleutian Chain Region</u>

The Aleutian Chain is generally considered to have no onshore oil and gas potential (USFWS 1988). Additionally, MMS (1996) describes the oil and gas potential of offshore sedimentary basins adjacent to the islands as negligible. Sedimentary basins of the Bering Shelf region at the east end of the Aleutian Chain (St. George Basin and North Aleutian Basin) are considered to have the potential for oil and gas in Tertiary deposits. Exploration wells drilled in the 1980s in St. George Basin northwest of Unimak Island (Figure G-15) did not encounter significant shows of oil or gas (MMS 1996).

On the Alaska Peninsula, two groups of sedimentary rocks have been designated as play areas for potential oil and gas reserves by USGS (Molenaar 1996a): 1) Mesozoic sedimentary rocks extending along the southeast part of the peninsula, and 2) Tertiary strata of the North Aleutian or Bristol Bay Basin, which extends along the northwest coast of the peninsula (Figure G-7). The stratigraphy of each group is introduced in Section 2.3.1 and depicted on Figure G-10.

To help improve the local economy and alleviate escalating energy costs in the Bristol Bay region, there is renewed interest in oil and gas leasing. The State is planning to offer oil and gas leases in the area in October 2005, including onshore acreage along the north half of the peninsula underlain by both Tertiary and Mesozoic plays (ADNR Division of Oil and Gas 2004a; Anchorage Daily News [ADN] 2004b).

Mesozoic Play. This has been described by the USGS (Molenaar 1996a and 1996b) as a hypothetical structural play for Mesozoic oil accumulations under large anticlines of the Alaska Peninsula. Mesozoic rocks outcrop along the southeast side of the peninsula and underlie part of the Bristol Bay Basin to the north. From the Cold Bay area to Port Heiden, the play area encompasses both sides the peninsula; at Port Heiden, the western edge of the play trends towards the center of the peninsula along the projected Bruin Bay Fault (Figure G-15).

Mesozoic strata on the Alaska Peninsula include Late Triassic limestone and shale of the Kamishak Formation; and a number of graywacke, sandstone, and shale formations of Jurassic and Upper Cretaceous age. The primary reservoir rock is a reefoid and biostromal limestone of the Kamishak Formation. The Jurassic and Cretaceous graywackes and dirty sandstones are considered to have poor reservoir potential. Good source rocks have been identified in marine mudstones in Upper Triassic and possibly Middle Jurassic strata, and large oil seeps have been documented along the peninsula. Exploration wells have encountered more mature Triassic source rocks at depth than in outcrops (Molenaar 1996a and 1996b).

Of 26 exploration wells drilled on the Alaska Peninsula between 1903 and 1983, 18 were for Mesozoic prospects on large structures that were all unsuccessful (Molenaar 1996a and 1996b). The earliest shallow wells, drilled on anticlines southeast of Becharof Lake, did not reach Triassic strata. At least three wells on the peninsula penetrated Triassic strata, but none encountered biostromal facies considered to have the best reservoir potential. Drilling depths for Triassic rocks are in the range of 12,000 to 20,000 ft.

The USGS considers the Alaska Peninsula Mesozoic play to be very speculative, limited mostly by the lack of good reservoir rock. The USGS rates oil and gas plays based on the probability of occurrence of three attributes: source, reservoir, and trap. The Mesozoic play has individual ratings of 0.9 for source rock, 0.3 for reservoir rock, and 0.9 for structural traps; with a combined probability of occurrence of 0.24 (or 24 percent). The USGS' estimate of undiscovered resources for this play averages 52.1 million barrels of oil (MMBO), based on modeled estimations of the size and number of undiscovered accumulations, gas-to-oil ratios, oil gravity, and depth.

Tertiary Play. The USGS describes this as a hypothetical play for both oil and gas in Tertiary shallow marine and nonmarine sandstone occurring in broad open folds that underlie alluvium of the Bristol Bay lowlands. The play area extends along the northwest side of the peninsula from about Cold Bay to the Egegik and Becharof Lake area (Figure G-15).

Tertiary strata of the Alaska Peninsula include mudstone, siltstone, sandstone, volcanics, coal, and conglomerate of the Tolstoi, Belkoski, Stepovak, Meshik, Bear Lake, and Tachilni Formations (Section 2.3.1, Figure G-10). Potential reservoir rocks include sandstone beds ranging from 50 to 100 ft thick that occur throughout the Tertiary sequence, as well as Oligocene volcaniclastic rocks in the Port Heiden area. Source rocks include nonmarine coaly and carbonaceous strata within the Tertiary sequence, and possibly Mesozoic source rocks underlying the southwestern part of the play area. The nonmarine origin of most source rocks in the area suggests that this is dominantly a gas play (Molenaar 1996a and 1996b).

Between 1959 and 1983, nine exploration wells were drilled on the peninsula for Tertiary prospects to depths of 8,000 to 15,000 ft. None were considered successful, although gas shows and slight oil shows were encountered. The sandstone reservoirs were generally of poor quality. The abundance of coal encountered, and low thermal maturity of the hydrocarbons, suggest that the area may be favorable for biogenic gas or CBNG (Section 3.1.3). The USGS gives the Alaska Peninsula Tertiary play a combined probability of occurrence of 0.32, based on individual probabilities of 0.5 for source rock, 0.8 for reservoir rock, and 0.8 for structural traps. Their estimates of undiscovered resources for this play average 1.3 MMBO for oil and 5.0 MMBO equivalent for natural gas (Molenaar 1996b).

Kodiak Region

The onshore portion of the Kodiak region is considered to have little geologic potential for oil and gas. Known sedimentary basins containing Tertiary rocks are located offshore to the northwest (Shelikof Basin), southwest (Tugidak Basin), and southeast (Kodiak shelf area). Some oil and gas leasing activities and exploration has been conducted on the Kodiak shelf and in Shelikof Strait, which is a southern extension of Cook Inlet Basin. Tertiary sedimentary rocks of the Kodiak Shelf outcrop in a narrow band along the southeast coast of Kodiak Island and on Tugidak and Trinity Islands, but the play area for oil and gas in this basin is primarily offshore to the east. The remainder of sedimentary rock types on Kodiak is Mesozoic, which are considered to have little to no petroleum potential in this area (USFWS 1987; Fisher 1996).

Southcentral Region

Cook Inlet Basin of the southcentral region is a known oil and gas province with about 15 currently producing oil and gas fields. These onshore fields are located near the inlet; the closest fields are approximately 15 miles east of BLM's unencumbered lands in the Neacola Mountains and approximately 50 miles west of the Knik River block of selected lands. Production and reservoir characteristics of existing onshore fields in the basin are provided in Table G-2. Exploration wells, active federal and state leases, and unitized fields are shown on Figures G-16 and G-17 for both the onshore and offshore parts of Cook Inlet Basin, although the Ring of Fire planning area comprises only the onshore part of the basin. The leases shown on the figures are conventional oil and gas leases, while the wells and fields/units include those for both conventional oil and gas, as well as for shallow gas, because the ADNR Division of Oil and Gas handles permitting functions for both resource categories. State shallow gas leases, for which CBNG is usually the target, are shown on Figure G-20, and CBNG is discussed separately in Section 3.1.3.

Exploration activities in Cook Inlet began in 1902, and the first field, Swanson River oil field, was discovered in 1957. Following its discovery, seven oil and 23 gas accumulations were discovered over the next 15 years, with drilling activity peaking in the late 1960s (Magoon 1994). Onshore oil and gas fields are listed in Table G-2 in order of discovery date. Recent onshore exploration has taken place in the Ninilchik and Deep Creek areas of Kenai Peninsula (Figure G-16, Table G-2), and in the Pretty Creek and Kustatan (Redoubt) areas on the west side of Cook Inlet (Figure G-17) (ADNR Division of Oil and Gas 2002, 2003a, and 2003c; Petroleum News 2003).

The stratigraphy of the Cook Inlet–Susitna Basin is introduced in Section 2.3.3 and depicted on Figure G-13. The USGS recognizes three different oil and gas plays in the basin based on reservoir age and petroleum type. From youngest to oldest, these are: 1) the Beluga-Sterling gas play, 2) the Hemlock-Tyonek oil play, and 3) the Late Mesozoic oil play. The boundaries of these three play areas are depicted on Figures G-16 and G-17, and their attributes are described in the following paragraphs.

Beluga-Sterling Gas Play, Cook Inlet-Susitna Basin. This is a play for additional gas accumulations in late Tertiary sandstone reservoir rocks of the Cook Inlet and Susitna basins. Discovered reserves in this play (both onshore and offshore) total 6.14 trillion cubic ft of gas (TCFG). Most of the onshore petroleum resources within the Ring of Fire planning area fall into this play category. The largest onshore fields in this play are the Kenai and Beluga gas fields (e.g., Brimberry *et al.* 1997). Many of the known gas fields are undeveloped because they are too small or too expensive to produce (Magoon 1996a and 1996b).

Most of the gas in this play is produced from the Pliocene Sterling Formation, followed by the Upper Miocene Beluga Formation and Oligocene-Miocene Tyonek Formation (Figure G-13). Siliclastic, slightly conglomeratic sandstones of the Sterling Formation are the most important reservoir rocks in this play. Individual sandstone layers range from 24 to 600 ft in thickness. The source of the gas is unclear, although chemical data indicate that it is part microbial and part thermal. Coals and kerogen in the Beluga Formation beneath the Sterling are in a good position to charge the overlying reservoirs with microbial gas. The traps for these accumulations are mostly structural, with some combined structural and stratigraphic traps related to siltstone seals (Magoon 1994 and 1996a). The structural traps are complex, discontinuous anticlines that developed through right-lateral and compressional forces related to subduction zone tectonics. Many of the gas field folds and faults are still actively deforming (Haeussler *et al.* 2000).

The USGS gives the Beluga-Sterling gas play a probability of occurrence of 1.0 because it is a confirmed play. Their estimate of undiscovered resources for this play average 13.9 MMBO gas equivalent or 738 billion cubic ft of gas (Magoon 1996b). A state lease sale in May 2004 in upper Cook Inlet indicated a high level of industry interest in onshore tracts that are likely targeting conventional gas and/or CBNG accumulations on the Kenai Peninsula in the Soldotna and Anchor Point areas, as well as on the west side of Cook Inlet from the MacArthur River (Trading Bay) to Big Lake (ADN 2004d) (Section 3.1.3.2).

Hemlock-Tyonek Oil Play, Cook Inlet Basin. The extent of the Hemlock-Tyonek oil play is similar to that of the Beluga-Sterling gas play, except that the oil play does not extend into the Susitna Basin north of the Castle Mountain Fault (Figure G-17). Most of the confirmed oil fields in this play are located in offshore Cook Inlet outside of the Ring of Fire planning area. The two onshore fields are located on the northern Kenai Peninsula: the Swanson River and Beaver Creek oil fields, with total production and reserves of about 230 MMBO and 5 MMBO, respectively (Magoon 1994 and 1996a). Production depths in these fields are on the order of 10,000 to 15,000 ft.

Most of the oil in this play (about 80 percent) comes from the Oligocene Hemlock Conglomerate, which is primarily a conglomeratic sandstone; with the remainder coming from overlying and underlying sandstones of the Tyonek and West Foreland Formations (Figure G-13). Reservoir thicknesses range from 100 to 1,300 ft. The source of the oil is the Upper Jurassic Chinitna Formation in upper Cook Inlet, and Upper Triassic - Middle Jurassic rocks in lower Cook Inlet (Magoon 1994, 1996a and 1996b). The USGS gives the Hemlock-Tyonek oil play a probability of occurrence of 1.0, and provides an average estimate of undiscovered reserves of 647 MMBO (Magoon 1996b).

Late Mesozoic Oil Play, Cook Inlet Basin. The USGS describes this as a hypothetical play for oil accumulations in Mesozoic structural traps that unconformably underlie the Tertiary sequence. Oil has previously been recovered from Mesozoic strata in several wells in offshore lower Cook Inlet, and in the Swanson River oil field on northern Kenai Peninsula (Magoon 1996a). The play area is similar to that of the Hemlock-Tyonek play, except that the Late Mesozoic play extends southwesterly along the west side of lower Cook Inlet to connect with the Mesozoic play of the Alaska Peninsula (Figure G-16).

Potential reservoir rocks in this play include Cretaceous and Jurassic-age sandstones and turbidites of the Matanuska, Kagayak, and Naknek Formations (Figure G-13). Potential traps include faulted anticlines, unconformities, and facies changes to siltstone. Reservoir rocks encountered in this sequence are mostly of poor quality. The source of the oil is the Upper Jurassic Chinitna Formation (Magoon 1994 and 1996a). The USGS gives the Mesozoic play a combined probability of occurrence of 0.09, based on individual probabilities of 1.0 for source rock, 0.3 for reservoir rock, and 0.3 for traps. The USGS has not conducted a quantitative estimate of reserves for this play (Magoon 1996b). In 2004, a federal lease sale in the offshore area adjacent to this play failed to draw any industry interest (ADN 2004a).

Copper River Basin. Potential oil and gas resources of the Copper River Basin are located mostly outside of the Ring of Fire planning area to the east. The USGS recognizes two oil and gas plays in the basin, one of which, a Mesozoic oil play, extends into the Ring of Fire planning area (Figure G-17). The reservoir rocks for the Mesozoic play are sandstones of the Matanuska Formation, and source rocks are possibly Jurassic shale, as is the case in Cook Inlet. Traps are structural, stratigraphic, or both. The overall probability for this play is considered to be low because evidence is lacking for traps or for sufficient oil to fill the traps. The USGS has not conducted a quantitative reserve estimate for this play (Magoon and Valin 1996).

Southeast Region

The eastern part of the Gulf of Alaska sedimentary basin extends into the Yakutat area of the southeast region (Figure G-18) (Ehm 1983; Kirschner 1992). The oil and gas potential of this and other areas of the southeast region, are discussed in the following paragraphs.

Yakutat Foreland/Lituya Play. The Gulf of Alaska sedimentary basin lies within the Yakutat tectonic terrane of the southeast region (Section 2.2.4). The basin is divided into three segments based on changes in basement rocks and Lower Tertiary strata thickness. The Dangerous River Zone, trending north-northwesterly through Yakutat Bay, represents the eastern margin and paleoslope of an older basin (MMS 1995). The Ring of Fire planning area lies mostly on the east side of this zone, in the easternmost segment of the Gulf of Alaska Basin. The stratigraphy of the Yakutat terrane is introduced in Section 2.3.4 and depicted on Figure G-11.

The Yakutat Foreland/Lituya play extends along the coastline from west of Yakutat Bay to about 15 miles southeast of Lituya Bay, and lies between the Boundary-Fairweather Fault system to the northeast and the offshore three-mile limit to the southwest (Figure G-18). The USGS describes this as a hypothetical play of oil and associated gas in relatively undeformed Cenozoic strata east of the Dangerous River Zone. The primary reservoir rocks are sandstones within the mostly nonmarine Late Tertiary formations of the Yakutat Terrane (Bruns 1996a). Equivalent plays in the adjacent offshore area include sandstones of the Kulthieth, Yakataga, and Poul Creek Formations (Figure G-11) as potential reservoir rocks (MMS 1995). The depth range of the Tertiary reservoirs in the onshore play is from 1,500 to 30,000 ft. The Tertiary strata dip steeply away from the Boundary-Fairweather Fault system and thicken rapidly seaward. Source rocks lie within Lower Tertiary strata west of Yakutat Bay, and hydrocarbons are speculated to have migrated updip towards the east and onshore area. Traps may include folds or faults associated with deformation near the Dangerous River Zone, or paleomargin-related stratigraphic traps such as updip pinch-outs or basement onlaps (Bruns 1996a and 1996b; Magoon 1994; MMS 1995).

The Yakutat onshore area was explored in the late 1950s through early 1960s. Eight wells were drilled on the coast southeast of Yakutat Bay to maximum depths of 12,000 ft. Only one of these had a show of oil and gas; the rest were dry (Selkregg 1974c). One well was drilled offshore of this area, but west of the Dangerous River Zone; it had oil shows but produced no hydrocarbons (MMS 1995). The USGS suggests that further exploration in the onshore play may be warranted if subtle structural or stratigraphic traps could be identified on seismic data, or if significant offshore accumulations were found. They give the Yakutat Foreland play a combined probability of occurrence of 0.4, based on individual probabilities of 0.8 for source rock, 1.0 for reservoir rock, and 0.5 for traps. They provide an average estimate of undiscovered reserves of 57 MMBO (Bruns 1996b).

Central and Southern Southeast Region. There have been reported indications of unconfirmed oil seeps in the Keku Islands southwest of Kake, and in the Heceta Island area south of Edna Bay (Figure G-18). Possible source rocks in these areas are Silurian or younger limestones that are reported to contain carboniferous materials. No serious exploration attempts have been made in these areas, and outside of the Yakutat area, the USGS considers the southeast region to have negligible hydrocarbon potential (Bruns 1996a; Selkregg 1974c).

3.1.1.2 Occurrence Potential

The potential for the occurrence of oil and gas resources in the Ring of Fire planning area is summarized on Figures G-15 through G-18. Criteria for this mapping effort were developed by URS and BLM geologists (Diel 2004) in accordance with BLM guidance for fluid minerals (1990). The purpose of these maps is to show potential resource areas; they are not intended to imply the potential for development or economic extraction of the resource. Development potential for the Ring of Fire planning area is addressed in Chapter 4.

Potential Ratings. The occurrence potential ratings for oil and gas resources are based on the following rationale:

High Oil and Gas Potential: BLM (1990) indicates that areas of high oil and gas potential should be based on their inclusion in an oil and gas play defined by the USGS National Assessment, or in the absence of a USGS play, the demonstrated presence of a source, reservoir, and trap. Since the 1995 USGS National Assessment addressed all areas of Alaska for conventional oil and gas resources, and no other viable play combinations were identified during literature review for this document, the high potential category for the Ring of Fire planning area is based on the USGS play areas as shown on Figures G-15 through G-18. In accordance with BLM (1990) guidance, these designations are made regardless of USGS probability ratings for each play area.

Medium Oil and Gas Potential: BLM (1990) indicates similar geologic requirements for this category as in the high category (i.e., source, reservoir, trap), but that the analysis can be based on geologic inference or indirect evidence. Areas within the Ring of Fire planning area were mapped as having medium potential if they lay outside of a USGS play, but within the boundaries of an oil and gas basin mapped by Ehm (1983).

Low Oil and Gas Potential: These are areas where one or more play attributes (e.g., source, reservoir, trap) may not be present (BLM 1990). Areas of the Ring of Fire planning area were considered to have low oil and gas potential where sedimentary rocks are present outside of the identified oil and gas basins.

No Oil and Gas Potential: Areas of igneous, metamorphic, and volcanic rock within the Ring of Fire planning area were generally considered to have no oil and gas potential. Areas of low and no potential are combined on Figures G-15 through G-18 for expediency; the division between the two categories, that is, areas of sedimentary versus non-sedimentary rocks, is provided on the geologic maps on Figures G-6 though G-9 and Table G-1.

Confidence Level. BLM (1985 and 1990) guidance suggests that level of confidence or certainty in the accuracy of mineral potential interpretation be indicated through standard cartographic techniques. Confidence level is indicated on Figures G-15 through G-18 as follows:

- Areas where abundant direct and indirect evidence support the interpretation are indicated by solid or continuous lines. High potential areas based on USGS plays with high probabilities in areas of proven reserves (e.g., Cook Inlet Tertiary plays) were considered to fall into this category.
- Areas where direct evidence is available but is quantitatively minimal are indicated by long-dashed lines. For example, high potential areas based on USGS plays with low probabilities (e.g., Alaska Peninsula and Yakutat area) were considered to fall in this category.
- Areas where indirect evidence alone supports the interpretation are indicated by short-dashed lines. Boundaries between areas of medium potential (within basins) and low-no potential (outside of basins) are mapped in this manner.

Summary. In accordance with BLM (1990) guidance, high potential ratings were given to all USGS plays, regardless of probability assigned by USGS; relative probabilities are indicated on the maps by solid versus dashed play boundaries. Plays of the Alaska Peninsula, Cook Inlet-Susitna Basin, Copper River Basin, and Yakutat area are all considered to have high occurrence potential. Small slivers of medium potential were mapped around the north, west, and northeast margins of Cook Inlet Basin where play area boundaries lie within basin boundaries. All other areas of the Ring of Fire planning area were considered to have low to no oil and gas potential.

3.1.2 Coal

3.1.2.1 Known Deposits, Fields, and History

Sedimentary rocks with coal deposits are known to occur in a number of areas within the Ring of Fire planning area, including the Alaska Peninsula, the Kodiak region, Cook Inlet-Susitna basin, and scattered areas of the southeast region. Figures G-19 through G-21 depict data used to identify the extent of coal occurrence within the Ring of Fire planning area, including: coal fields and districts mapped by Merritt and Hawley (1986); coal-bearing sedimentary units mapped by Beikman (1980); a coal-bearing mineral terrane unit mapped by Resource Data Center, Inc. [RDI] *et al.* (1995); sedimentary basin boundaries from Ehm (1983); coal occurrences identified in BLM's Mineral Availability System/Mineral Industry Location System (MAS/MILS) database (USBOM 1995); and coal occurrence potential (described in Section 3.1.2.2). These data, as well as the production history of existing coal fields, are summarized below by geographic region.

The term "district" was originally assigned to coal fields identified under the Bituminous Coal Act of 1937, which included all mines in Alaska. Although the act was later repealed, district designations remained in usage in many areas of the U.S. (USDOE 2004b). The term district is also used in Alaska (e.g., Merritt and Hawley 1986) to refer to subunits within larger coal fields. Thus, areas referred to as coal districts may be smaller, and of lesser historical importance, than coal fields. Terms of coal classification by rank, and a summary of geochemical data for each coal province, are provided in Section 2.4.2.

Alaska Peninsula/Aleutian Chain Region

The Aleutian Chain is not known to contain coal-bearing sedimentary rocks. Several Tertiary sedimentary units, which are coal-bearing elsewhere in Alaska, outcrop on Attu, Amchitka, Umnak, and Unalaska Islands (Figure G-6, Table G-1). These formations, however, consist primarily of siliclastic and volcaniclastic deposits in the Aleutians, and likely do not contain coal layers (USFWS 1988; Vallier *et al.* 1994).

The Alaska Peninsula contains two distinct coal-bearing basins. Coals deposited in the Cretaceous located along the southeast half of the peninsula are primarily bituminous rank, while coals deposited in the Tertiary are located mostly along the northwest side of the peninsula and are bituminous to lignite in rank (Smith 1995) (Figure G-19, Section 2.4.2). The two basins have different structural and depositional histories, and are separated by a regional unconformity (Section 2.3.1).

The Herendeen Bay and Chignik coal fields contain coals of the upper Cretaceous Coal Valley Member of the Chignik Formation (Figure G-10). Similar coal-bearing rocks extend from these areas northeast into the Ugashik district. The Coal Valley Member is laterally discontinuous along the peninsula, becoming thickest at Herendeen bay and absent in other areas. Coals of the Herendeen Bay field outcrop in up to 17 individual beds typically less than 2 ft thick, which are distributed over a 1,250-ft stratigraphic section, and occupy an area of over 1,100 square miles. Coals of the Chignik field occupy over 150 square miles and are typically less than 9 ft thick (Merritt 1986a; Smith 1995).

Tertiary coal on the Alaska Peninsula occurs in the Tolstoi, Stepovak, and Bear Lake Formations (Figure G-10). The coal district on Unga Island is composed of lignite of the Miocene Bear Lake Formation. The Unga Island district occurs over an area less than 40 square miles in seams ranging from 1½ to 3 ft thick (Merritt 1986a). Tertiary coal-bearing rocks are widely distributed at depth in the coastal area along Bristol Bay based on strata encountered in oil exploration wells (Merritt and Hawley 1986). These strata subcrop in an area over 250 miles long and extending at least 35 miles offshore into the North Aleutian Basin (Figure G-19).

The coal fields and districts of the Alaska Peninsula were mined by small scale operations in the late 1800s and early 1900s (DGGS 1993a; Merritt 1986b; Wahrhaftig *et al.* 1994). DGGS (1993a) indicates identified reserves of 130 million tons and 230 million tons for the Herendeen and Chignik fields, respectively, and 1,500 million tons of hypothetical reserves in each of these fields. Past production of these two fields has been less than 100,000 tons (Merritt 1986a). Identified resources of the Unga Island Field are estimated at 70 million short tons (Merritt 1986a). Merritt (1986c) rates the coal potential of the Chignik, Herendeen, and Unga Island areas as high, and indicates that while these areas have proven reserves, they are likely not large enough for the export market.

Kodiak Region

Coal is known to occur on Sitkinak and Sitkalidak Islands off the southeast side of Kodiak within the Oligocene Sitkinak Formation (Figures G-7, G-11, and G-19). On Sitkinak Island, outcropping coal beds are 10 to 12 ft thick. Merritt (1984) lists the coal development potential of Sitkinak Island as low. Additional occurrences of coal have been mapped within other Tertiary rocks along southeast Kodiak Island and within upper Cretaceous rocks of central Kodiak Island, although the extent of these deposits is unknown (Merritt and Hawley 1986). Alluvial coal clasts are known to occur in a fossil beach deposit near the Ayakulik River on southwest Kodiak Island (USFWS 1987).

Southcentral Region

Several major coal fields occur in the Cook Inlet-Susitna Basin of south central Alaska. From northwest to southeast, these include the Yentna, Susitna, Matanuska, Beluga, and Kenai fields (Figure G-20). These fields accumulated in peat-forming swamp deposits that were part of a large Tertiary river system, in which Cook Inlet was the main trunk stream, and the Susitna and Matanuska Valleys were tributaries (Wahraftig *et al.* 1994).

Yentna Coal Field. The Yentna Field occurs in the Susitna lowland of the northern part of the basin. The coal is subbituminous and occurs within the Oligocene to Miocene Tyonek Formation (Figure G-13). The Yentna field is comprised of three coal districts; from south the north, these are the Canyon Creek, Johnson Creek, and Fairview Mountain districts. Coal beds reach up to 50 ft thick in the Fairview Mountain district. Identified resources to a depth of 250 ft in the combined Johnson Creek and Canyon Creek districts are more than 500 million short tons (Merritt and Hawley 1986). Only minor production has occurred in the Yentna field in the past.

Susitna Coal Field. The Susitna field contains two districts: the Susitna Flats district to the west and the Little Susitna district to the east. The coal is borderline bituminous-subbituminous and occurs within the Miocene- to Pliocene-age Beluga and Sterling Formations (Figure G-13). The Susitna Flats district occupies a broad area beneath Quaternary overburden and straddles the Castle Mountain Fault. North of the fault, coal seams at depth are up to 15 ft thick within a

2,000-ft thick section overlying basement; just south of the fault, oil well logs show a total of about 300 ft of coal in 37 seams over more than 8,500 ft of strata (Merritt and Hawley 1986). The Little Susitna district is located near surface to the east of the Susitna Flats district. A strip mine operated for several years near Houston in this coal district, depleting much of the recoverable resource. Merritt and Hawley (1986) and Merritt (1986a and 1986b) indicate that the Little Susitna district has a potential remaining resource of 14.7 million tons, but has low development potential because most seams are too thin to be considered mineable (less than 2 ft thick).

Matanuska Coal Field. The Matanuska field underlies much of the Matanuska Valley in the northeast part of south central Alaska. Coal deposits in this area occur within the folded and faulted Chickaloon Formation of Paleocene to lower Eocene age (Figure G-13), and have been well-defined by Barnes and Payne (1956) and Barnes (1962). The Matanuska field is comprised of five coal districts; from southwest to northeast, these are the Wishbone Hill, Young Creek, Castle Mountain, Chickaloon, and Anthracite Ridge districts. Each district covers roughly a 10- to 20-square mile area. High rank anthracite coals occur in the northeast part of the field, and change to lower rank bituminous coals towards the southwest (Merritt and Hawley 1986; DGGS 1993a).

Extraction from the Matanuska field began in about 1913. In 1916, the Alaska Railroad was built through the southcentral region to access the Matanuska field as well as other fields to the north (Barnes and Payne 1956; Merritt 1986b). Seven separate mining operations operated in the field between 1913 and 1968, when natural gas from Cook Inlet replaced coal use in the Anchorage area. Minor production continued until 1982 for local needs. Total past production was about 7.5 million tons, mostly from the Evan Jones Mine in the Wishbone Hill district. DGGS (1993a) estimates remaining identified reserves in the combined Wishbone Hill, Chickaloon, and Anthracite Ridge districts to be about 150 million tons.

Beluga Coal Field. Potentially mineable subbituminous coal occurs in three districts of the Beluga field, referred to as the Capps, Chuitna, and Threemile districts. Coal in the Capps and Chuitna districts lies within the Tyonek Formation, while coal of the Threemile district lies within the Miocene Beluga Formation (Figure G-13). Individual coal beds range from approximately 10 to 40 ft thick in these districts (Merritt and Hawley 1986). Drilling in the 1980s proved up measured reserves of approximately 1.2 billion tons of coal in the Chuitna district (Merritt 1986b). Identified resources of the Beluga Field as a whole are estimated at ten billion short tons (Merritt and Hawley 1986). Only minor production has occurred in the Beluga field in the past (Merritt 1986a).

Kenai Coal Field. The Kenai field consists of three subbituminous coal districts: Kenai Onshore, Kenai Offshore, and the Seldovia-Port Graham district. Most of the near-surface coal in the Kenai Onshore and Offshore districts lies in 2.5- to 20-ft thick beds within the Beluga and Sterling Formations (Figure G-13). Coal-bearing strata are also present at depth in the Tyonek Formation within the Kenai Onshore and Offshore districts, and Tyonek Formation coals outcrop in the Seldovia-Port Graham district (Merritt and Hawley 1983).

The Kenai Onshore district occupies an area of over 2,000 square miles. Identified resources of the Kenai Onshore district total approximately 320 million short tons, with hypothetical resources estimated at 35 billion short tons. Up to 1,500 billion short tons of hypothetical coal resources are estimated to underlie parts of Cook Inlet up to depths of 10,000 ft (Merritt 1986a; Merritt and Hawley 1986). The first coal extraction from the Kenai field began in the late 1800s with small mining operations in the Homer and Port Graham areas (Merritt 1986b). Total past production in the Kenai field has been less than 100,000 tons.

Southeast Region

Several localized areas in the southeast region are known to contain coal. Coal occurs within Tertiary continental rocks of the Kootznahoo Formation in the Angoon, Admiralty, and Kuiu coal districts (Table G-1; Figures G-9 and G-21). As indicated in Section 2.4.2, coals of the Admiralty and Angoon districts are considered bituminous, and Kuiu district contains lignite (Merritt and Hawley 1986). The largest of these deposits is in the Angoon district, where 2- to 3-ft thick coal beds are exposed on the north and south sides of Kootznahoo Inlet, and are estimated to extend over a 20-square mile area (Selkregg 1974c). Isolated occurrences of Tertiary lignites have also been reported near Yakutat and Lituya Bays, in the northeast Glacier Bay area, in the northeast corner of Admiralty Island, on southwest Baranof Island, and at Kasaan Bay on Prince of Wales Island (Merritt 1986b; Merritt and Hawley 1986).

Several small-scale mines operated on Admiralty Island in the late 1800s and early 1900s. One of those in the Angoon district operated from an inclined shaft dug to a depth of several hundred ft (Merritt 1986b; Selkregg 1974c). Merritt (1986b) and Merritt and Hawley (1986) suggest that, except for local use, the coal districts of the southeast region have low development potential due to their small size.

3.1.2.2 Occurrence Potential

The potential for coal occurrence in the Ring of Fire planning area is summarized on Figures G-19 through G-21. Criteria for this mapping effort were developed by URS and BLM geologists (Diel 2004) in accordance with BLM guidance documents (BLM 1985 and 1990). The purpose of these maps is to show potential resource areas; they are not intended to imply the potential for development or economic extraction of the resource. Development potential for the Ring of Fire planning area is addressed in Chapter 4.

Potential Ratings. The occurrence potential ratings for coal resources are based on the following rationale:

High Coal Potential: BLM (1985) guidance suggests that areas of high mineral potential be demonstrated based on geologic environment, inferred geologic processes, reported mineral occurrences, and known mines or deposits. Within the Ring of Fire planning area, areas were mapped as high coal potential if they are part of a designated coal field or district. These areas generally contain proven or inferred reserves and a history of coal extraction.

Medium Coal Potential: Areas mapped as medium potential include the following: coal-bearing formations mapped by Beikman (1980) that are not included within coal field or coal district boundaries; sedimentary basins mapped by Ehm (1983) that contain coal-bearing rocks; and a coal-bearing mineral terrane unit mapped by RDI *et al.* (1995).

Low Coal Potential: Areas of non-coal-bearing sedimentary rocks located outside of basin boundaries were considered to have low potential for coal.

No Coal Potential: Areas of non-sedimentary rocks were considered to have no coal potential. Areas of low and no potential are combined on Figures G-19 through G-21 for expediency; the division between the two categories (i.e., areas of sedimentary versus non-sedimentary rocks) is provided on geologic maps on Figures G-6 though G-9 and Table G-1.

Confidence Level. BLM (1985, 1990) guidance suggests that level of confidence or certainty in the accuracy of mineral potential interpretation be indicated through standard cartographic techniques. Confidence level is indicated on Figures G-19 through G-21 as follows:

- Areas where abundant direct and indirect evidence support the interpretation are indicated by solid or continuous lines. High potential areas based on coal fields mapped by Merritt and Hawley (1986) were considered to fall into this category.
- Areas were indicated by dashed lines where either 1) direct evidence of a potential coal resource is available but is quantitatively minimal, or 2) indirect evidence is available. These include coal district boundaries where they occur outside of designated fields, as well as all areas included in the medium potential category (coal-bearing formations, mineral terranes, and basin boundaries).

Summary. Areas of high coal potential are found in all regions of the Ring of Fire planning area except for the Aleutian Chain. Coal fields and districts that represent a high potential for coal occurrence are described in Section 3.1.2 by geographic region. Large areas of medium coal potential lie on the Alaska Peninsula, Kodiak region, and southcentral region where coal-bearing formations, basins, or mineral terranes extend outside of, or in between, high potential areas. Areas of non-coal-bearing sedimentary rocks and non-sedimentary rocks are designated as having low to no coal potential on Figures G-19 through G-21.

3.1.3 Coalbed Natural Gas

CBNG, also known as coalbed methane, occurs in association with coal-bearing formations in which the gas is generated. The occurrence of coal in the Ring of Fire planning area is summarized in Section 3.1.2 and depicted on Figures G-19 through G-21. These figures also show State of Alaska non-competitive shallow gas leases issued under a recent program intending to provide incentive to locate natural gas, including CBNG, from depths less than 3,000 ft, which can be delivered to remote consumers at less cost than alternative energies (ADNR Division of Oil and Gas 2004b and 2004d). The shallow gas leasing program was repealed by the State in December 2004 (ADNR Division of Oil and Gas 2005). Conventional gas fields, leases, wells, and plays are combined with oil data on Figures G-15 through G-17, and described in Section 3.1.1. Criteria used for evaluating the occurrence potential of CBNG, as well as a summary of potential resources by geographic region, are summarized below.

3.1.3.1 Conditions for Occurrence

Geologic conditions required for the occurrence of CBNG are as complex as conditions for the occurrence of conventional oil and gas. Detailed basin analysis and an understanding of the interplay between many geologic factors are generally required to delineate the presence and origin of CBNG (Tyler *et al.* 2000). Although near-surface coal has been studied and commercially utilized in Alaska for over 100 years and most surficial coal occurrences have been mapped, subsurface coal containing potential CBNG resources have received considerably less attention (Smith 1995). Although the USGS has developed CBNG plays for the contiguous U.S. (Rice 1996), they have not yet been assessed for Alaska. A review of contributing factors for CBNG occurrence was conducted to provide an understanding of the CBNG potential within the Ring of Fire planning area.

High CBNG productivity tends to occur under the following conditions: 1) thick, laterally continuous coal beds; 2) high thermal maturity or rank; 3) adequate permeability; 4) groundwater flow through coals; 5) flow direction perpendicular towards groundwater barriers or structural/stratigraphic traps; 6) additional sources of gas beyond that which is generated during coalification; 7) accumulation of gas against traps and groundwater barriers; and 8) adequate pressure regime, i.e., depths between about 500 and 6,000 ft (Belowich 2003; DGGS 2003; Dolan 2002; Rice 1996; Rice *et al.* 1996; Tyler *et al.* 2000).

Unlike conventional oil and gas, coal beds function as both the source and reservoir for CBNG, such that their thickness and distribution within a basin is important to understanding the extent of the resource. Large amounts of gas are generated during coalification by both biogenic and thermogenic processes, the gas being sorbed onto internal surfaces of the microporous coal (Rice *et al.* 1996). As indicated in Section 2.4.2, coals must reach a certain threshold of thermal maturity before significant volumes of thermogenic methane can develop. Although high rank coals generally have higher gas contents, gas content is not determined by rank alone. Gas content can be enhanced by the generation of secondary biogenic gas, or by groundwater migration of gas towards traps or no-flow boundaries. Permeability in coal beds is determined by fractures (or cleats), which are largely controlled by tectonic setting. Cleats function as pathways for migration of gas and water to the wellhead (Rice *et al.* 1996; Tyler *et al.* 2000). Although thermal maturity increases at deeper depths, shallower depths contain less compressed gas and greater permeability and storage capacity in cleats. Because of their plastic nature, coal beds tend to lose permeability and have non-economic production levels below about 4,000 to 6,000 ft, and in areas of high structural deformation (Belowich 2003; Dolan 2002; Rice *et al.* 1996). At depths shallower than about 500 ft, gas contents are generally too low for commercial production (Rice 1996). The direction of groundwater flow relative to potentially trapping mechanisms is important, because the largest possible area of flow is intercepted when flow direction is orthogonal (perpendicular) to traps, maximizing the opportunity for gas resorption and accumulation (Tyler *et al.* 2000).

CBNG can be developed in settings both in association with, and away from, underground coal mines. Pressure reduction during coal mining results in the release of CBNG, which is commonly vented to the atmosphere to prevent explosive hazards. Different types of wells, including vertical gob wells and horizontal wells drilled from inside mines, have been used in the contiguous U.S. to recover CBNG from underground mines. The largest resources of CBNG, however, are typically away from coal mining areas where the coal layers are deeper. Generally, vertical wells drilled in this type of setting use a variety of completion techniques to enhance permeability, such as hydraulic fracturing (Evergreen Resources 2003b; Rice 1996). Water is commonly produced from CBNG wells, especially during early stages of production when dewatering is required to reduce reservoir pressure and initiate gas desorption from the coal (Rice *et al.* 1996).

3.1.3.2 CBNG Occurrence by Region

The following is a summary of the known or suspected occurrence of CBNG in subsurface coal deposits within each region of the Ring of Fire planning area.

Alaska Peninsula/Aleutian Chain Region

As indicated in Section 3.1.2.1, the Aleutian Chain is not known to contain coal-bearing sedimentary rocks. The Cretaceous and Tertiary coal-bearing sedimentary rocks and coal fields of the Alaska Peninsula are described in Section 3.1.2.1 and shown on Figure G-19. The rank and gas-generating potential of these rocks are described in Section 2.4.2.

CBNG in Cretaceous Strata. Smith (1995) and Tyler *et al.* (2000) describe the CBNG potential of Cretaceous coals in the Chignik and Herendeen Bay areas of the Alaska Peninsula. The coals occur in thin individual beds, are laterally discontinuous, highly cleated, and moderately to intensely deformed. Structural complexity in the Chignik area is typified by compressional folding, overthrusting, and high-angle faulting, with the trend of structural features subparallel to the axis of the peninsula.

Chignik area coals encountered in oil exploration wells at depths greater than 4,000 ft are low- to high-volatile bituminous rank. These coals are within or approaching the range of thermogenic gas generation, and have shown significant gas shows on mudlogs. Coals of similar rank are found in outcrops in the Chignik and Herendeen Bay areas, indicating considerable uplift since maximum burial. The permeability of the cleat system could be enhanced in the uplifted areas, but high stresses related to present-day tectonism could also result in low permeabilities. The rainy climate and presence of groundwater in one of Chignik's abandoned mines suggest that the coals may have the recharge potential and permeability to potentially enhance CBNG accumulation with secondary biogenic gas (Tyler *et al.* 2000).

Smith (1995) and Tyler *et al.* (2000) conclude that the thin beds, discontinuous strata, and structural complexity of the Cretaceous coals would make subsurface exploration for large scale CBNG operations difficult in these areas. Exploration for localized CBNG for village use may prove viable, but costs and risks would be high due to the depth, structural and stratigraphic complexities, and potentially high dewatering costs.

In 1996, the State of Alaska DGGS established a program to evaluate the potential for CBNG to meet the energy needs of roadless communities that currently depend on fuel oil for heating and power generation (Clough 2001). Based on the work of Tyler *et al.* (2000), DGGS is further evaluating three coal basins in Alaska, one of which is in the Chignik area of the Alaska Peninsula. As part of this program, a water supply well drilled by the Alaska Native Tribal Health Consortium near Chignik Lake in 2002 was monitored by DGGS for potential coal beds and CBNG to a depth of 750 ft (DGGS 2003). No coal beds were encountered at these depths; however, these results do not rule out the potential for Cretaceous coal beds at deeper levels in the area (Clough 2004).

CBNG in Tertiary Strata. Tertiary coals of the Unga Island district and beneath the Bristol Bay coastal area (North Aleutian Basin) are generally lower rank than the Cretaceous coals. Of the three Tertiary coal-bearing formations of the peninsula (Tolstoi, Stepovak, and Bear Lake), only the Tolstoi Formation contains bituminous coals of sufficient rank for thermogenic CBNG generation. Minor to good gas shows were encountered in Tertiary coals during drilling of exploration wells in the Port Heiden area on Bristol Bay. Gassy coal sections within the Tolstoi Formation were encountered in wells between 5,800 and 10,400 ft (Smith 1995; Tyler *et al.* 2000).

Smith (1995) concludes that although most Tertiary coal-bearing strata on the peninsula are too low rank to have good gas potential, it is possible that if Tolstoi Formation coals were found in structurally high areas within the North Aleutian Basin above 5,000 ft in depth, they may have some CBNG potential. The low maturity of most Tertiary coals of the peninsula indicates that the area may be favorable for secondary biogenic gas (Molenaar 1996a; Molenaar 1996b). It is also possible that groundwater flow through the basin may enhance gas contents through migration to traps.

Kodiak Region

As indicated in Section 3.1.2.1, with the exception of several known outcrops in the southeast part of Kodiak, the extent and rank of coal layers within the coal-bearing sedimentary rocks shown on Figure G-19 are largely unknown. Based on very limited information, the potential for CBNG occurrence on Kodiak is estimated to be similar to that of the coal itself.

Southcentral Region

The major coal fields and districts of the Cook Inlet-Susitna Basin are described in Section 3.1.2.1 and shown on Figure G-20. Coal is found in several Tertiary formations in the basin, including the Chickaloon, Tyonek, Beluga, and Sterling Formations (Figure G-13). Of these, the Oligocene-Miocene Tyonek Formation and the Paleocene Chickaloon Formation have the highest CBNG potential (Smith 1995). The Tyonek Formation is widespread across Cook Inlet-Susitna basin, comprising the large coal fields along the west side of the basin (Yentna and Beluga fields), and is found at depth in the Kenai field. The Chickaloon Formation is limited to the northeast portion of the basin in Matanuska Valley.

Cook Inlet Basin. The cumulative thickness of Tyonek Formation coal ranges from 200 ft along the eastern edge of Cook Inlet basin, to more than 1,200 ft in two areas along the west coast of Cook Inlet: near the north end of Trading Bay southwest of Tyonek, and near the north end of Redoubt Bay (Wahrhaftig *et al.* 1994). These coal thicknesses are considered very high compared to CBNG fields in the contiguous U.S. (Smith 1995).

Because of post-depositional Holocene uplift along the margins of Cook Inlet Basin, older coal-bearing strata with higher thermal maturities are exposed along its margins, making these areas attractive for CBNG exploration. Vitrinite reflectances of 0.6 percent, marking the threshold of thermal maturity needed for CBNG generation (Section 2.4.2), are reached at a depth of approximately 15,000 ft near the axis of Cook Inlet Basin and at roughly 5,000 ft along its margins (Smith 1995). The presence of numerous conventional gas fields containing migrated gas from both thermogenic and biogenic sources (Table G-2, Section 2.4.2) suggests that migrated gas may also be available to enhance gas contents in coal beds through groundwater flow and trapping. In May 2004, a state lease sale in upper Cook Inlet indicated a high level of industry interest in onshore tracts that may be targeting CBNG deeper than 3,000 ft along the west side of Cook Inlet basin southwest of Tyonek, as well as possibly a mixture of conventional gas reservoirs and coalbed accumulations on Kenai Peninsula (ADN 2004d). The State issued several shallow gas leases in the Homer area in 2003 totaling approximately 22,600 acres (ADNR Division of Oil and Gas 2005).

Susitna Basin. Susitna Basin is a smaller, shallower, and younger extension of Cook Inlet Basin, and is separated from Cook Inlet Basin by the Castle Mountain Fault (Figure G-20). Like the Cook Inlet Basin, the uplifted basin margins around Susitna Basin are considered highly prospective for CBNG (Smith 1995). Exploratory wells drilled in the deeper central part of the Susitna Basin encountered Tyonek Formation coals with good gas shows between 11,700 and 13,700 ft (Smith 1995). In 2003 and 2004, several exploratory coreholes likely targeting Tyonek Formation CBNG along the basin margin were drilled by Evergreen Resources along the Parks Highway (ADNR Division of Oil and Gas 2003b; Evergreen Resources 2003a).

Castle Mountain Fault Area. The Castle Mountain Fault is an active, north-dipping, oblique (right lateral) thrust fault, which separates the Susitna Basin to the north, from the Cook Inlet basin to the south (Plafker *et al.* 1993). Areas along both sides of the fault from Houston to Sutton are considered highly prospective for CBNG due to a combination of high rank Tyonek and Chickaloon Formation coals at depths less than 5,000 ft (Smith 1995), as well as possible fault-parallel fold traps similar to those mapped at the surface in the Matanuska coal field (Barnes 1962; Barnes and Payne 1959). On the south side of the fault, coal-bearing rocks form a southwest-dipping wedge, with the depth to mature coals (Ro = 0.6 percent) ranging from zero near Palmer where mature coals outcrop at the surface, to 2,000 to 3,000 ft near the Parks Highway, to 10,000 ft further southwest near the Susitna River mouth (Smith 1995).

The presence of CBNG in the Chickaloon Formation was documented by mine explosions in the Matanuska Mine in 1937 and 1957. Exploratory oil and gas wells drilled in the 1950s and 1960s in the Houston area just north of the Castle Mountain Fault (Figure G-17) encountered gassy coals and sandstones probably within the Tyonek Formation. In 1994, the State funded a corehole to sample Tyonek Formation CBNG near Wasilla on the south side of the Castle Mountain Fault. Cumulative coal thickness in this hole exceeded 100 ft. The geochemistry of the gas is summarized in Section 2.4.2. Based on the results of this corehole, high-volatile bituminous coals were estimated to be present between 500 and 6,000 ft in the area (Smith 1995).

In 2002, Evergreen Resources drilled two 4-well pilot projects in the Pioneer Unit located on the south side of the Castle Mountain Fault (Figure G-17). All wells penetrated aggregate coal thicknesses greater than 100 ft. The State issued a number of shallow gas leases in this area in 2003 totaling about 230,000 acres (ADNR Division of Oil and Gas 2005). Evergreen announced that the first two pilot projects were probably not capable of commercial production in November 2003. A third pilot project drilled in 2003 tested the potential of the unit’s deeper coals (Evergreen Resources 2003b). In 2003 and 2004, Evergreen drilled two exploratory coreholes to further test for CBNG near the fault, one located in the southwest part of the Pioneer Unit and one located about 18 miles to the northeast in the southwest corner of the Matanuska coal field (ADNR Division of Oil and Gas 2004c; Evergreen Resources 2003a). In May 2004, a state conventional gas lease sale in upper Cook Inlet indicated a high level of industry interest in onshore tracts that are likely targeting CBNG further south of the fault between Big Lake and Point MacKenzie (ADN 2004d). The state repealed the shallow gas leasing program in December 2004 (ADNR Division of Oil and Gas 2005).

Southeast Region

As indicated in Section 3.1.2.1 and Figure G-21, several localized areas in the southeast region are known to contain coal. The structure and stratigraphy of related conventional oil and gas plays in the southeast region are described in Section 3.1.1.1.

Gulf of Alaska-Yakutat Basin. The CBNG potential of the eastern Gulf of Alaska-Yakutat Basin (Figure G-21) is highly speculative and hinges on the presence of the Eocene Kulthieth Formation in the subsurface (Figure G-11). The Bering River coal field, located about 150 miles west-northwest of Yakutat (outside of the Ring of Fire planning area), is composed of high rank bituminous to anthracite coals of the Kulthieth Formation. Warhaftig *et al.* (1994) suggests that the thermal maturity of Kulthieth Formation coals is anomalously high compared to other Tertiary strata in Alaska, due to igneous intrusive activity prior to accretion of the Yakutat block to the Alaskan continental margin.

The Kulthieth Formation is more than 4,700 ft thick where it outcrops in the Samovar Hills about 50 miles northwest of Yakutat (Wahrhaftig *et al.* 1994) (Figure G-21). It has also been reported in exploration wells in the Yakutat area (Bruns 1996a; Bruns 1996b) (Figure G-18), and is inferred to be up to 2,000 ft thick beneath the adjacent shelf (MMS 1995). The Kulthieth Formation pinches out to the southeast about halfway between Yakutat and Lituya Bays, where it onlaps a Paleogene high east of the Dangerous River structural zone (Section 3.1.1.1). The depth to the top of the Kulthieth Formation along the nearshore shelf is estimated to range from less than 6,000 ft near the Dangerous River (about 25 miles southeast of Yakutat) to 13,000 ft near Yakutat (MMS 1995).

While coal seams in the Bering River field are up to 60 ft thick and intensely deformed, they are estimated to be thinner and less deformed in the broad subsurface area extending southeast towards Yakutat Bay (Smith 1995). Smith (1995) suggests that CBNG plays may be found in structurally less deformed areas along the coast near the Bering River field. It is possible that this play may also apply to buried structural highs in the coastal area southeast of Yakutat, if Kulthieth coalbeds of sufficient thickness are present.

Central Southeast Region. The Admiralty and Angoon coal districts of the southeast region (Figure G-21) contain bituminous coals of the Eocene- to Miocene-age Kootznahoo Formation (Gehrels and Berg,1992; Merritt and Hawley 1986; Selkregg 1974c). Petrographic similarities between sandstones of the Kooztnahoo and the Kulthieth Formations suggest that they may have similar origins and histories (Wahrhaftig *et al.* 1996). Coal-bearing strata in the Angoon district are known to extend at least several hundred ft into the subsurface (Section 3.1.2.1). Based on the high rank of the coals and their limited extent in this area, the Angoon and Admiralty districts are considered potentially prospective for CBNG for local use.

The potential for CBNG in Kuiu district coals, located on Kuiu, Kupreanof, and Zarembo Islands (Figure G-21), is considered to be limited due to the low rank of the coal (lignite) (Merritt and Hawley 1986).

3.1.3.3 Occurrence Potential

The potential for CBNG occurrence in the Ring of Fire planning area is depicted on Figures G-19 through 21. As described in Section 3.1.3.1, the presence of CBNG resources depends on an understanding of subsurface coal extent and other complex geologic factors. The following criteria incorporate published interpretations of these factors where available, as well as preliminary interpretations based on broad-based criteria for areas where subsurface data are lacking. In the absence of specific BLM guidance for CBNG potential, the criteria below generally follow those outlined in BLM (1990) guidance for fluid minerals that are intended for use in classifying conventional oil and gas potential.

<u>High CBNG Potential:</u> BLM (1990) indicates that areas of high conventional gas potential be based on their inclusion in a play defined by the USGS National Assessment (USGS 1995). USGS has not yet defined CBNG plays for Alaska. Their approach for identifying plays in the contiguous U.S. is based on the geologic conditions described in Section 3.1.3.1; in addition, they provide a qualitative rating of “good,” “fair,” or “poor” based on a combination of these criteria. Under BLM (1990) guidance, all of these plays, regardless of rating, would be considered high potential for the purposes of planning documents. In the absence of a USGS play, BLM (1990) indicates that areas of high potential for conventional gas be based on the demonstrated presence of a source, reservoir, and trap. In the case of CBNG, coal beds provide

both the source and reservoir, and often the trap as well. Based on the above considerations, and the lack of data available to refine CBNG interpretations, most areas of the Ring of Fire planning area with known or suspected high rank coal in the subsurface, regardless of relative risk of CBNG exploration success, were considered high potential.

Section 3.1.3.2 presents various CBNG prospects or plays in the Ring of Fire planning area by geographic region. Areas designated as having high potential for CBNG include the subsurface beneath high rank coal fields and districts, as well as areas adjacent to coal fields where coal-bearing formations extend into the subsurface. High rank was generally considered to be bituminous or greater at the surface, or the potential for bituminous or greater with depth. Other favorable geologic conditions, such as groundwater flow, trapping mechanisms, or other sources of gas, were considered on a regional basis where such information was available.

<u>Medium CBNG Potential:</u> BLM (1990) indicates similar geologic requirements for conventional gas potential in this category as for the high potential category (i.e., source, reservoir, trap), but that the analysis be based more on inference or indirect evidence. Areas within the Ring of Fire planning area mapped as having medium potential include: 1) areas estimated to contain coals of subbituminous to lignite rank at depth; 2) areas where coal-bearing formations are mapped adjacent to coal districts that are not part of designated fields; and 3) areas mapped as coal-bearing sedimentary rocks (Beikman 1980) or coal-bearing mineral terrane (RDI *et al.* 1995) that are located outside of known fields and districts.

<u>Low CBNG Potential</u>: Areas of non-coal-bearing sedimentary rocks were considered to have low potential for CBNG.

<u>No CBNG Potential</u>: Areas of non-sedimentary rocks were considered to have no CBNG potential. Areas of low and no potential are combined on Figures G-19 through G-21 for expediency; the division between the two categories (i.e., areas of sedimentary versus non-sedimentary rocks) is provided on the geologic maps on Figures G-6 though G-9 and Table G-1.

Confidence Level. Confidence level is indicated on Figures G-19 through G-21 as follows:

- Areas where abundant direct and indirect evidence support the interpretation are indicated by solid or continuous lines. High CBNG potential areas based on coal fields mapped by Merritt and Hawley (1986) fall in this category.
- Areas were indicated by dashed lines where either 1) direct evidence of a potential CBNG resource is available but is quantitatively minimal, or 2) indirect evidence is available. These include coal district boundaries (where they occur outside of designated fields), coal-bearing formations, mineral terranes, and basin boundaries.

Summary. Areas of high CBNG potential were mapped in all regions of the Ring of Fire planning area except for the Aleutian Chain. These include areas of Cretaceous strata beneath and adjacent to the Herendeen Bay and Chignik coal fields, Cretaceous strata beneath the Ugashik coal district, and areas of Tertiary strata beneath the Bristol Bay coastal plain on the Alaska Peninsula (Figure G-19); the Cook Inlet and Susitna Basins of the southcentral region (Figure G-20); the Gulf of Alaska-Yakutat Basin, and the areas beneath the Angoon and Admiralty coal districts of the southeast region (Figure G-21). Areas of medium CBNG potential lie on the Alaska Peninsula, Kodiak region, and southeast region where coal fields or districts are estimated to be low rank at depth; and where coal-bearing formations, basins, or mineral terranes extend outside of, or in between, high potential areas. Areas of non-coal-bearing sedimentary rocks and non-sedimentary rocks are designated as having low to no CBNG potential on Figures G-19 through G-21.

3.1.4 Geothermal

3.1.4.1 Known Deposits and Occurrences.

Geothermal resources of varying temperatures are known to occur throughout much of the Ring of Fire planning area. Thermal springs are the surface manifestation of subsurface hydrothermal systems, where heat is transferred to the surface primarily by convective circulation of fluids, rather than by thermal conductance through solid rock.

Geothermal systems have been classified by USGS according to their subsurface temperatures and potential uses: they are considered high temperature systems where subsurface temperatures are greater than 150 degrees Celsius (^oC), moderate temperature systems between 90^{o}C and 150^{o}C, and low temperature systems where less than 90^{o}C (Motyka *et al.* 1983). This classification is based on the concept that temperatures greater than 150^{o}C are generally required for the generation of electricity; systems in the mid-range are better suited to space heating, agriculture, and industrial applications with some possibility of electricity production from binary generating plants; and low temperature systems may be useful in the immediate vicinity of the resource for space heating, agricultural, or aquacultural uses (Turner *et al.* 1980).

High-Temperature Systems. High-temperature geothermal resources are known or suspected to occur within the Ring of Fire planning area in regions of Quaternary igneous activity (Figures G-22 through G-25). These systems are typically associated with shallow silicic volcanism on the flanks of, or in the calderas of, active stratovolcanoes (Turner *et al.* 1980). These include the volcanoes of the Aleutian arc, the Alaska Peninsula, the west side of Cook Inlet, and the Edgecumbe volcanic field along the western edge of the southeast region. Estimates of reservoir temperatures in these areas have been derived either from direct measurement in exploratory holes, or from estimates based on the geochemistry of thermal springs (Motyka *et al.* 1993; Selkregg 1974b; Turner *et al.* 1980).

A number of publications (e.g., Motyka *et al.* 1983 and 1993; Turner *et al.* 1980; USFWS 1988) document at least 13 sites in the Aleutian Chain with high-temperature reservoirs. These include sites near population centers or small villages such as Adak, Atka, Umnak (Nikolski), Makushin (Unalaska), and Akutan, with estimated subsurface temperatures in the range of 160^{o}C to 300^{o}C; as well as others located in more remote areas such as Great Sitkin and Korovin volcanoes. Three volcanoes on the Alaska Peninsula, Pavlov (Mount Emmons), Mount Veniamanof, and Mount Chignagak, are estimated to have high-temperature systems (Motyka *et al.* 1993; USFWS 1985). Thermal springs and fumeroles on Mount Augustine and Mount Spurr along the west side of Cook Inlet exhibit temperatures and geochemical signatures potentially indicative of high-temperature subsurface systems (Motyka *et al.* 1983; Wescott *et al.* 1985). Motyka *et al.* (1983) suggest that Mount Edgecumbe volcanic field in the southeast region has the potential for high-temperature subsurface systems, based on favorable geology and the presence of a caldera, although no fumeroles or hot springs are present at the surface.

Moderate- to Low-Temperature Systems**.** Motyka *et al.* (1993) report four sites in the Aleutians and Alaska Peninsula with moderate temperature geothermal systems, and six sites with low temperature systems. These include sites near Akutan, Unalaska, Cold Bay, and Port Moller.

Several exploratory oil wells drilled in the Lower Susitna Basin area of the southcentral region indicate the presence of a low-grade, deep, hot-water aquifer that could potentially be tapped for direct use (Motyka *et al.* 1983; Turner *et al.* 1980; Miller 1994). Several moderate and low-temperature systems occur in the southeast region where hydrothermal waters circulate and become heated along deep fractures and faults at the margins of older plutons. These type of systems are present on Chichagof and Baranof Islands as evidenced by at least nine thermal springs; in the Stikine River area northeast of Wrangell; and in the Bell Island and Bradfield Canal areas north of Ketchikan, where reservoir temperatures are estimated in the range of 125 to 135 ^{o}C (Motyka *et al.* 1983; Motyka and Moorman 1987).

3.1.4.2 Prospects and Leases

Past Prospects and Uses. Several areas of the Ring of Fire planning area have been investigated for potential development of geothermal resources for electrical power generation, but none have been developed in the region to date. The high-temperature reservoirs of the Aleutians and Alaska Peninsula have been estimated to contain between $13x10^{18}$ to $1,440x10^{18}$ joules of thermal energy each (Miller 1994). Motyka *et al.* (1993) estimate that the combined 30-year electrical production potential of the Aleutian arc is greater than 1,000 megawatts (MW).

In the early 1980s, the State funded investigations of several geothermal areas of Alaska in an effort to stimulate public interest in the resource as a viable energy option for the State (Turner *et al.* 1980). An extensive exploration project took place on Unalaska Island in the early 1980s to investigate the potential for tapping thermal waters flanking Makushin volcano. Republic Geothermal (1985) estimated that the Makushin reservoir was capable of generating 7 to 13 MW for over 500 years. They also concluded that a geothermal power system with diesel generators as backup, would be more economic than the use of diesel generators alone. A similar conclusion was reached in preliminary studies of geothermal resources on Adak, based on analyses of three resource applications, including a 10 MW binary power plant. Electric power production potential was estimated for Akutan Island and the Geyser Bight area of Umnak Island to be 9.2 MW and 132–225 MW, respectively, for a 30-year period (Motyka and Nye 1985; Nye *et al.* 1992).

Recent interest in alternative power sources to supply the southcentral region and the Railbelt grid has resulted in completion of the initial phase of a USDOE-funded geothermal energy assessment project for Mount Spurr (Turner and Wescott 2004). The results of these studies suggest the presence of a geothermal system at a depth of about 2,000 ft on the south flank of Crater Peak, with additional geophysical and geochemical surveys recommended to better define the extent of potential reservoirs prior to drilling. Any future drilling in this area would need to consider angled drilling to mitigate volcanic hazards.

Several low- to moderate-temperature thermal springs in the southeast region have been developed for various local uses, including tourism, community bathhouses, agriculture, aquaculture, and heating of local dwellings. These sites include the communities of Bell Island, Tenakee Springs, Baranof, and Goddard (near Sitka) (Motyka *et al.* 1983; Turner 1980). A shallow warm-water aquifer delineated at Summer Bay on eastern Unalaska Island was found to be too low in temperature for direct-heat applications (Motyka *et al.* 1993). Selkregg (1974c) noted industry interest in geothermal potential at Augustine Island in Lower Cook Inlet in the early 1970s, but the area was never developed. Similarly, the State leased two tracts at Mount Spurr in the early 1990s for potential hydroponic gardening development, but no development has taken place (Motyka *et al.* 1993).

Known Geothermal Resource Areas (KGRAs) and Leases. KGRAs are land areas designated by BLM where it has been determined that persons knowledgeable in the field of geothermal development would spend money to develop the resource (43 Code of Federal Regulations [CFR] 3200.1). BLM determines the boundaries of a KGRA based on geologic and technical evidence, proximity to wells capable of commercial production, and the existence of a competitive interest, that is, where two or more parties apply for leases. KGRAs typically encompass a geologic structure in which geothermal water or steam has been discovered by drilling and determined to be productive (43 CFR 3203.11).

There are currently two KGRAs in the Ring of Fire planning area. These are located at Okmok Caldera and Geyser Bight Valley on Umnak Island in the eastern Aleutians (Diel 2004; Motyka *et al.* 1983). In the absence of an established KGRA, BLM may issue a noncompetitive lease to the first qualified applicant, or determine if overlapping lease applications warrant converting the land to a KGRA (BLM 2001).

3.1.4.3 Occurrence Potential

The potential for occurrence of geothermal resources in the Ring of Fire planning area is summarized on Figures G-22 through G-25. Criteria for this mapping effort were developed by URS and BLM geologists (Diel 2004) in accordance with BLM guidance documents (BLM 1985 and 1990). The purpose of these maps is to show potential resource areas; they are not intended to imply the potential for development or economic extraction of the resource. Development potential for the Ring of Fire planning area is addressed in Chapter 4.

Potential Ratings. The occurrence potential ratings for geothermal resources are based on the following rationale:

High Geothermal Potential: BLM (1990) indicates that high geothermal potential areas should include existing KGRAs, or areas where the presence of a hydrothermal convection system is well demonstrated by geological evidence. Within the Ring of Fire planning area, areas were mapped as high potential where Quaternary volcanism is present, as well as thermal features such as hot springs, fumaroles, vents, or geysers. Thermal springs with surface temperatures greater than 50^{o}C were included in the high potential category.

Medium Geothermal Potential: Areas were mapped as having medium potential where Quaternary to Late Tertiary volcanism is present, but thermal springs greater than 50^{o}C or other surface features are absent. Hot springs with surface temperatures less than 50^{o}C were included in this category.

Low Geothermal Potential: Low potential areas include broad regions of potential thermal waters mapped by Motyka *et al.* (1983). These areas are described as being favorable for future exploration and discovery of thermal waters at temperatures sufficient for direct-heat applications. The regions are defined on the basis of geologic evidence such as youthful volcanism, tectonic trends, thermal spring activity, mineralization, and seismicity. Motyka *et al.* (1983) acknowledge that probably only small areas within these regions are likely to be underlain by usable thermal waters.

No Potential/Not Determined: According to BLM (1990), the absence of geothermal potential should be demonstrated based on physical evidence or documentation in the literature. Portions of the Ring of Fire planning area outside of the potential areas described above have not been explored for geothermal resources in sufficient detail to prove an absence of potential. Thus, no areas were mapped as “no potential” within the Ring of Fire planning area. Areas outside of the high-medium-low potential regions are labeled “N” on the maps, indicating “not determined” due to insufficient evidence.

Confidence Level. BLM (1985 and 1990) guidance suggests that level of confidence or certainty in the accuracy of the mineral potential interpretation be indicated through standard cartographic techniques. For the purposes of this document, confidence level is indicated on the maps by line type as follows:

- Areas where abundant direct and indirect evidence support the interpretation are indicated by solid lines. All high geothermal potential areas based on known hot springs or fumaroles fall into this category.
- Areas where direct evidence is available but is quantitatively minimal are indicated by long-dashed lines. For example, areas of the southeast region where hot springs are widely spaced, or areas interpreted based on Quaternary volcanism alone in the absence of vents or springs, fall into this category.
- Areas where indirect evidence alone supports the interpretation are indicated by short-dashed lines. For example, most areas of low geothermal potential interpreted on the basis of tectonics and structural trends fall into this category.

Summary. High and medium potential ratings were generally given to discontinuous areas described above in the Aleutians, on the Alaska Peninsula, along the west side of Cook Inlet in the southcentral region, and in the southeast region (Figures G-22 through G-25). Low potential areas generally encompass the entire Aleutian arc and in the western southcentral region, plus several isolated areas within the southeast region. Areas within the Ring of Fire planning area not exhibiting any of the above characteristics are designated as having no geothermal potential; that is, there is a demonstrated absence of geologic evidence indicating the existence of hydrothermal convection systems (BLM 1990).

3.1.5 Solid Leasables

Several varieties of solid mineral commodities are considered leasable minerals under the Mineral Leasing Act for Acquired Lands of 1947 (Nichols 1999). Examples include potassium, sodium, phosphate, and oil shale. Only one of these, phosphate, has been documented in the Ring of Fire planning area. Two occurrences are been reported by USBOM (1995) and Kline and Pinney (1994): one at an unknown site in Tuxedni Bay along the southwest side of Cook Inlet, and one in the southeast region on Snettisham Peninsula.

3.2 Locatable Minerals

As indicated in Section 1.2, locatable minerals include primarily metallic and certain nonmetallic industrial minerals generally found in lode or placer deposits. The following sections provide an overview of available information on locatable minerals within the Ring of Fire planning area, a discussion of the occurrence potential criteria used in this analysis, and a summary of locatable minerals by geographic region within the planning area.

3.2.1 Overview of Available Data

Substantial studies of mineral deposits and the mineral resource potential of Alaska have been conducted over the past few decades by the USGS, DGGS, USBOM, and BLM due to interest in exploration by private mining companies and the establishment of new parks, wildlife refuges, and Native Corporations as a result of ANCSA and ANILCA. These studies have resulted in abundant information on mineral deposits within the Ring of Fire planning area. The following provides an overview of data available that are pertinent to the understanding of locatable minerals in the Ring of Fire planning area, and which provide the basis for mapping mineral potential (Figures G-26 through G-29).

3.2.1.1 Mineral Terranes

The word "terrane" is typically used where an assemblage of related rocks occupy a certain geographic area. Mineral terrane maps were developed to depict rock assemblages that share origins and formation processes known to result in certain types of mineral deposits (Hawley and Arctic Environmental Information and Data Center [AEIDC] 1982). Mineral terranes were originally described and mapped in Alaska by USBOM in the 1970s and subsequently revised several times (e.g., AEIDC 1979; Hawley and AEIDC 1982; RDI *et al.* 1995; Szumigala 1999). The most recent electronic version of mineral terranes available (RDI *et al.* 1995; Williams and Ellefson 2004) is depicted on Figures G-26 through G-29. Mineral terrane data are unavailable for the Aleutian Chain.

Table G-3 provides a legend describing each of the terrane types on the maps. Mineral deposit types are divided into categories by formation process and rock type. Syngenetic mineral deposits form about the same time as the rocks they are encased in, while epigenetic deposits form by metamorphic or hydrothermal alteration processes following host rock deposition (AEIDC 1979). Further subdivisions of mineral terranes into rock types are based on the recognition that certain kinds of minerals are specifically associated with certain kinds of host rocks. For example, the metallic elements copper, nickel, and chromium, and the nonmetallic mineral asbestos, are typically associated with mafic igneous rocks or gabbro; while copper and zinc are typically associated with layered submarine volcanic rocks and sulfide-rich sediments, referred to as VMS deposits (AEIDC 1979; Hawley and AEIDC 1982).

3.2.1.2 Mineral Occurrences, Deposits, and Claims

There is an abundance of publicly available electronic database information that provides data on mineral occurrences within the Ring of Fire planning area. As discussed in Section 2.4.2, several online USGS databases contain geochemical analyses of stream samples that can be reviewed for anomalies indicating the potential presence of mineralized areas. At least two additional databases provide information specific to mineral occurrences and sites. BLM's MAS/MILS database contains spatial and commodity data for mineral occurrences, deposits, mines, and processing plant sites in Alaska (USBOM 1995). An update of this database, referred to as the Alaska Minerals Information Service (AMIS) (BLM 2004b) is available at the BLM Alaska State office. USGS' Alaska Resource Data File (ARDF) database provides locations and descriptions of mines, prospects, and mineral occurrences for metallic mineral commodities and certain high-value industrial minerals (USGS 2004a). Much of the data are based on earlier systematic listings compiled by quadrangle by USGS geologists (e.g., Cobb and Elliot 1980; Cobb and Kachadoorian 1961; Cobb and Reed 1980). Together, more than 10,000 mineral sites are listed in these databases within the Ring of Fire planning area.

Cox and Singer (1986) define “mineral occurrence” as a concentration of a mineral considered to have some value or scientific interest, and “mineral deposit” as an occurrence of sufficient size and grade that it could have economic potential. While the electronic databases list all reported occurrences and deposits regardless of economic potential, Nokleberg *et al.* (1987 and 1994) provide summaries of lode and placer deposits considered significant based on size, favorable geology, or industry interest. The location of these deposits is available electronically from ADNR (2001) and is plotted on Figures G-26 through G-29.

Mining claims are available electronically from BLM (2004c) and ADNR (2001) for those larger than one-half of a section or 320 acres in size. State and federal claims that exceed this size threshold are shown on Figures G-26 through G-29. Claim locations generally indicate the level of mineral potential known in 1971 and before, as there has been no opportunity to stake federal mining claims on most BLM lands within the Ring of Fire planning area since that time due to ANSCA and ANILCA land withdrawals (Section 1.1).

3.2.1.3 Known Mineral Deposit Areas

Known mineral deposit areas (KMDAs) were established in the southeast region during development of the Tongass National Forest (TNF) Land Management Plan in 1991, and during the mid-1990s for the rest of the Ring of Fire planning area by USBOM (RDI *et al.* 1995). KMDAs are described as a management tool for determining the likelihood of future discoveries in a particular area. They are based on a high concentration of historic mines and prospects, mineral occurrences in the MAS/MILS database, and favorable geologic trends determined by mineral terrane mapping (Maas *et al.* 1995; RDI *et al.* 1995). Bittenbender *et al.* (1999) and Still *et al.* (2002) define KMDAs as having a high concentration of mineral occurrences of a single type, which suggest an increased likelihood that the rocks host significant mineral deposits compared to other areas. The most recent version of KMDAs is electronically available (RDI *et al.*, 1995) and is depicted on Figures G-26 through G-29. In some areas of the Ring of Fire planning area, more recent BLM or USGS have resulted in revisions of KMDA boundaries investigations (e.g., Bittenbender *et al.* 1999; Nelson and Miller 2000; Still *et al.* 2002).

3.2.1.4 Mineral Resource Reports

A number of investigations specific to mining districts and specific deposit localities have been conducted by AEIDC, the former USBOM, BLM, DGGS, and USGS over the past few decades. In the early 1970s, AEIDC mapped and described mineral deposits, metalliferous provinces, and mining activity throughout the State (e.g., Selkregg 1974a). USBOM conducted numerous field investigations at specific mineral localities within the Ring of Fire planning area (e.g., Foley 1989; Kurtak 1982). Mineral potential was analyzed on several land parcels within the Ring of Fire planning area as part of the state-selection process (e.g., DGGS 1993b). Mineral potential was mapped in the TNF in the early 1990s as part of the TNF Land Management Plan (USFS 1997). BLM is responsible for conducting mineral assessments on public land in Alaska as authorized by ANILCA. Their primary focus within the Ring of Fire planning area has been on conducting investigations within five regional mining districts: PWS/Hope, Juneau, Chichagof, Petersburg/Kupreanof, and Ketchikan/Hyder (BLM 2004a). Most lands in these districts consist of federal mineral estate managed by the USFS, with little to no BLM-managed surface parcels.

The science of mineral prediction is based partly on classifications derived from mineral deposit models. Mineral deposit models describe the essential attributes of different classes of deposits, including the origin of the mineral-hosting rocks and their relationship to the commodity types found. Such models have been developed for numerous mineral types by the USGS and other researchers (e.g., Cox and Singer 1986; Orris and Bliss 1991; Mosier and Bliss 1992), and have been refined and expanded for Alaska-specific lode and placer deposits by Nokleberg *et al.* (1987 and 1994).

For over 20 years, DGGS has produced a series of annual reports and other documents on the status of exploration, development, and production in Alaska's mining industry (e.g., Bundtzen *et al.* 1982; Szumigala *et al.* 2002). Mineral resources and mining activity are described for national forests and wildlife refuges within the Ring of Fire planning area by USFS (1997 and 2000) and USFWS (1985, 1987, and 1988). A summary of pertinent information from the above reports is presented on a geographic basis in Section 3.2.3.

3.2.1.5 Strategic and Critical Minerals

Certain mineral commodities have been termed "strategic" or "critical" by the U.S. government. Strategic minerals are those that are essential to national defense, for which we are mostly dependent on foreign sources for during war, and for which strict measures controlling conservation and distribution are necessary. Critical minerals are also essential to national defense, but their procurement during war is less serious because they are either produced domestically or can be obtained through more reliable foreign sources (Thrush 1968).

Bundtzen *et al.* (1980 and 1982) summarize significant sources and reserves of strategic and critical minerals in Alaska. In addition, the MAS/MILS database was initially developed as a systematic assessment of strategic and critical minerals. Of 17 strategic minerals, 10 have been identified within the Ring of Fire planning area, including cobalt, chromium, fluorine, manganese, nickel, niobium, optical mica, platinum group metals (PGE), tantalum, and tungsten. With the exception of chromium, manganese, and tungsten, these minerals have only been identified in mineral deposits of the southeast region. Chromium, manganese, and tungsten are also found at several southcentral region locations (Bundtzen *et al.* 1980 and 1982; Kurtak 1982).

Reserves of certain critical minerals, such as barite, gold, gypsum, silver, titanium, and zinc, also occur in the southeast region (Bundtzen *et al.* 1980), as well as gold, gypsum, silver, and zinc in the southcentral region (Bundtzen *et al.* 1980; Nelson and Miller 2000). Nokleberg *et al.* (1987) suggest reserves of gold, silver, and zinc may be present on the Alaska Peninsula and eastern Aleutians.

3.2.2 Occurrence Potential

The occurrence potential for locatable mineral resources within the Ring of Fire planning area is summarized on Figures G-26 through G-29. Criteria for this mapping effort were developed by URS and BLM geologists in accordance with pertinent BLM guidance (BLM 1985; Persson 2004). The maps show potential locatable mineral resource areas for all commodities combined, and without regard to land status.

Potential Ratings. Occurrence potential ratings for locatable minerals are based on the following rationale:

<u>High Locatable Minerals Potential</u>: BLM (1985) guidance suggests that areas of high mineral potential be demonstrated based on geologic environment, inferred geologic processes,

reported mineral occurrences, valid geochemical/geophysical anomalies, and known mines or deposits. Within the Ring of Fire planning area, areas were mapped as high potential where existing state and federal mining claims indicate industry interest in a region or locality, where significant lode deposits have been documented (ADNR 2001; Nokleberg *et al.*, 1987), and/or where specific investigations have previously identified high potential areas (Bittenbender *et al.* 1999; DGGS 1993b; Maas *et al.* 1995; Nelson and Miller 2000; Still *et al.* 2002; USFS 1997).

Medium Locatable Minerals Potential: Areas mapped as medium potential include mineral terranes, placer mining districts, and KMDAs not specifically mapped as high potential by previous authors. The medium potential category also encompasses nearly all of the mineral locations and occurrences identified in the MAS/MILS and ARDF databases.

Low Locatable Mineral Potential: Most areas outside of the medium and high potential boundaries were interpreted to have low potential for locatable mineral occurrence. No areas of the Ring of Fire planning area were considered to have “no” potential, because all geologic units have some measure of mineral potential.

Not Determined: In several areas of the Ring of Fire planning area, locatable mineral potential cannot be determined due to lack of data, for example, beneath ice-cover of the southcentral and southeast regions. These areas are labeled “N” for not determined.

Confidence Level. Level of certainty in the data is indicated on the maps by line type as follows:

- Areas where abundant direct and indirect evidence support the interpretation are indicated by solid lines. This was considered to be the case for all mineralized areas identified as high potential with the exception of the Aleutians.
- Areas where direct evidence is available, but is quantitatively less, are indicated by long-dashed lines. Most areas of medium potential and two areas of high potential in the Aleutians fall into this category.
- Areas where indirect evidence alone supports the interpretation are indicated by short-dashed lines. Most areas of the Aleutians fall into this category, that is, mineral terrane mapping has not been conducted, and mineral potential is based on database listings alone.
- Areas where data are insufficient are indicated by dotted lines, for example, in high elevation regions and ice-covered areas of the Chugach Mountains and the southeast region.

3.2.3 Summary of Deposits and Production by Region

3.2.3.1 Alaska Peninsula/Aleutian Chain Region

Aleutian Chain. Mineral terrane information is generally unavailable for the Aleutian Chain. As such, mineral occurrence potential for the Aleutians is based primarily on MAS/MILS and ARDF occurrences, and is considered to have a lower level of certainty than the rest of the Ring of Fire planning area (Figure G-26).

USBOM (1995), USGS (2004a), and Cobb (1980) document several occurrences of copper and lead on Attu Island; gold, copper, lead, and zinc on Adak Island; and copper on Salt Island near Atka. ADNR (2001) identifies significant deposits of gold and silver on Umnak and Unalaska Islands based on ADRF data. These are located in the Geyser Bight and Makushin geothermal areas (Section 2.1.4), and are likely related to hydrothermal alteration of volcanic deposits (Berger and Singer 1992). Bundtzen *et al.* (1982) report exploration of caldera-hosted lode deposits in the Aleutians in the 1980s. Sedanka Island, located off the southwest corner of Unalaska, contains a significant polymetallic vein deposit containing base-metal sulfides of zinc, lead, and copper, which intrude a fault zone in Tertiary diorite (Nokleberg *et al.* 1987 and 1992). The nonmetallic mineral zeolite has also been reported on Unalaska.

Alaska Peninsula. Much of the Alaska Peninsula is classified as having medium potential for occurrence of locatable minerals based on mineral terrane maps, with the exception of several localized areas classified as high based on documentation of significant deposits (Figure G-27). Significant mineral deposits of the Alaska Peninsula are generally classified as one of three model types: 1) polymetallic vein deposits, 2) epithermal vein deposits, or 3) porphyry deposits. Polymetallic vein deposits generally consist of quartz-carbonate veins related to intrusions into sedimentary and metamorphic terranes, or to fluids forming during waning regional metamorphism. The veins typically contain base-metal sulfides, silver, and gold. Examples include shallow emplacement of andesitic stocks into sedimentary rocks, and disseminated sulfides in joints and veins of igneous rocks, both of which occur in the Chignik area (Nokleberg *et al.* 1987).

Epithermal vein deposits of the Alaska Peninsula are generally hosted in felsic to intermediate volcanic rocks. Notable examples include the Shumagin, Aquila, and Apollo-Sitka deposits near Sand Point that contain gold and silver in quartz veins within volcanic rocks. Reserves of gold and silver at the Shumagin prospect are estimated at about 600,000 tons of ore (Nokleberg *et al.* 1987; Szumigala *et al.* 2002). The Apollo-Sitka mine on Unga Island produced about 108,000 ounces of gold in the early 20th century, and inferred reserves are estimated at 748,000 tons. The underground workings at Apollo were reportedly reopened in the early 1980s; however, no recent production activity has been documented (Bundtzen *et al.* 1982; Szumigala *et al.* 2002). The Apollo Mine is currently the only actively held state claim on the Alaska Peninsula; there are no current federal claims in this region.

Porphyry mineral deposits on the Alaska Peninsula generally consist of stockwork veinlets in or near porphyritic intermediate to felsic intrusions. Examples include the Rex, Mike, and Bee Creek deposits of central Alaska Peninsula, which contain copper and/or molybdenum in andesitic stocks and dike swarms that intrude sedimentary and volcanic rocks. Grade estimates for these and other porphyry deposits of the Alaska Peninsula range from 0.3 to 0.7 percent copper, and 0.030 to 0.035 percent molybdenum. The Pyramid porphyry deposit near Herendeen Bay is estimated to have inferred reserves of 125 million tons of ore.

Several nonmetallic industrial minerals may also be present on the Alaska Peninsula. USFWS (1985) reports sublimation deposits of sulphur near volcanic fumaroles. Uranium may occur on the peninsula in association with sedimentary and volcanic terranes, although geiger counter surveys in the 1970s did not show significant readings. Zeolite and bentonite are probably present in association with volcanic ash (USFWS 1985).

3.2.3.2 Kodiak Region

Like the Aleutian Chain, the Kodiak region has been less explored than other areas of the Ring of Fire planning area. Mineral terranes depicted on Figure G-27 encompass a number of chromium, gold, silver, copper, and lead occurrences reported in the MAS/MILS database. With the exception of several state mining claims and one chromite deposit noted below, these areas are mapped as medium potential with respect to locatable minerals.

Selkregg (1974a) identifies a 10-mile wide swath along the northwest coast of Kodiak Island as a regional mineralized province potentially containing chromium and copper. This area corresponds to Peninsular terrane rocks extending along the Border Ranges fault zone (Sections 2.2.2 and 2.3.2). Nokleberg *et al.* (1992) and USFWS (1987) identify a significant deposit of podiform chromite within these rocks in the Kodiak National Wildlife Refuge (NWR) in the southwest corner of the island. The deposit contains an estimated 200,000 tons of ore. Podiform chromite deposits typically form as pod-like masses in the ultramafic parts of ophiolite complexes. Ultramafic rocks have been mapped in a narrow linear zone along Kodiak's northwest coast (Figure G-7).

Placer deposits of gold and other heavy minerals occur along the western beaches and have been mined on a small scale (Noklberg *et al.* 1987; Selkregg 1974a). Placer gold claims are also located in the Trinity Islands at the south end of the Kodiak region. Lode gold prospects occurring mainly in quartz veins occur throughout the island and have been sporadically explored. Minor production of lode gold has been reported from the Uyak Bay area on the west side of Kodiak. Lode occurrences of other commodities such as copper, silver, lead, zinc, and tungsten have also been reported throughout the island (Selkregg 1974a; USBOM 1995; USGS, 2004a).

3.2.3.3 Southcentral Region

The southcentral region is traversed by several mineralized regions and historical mining districts, as described in the following paragraphs.

West Side of Cook Inlet. KMDAs and mineral terranes along the west side of Lower Cook Inlet (Figure G-28) are characterized by reported occurrences of copper, gold, iron, lead, molybdenum, silver, and zinc (USBOM 1995; Selkregg 1974a; USGS 2004a). Although outside of the Ring of Fire planning area, the large Pebble copper-gold porphyry deposit on the north side of Illiamna Lake just west of the Ring of Fire planning area boundary (e.g., Alaska Department of Community, Commerce and Economic Development 2004) provides an indication of the type of deposits that may occur in association with intrusive rocks along the northern Aleutian and Alaska Ranges. Nokleberg *et al.* (1987 and 1994) identify a significant prospect of gold, silver, zinc, copper, and lead in an epithermal vein deposit hosted in volcanic rocks on the northeast side of Illiamna volcano near Tuxedni Bay. Estimated reserves are 1,100,000 tons of ore (Szumigala *et al.* 2002). Referred to as the Johnson River prospect, this deposit is currently being reevaluated for possible development (Kraus 2004).

A number of mineral occurrences of lead, zinc, silver, copper, and molybdenum have been reported in the Alaska range northwest of Mount Spurr where a KMDA has been mapped by RDI *et al.* (1995). On the western flank of Mount Spurr, DGGS (1993b) mapped a copper-molybdenum porphyry deposit as having high mineral potential based on probabilistic modeling. Nokleberg *et al.* (1987 and 1992) identify a significant porphyry molybdenum deposit in the Hayes Glacier area north of Mount Spurr, which occurs in quartz veins intruded into Tertiary granitic rocks. A number of state mining claims are concentrated in the Rainy Pass area in the northwest corner of the Ring of Fire planning area, indicating recent exploration interest in an area of Tertiary-Cretaceous intrusive rocks (Kraus 2004).

Yentna-Petersville Area. The Yentna placer district is located in the north-central part of the southcentral region. This area contains numerous state mining claims and several federal claims (Figure G-28). Total placer gold production from this area over the years has been on the order of 200,000 ounces. Recent production is reported from small placer operations (Szumigala *et al.* 2002). A recent discovery of lode diamonds was reported in the Shulin Lake area at the southern end of the Yentna district about 30 miles west of Talkeetna. The deposit is thought to represent the crater facies of a volcanic pipe-like structure within interbedded volcaniclastic and tuffaceous rocks (Szumigala *et al.* 2002).

Talkeetna Mountains. Selkregg (1974a) reports a mineralized area with potential copper deposits in the northern Talkeetna Mountains. Mineral occurrences of cobalt, gold, lead, molybdenum, silver, and zinc are also reported in this area (USBOM 1995; USGS 2004a). Several state claims are located in this area.

The Hatcher Pass-Willow Creek mining district extends from the southern Talkeetna mountains north of Palmer, towards the northeast corner of the Ring of Fire planning area. Nokleberg *et al.* (1987 and 1992) describe the lode gold deposits of the Hatcher Pass area as polymetallic quartz veins hosted primarily in granitic rocks. Total gold production in the area has been on the order of 600,000 ounces from lode gold and 60,000 ounces from placer deposits (Szumigala *et al.* 2002). Most development and production in the area took place between 1909 and 1950 (Nokleberg *et al* 1987 and 1992.). A number of state and federal claims are currently located in this area (Figure G-28), and some recent production is reported from small placer operations. Mineral occurrences of copper, mercury, molybdenum, silver, tungsten, and zinc are also reported in this district, as well as occurrences of the nonmetallic mineral talc (USBOM 1995; USGS 2004a).

Chugach and Kenai Mountains. Selkregg (1974a) identifies a metalliferous province along western front of the Chugach and Kenai Mountains extending from Homer to Palmer. Chromium and copper are the primary commodities in these Peninsular terrane rocks, which are similar to those along the northwest coast of Kodiak Island. Nokleberg *et al.* (1987 and 1992) report significant deposits and reserves of podiform chromite related to mafic-ultramafic rocks and placer deposits on the southwest coast of Kamishak Bay, with chromite contents in ore ranging as high as 43 percent. One of these two deposits, Red Mountain, produced about 29,000 tons of ore in the 1940s and 1950s. Chromite-bearing ultramafic rocks have also been reported in the Eklutna area of the Chugach Mountains north of Anchorage (Rose 1966).

A number of significant gold quartz vein deposits intrude Cretaceous metasedimentary rocks of the Chugach terrane in the Kenai and Chugach Mountains. These deposits, also referred to as Chugach-type low-sulfide gold-quartz veins, extend from the southern end of the Kenai Peninsula to the northwest and northeast corners of PWS (Figure G-28). Past production from each of these sites ranges from 2,000 to 52,000 ounces of gold (Nokleberg *et al* 1987.). The Hope-Girdwood area is also a significant placer mining district, with total production since the early 1900s of about 67,000 ounces gold and lesser amounts of silver. Recent production is reported from small placer mines in Girdwood and Hope area (Szumigala *et al.* 2002). Mineral potential has recently been mapped Chugach National Forest (CNF) by Nelson and Miller (2000). Several areas identified as being highly favorable for undiscovered Chugach-type vein gold and placer deposits were mapped as high potential on Figure G-28.

Nelson and Miller (2000) describe several VMS deposits, also referred to as Cyprus-type massive sulfide deposits, in Ghost Rocks and PWS terrane rocks of the western and northern margins of PWS (Sections 2.2.3 and 2.3.3). Deposits of this type are found in ophiolite assemblages containing pillow basalt, gabbro, sheeted dikes, and deep-water sedimentary rocks, and are favorable for concentrations of copper, lead, zinc, gold, and silver. Deposits rated highly favorable for future development were mapped on Knight and Latouche Islands in southwestern PWS.

Cook Inlet-Susitna Basin. The identification of Cook Inlet-Susitna Basin sedimentary deposits as a mineral terrane was primarily intended by AEIDC (1979) and Hawley and AEIDC (1982) to indicate the potential for coal, which is not considered a locatable mineral (Section 3.1.2). However, this terrane is included on Figure G-28 due to the potential presence of placer deposits, uranium, or other locatable minerals associated with sedimentary deposits. Several authors (Hawkins 1973; Kline and Pinney 1994; Rutledge *et al.* 1953) indicate the presence of gypsum and sedimentary zeolite deposits in upper Matanuska Valley, and diatomite on the Kenai Peninsula near Nikiski.

3.2.3.4 Southeast Region

The southeast region has a long history of mineral prospecting and mining. Mining districts of the southeast region are described in the following paragraphs generally from northwest to southeast. Much of this region is comprised of federal lands that are not actively managed by BLM for locatable minerals, such as USFS and NPS lands. Because the Ring of Fire PRMP/FEIS addresses federal mineral estate as well as BLM-managed surface lands, however, these areas are included in the following sections. This discussion is intended to be an overview, with more emphasis placed on areas with known BLM-managed lands.

Metallic Minerals – Northern Southeast Region

Yakutat Area. Gold and other heavy minerals such as titanium, platinum, and ilmenite (iron) have been found in beach sands along the northwest coast of the southeast region from Yakutat Bay to La Perouse Glacier near Icy Point (Nokleberg *et al.* 1987 and 1992). A total of about 2,000 ounces of gold have been mined from these placer deposits (Szumigala *et al.* 2002). Several offshore prospecting claims are located just south of Yakutat Bay (Figure G-29).

KMDAs related to mafic and ultramafic intrusive rocks of the Chugach terrane are located in the northeastern and southern parts of Yakutat area. A significant deposit of gabbroic nickel and copper occurs within these type of rocks at Brady Glacier in western Glacier Bay National Park and Preserve.

Glacier Bay to Skagway. Mineral resources of the Glacier Bay area have been investigated in detail by Still (1988). Based on these results, a large KMDA was identified surrounding Glacier Bay (RDI *et al.* 1995), which encircles numerous occurrences of copper, gold, molybdenum, silver, tungsten, and zinc (USBOM 1995; Nokleberg *et al.* 1987; USGS 2004a). The Glacier Bay area contains several different mineral deposit types that occur within Alexander terrane rocks, including VMS deposits, porphyry copper-molybdenum deposits, and polymetallic and gold-quartz vein deposits (Nokleberg *et al.* 1987; Szumigala *et al.* 2002).

Mineral resources of the Haines-Klukwan-Porcupine subarea of the Juneau Mining District have been investigated in detail by USBOM (1988), DGGS (1993b), and others. A number of overlapping mineral deposit types were mapped west of Klukwan along the Klehini River valley, extending southwesterly to Mount Henry Clay. The mineral deposits described in this area include: 1) stratiform VMS deposits containing bedded barite and associated lead, zinc, copper, and gold; 2) zoned mafic-ultramafic plutons intruding older Alexander terrane rocks, which contain significant lode and placer deposits of iron, titanium, vanadium, and nickel; 3) copper-gold and lead-zinc bearing skarn deposits; 4) placer gold and other heavy minerals in the Porcupine Creek area; and 5) granitic gold vein deposits throughout the area (USBOM 1988; DGGS, 1993b; Nokleberg *et al.* 1987; Szumigala *et al.* 2002). DGGS (1993b) rate the ultramafic and skarn deposits, and parts of the VMS and vein gold deposits, as having high mineral potential. Identified resources in the area include an estimated three million tons of gold ore (at 0.008 ounces/ton), 750 billion tons of zinc and silver ore (at 1.73 percent zinc and 1.75 ounces/ton silver), and 990 billion tons of soluble iron (at 10.8 to 16.8 percent) (USBOM 1988). The Porcupine placer deposits have produced a total of about 80,000 ounces of gold since their discovery, and are currently still actively producing at Big Nugget Mine (Szumigala *et al.* 2002). Approximately 555,000 cubic yards of placer gold deposits (at >0.005 ounces/cubic yard) are estimated to remain in the area. A number of current federal and state mining claims are held in the Klukwan area (Figure G-29). Relatively large parcels of BLM-managed State-selected lands are located to the north and south of Klukwan (Figure G-5).

Mineralized terrane in the Skagway area is related to Cretaceous intrusive rocks. Several occurrences of uranium, gold, silver, and copper are reported in this area (USBOM 1995; Clough 1988; USGS 2004a). Two areas of the Juneau Mining District, located northwest of Skagway and east of Haines, are largely unexplored and partly under glaciers (Gehrels and Berg 1992; RDI *et al.* 1995).

Metallic Minerals – Central and Southern Southeast Region

Most of the central and southern areas of the southeast region consist of federal mineral estate managed by the USFS or NPS. Scattered small areas of BLM-managed state- or Native-selected lands are located near the city of Juneau; on southern Admiralty Island; near the towns of Hoonah, Kake, Wrangell, and Ketchikan; and on southern Prince of Wales Island (Figure G-5).

Juneau and Admiralty Island. Mining resources of the Juneau Gold Belt and Coast Ranges subareas of the Juneau Mining District have been investigated by Redman *et al.* (1988) and Clough (1988). Significant lode deposits of the Juneau and Admiralty Island areas generally fall into one of four categories: 1) gold-quartz veins occurring in a belt along the east side of Lynn Canal and Stephens Passage (e.g., Kensington Mine) that were formed by hydrothermal fluids migrating along the Coast Ranges meagalineament and related fractures during regional metamorphism; 2) VMS deposits in volcanic rocks on northern Admiralty Island with significant reserves of zinc, lead, copper, silver, and gold (e.g., Greens Creek Mine); 3) massive sulfide deposits in metasedimentary rocks along the upper reaches of the Coast or Boundary Ranges; and 4) gabbroic nickel-copper deposits intruding Alexander terrane metamorphic rocks at the north end of Admiralty Island (Clough 1988; Nokleberg *et al.* 1987 and 1992; Redman *et al.* 1988).

Numerous federal and state mining claims are active in this area. Greens Creek is the largest producing mine in the southeast region, milling on the order of 500,000 to 700,000 tons of ore per year for the past several years (Szumigala *et al.* 2002). Kensington Mine, probably the largest deposit in the Juneau Gold Belt, produced 10,900 tons of ore prior to 1930, and is estimated to have about 11 million tons of ore remaining at 0.16 ounces/ton gold (Szumigala *et* *al.* 2002). Placer gold was discovered in the Juneau area in the 1800s. Total placer gold production in this area has been on the order of 80,000 ounces.

Chichagof and Baranof Islands. The mineral resources of Chichagof and Baranof Islands in the west-central part of the southeast region have been recently investigated by Bittenbender *et al.* (1999). Five types of mineral deposits are found on these islands: 1) gabbroic nickel-copper deposits within Chugach terrane rocks on Baranof Island and along the west coast of Chichagof; 2) gold quartz vein deposits that cross-cut Mesozoic graywacke and diorite mostly within Wrangellia terrane of western Chichagof; 3) porphyry copper-molybdenum deposits; 4) VMS deposits mostly within Chugach terrane rocks; and 5) skarn deposits on the east coast of Chichagof within Alexander terrane rocks. Two of the vein gold deposits and one of the porphyry deposits were identified as having relatively high development potential by Bittenbender *et al.* (1999). Active claims are currently held in three vein gold areas on these islands (Figure G-29).

Stikine Area. The Stikine area (Petersburg and Kupreanof Mining District) includes Kuiu, Kupreanof, Mitkof, Zarembo, Woronofski, Etolin and Wrangell Islands, as well as the mainland east of these islands. Still *et al.* (2002) recently mapped and refined the KMDAs for this area, and identified several of them as having high Mineral Exploration Potential (MEP). The deposits on these islands include: 1) VMS deposits that extend from northeast Kuiu Island, through the Duncan Canal area and central Zarembo Island, that are rich primarily in zinc and lead but locally include copper, gold, and silver; and 2) a mixture of polymetallic vein, porphyry, skarn, and vein gold deposits in the Groundhog-Berg basin area east of Eastern Passage, that are related to granitic sills and dikes intruding metamorphic rocks. Active state and federal claims are located in these areas, most notably on Woewodski Island in southern Duncan Canal (Figure G-29).

Ketchikan and Hyder District. Maas *et al.* (1995) mapped the mineral resources of the Ketchikan Mining District, which includes Prince of Wales Island, Revillagigedo Island, and the mainland area surrounding Revillagigedo. Several locations within this district were mapped as high potential on Figure G-29 on the basis of a high rating by Maas *et al.* (1995) as well as existing claims in the area. These include a number of different mineral deposit types: 1) VMS deposits in southeast and west-central Prince of Wales; 2) copper-iron skarn deposits related to granitic intrusions into limestone and calcium-rich volcanic rocks on Kasaan Peninsula; 3) polymetallic vein and small vein gold deposits in the Hyder area, Helm Bay, and central and southeast Prince of Wales; 4) porphyry copper-molybdenum deposits on southeast Prince of Wales and east of Behm Canal (e.g., Quartz Hill molybdenum deposit in Misty Fiords National Monument); 5) mafic-ultramafic deposits on the north side of Cleveland Peninsula, Salt Chuck Bay, and Duke Island; and (6) granitic ring-dike swarms rich in uranium and rare-earth elements (REE) (e.g., Bokan Mountain mine, southeast Prince of Wales).

Nonmetallic Industrial Minerals

Several varieties of nonmetallic industrial minerals are located in the southeast region. These include: 1) gypsum deposits on eastern Chichagof Island that are hosted in limestone skarn deposits (Bittenbender *et al.* 1999; Bundzten *et al.* 1982); 2) asbestos occurrences in schist and gneiss rocks of the Stikine area, at the north end of Admiralty Island, and on Annette Island (Kline and Pinney 1994; Still *et al.* 2002); 3) gemstones such as garnet and zirconium; 4) an occurrence of graphite in the Stikine area (USBOM 1995); 5) fluorite in the Wrangell area (Kline and Pinney 1994); 6) mica on Sitklan Island near the southern Canadian border; 7) wollastonite on southern Prince of Wales; 8) numerous outcrops of high purity limestones; and 9) barite deposits located throughout the southeast region.

Limestones of chemical or metallurgical grade, or that are suitable for making cement (generally greater than about 96 percent calcium carbonate), are considered locatable under mining law (43 CFR 3830.12; Warfield 1962). There are a number of occurrences of limestone and marble with high purity throughout the southeast region, particularly on Prince of Wales Island (Maas *et al.* 1995).

Barite occurrences have been reported at a number of locations: in northwest Glacier Bay area, west of Klukwan near Mount Henry Clay, on Lemesurier Island in Icy Strait, on northern Admiralty Island, on northwest Kuiu Island, in the southeastern part of Kupreanof Island near Petersburg, on southern Prince of Wales Island, and on Annette Island north of Metlakatla (BLM 1995; Bundtzen *et al.* 1982; Kline and Pinney 1994; Nokleberg *et al.* 1987 and 1994). Most of these occur within VMS deposits. The northernmost deposit near Klukwan is described as bedded barite in a massive sulfide deposit within pillow basalts, and is reported to contain 750 million tons of ore with 60–65 percent barite, along with several metallic minerals described above (USBOM 1988). The deposit near Petersburg, located on the Castle Islands in Duncan Canal, was mined in the 1960s and 1970s, producing about 850,000 tons of high-grade barite ore. It is estimated that millions of tons of barite ore remain underwater at this site (Bundzten *et al.* 1982).

3.3 Salable Minerals

As indicated in Section 1.2, salable minerals include certain mineral materials that can be disposed of either through a contract of sale or a free-use permit, such as common varieties of construction aggregate (sand and gravel), building stone, pumice, clay, and limestone. The following sections provide a description of each of these material types and their extent within the Ring of Fire planning area, as well as a discussion of the occurrence potential criteria used in this analysis. Figures G-30 through G-33 depict the extent of geologic units that are favorable for the presence of the primary salable minerals within the Ring of Fire planning area, as well as known occurrences and extraction sites documented in the USBOM (1995) MAS/MILS database.

3.3.1 Known Deposits and Resources

3.3.1.1 Sand and Gravel Aggregate

Sand and gravel and other aggregate resources are common throughout the Ring of Fire planning area, occurring primarily in association with unconsolidated surficial deposits of fluvial, glacial, and eolian origin. Unconsolidated deposits are described in Sections 2.3.1 through 2.3.4 for each region of the Ring of Fire planning area.

Broad areas of Quaternary and late Tertiary geologic units that are favorable for the occurrence of sand and gravel are depicted in yellow on Figures G-30 through G-33. These include alluvium and glacial outwash along the north coastal plain of the Alaska Peninsula (Figure G-31); a wide variety of glaciofluvial and eolian deposits in the Anchorage Bowl, western Kenai Peninsula, and Matanuska-Susitna Valley (Figure G-32); and beach ridges of the Yakutat area in the southeast region (Figure G-33) (Beikman 1980). Outside of these broad mapped areas, additional localized sources of sand and gravel include individual stream valleys, slope deposits, and beach deposits (e.g., Maas 1988; Maas *et al.* 1995; Selkregg 1974a, 1974b and 1974c; Sherman *et al.* 1997; Still *et al.*, 2002; USFWS 1988). Other forms of aggregate besides sand and gravel include crushed rock, tailings, and cinders.

The potential for locating sand and gravel deposits within different types of surficial landforms in Alaska has been classified by Reger (1988). Surficial deposits considered to have a high potential for containing quality sand and gravel deposits include floodplains, stream terraces, beach deposits, and some glacial landforms such as outwash plains, kames, and eskers. Those with low to moderate potential include alluvial fans, moraines, sand dunes, loess, tidal flats, and slope deposits such as landslides, debris flows, and talus cones.

Sand and gravel is an important commodity in Alaska, ranking only behind oil and gas in value to the State's economy. Past production in the Ring of Fire planning area has largely been project driven, with peaks occurring during periods of military construction, discoveries of oil and gas fields in Cook Inlet, and urban growth in the Anchorage and Matanuska-Susitna Valley areas (Bundtzen *et al.* 1982). Figures G-30 through G-33 depict sand and gravel extraction sites documented by USBOM (1995), many of which are related to past road construction, where sand and gravel or crushed rock aggregate have been mined to support roads and other construction needs (ADNR 1982; Kline and Pinney 1994). Recent annual production of sand and gravel and crushed rock aggregate in the Ring of Fire planning area is reported to be on the order of 8.6 millions tons in the southcentral region, 1.1 million tons in the southeast region, and 40,000 tons for the Alaska Peninsula/Aleutian Chain and Kodiak regions combined (Szumigala *et al.* 2002). Pinney and Duenwald (2001) provide a listing of private producers of aggregate in the State of Alaska based on DGGS surveys. Thirteen companies are currently listed in the southcentral region and five in the southeast region. None are listed for the Alaska Peninsula/Aleutian Chain or Kodiak regions.

3.3.1.2 Dimension Stone, Limestone, and Marble

Dimension stone, also referred to as building stone, is natural rock material of sufficient integrity and quality that it can be quarried, cut, shaped, and finished for specific construction purposes. Examples of rock types used for building stone include granite, basalt, greenstone, limestone, marble, serpentinite, and sandstones (ASTM 2004; Pinney and Duenwald 2001).

Most past production of building stone within the Ring of Fire planning area has been from limestone and marble quarries in the southeast region. The extent of geologic units containing limestone or marble is depicted on Figures G-30 through G-33 in blue. Quarries and stone pits documented by USBOM (1995) are also depicted on these figures. The most extensive sequences of carbonate rocks in the Ring of Fire planning area belong to the Silurian Heceta Limestone and the pre-Ordovician Wales Group of metamorphic rocks in the southern southeast region (Maas *et al.* 1995). Measured reserves of high quality marble in the southeast region are estimated to be over 800 million tons. Mining of ornamental marble from Prince of Wales Island began in the early 1900s. By 1949, more than two million tons of high-grade limestone and marble and 450,000 tons of structural grade limestone had been mined from quarries on Prince of Wales and Dall Islands. The southeast region marble industry declined after World War II due to changes in building styles and exploitation of marbles in contiguous U.S. states (Bundtzen *et al.* 1982). Many of the quarries in the southeast region were also developed for use as crushed rock in making logging roads.

In addition to the limestone and marble quarries of the southeast region, several stone pits have been documented near the town of Kodiak (USFWS 1988), along Turnagain Arm, along the east and west sides of lower Cook Inlet, and in the Matanuska-Susitna Valley (USBOM 1995; Kline and Pinney 1994). These may have been used for extraction of dimension stone, as well as riprap used for bank and slope protection (ASTM 2002; Pinney and Duenwald 2001).

3.3.1.3 Pumice and Pumicite

Pumice is a vesicular pyroclastic volcanic glass, usually with a felsic or rhyolitic composition. Where large amounts of water vapor and gas are present, a finer fragmentary deposit called pumicite may result (American Geological Institute [AGI] 1974; Rutledge *et al.* 1953). Pumice and pumicite are used as lightweight aggregate in the building industry, where lighter loads and higher insulating properties are desired, and as an ingredient in portland-pozzolan cements (AGI 1974; Rutledge *et al.* 1953).

Quaternary volcanic units favorable for the occurrence of pumice and pumicite are depicted on Figures G-30 through G-33 in pink. Most of these deposits are located on the Aleutian Chain and Alaska Peninsula, far from centers of construction. Occurrences of pumice documented by USBOM (1995) are also shown on the figures as triangles. Pumice has been documented at Mount Katmai on the Alaska Peninsula and on Augustine Island in lower Cook Inlet, and is likely present at other pyroclastic volcanoes throughout the Aleutian arc (AVO 2004). Volcanic ash is also likely to be present in large amounts throughout the Aleutians, Alaska Peninsula, and Cook Inlet area. Block pumice less than 2 inches in size is considered a salable material under mining law, while pumice greater than 2 inches is considered locatable (43 CFR 3830.12). Based on the results of pumice particle size analyses at Katmai and Augustine (Dahners 1947; Rutledge *et al.* 1953), most pumice in these areas appears to be of salable, not locatable, grade. Pumice and pumicite have been mined historically from Katmai and Augustine, and shipped by barge to Anchorage for use as building blocks (Rutledge *et al.* 1953).

3.3.1.4 Other Mineral Materials

Other salable minerals documented within the Ring of Fire planning area include clay used in making bricks and ceramic products, and quartz crystals used as gemstones and in industrial applications.

Kline and Pinney (1994) and Rutledge *et al.* (1953) document the location of several clay deposits in the southcentral region. Rutledge *et al.* (1953) provide the results of chemical and physical tests for several clay and shale locations in the Alaska Railroad corridor that indicate their suitability for use in the clay products industry. Clay has historically been mined from at least two formations in the southcentral region: the Pleistocene Bootlegger Cove Clay in the Anchorage area, and alteration products of Jurassic volcanic rocks in eastern Matanuska Valley near Sheep Mountain. Clay occurrences have also been identified in the Tertiary Chickaloon and Matanuska Formations of the Matanuska Valley, the Tertiary Beluga Formation near Homer, and near Moose Pass on the Kenai Peninsula (USBOM 1995; Kline and Pinney 1995; Magoon *et al.* 1976; Rutledge *et al.* 1953).

Quartz crystals have been documented by USBOM (1995) on Unalaska Island, and likely occur in many other places throughout the Ring of Fire planning area. Quartz is a nearly ubiquitous mineral found in association with granite, rhyolite, sandstone, quartztite, gneiss, and many other rock types. Large quartz crystals are typically found near hot springs, in granite porphyries, and epithermal veins (Sorden 2002).

3.3.2 Occurrence Potential

The occurrence potential for several salable mineral types within the Ring of Fire planning area is summarized on Figures G-30 through G-33. Criteria for this mapping effort were developed by URS and BLM geologists in accordance with pertinent BLM guidance (BLM 1985; Persson 2004). The maps show potential resource areas for the three primary mineral materials described in Section 3.3.1 without regard to land status.

Potential Ratings. Occurrence potential ratings for salable minerals are based on the following rationale:

<u>High Salable Minerals Potential</u>: BLM (1985) guidance suggests that areas of high mineral potential be demonstrated based on geologic environment, inferred geologic processes, reported occurrences, and known quarries or deposits. Areas within the Ring of Fire planning area were considered to be high potential where known occurrences and extraction sites have been identified in the MAS/MILS database (USBOM 1995), and along road systems where aggregate resources are likely to have been previously developed (Kline and Pinney 1994).

<u>Medium Salable Minerals Potential</u>: Areas mapped as medium potential on the basis of geologic environment and inferred processes (BLM 1985) include geologic units or terranes favorable for the primary mineral materials addressed in Section 3.3.1.

<u>Unknown Salable Mineral Potential</u>: All areas outside of the medium and high potential boundaries were interpreted to have an unknown potential for salable minerals occurrence. No areas of the Ring of Fire planning area were considered to have “no” or “low” potential, because nearly all geologic units have some potential for use as mineral materials, such as crushed rock.

Confidence Level. Level of certainty in the data is indicated on the maps by line type as follows:

- Areas where abundant direct and indirect evidence support the interpretation are indicated by solid lines. This was considered to be the case for road systems identified as a high potential based on historic aggregate extraction sites (Kline and Pinney 1994).
- Areas where direct evidence is available but is quantitatively less, or where indirect evidence alone supports the interpretation, are indicated by dashed lines. Geologic units mapped as medium potential fall into this category.

Summary. High potential ratings were given to isolated road systems on several islands in the Aleutian Chain, as well as near Cold Bay and Port Moller on the Alaska Peninsula. Documented pumice sites near Chignik Lagoon and Mount Katmai on the Alaska Peninsula, and along the southwest side of Lower Cook Inlet were also given high potential ratings. Stone and aggregate extraction sites and roaded areas on northeast Kodiak Island were considered high potential, as well as all of the primary road systems and known sand and gravel sites in the southcentral region. In the southeast region, much of Prince of Wales, Kupreanof, and northern Kuiu Islands were considered high potential based on existing stone quarries, as were isolated roaded areas near many of the southeast region communities. Areas of medium potential for sand and gravel, pumice, and limestone, were mapped throughout the Ring of Fire planning area based on geologic unit associations (Figures G-30 through G-33).

4.0 MINERAL RESOURCES DEVELOPMENT POTENTIAL

The potential for future mineral resource development in the Ring of Fire planning area is partly dependant upon the location of prospective resources as described in Chapter 3, and partly upon economic factors such as price trends, access, demand, etc. An analysis of development potential requires the projection of RFD per BLM guidance (BLM 1990). RFD scenarios have been prepared by BLM geologists for the Ring of Fire planning area (BLM 2004e and 2005). These documents are provided in Attachments A and B, respectively, and incorporated into the following sections.

While development potential for leasables applies to both BLM-managed surface and split estate lands, BLM does not actively manage locatable or salable minerals on split estate lands. Thus, the description of development potential for leasables is regional in scope, while that for locatables and salables is intended to apply only to BLM-managed surface lands.

4.1 Leasable Minerals

4.1.1 Oil, Gas, and Coalbed Natural Gas

Exploration and development of oil, conventional gas, and CBNG is anticipated to occur in the southcentral region as described in the RFD developed by BLM (2004e) for the Ring of Fire planning area (Attachment A). While these fluid minerals may be present in other regions of the Ring of Fire planning area (e.g., Alaska Peninsula and northwest corner of the southeast region), they are considered uneconomic to explore and develop in these areas due to inaccessibility and past exploration history. Thus, no foreseeable actions are anticipated by BLM over the next 10 to 15 years for oil, natural gas, or CBNG outside of the southcentral region.

Based on occurrence potential, as well as past exploration, accessibility, and existing infrastructure, the RFD predicts that exploration and development of oil, conventional gas, and CBNG in the Cook Inlet Basin of the southcentral region will continue to occur over the next 10 to 15 years. Cook Inlet Basin is a maturely developed basin that has produced oil and gas since 1957. The region continues to be of interest to the oil industry. Although oil exploration and production are generally in decline, steady growth in the demand for natural gas in the southcentral region has stepped up exploration drilling for this resource in recent years. The ADNR Division of Oil and Gas leasing trends suggest that there would be about 12 lease sales over the next 10 to 15 years.

The RFD projects that exploration and development would occur within three stratigraphic plays within the Cook Inlet Basin. The Beluga-Sterling Gas and Hemlock-Tyonek Oil plays (Section 3.1.1.1) are designated as having high development potential in the RFD, while CBNG resources in Cook Inlet basin (Section 3.1.3.2) are designated as having moderate development potential. The development potential ratings are based on the available data and professional judgment; however, actual future industry activity will depend on accessibility to resources, lease stipulations, exploration and development costs, success rate of future wells, oil and gas prices, and industry return on investment. In the case of CBNG, industry activity will also depend on local acceptance of split estate land issues and produced water disposal.

The RFD does not distinguish between basin-wide activity and predicted activities on specific BLM-managed lands. It is estimated that these lands (unencumbered, State- or Native-selected, and state or private split estate) encompass less than ten percent of the total basin area. Future exploration and development activity on specific BLM-managed lands would be subject to a step-down or tiered planning document prior to leasing.

Currently producing oil and gas fields in Cook Inlet Basin with federal mineral interests include the Swanson River, Beaver Creek, Kenai, and Sterling Fields. With the exception of the Swanson River Field, production from these fields is expected to continue through the next 10 to 15 years. The Swanson River Field, located in the Kenai NWR, is projected to cease production around 2017. Gas storage is currently being considered for the Swanson River Field, whereby additional gas would be brought in from outside sources and stored in the field's reservoirs. This proposed use is not expected to extend the life of the field, however (ADN 2005).

The RFD projects the following land usage and infrastructure related to oil, gas, and CBNG development in Cook Inlet Basin over the next 10 to 15 years:

- Based on drilling activity over the past decade, it is projected that a total of approximately 41 exploration wells and 75 production wells targeting oil and conventional gas would be drilled in Cook Inlet Basin over the next 10 to 15 years. CBNG development would likely occur in the Matanuska-Susitna Valley, and could be similar in size and extent to the existing Pioneer Unit.

- Total short-term surface disturbance from initial exploration and development activities in the basin over the next 10 to 15 years is projected to be 1,094 acres for oil and conventional gas, and 1,464 acres for CBNG. Total long-term disturbance (for example, production pads and roads) is estimated to be about 75 percent of the total short-term disturbance. These estimates account for a certain percentage of wells that would be plugged and abandoned as dry holes or subeconomic, and the land reclaimed.

- Surface disturbance for oil/gas/CBNG exploration and development would include drill pads, access roads, pipelines, and utilities. CBNG development would also include compressor stations and a water disposal facility.

- Approximately 1,000 acres of additional short-term disturbance is estimated to occur as a result of geophysical exploration over the next 10 to 15 years.

- Based on historic rates of well abandonment in the basin, the RFD projects that about 161 currently existing oil and gas wells within the Ring of Fire planning area would be plugged and abandoned over the next 10 to 15 years. This includes wells at the Swanson River field. Well abandonment includes removal of equipment and structures, as well as restoration and revegetation of well sites.

4.1.2 Coal

While coal resources are present throughout much of the Ring of Fire planning area (Section 3.1.2), they were considered by BLM to be uneconomic to explore and develop over the next 10 to 15 years due to inaccessibility and past exploration history. Thus, no foreseeable actions are anticipated over the next 10 to 15 years for coal on BLM-managed lands. Most areas with coal resources within the Ring of Fire planning area were known at the time of State-and Native-land selections and were withdrawn from federal land status. Remaining BLM-managed lands are largely scattered in areas of low to medium occurrence potential (Figures G-19 through G-21).

The economics of coal development in Alaska have been challenged by the remoteness and lack of transport infrastructure at most fields, lack of terminal/port facilities, short construction seasons, steady to declining commodity prices, supply and demand balances in Asia, ocean freight rates, and the economics of scale necessitating large generation units. After two decades of steady to declining prices, Asian contract prices for thermal coal rose in 2004, a trend that is projected to continue due to global economic growth stimulating increased electricity generation requirements (AME Research 2005; Stiles 2002).

Within the Ring of Fire planning area, coal resources that have recently received industry attention include the Beluga and Matanuska fields of the southcentral region (Figure G-20). Coal in the Chuitna district of the Beluga Field has been marketed to electric utilities, cement, and industrial users in the U.S. and Asia in past decades (U.S. Environmental Protection Agency [USEPA] 1990). Economic issues of infrastructure, remoteness, and environmental impacts have combined to make development of this field subeconomic in the past. However, there may be potential industry interest in future years, as natural gas prices rise, local gas resources decline, and coal becomes a competitive energy source in the southcentral region. Conceptual ideas of a coal-fired power plant located in the Chuitna district have been floated in the past. Such a plant is currently considered competitive for supplying power to the southcentral region and the Railbelt (Stiles 2002). Based on the lack of BLM-managed lands within this district, however, the potential for coal development over the next 10 to 15 years on BLM lands is anticipated to be low.

DGGS has rated the Wishbone Hill district of the Matanuska Field as having high coal development potential (ADNR 2005; Merritt 1986c; Merritt and Relowich 1984). There has been some recent interest in leasing of State lands in this district for processing of existing coal tailings into a synthetic fuel product. In 2005, ADNR conducted a Best Interest Finding to competitively lease a 40-acre area of the Evan Jones Mine for development of the tailings as well as other coal deposits. Usibelli Coal Mine, Inc. currently has landholdings in the Wishbone Hill district and elsewhere in the Matanuska Field (Usibelli 2004). Matanuska Electric Association (MEA) recently began discussions with Usibelli to potentially construct a coal-fired power plant in the area (MEA 2005). Should Usibelli pursue coal development for utility use or export over the next 10 to 15 years, there could be interest in adjacent or nearby BLM-managed lands. The development potential of these lands is expected to be low; however, due to their location in structurally complex areas around the perimeter of the field and likely small deposit sizes.

4.1.3 Geothermal

While geothermal resources are present throughout much of the Ring of Fire planning area (Section 3.1.4), they were considered by BLM to be uneconomic to explore and develop over the next 10 to 15 years due primarily to issues of remoteness and inaccessibility to market. Future use of geothermal energy in Alaska will likely depend on funding from USDOE in the form of grants for resource exploration and definition studies (USDOE 2004a). Thus, while some geothermal exploration activities may occur over the next 10 to 15 years, development of the resource is not anticipated.

Past prospects and localized uses of geothermal resources in the Ring of Fire planning area are described in Section 3.1.4.2. Geothermal resources that have received recent industry attention the Ring of Fire planning area include Unalaska, Akutan, and Umnak Islands in the Alaska Peninsula/Aleutian Chain region, and Mount Spurr in the southcentral region (Section 3.1.4.2, Figures G-22 and G-24). Of the Aleutian prospects, Unalaska's Makushin volcano contains the largest resource, but has not been developed due to transmission line costs (Liles 2004).

Remoteness is the biggest roadblock to development of alternative power in Alaska. The profitability of geothermal power depends on the economics of scale to provide a return on investment. Remoteness necessitates high transmission line costs; thus, a geothermal-powered generating unit would need to be large to justify development. The southcentral region and the Railbelt power grid provide the only market in the Ring of Fire planning area that could make use of such generation. The closest high temperature geothermal source to this region is the Mount Spurr volcano. As indicated in Section 3.1.4.2, investigations at Mount Spurr are in the initial phases, and additional studies will be required to define the economic potential of this resource. The most promising location identified for future exploration at Mount Spurr lies on the south flank of Crater Peak (Turner and Wescott 2004), which is not located on BLM-managed lands. Thus, the development potential for this resource on BLM lands is considered to be low.

4.2 Locatable Minerals

BLM (1985) guidance pertinent to locatable minerals indicates that whenever known, projected development or economic potential should be part of the resource assessment, to the extent that it is necessary at the level of detail required for the action. Based on the intermediate level of detail specified for the Ring of Fire planning area action, and the scattered and unknown nature of BLM-managed lands within the planning area, the following sections are intended to be a qualitative overview of economic and technical factors effecting the exploitability of the resource (Sections 4.2.1 and 4.2.2), followed by a summary of development potential by region (Section 4.2.3). The summary by region incorporates projections contained in the RFD scenario developed by BLM (2005) for locatables (Attachment B). Because BLM does not actively manage locatable mineral activities on federal mineral estate lands (Section 1.4), the summary by region is intended to apply only to BLM-managed surface tracts.

There is no possibility of development of unclaimed mineral deposits in most of the Ring of Fire planning area, unless existing land withdrawals in place since the early 1970s are removed (Section 1.1). The RFD assumes that all potentially productive areas will be open to mineral entry except those closed by law, regulation, or executive order (e.g., wild and scenic rivers, Area of Critical Environmental Concern, etc.). Further, projected acreages in the RFD are based on the assumption that land conveyances will be completed and withdrawals lifted by the year 2010, which should allow for additional exploration that, in some areas, will increase the related reserve base to make mining economically feasible.

4.2.1 Economic Factors

Demand for locatable resources, most notably gold, depends strongly on the current price of gold, and the operational and administrative costs imposed by regulation and inaccessibility. After the U.S. deregulated gold in 1971, the price increased markedly, reaching a high of more than $800/ounce in 1980, which encouraged the opening of new mines in Alaska in the 1980s. The price of gold leveled off in the range of $320 to $460 per ounce after 1980, eventually resulting in a decline in mining and exploration activities in the State. In late 2003, after several years of lackluster prices, gold rose above the $400 mark for first time in seven years (Freeman 2003; Kirkemo *et al.* 1997). Today, the gold price is over $700 per ounce.

Nelson and Miller (2000) provide an example of the effect of gold prices on development potential in the CNF. They suggest that gold prices would have to be $400 to $450 per ounce for large-scale placer or lode gold operations to be economically viable, with needed reserves far exceeding what is estimated in the Chugach. Based on this, they conclude that future production in this area of the Ring of Fire planning area would require significantly higher prices to be economic.

Accessibility is also a major factor in the economics of mineral extraction in Alaska. For example, the economic potential of a mineral deposit can be directly related to the length of road required to be built for access to market. High value minerals that can be flown out by aircraft (i.e., gold) have a significant economic advantage over base metals that need road and/or port access.

4.2.2 Industry Interest

Mineral potential was reviewed in the decades following statehood, as well as following ANCSA and ANILCA, as part of land-selection processes. Because most lands with known mineral potential were previously selected and conveyed, development of locatable minerals on remaining BLM lands within the Ring of Fire planning area is expected to be minimal over the next 10 to 15 years, except where technical or economic conditions have changed since the original assessments and land selections. Thus, investigation techniques, mining processes, and industry economics that have evolved since the 1970s have a bearing on the interpretation of development potential.

Mineral investigations conducted since the 1970s have expanded the knowledge of mineral potential within the Ring of Fire planning area. These investigations have been incorporated into the current interpretation of occurrence potential presented in Section 3.2. While gold was the primary commodity of interest prior to 1970, industry economics have evolved in the last 30 years to include an interest in base metals (copper, lead, and zinc) that are typically contained within VMS deposits. In addition, in the past two decades, low-grade disseminated gold and copper deposits have become increasingly important due to the advancement of large-scale heap-leach technologies.

Heap leaching is a process whereby large piles of crushed rock are leached with various chemical solutions that extract valuable minerals (Thiel and Smith 2003), allowing for economic recovery of lower grade deposits than is possible using standard milling techniques. Disseminated gold deposits, like those of the Pogo and Fort Knox Mines in interior Alaska, occur in the distal parts of intrusion-related quartz vein systems (Cox 1992; Logan 2002). Large intrusive bodies within the Ring of Fire planning area are located along the spine of the northern Aleutian Range, along the east side of the southern Alaska Range, in the Talkeetna Mountains, and along the Boundary Ranges of the southeast region. These trends are noted below as they relate to development potential in the Ring of Fire planning area.

4.2.3 Summary by Region

The location of known BLM-managed lands depicted on Figures G-2 through G-6 (BLM, Native-selected, and State-selected) were reviewed in relation to mineral occurrence potential outlined on Figures G-26 through G-29 and significant mineral deposits mapped by Nokleberg *et al.* (1987 and 1994) to assess development potential in specific areas of the Ring of Fire planning area. In addition, the RFD reviewed individual mineral occurrences listed in BLM (2004b) and USGS (2004a) databases to identify those that are located both within high occurrence potential boundaries and on BLM-managed lands (unencumbered, State- and Native-selected) (Attachment B, Table G-2). Mineral deposit model types identified in the RFD that are projected to be economic and receive industry attention over the next 10 to 15 years include epithermal gold and gold-quartz vein deposits, placer gold, porphyry copper, VMS deposits (copper-lead-zinc), and polymetallic vein deposits.

Alaska Peninsula/Aleutian Chain Region. Development potential in this region is generally expected to be low on BLM-managed lands over the next 10 to 15 years due to its remoteness and inaccessibility. Most of the region is underexplored compared to the rest of the Ring of Fire planning area, and there is only one current mining claim in the area, indicating low overall interest. BLM-managed lands make up a very small portion of this region as well.

Several of the significant lode deposits in this region described by Nokleberg *et al.* (1987 and 1994) and mapped as having high occurrence potential may be located partly on Native-selected land. These include Sedanka Island at the southeast corner of Unalaska, the Pyramid deposit in the Herendeen area, Bee Creek at Chignik Bay, and the Mike and Rex deposits near Mount Chiginagak. Interest in developing these prospects may increase over the next 10 to 15 years if commodity prices were to increase substantially.

The RFD identifies several mineral occurrence sites on the Alaska Peninsula containing epithermal gold-silver, porphyry copper, or lead-zinc deposits that could be explored over the next 10 to 15 years, potentially disturbing a total of up to 15 acres. Mine development on any one of these sites could occur beyond the next 10 to 15 years, potentially disturbing up to 70 acres.

Kodiak Region. BLM-managed lands on Kodiak are expected to have low development potential due to remoteness and inaccessibility, and the lack of BLM lands in areas of high occurrence potential. The areas of the Kodiak region rated as having high occurrence potential are either located within the Kodiak NWR or are based on State claims. It is possible that BLM-managed lands in beach placer areas, or in the underexplored ultramafic belt along the northwest coast, may see renewed exploration interest if commodity prices were to increase substantially. Scattered Native-selected lands are located in these areas.

Southcentral Region. The southcentral region is an area with relatively higher accessibility than other parts of the state. With a few exceptions, development potential in this region is generally considered to be 1) medium for areas of high occurrence potential, and 2) low for areas of medium occurrence potential.

Based on recent industry interest in intrusion-related disseminated gold deposits and porphyry copper-gold deposits similar to the Pebble prospect at Illiamna Lake, BLM-managed lands located on the west and south sides of Mount Spurr in an area of medium occurrence potential (Figures G-4 and G-28) may have as much as medium development potential, although overlying host rocks are sparse in this area (Figure G-8).

VMS deposits on Knight Island in western PWS, which were rated highly favorable for future development by Nelson and Miller (2000), may overlap with scattered Native-selected parcels in the area.

Several areas of State-selected lands on the Kenai Peninsula may overlap areas of high occurrence potential/medium development potential in the gold mining district extending from Girdwood and Hope to the Seward area. Small-scale placer production on the more easily accessible lands within this area is possible over the next 10 to 15 years. The RFD projects that exploration at a number of gold-quartz vein and placer gold deposits could disturb up to a total of 16 acres of land. Current and future development at an existing operation in the Girdwood area is anticipated to disturb up to an additional 15 acres over the next 10 to 15 years.

Southeast Region. Small tracts of BLM-managed lands overlap areas designated as high occurrence potential in the following areas: near Klukwan, near the city of Juneau, Hawk Inlet at the north end of Admiralty Island, near Sitka, near Hyder, and at three locations on southern Prince of Wales Island (Trocadero Bay, Billie Mountain, and Aiken Cove). With three exceptions noted below, these sites are considered to have medium development potential. Areas of medium occurrence potential in the southeast region are generally considered to have low development potential.

The State-selected tracts near Klukwan, Hawk Inlet, and Aiken Cove are considered to have medium to high development potential. The tracts near Klukwan lie along the east and south edges of a large area of VMS, placer gold, and other types of mineral deposits, with recent industry interest and many claims in the area. The Hawk Inlet tracts are adjacent to the Greens Creek VMS deposit. Aiken Cove in southeast Prince of Wales Island lies at the north end of the Niblack VMS prospect, which was rated as having high development potential by Maas *et al.* (1995).

The RFD projects that several of the placer gold, VMS, and polymetallic vein deposits in the southeast region may be explored over the next 10 to 15 years, potentially disturbing up to 18 acres. One existing inactive placer operation located in the Klukwan area on State-selected land is projected to disturb up to five acres.

4.3 Salable Minerals

BLM (1985) guidance pertinent to salable minerals indicates that whenever known, projected development or economic potential should be part of the resource assessment, to the extent that it is necessary at the level of detail required for the action. Based on the intermediate level of detail specified for the Ring of Fire planning area, and the scattered and unknown nature of BLM-managed lands within the planning area, the following is intended to be a qualitative overview of salables development potential based on projected demand.

4.3.1 Material Types and Demand

There are four types of salable minerals with a history of exploration and/or development in the Ring of Fire planning area: aggregate (sand and gravel), building stone, clay, and pumice (Section 3.3.1). The RFD for salable minerals (BLM 2005) (Attachment B) projects that there will be little or no foreseeable development potential for clay and pumice over the next 10 to 15 years due to lack of markets and great distances to markets for these materials. Thus, the summary by region below focuses on aggregate and stone.

Most aggregate development in the Ring of Fire planning area in the past has been project driven, as most lands are too remote for salable minerals to be marketable in the absence of specific projects. The assessment of development potential assumes that demand for aggregate will increase over the next 10 to 15 years as road maintenance and construction activities continue on state highways and non-BLM lands. The projection of demand within each region considers future activities external to BLM lands that may affect the need for these materials. Future external events considered in this analysis are contained in Chapter 4 of the PRMP/FEIS document, and included in the following discussion.

4.3.2 Summary by Region

There are currently no known salable mineral activities on BLM-managed lands within the Ring of Fire planning area (BLM 2005). Because demand for aggregate is expected to increase, there may be interest in aggregate on BLM-managed lands located near future projects if there are no pre-existing alternative non-BLM extraction sites available. Generally, areas with expected future projects and no existing extraction sites were considered to have medium development potential for localized sources of aggregate on BLM-managed lands. Areas with existing non-BLM extraction sites, or with no anticipated future projects, were estimated to have low development potential. No areas of high development potential (e.g., major sand and gravel deposit in an area with future projects, with no existing extraction sites nearby) were identified in the Ring of Fire planning area.

Alaska Peninsula/Aleutian Chain Region. There are no anticipated future projects in the Aleutians that could effect demand for aggregate over the next 10 to 15 years. Future projects on the Alaska Peninsula are expected to include areawide oil and gas leasing and new state road construction near Chignik. Because the development potential for oil and gas in this area is anticipated to be low over the next 10 to 15 years (Section 4.1.1), the results of the leasing program are not expected to increase demand for salables extraction. There are no major sources of sand and gravel in the Chignik area (Figure G-31); hence road construction could increase the demand for localized sources such as beach or river deposits. Localized deposits on BLM-managed lands in the Chignik area may have medium development potential.

Kodiak Region. Future projects that could effect demand for aggregate on Kodiak are expected to be limited to rehabilitation and maintenance of existing roads. As there are several existing non-BLM aggregate and stone extraction sites currently on Kodiak (Figure G-31), development of new extraction sites on BLM-managed lands is not expected to occur.

Southcentral Region. Future projects that could effect demand for aggregate in the southcentral region are expected to include: state oil and gas leasing; an access road to the proposed Pebble Mine on the west side of lower Cook Inlet (Illiamna or Iniskin Bays); State coal leasing in the Matanuska Valley; and road projects in the Anchorage Bowl and Kenai Peninsula.

Because there are currently a number of existing non-BLM sand and gravel extraction sites in the Anchorage, Matanuska-Susitna, and Kenai areas (Figure G-32), development of new extraction sites is not anticipated on BLM-managed lands in these areas. Pebble Mine road construction could increase demand for localized sources of aggregate such as beach or river deposits, as there are no major sources of sand and gravel mapped in the Illiamna-Iniskin Bay areas. Thus, there may be interest in development of new extraction sites on Native-selected lands in this area. Localized deposits on these lands may have medium development potential.

Southeast Region. Future projects that could effect demand for salable minerals in the southeast region over the next 10 to 15 years are expected to include: existing mine development (e.g., Greens Creek, Kensington); timber sales in the TNF; and state road projects in the Juneau-Skagway, Sitka, and Bradfield Canal areas. Although there are no major geologic sources of sand and gravel in these areas, there are currently a number of existing non-BLM limestone quarries and localized sand and gravel extraction sites throughout the southeast region (Figure G-33). Thus, it is anticipated that new salables extraction sites would not be developed on BLM-managed lands in this area.

5.0 RECOMMENDATIONS

Recommendations and stipulations related to the management of future mineral development in the Ring of Fire planning area were developed concurrently as part of the PRMP alternatives process, and are presented in the PRMP/FEIS document in Appendix D.

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Tables

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TABLE 1
LEGEND FOR GEOLOGIC MAPS
Ring of Fire Planning Area, Alaska

SYMBOL	NAME AND DESCRIPTION
	STRATIFIED SEDIMENTARY SEQUENCE
Qh	HOLOCENE DEPOSITS - Alluvial, glacial, lake, estuarine, swamp, landslide, flood plain, and beach deposits.
Q	QUATERNARY DEPOSITS – Alluvial, glacial, lake, eolian, beach, and volcanic deposits. Includes the marine Bootlegger Cove Clay.
Qp	PLEISTOCENE DEPOSITS – Alluvial, glacial, dune sand, loess, and reworked sand and silt deposits.
Tp	PLIOCENE ROCKS – Sandstone, siltstone, and conglomerate. Includes Tachilni Formation on the Alaska Peninsula, and Tugidak Formation on Tugidak and Chirkof Islands.
UT	UPPER TERTIARY ROCKS – Mostly marine sandstone, siltstone, shale, mudstone, and conglomerate of Miocene and Pliocene age. Includes Yakataga Formation in the Gulf of Alaska area.
uTc	UPPER TERTIARY CONTINENTAL DEPOSITS – Sandstone, siltstone, claystone, minor conglomerate, and coal beds. Includes upper part of Kenai Group in Cook Inlet area. Rocks range in age from Oligocene(?) through Pliocene.
Tm	MIOCENE ROCKS – Sandstone, siltstone, conglomerate, argillite, graywacke, and basaltic rocks. Includes Bear Lake Formation on the Alaska Peninsula, Narrow Cape Formation (Oligocene or Miocene) on Kodiak and Sitkinak Islands, and Chuniksak Formation (Miocene?) on Attu Island.
To	OLIGOCENE ROCKS – Volcanic conglomerate, sandstone, volcanic breccia, shale, and siltstone. Includes the Meshik Formation and Stepovak Formation on the Alaska Peninsula and the Sitkinak Formation on Sitkalidak, Sitkinak, and Chirikof Islands.
Te	EOCENE ROCKS – Sandstone, siltstone, and shale interbedded with mafic flows and sills of the Andrew Lake Formation on Adak Island.
T	TERTIARY ROCKS – Volcanogenic sedimentary rocks and flows, dikes, and sills on the Alaska Peninsula and Umnak Island.
Tc	TERTIARY CONTINENTAL DEPOSITS – Sandstone, coal, conglomerate, and shale of the Kootznahoo Formation on Admiralty, Kuiu, Kupreanof, and Zarembo Islands.
MT	MIDDLE TERTIARY ROCKS – Mostly marine siltstone, sandstone, organic shale, and locally, volcanic rocks. Includes Poul Creek, Katalla, and Topsy Formations ranging from Oligocene to Miocene age in Gulf of Alaska area.
mTc	MIDDLE TERTIARY CONTINENTAL DEPOSITS – Sandstone, siltstone, claystone, and coal beds. Includes the Tsadaka Formation in Matanuska Valley. Rocks range in age from Oligocene through Miocene.
lT	LOWER TERTIARY ROCKS – Mostly marine interbedded sedimentary, volcanogenic, and volcanic rocks of Paleocene, Eocene, and Oligocene age on Alaska Peninsula and Aleutian Islands; and intensely deformed marine and continental clastic rocks of Paleocene and Eocene age in the Gulf of Alaska area. Includes Tolstoi and Belkofski Formations in the Alaska Peninsula; Ghost Rocks Formation on Kodiak Island; Amchitka and Banjo Point Formations on Amchitka Island; Gunners Cove Formation on Rat Island; Krugloi Formation on Agattu Islands; and Kulthieth, Kushtaka, and Tokun Formations and clastic rocks of the Orca Group in the Gulf of Alaska area.
lTc	LOWER TERTIARY CONTINENTAL DEPOSITS – Claystone, siltstone, sandstone, conglomerate, and coal beds. Includes the Chickaloon and Wishbone Formations in Matanuska Valley. Rocks range in age from Paleocene through Oligocene.
Txc	PALEOCENE CONTINENTAL DEPOSITS – Conglomerate, sandstone, coaly shale, and shale.

TABLE 1 (Cont.)
LEGEND FOR GEOLOGIC MAPS
Ring of Fire Planning Area, Alaska

SYMBOL		NAME AND DESCRIPTION
STRATIFIED SEDIMENTARY SEQUENCE (CONT.)		
	TKc	TERTIARY AND CRETACEOUS CONTINENTAL DEPOSITS – Conglomerate, breccia, sandstone, arkose, mudstone, shale, tuffaceous rocks, and lignite. Includes Arkose Ridge Formation (Cretaceous?) in Matanuska Valley.
	uK	UPPER CRETACEOUS ROCKS – Nonmarine and marine classic rocks, siltstone, and shale of the Chignik and Hoodoo Formations on the Alaska Peninsula; graded beds of sandstone and slate of the Kodiak Formation on Kodiak and Afgonak Islands; sandstone and mudstone of Shumagin Formation on Shumagin and Sanak Islands.
	K	CRETACEOUS ROCKS – Includes the Matanuska Formation in Matanuska Valley; and the Kaguyak Formation on Alaska Peninsula.
	lK	LOWER CRETACEOUS ROCKS – Unnamed graywacke, argillite, and minor andesite on Etolin Island.
	KJ	CRETACEOUS AND JURASSIC ROCKS – Argillite, shale, graywacke, quartzite, conglomerate, lava, tuff, and agglomerate. Almost barren of fossils and probably includes rocks ranging in age from Early Jurassic to Late Cretaceous. In places moderately to highly metamorphosed (amphibolite facies).
	KJ_1	CRETACEOUS AND UPPER JURASSIC ROCKS – Graywacke, slate, argillite, minor conglomerate, volcanic detritus, and interbedded mafic volcanic rocks. Includes Valdez and part of Yakutat Groups and Sitka Graywacke. Mildly metamorphosed, locally to greenschist.
	KJ_2	LOWER CRETACOUS AND UPPER JURASSIC ROCKS – Includes sandstone, arkose, siltstone, and limestone of the Staniukovich Formation and Herendeen Limestone on the Alaska Peninsula; and slate, graywacke and conglomerate of the Seymour Canal Formation on Admiralty and Kupreanof Islands.
	KJ_3	LOWER CRETACEOUS AND UPPER JURASSIC(?) ROCKS – Melange of flysch, greenstone, limestone, chert, granodiorite, glaucophane-bearing greenschist, and layered gabbbro and serpentenite. Melange consists of Upper Jurassic(?) and Lower Cretaceous pelitic matrix enclosing blocks several kilometers in dimension of Permian to Lower Jurassic rocks. Includes the Uyak Formation, McHugh Complex, mélange within the Yakutat Group, and Waterfall Greenstone and Khaz Formation of the Kelp Bay Group.
	uJ	UPPER JURASSIC ROCKS – Sandstone, siltstone, shale, and conglomerate on the Alaska Peninsula, Cook Inlet area, and southern flank of Talkeetna Mountains. Includes the Chinitna and Naknek Formations.
	mJ	MIDDLE JURASSIC ROCKS – Sandstone, shale, siltstone, and conglomerate on the Alaska Peninsula and Cook Inlet area where it includes the Kialagvik and Shelikof Formations and Tuxedni Group.
	lJ	LOWER JURASSIC ROCKS – Sandstone and argillite interbedded with volcanic flows and pyroclastic rocks of the Talkeetna Formation in the Cook Inlet area and southern Talkeetna Mountains.
	JTR	JURASSIC AND/OR TRIASSIC ROCKS – Hornfels and phyllite of the Hazelton(?) Group in southeast Alaska.

TABLE 1 (Cont.)
LEGEND FOR GEOLOGIC MAPS
Ring of Fire Planning Area, Alaska

SYMBOL	NAME AND DESCRIPTION
	STRATIFIED SEDIMENTARY SEQUENCE (CONT.)
uTR	UPPER TRIASSIC ROCKS – Limestone, shale, and chert of the Kamishak Formation in the Cook Inlet area; a shelf facies of limestone, tuff, tuffaceous conglomerate and breccias at the southern tip of the Kenai Peninsula (west of the Border Ranges fault) and equivalent rocks on Shuyak, Afognak, and Kodiak Islands; a deep water flysch and mélange facies of chert, pillow basalt and associated graywacke, argillite, and minor ultramafic rocks (east of the Border Ranges fault) on the southern Kenai Peninsula; chert, limestone, sandstone, and greenstone of the Whitestripe Marble and Pinnacle Peak Phyllite (both Triassic?) on Chichagof and Baranof Islands, of the Hyd Group on Admiralty Island and Keku Straits area, and of the Nehenta and Chapin Peak Formations on Gravina Island.
TRP	TRIASSIC AND PERMIAN ROCKS – Schist, graywacke, slate, conglomerate, phyllite, andesite flows and tuffs on Admiralty Island where it includes the Barlow Cove Formation.
MzPz	MESOZOIC AND PALEOZOIC ROCKS – Lower Jurassic, Pennsylvanian, and Permian rocks, in part covered by Tertiary sedimentary rocks and intruded by granitic rocks of Tertiary age in north-central Chugach Mountains; and slate, quartzite, schist, and phyllite with interlayered beds of marble, layered gneiss and amphibolite of Ordovician to Jurassic or Cretaceous age along the wet flank of the Coast Mountains.
P	PERMIAN ROCKS – Volcanic argillite and graywacke with local chert, pillow flows, limestone, and dolomite of the Cannery, Pybus, and Halleck Formations on Admiralty, Kuiu, and Kupreanof Islands.
PIP	PERMIAN AND PENNSYLVANIAN ROCKS – Basaltic to andestic lavas and derivative volcaniclastic rocks, tuffs, minor gabbro, and local shallow-water sedimentary rocks metamorphosed to greenschist facies, and locally, amphibolite facies. Includes Skolai Group, Strelna Formation (Permian), and Tetelna Volcanics in the Talkeetna Mountains. Consists of unnamed phyllite, slate, schist, greenschist, amphibolite, gneiss, and migmatite in St. Elias Mountains.
IP	PENNSYLVANIAN ROCKS – Siltstone, sandstone, and limestone of the Klawak Formation and Ladrones Limestone on Prince of Wales Island.
M	MISSISSIPPIAN ROCKS – Limestone, dolomite, and interbedded chert of the Iyoukeen Formation on Chichagof Island and Peratovich Formation on Prince of Wales Island.
uPz	UPPER PALEOZOIC ROCKS – Argillite, chert, shale, limestone, and siltstone. Greenstone, limestone, shale, clastic sedimentary rocks, schist, gneiss, and undifferentiated metamorphic rocks east of Juneau.
Pz	PALEOZOIC ROCKS – Sedimentary, metasedimentary, and metavolcanic rocks in southeastern Alaska.
D	DEVONIAN ROCKS – Clastic rocks and limestone of the Kennel Creek Limestone (which may also include Silurian rocks) and Cedar Cove Formation on Chichagof Island; schist, phyllite, marble, and amphibolite of the Retreat Group and Gambler Bay Formation on Admiralty and Kupreanof Islands and equivalent rocks to the north and south; and limestone, shale, graywacke, conglomerate and basaltic rocks of the St. Joseph Island Volcanics (Devonian?), Wadleigh Limestone, and Port Refugio Formation on Prince of Wales Island.
DS	DEVONIAN AND SILURIAN ROCKS – Limestone, dolomite, marble, and shale of the Karheen Formation in Prince of Wales Island.

TABLE 1 (Cont.)
LEGEND FOR GEOLOGIC MAPS
Ring of Fire Planning Area, Alaska

SYMBOL		NAME AND DESCRIPTION
		STRATIFIED SEDIMENTARY SEQUENCE (CONT.)
	S	SILURIAN ROCKS – Graywacke, shale, siltstone, limestone, sandstone, and argillite. Includes siltstone, mudstone, limestone, conglomerate, sandstone, graywacke, minor red beds and volcanic rocks of the Rendu Formation, and Willoughby Limestone in Glacier Bay areas, the Point Augusta Formation on Chichagof Island; Bay of Pillars Formation on Admiralty, Kuiu, and Prince of Wales Islands; and Kuiu Limestone and Heceta Limestone on Prince of Wales Island.
	O	ORDOVICIAN ROCKS – Argillite, chert, and limestone of the Hood Bay Formation on Admiralty Island.
	SO	SILURIAN AND ORDOVICIAN ROCKS – Graywacke, conglomerate, shale, siltstone, tuff, lava, and local limestone of the Descon Formation on Prince of Wales Island.
	lPzp€	LOWER PALEOZOIC AND/OR PRECAMBRIAN ROCKS – Volcanogenic greenschist with interstratified marble in Prince of Wales, Long and Dall Islands, where it includes the Wales Group and possibly Descon Formation.
		METAMORPHIC ROCKS
	lJm	LOWER JURASSIC METAMORPHIC ROCKS – Intercalated blue schist, quartz mica schist, greenschist with subordinate amphibolite, marble, and metachert at southern tip of Kenai Peninsula and on Afognak Island.
	Mzm	MESOZOIC METAMORPHIC ROCKS – Small masses of metamorphosed sedimentary, volcanic, and igneous rocks, largely of pre-Cretaceous age, scattered throughout the Aleutian Range batholith. Amphibolite facies schist along north side of Matanuska Valley.
	JPm	JURASSIC, TRIASSIC, AND PERMIAN METAMORPHIC ROCKS – Metasedimentary, metaplutonic, and metavolcanic rocks near Anchorage and along south side of Matanuska Valley.
	Pzm	PALEOZOIC METAMORPHIC ROCKS – Hornfels, schist, amphibolite, minor marble, and undivided metamorphic rocks north of Icy Strait in southeastern Alaska.
		VOLCANIC ROCKS
	Qhvf	QUATERNARY – HOLOCENE volcanic rocks of felsic composition
	Qhvi	QUATERNARY – HOLOCENE volcanic rocks of intermediate composition
	Qhvm	QUATERNARY – HOLOCENE volcanic rocks of mafic composition
	Qhv	QUATERNARY – HOLOCENE volcanic rocks, undifferentiated
	Qpvi	QUATERNARY – PLEISTOCENE volcanic rocks of intermediate composition
	Qpv	QUATERNARY – PLEISTOCENE volcanic rocks, undifferentiated
	Qvi	QUATERNARY volcanic rocks of intermediate composition
	Qvm	QUATERNARY volcanic rocks of mafic composition
	Qv	QUATERNARY volcanic rocks, undifferentiated
	QTv	QUATERNARY or TERTIARY volcanic rocks, undifferentiated
	Tpv	TERTIARY – PLIOCENE volcanic rocks, undifferentiated
	Tmvi	TERTIARY – MIOCENE volcanic rocks of intermediate composition
	Tmv	TERTIARY – MIOCENE volcanic rocks, undifferentiated
	uTv	UPPER TERTIARY volcanic rocks, undifferentiated
	lTvi	LOWER TERTIARY volcanic rocks of intermediate composition
	lTvm	LOWER TERTIARY volcanic rocks of mafic composition

TABLE 1 (Cont.)
LEGEND FOR GEOLOGIC MAPS
Ring of Fire Planning Area, Alaska

SYMBOL		NAME AND DESCRIPTION
		VOLCANIC ROCKS (CONT.)
	lTv	LOWER TERTIARY volcanic rocks, undifferentiated
	Tvf	TERTIARY volcanic rocks of felsic composition
	Tvi	TERTIARY volcanic rocks of intermediate composition
	Tvm	TERTIARY volcanic rocks of mafic composition
	Tv	TERTIARY volcanic rocks, undifferentiated
	Kvi	CRETACEOUS volcanic rocks of intermediate composition
	KJvm	CRETACEOUS and/or JURASSIC volcanic rocks of mafic composition
	₨vm	TRIASSIC volcanic rocks of mafic composition
	Mzvm	MESOZOIC volcanic rocks of mafic composition
	MzPzvm	MESOZOIC and PALEOZOIC volcanic rocks of mafic composition
	Dv	DEVONIAN volcanic rocks, undifferentiated
		INTRUSIVE ROCKS
	Tmif	TERTIARY – MIOCENE intrusive rocks of felsic composition
	Tmim	TERTIARY – MIOCENE intrusive rocks of mafic composition
	Toif	TERTIARY – OLIGOCENE intrusive rocks of felsic composition
	mTii	MIDDLE TERTIARY intrusive rocks of intermediate composition
	mTim	MIDDLE TERTIARY intrusive rocks of mafic composition
	Teif	TERTIARY – EOCENE intrusive rocks of felsic composition
	Txif	TERTIARY – PALEOCENE intrusive rocks of felsic composition
	Tif	TERTIARY intrusive rocks of felsic composition
	Tii	TERTIARY intrusive rocks of intermediate composition
	Tim	TERTIARY intrusive rocks of mafic composition
	Ti	TERTIARY intrusive rocks, undifferentiated
	TKif	TERTIARY and/or CRETACEOUS intrusive rocks of felsic composition
	TKii	TERTIARY and/or CRETACEOUS intrusive rocks of intermediate composition
	TKim	TERTIARY and/or CRETACEOUS intrusive rocks of mafic composition
	TKi	TERTIARY and/or CRETACEOUS intrusive rocks, undifferentiated
	Kif	CRETACEOUS intrusive rocks of felsic composition
	Kii	CRETACEOUS intrusive rocks of intermediate composition
	Kim	CRETACEOUS intrusive rocks of mafic composition
	Ki	CRETACEOUS intrusive rocks, undifferentiated
	KJii	CRETACEOUS and/or JURASSIC intrusive rocks of intermediate composition
	Jif	JURASSIC intrusive rocks of felsic composition
	Jii	JURASSIC intrusive rocks of intermediate composition
	Jim	JURASSIC intrusive rocks of mafic composition
		INTRUSIVE ROCKS (CONT.)

TABLE 1 (Cont.)
LEGEND FOR GEOLOGIC MAPS
Ring of Fire Planning Area, Alaska

SYMBOL		NAME AND DESCRIPTION
	Mzii	MESOZOIC intrusive rocks of intermediate composition
	Mzi	MESOZOIC intrusive rocks, undifferentiated
	MzPzii	MESOZOIC and PALEOZOIC intrusive rocks of intermediate composition
	MzPzi	MESOZOIC and PALEOZOIC intrusive rocks, undifferentiated
	Pi	PERMIAN intrusive rocks, undifferentiated
	Sii	SILURIAN intrusive rocks of intermediate composition
	Oi	ORDOVICIAN intrusive rocks, undifferentiated
	Pzii	PALEOZOIC intrusive rocks of intermediate composition
	i	intrusive rocks, age unknown, undifferentiated
		ULTRAMAFIC ROCKS
	Ku	CRETACEOUS ultramafic rocks
	Mzu	MESOZOIC ultramafic rocks
	MzPzu	MESOZOIC and PALEOZOIC ultramafic rocks
	Ou	ORDOVICIAN ultramafic rocks
	u	ultramafic rocks, age unknown
		MAP SYMBOLS
	VOLCANO, volcanic vent, or intrusive crater	
	FAULT, dashed where concealed or inferred	
	STRIKE-SLIP FAULT, dashed where concealed or inferred	
	THRUST FAULT, dashed where concealed or inferred	

Source: Beikman (1980)

TABLE 2
GEOCHEMISTRY, RESERVOIR CHARACTERISTICS, AND PRODUCTION DATA FOR ONSHORE OIL AND GAS FIELDS OF COOK INLET BASIN
Ring of Fire Planning Area, Alaska

FIELD/UNIT NAME	YEAR DISCOVERED	LAND STATUS	PRODUCING UNIT	MEMBER OR POOL[2]	RESEVOIR LITHOLOGY	PRODUCTION STATUS	TRAP TYPE	CUMULATIVE PRODUCTION[3]		ESTIMATED RESERVES		PRODUCTION DEPTH (FEET)	NET PAY (FEET)	POROSITY (%)	PERMEABILITY (MD)	ORIGINAL GAS/OIL RATIO (SCF/STB)	WATER SATURATION (%)	UNIT AREA (ACRES)	OIL CHEMISTRY		GAS CHEMISTRY		
								OIL ($X10^3$ BBL)	GAS (BCF)	OIL ($X10^6$ BBL)	GAS (BCF)								OIL GRAVITY (API)	SULFUR (%)	GAS SPECIFIC GRAVITY	BTU (BTU/FT^3)	METHANE FRACTION (%)
OIL FIELDS – KENAI PENINSULA																							
Swanson River	—	Federal/Native	Hemlock	Soldotna	conglomerate	producing	faulted anticline	—	—	—	—	10,300	220	20-24	40-360	350	40	—	36.5	—	—	—	—
Swanson River	—	Federal/Native	Hemlock	34-10	conglomerate	producing	faulted anticline	—	—	—	—	10,560-10,770	145	20-21	55-75	175	40	—	30	0.1	—	—	—
Swanson River	1957	Federal/Native	Field Total					230,000	3,200	4	50							7,880					
Beaver Creek	1972	Federal	Tyonek	Beaver Creek	sandstone/ conglomerate	producing	—	5,800	2	0.26	—	14,790	100	—	—	380	—	825	35	<0.1	—	—	—
GAS FIELDS – KENAI PENINSULA																							
Kenai	1959	Federal/Native/State	Sterling	A, 3-6	sandstone	producing	dome	—	1,850	—	—	3,710-4,565	420	35.5	—	—	35	—	—	—	0.577	—	99.9
Kenai	1959	Federal/Native/State	Beluga – Upper Tyonek	—	sandstone	producing	dome	—	260	—	—	4,000-4,990	215	15-20	—	—	40	—	—	—	0.555	—	—
Kenai	1959	Federal/Native/State	Deep Tyonek	Tyonek	sandstone	producing	dome	11	190	—	—	9,000	100	18-22	—	—	40	—	—	—	0.560	—	99.8
Kenai	1959	Federal/Native/State	Field Total					11	2,300	0	60							8,264				1,005	98.9
Swanson River	1960	Federal	Sterling	B,D,E Sands	sandstone	producing	anticline	—	43	—	—	2,870-7,500	—	30	650	—	35	640	—	—	0.600	1,002	99.9
West Fork	1960	Native	Sterling	—	sandstone	shut-in	faulted anticline	0	4.2	—	3	4,990	25	30	4,400	—	—	457	—	—	0.560	—	—
Falls Creek	1961	State	Tyonek	MGS	sandstone	shut-in	—	0	0.019	—	10	4,690-7,040	189	15-25	6	—	—	564	—	—	0.600	1,015	99.1
Sterling	1961	Federal/Native/State	Sterling - Tyonek	—	sandstone	producing	dome	0	4.3	—	20	5,030-9,450	180	10-26	0.1-125	—	40	3,600	—	—	0.560 - 0.569	991	99.8
Birch Hill	1965	Federal/Native	Tyonek	MGS	sandstone	shut-in	faulted dome	0	0.065	—	10	7,690	30	25	5-6	—	—	1,240	—	—	0.561	1,014	98.6
North Fork	1965	Federal/State	Tyonek	MGS	sandstone	shut-in	—	0	0.105	—	10	7,200	40	18	3.5	—	50	50	—	—	0.562	1,002	98.1
Beaver Creek	1967	Federal	Sterling	Sterling	sandstone	producing	dome	—	120	—	—	5,000	110	30	2,000	—	40	—	—	—	0.570	—	98.9
Beaver Creek	1967	Federal	Beluga	Beluga	sandstone	producing	dome	—	40	—	—	8,100	50	10	—	—	—	—	—	—	—	—	—
Beaver Creek	1967	Federal	Field Total					—	160		80							4,960				998	98.3
Cannery Loop	1979	State	Beluga - Sterling	Beluga - Tyonek	sandstone	producing	—	<1	111	—	4	4,965-10,000	150	—	25-250	—	—	1,900	—	—	0.556 – 0.562	—	—
Wolf Lake	1998	Native	—	—	—	—	—	—	0.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ninilchik/ South Ninilchik	2001	State/Native	Tyonek	Oskolkoff, Dionne	sandstone	producing	anticline	—	2.1	—	90	3,338-3,496	97-233	15-21	8-14	—	—	34,858	—	—	—	—	—
Deep Creek	2003	State/Native	—	—	—	exploration	—	0	0	—	75-100	—	110	—	—	—	—	22,617	—	—	—	—	—
GAS FIELDS – WEST SIDE OF COOK INLET																							
West Foreland	1962	Native	Tyonek	MGS	sandstone	shut-in	—	—	—	—	20	—	25	—	—	—	—	640	—	—	0.600	929	92.1
Beluga River	1962	Native/State	Sterling	—	sandstone	producing	anticline	—	—	—	—	3,300	110	31	—	—	37	—	—	—	0.556	—	—
Beluga River	1962	Native/State	Beluga	—	sandstone	producing	anticline	—	—	—	—	4,000-4,490	105	24	—	—	42	—	—	—	0.556	—	—
Beluga River	1962	Native/State	Field Total					0	850	0	320							12,743				1,014	99.7
Moquawkie	1965	Federal/Native	Tyonek	—	sandstone	shut-in	—	0	0.984	—	—	2250	106	20-24	20-50	—	35-40	1,280	—	—	0.560	1,006	99.0
Nicolai Creek	1966	State	Beluga-Tyonek	A, B	sandstone	producing	—	0	1.67	—	1	2,160	35	—	—	—	—	9,123	—	—	0.575	976	99.5
Ivan River	1966	State	Tyonek	Chuitna	sandstone	producing	dome	0	72	—	35	7,790	35	20	1,600	—	45	9,301	—	—	0.560	1,004	98.9
Albert Kaloa	1968	Native	Tyonek	—	sandstone	shut-in	—	0	0.119	—	—	3,210	—	—	—	—	—	—	—	—	—	—	—
Lewis River	1975	State	Beluga	—	sandstone	producing	faulted anticline	0	10.3	—	10	4,710	85	22	45	—	—	3,200	—	—	0.566	—	—
Stump Lake	1978	State	Beluga	—	sandstone	shut-in	anticline	0	5.6	—	<1	6,690-6,740	91	24	5	—	—	13,691	—	—	0.558	—	—
Pretty Creek/ Theodore River	1979	State	Beluga	—	sandstone	producing	anticline	0	7	—	<1	3,710-6,000	60	22	—	—	—	6,718	—	—	0.559	—	—
Pioneer	1999	State/Native	Tyonek	—	coal	exploration	—	—	0.002	—	—	—	>100	—	—	—	—	49,263	—	—	—	—	98

Sources: ADNR/DOG (2002, 2003c, 2004f), AOGCC (2004), Evergreen Resources (2003b), Magoon (1994), Petroleum News (2001, 2003), Schlumberger-Geoquest (1996), Smith (1995), Veco (2002).

— = information not available
% = percent
API = American Petroleum Institute
bbl = barrel
bcf = billion cubic feet
BTU/ft^3 = British Thermal Unit/cubic foot
Md = millidarcy
MGS = Middle Ground Shoal Member
SCU = Soldotna Creek Unit
SCF/STB = standard cubic feet of gas per stock tank barrel of oil

1. Federal includes federal, federal-leased, native-selected, and state-selected lands. State includes state, state-leased, and mental health trust lands.
2. Industry pool designation.
3. Approximate cumulative production through 2002-2003 (ADNR/DOG, 2003c; AOGCC, 2004).

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TABLE 3
LOCATABLE MINERAL TERRANE UNITS[1]
Ring of Fire Planning Area, Alaska

Map Unit	Rock Type	Locatable Mineral Commodities
SYNGENETIC DEPOSITS		
Intrusive Terranes		
IGA	ALKALIC GRANITIC ROCKS – syenite, and locally peralkaline granite and monzonite	Favorable for deposits of U, REE, Mo
IGF	FELSIC GRANITIC ROCKS – granite and quartz monzonite	Favorable for deposits of Sn, W, Mo, U, Th
IGI	INTERMEDIATE GRANITIC ROCKS – granodiorite and quartz diorite	Favorable for Deposits of Cu, Au, Mo
IGU	UNDIVIDED GRANITIC ROCKS – may include mineral deposits of the three above groups	
IMA	MAFIC INTRUSIVE ROCKS – gabbro, and locally mafic-rich intermediate rocks such as mafic monzonite and diorite	Favorable for deposits of Cu, Ni, with byproduct Pt, Co
IUM	ULTRAMAFIC ROCKS – peridotite and dunite	Favorable for deposits of Cr, Ni, PGE with byproduct Co
Volcanic – Sedimentary Terranes		
VFU	FELSIC VOLCANIC ROCKS, undivided – rhyolite and quartz latite	Favorable for deposits of Cu, Pb, Zn with byproduct Ag, Au
VFI	INTERMEDIATE VOLCANIC ROCKS – trachyandesite, andesite	Favorable for deposits of U, Th
VMU	MAFIC VOLCANIC ROCKS, undivided – primarily basalt	Favorable for deposits of Cu, Zn with byproduct Ag, Au
VSF	SEDIMENTARY AND FELSIC VOLCANIC ROCKS, undivided – rhyolite, quartz latite, and associated sediments	Favorable for deposits of Cu, Zn with byproduct Ag, Au
VSM	SEDIMENTARY AND MAFIC VOLCANIC ROCKS, undivided – basalt and associated sediments	Favorable for deposits of Cu, Zn with byproduct Ag and Au
SCB	CONTINENTAL SEDIMENTARY ROCKS – sandstone, shale and conglomerate, coal-bearing	Favorable for deposits of U with byproduct V
EPIGENETIC DEPOSITS		
Sedimentary Terranes		
SGS	GRAYWACKE AND SHALE – interbedded with minor volcanic rocks, favorable for mineral deposits introduced by metamorphic or epithermal processes	Favorable for deposits of Au, plus deposits like those of igneous terranes

Sources: AEIDC (1979); Hawley and AEIDC (1982); RDI et al. (1995)

1	=	Figures 26 through 29
Ag	=	silver
Au	=	gold
Co	=	cobalt
Cr	=	chromium
Cu	=	copper
Mo	=	molybdenum
Ni	=	nickel
Pb	=	lead
PGE	=	platinum group elements (e.g., platinum, palladium, iridium)
Pt	=	platinum
Sn	=	tin
REE	=	rare earth elements (e.g., lanthanum, cerium, neodymium)
U	=	uranium
V	=	vanadium
W	=	tungsten
Zn	=	zinc

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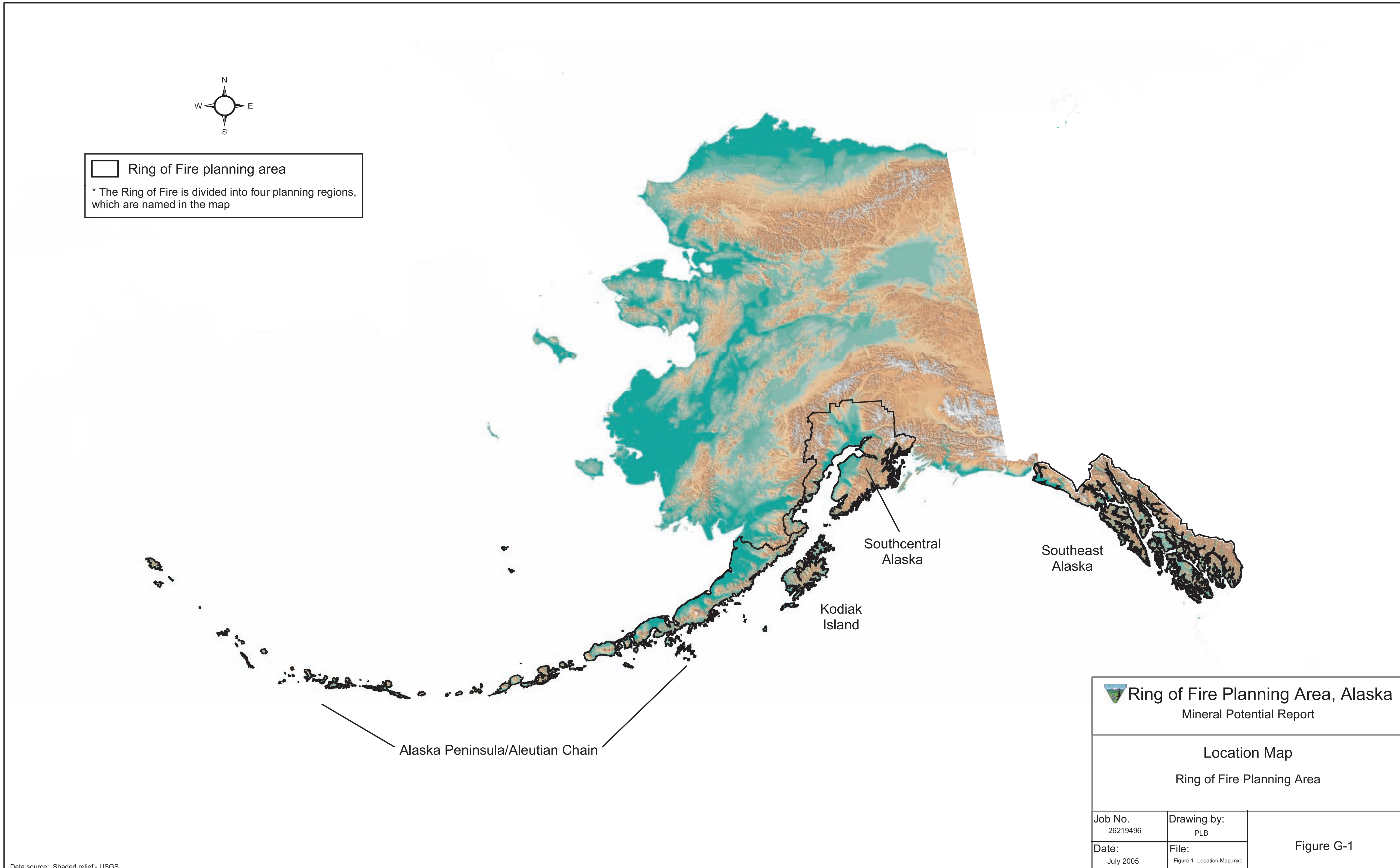
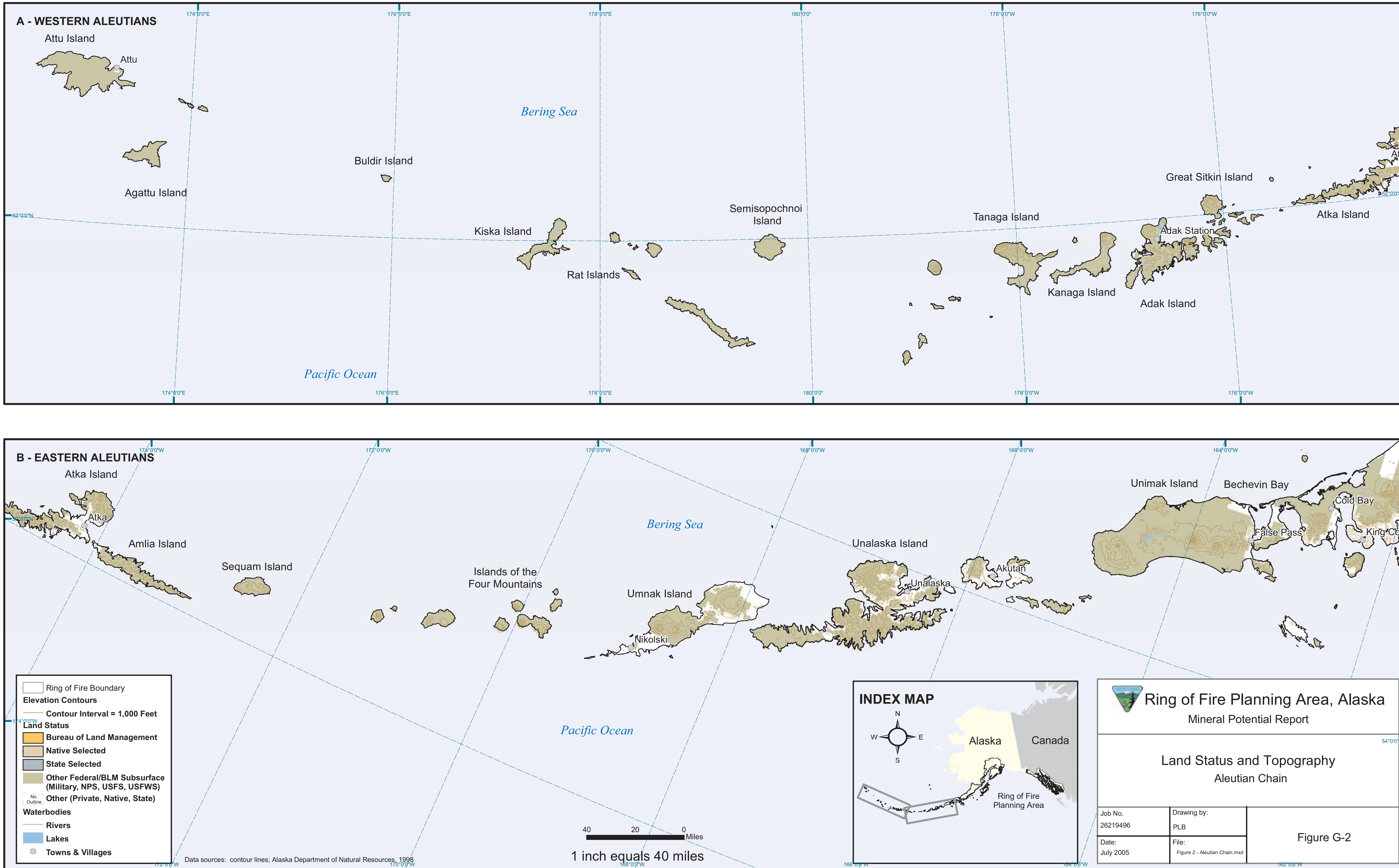
Figures



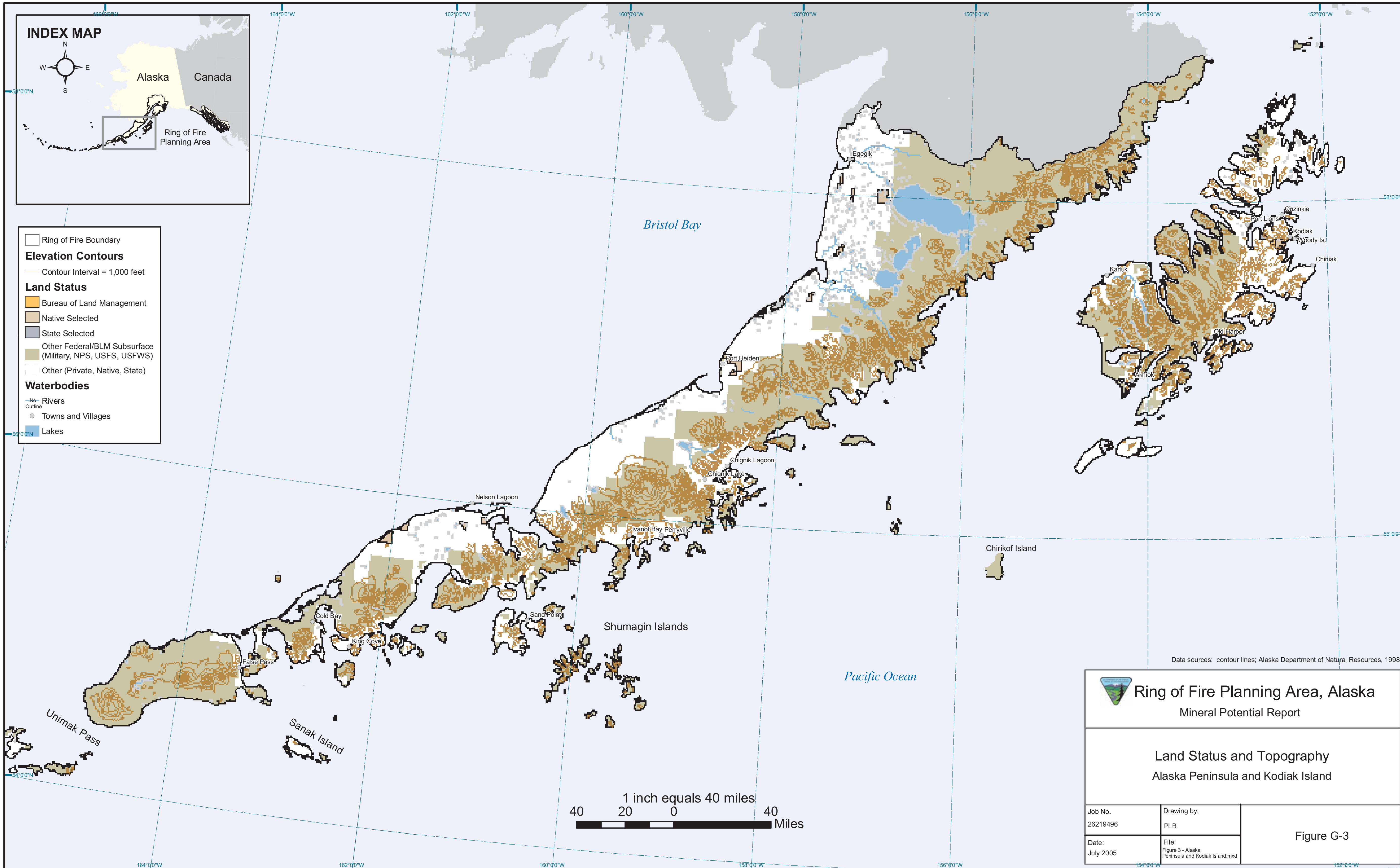
U.S. Geological Survey

Figure G-1, Location Map, Ring of Fire Planning Area



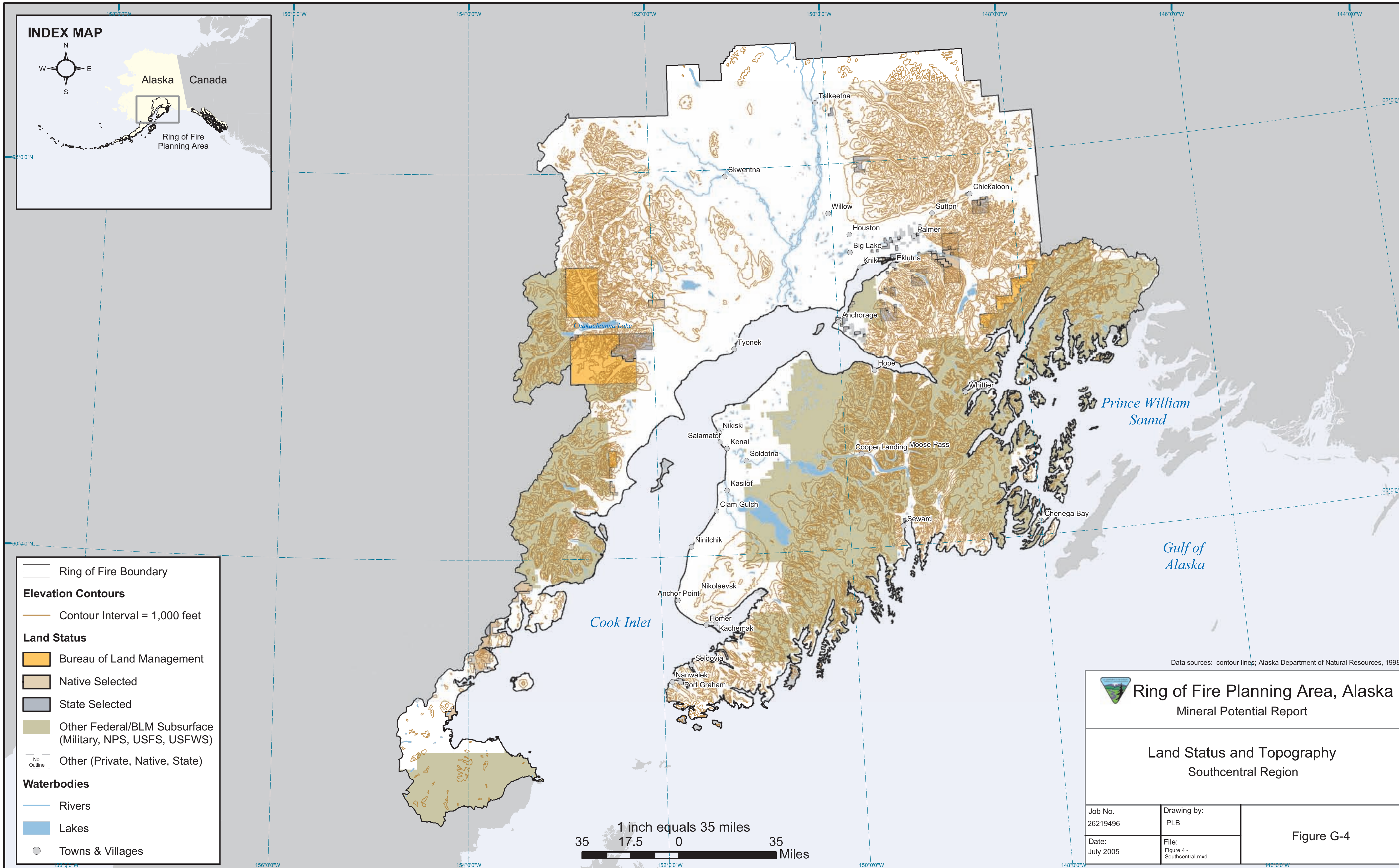
Bureau of Land Management

Figure G-2, Land Status and Topography of the Aleutian Chain



State of Alaska Department of Natural Resources

Figure G-3, Land Status and Topography of the Alaska Peninsula and Kodiak Island

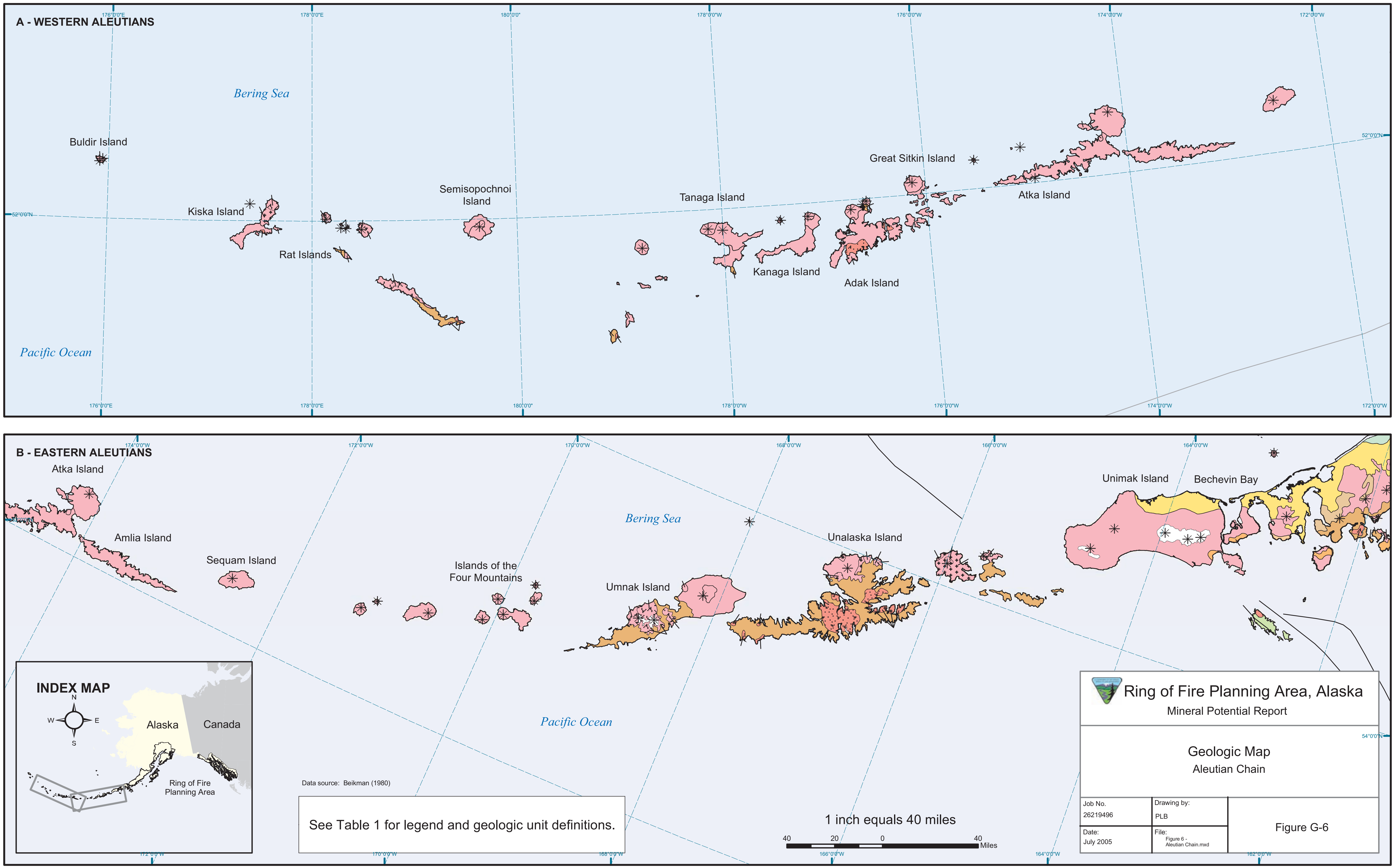


State of Alaska Department of Natural Resources

Figure G-4, Land Status and Topography of the Southcentral Region

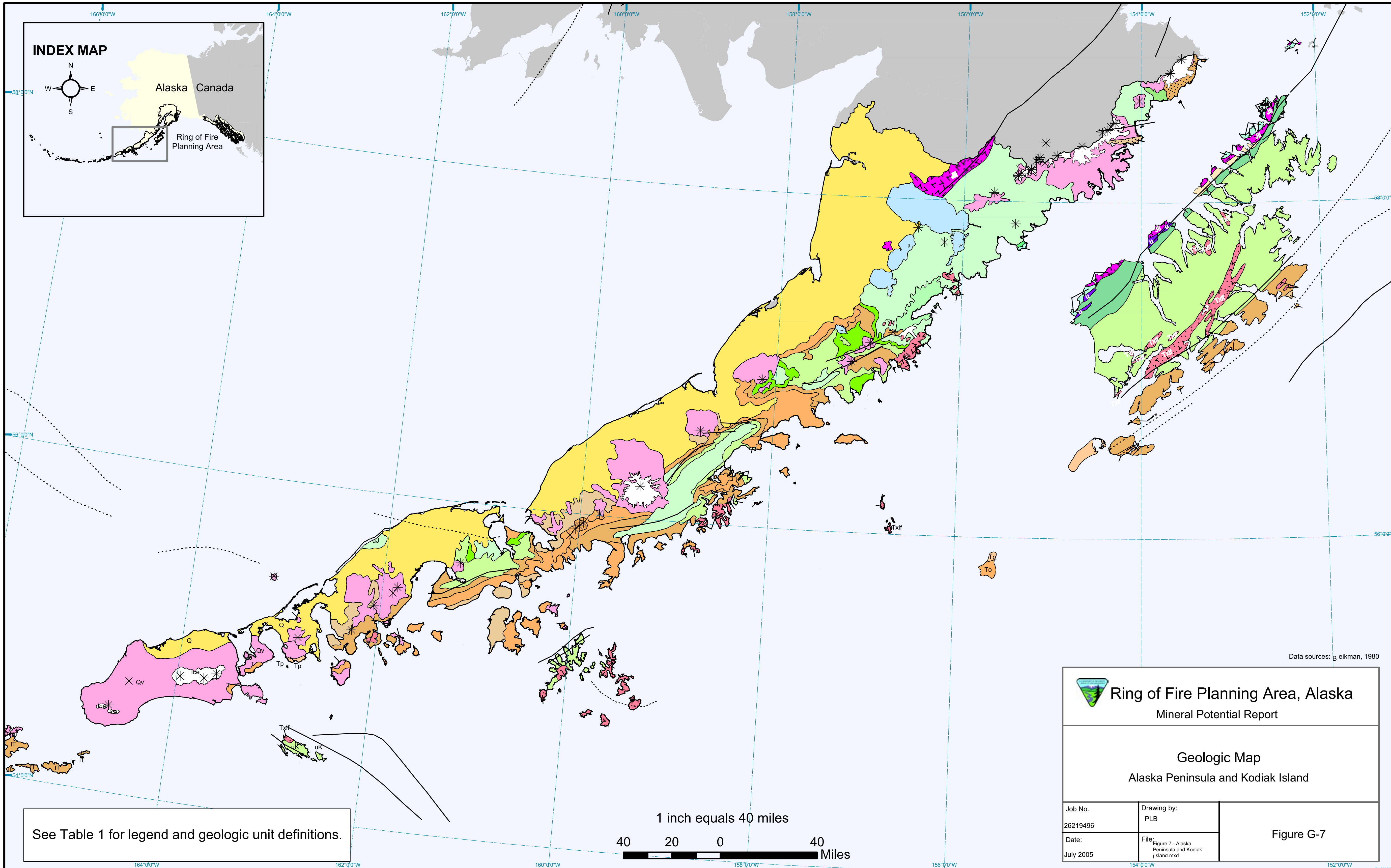
State of Alaska Department of Natural Resources

Figure G-5, Land Status and Topography of the Southeast Region



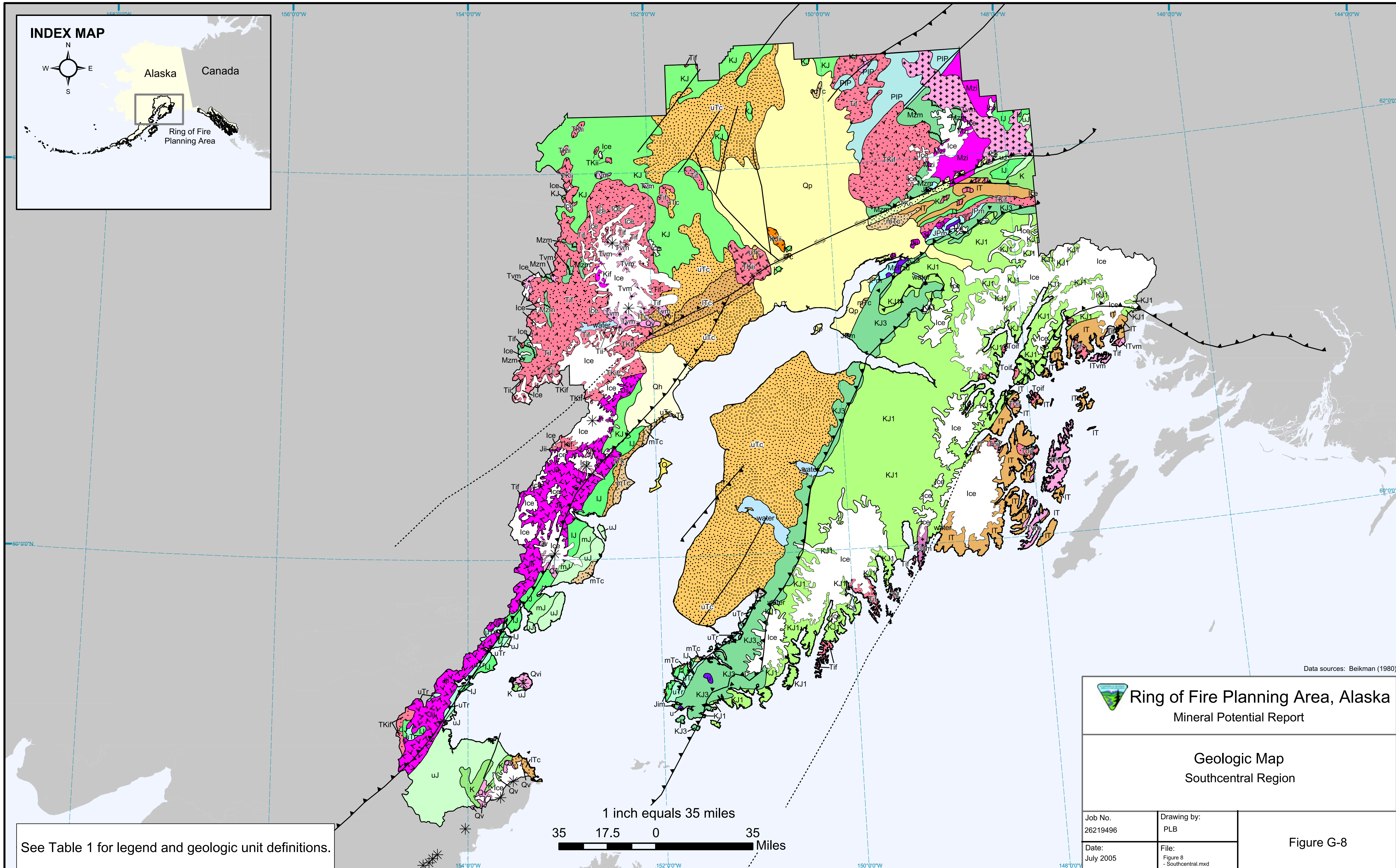
U.S. Geological Survey

Figure G-6, Geologic Map of the Aleutian Chain



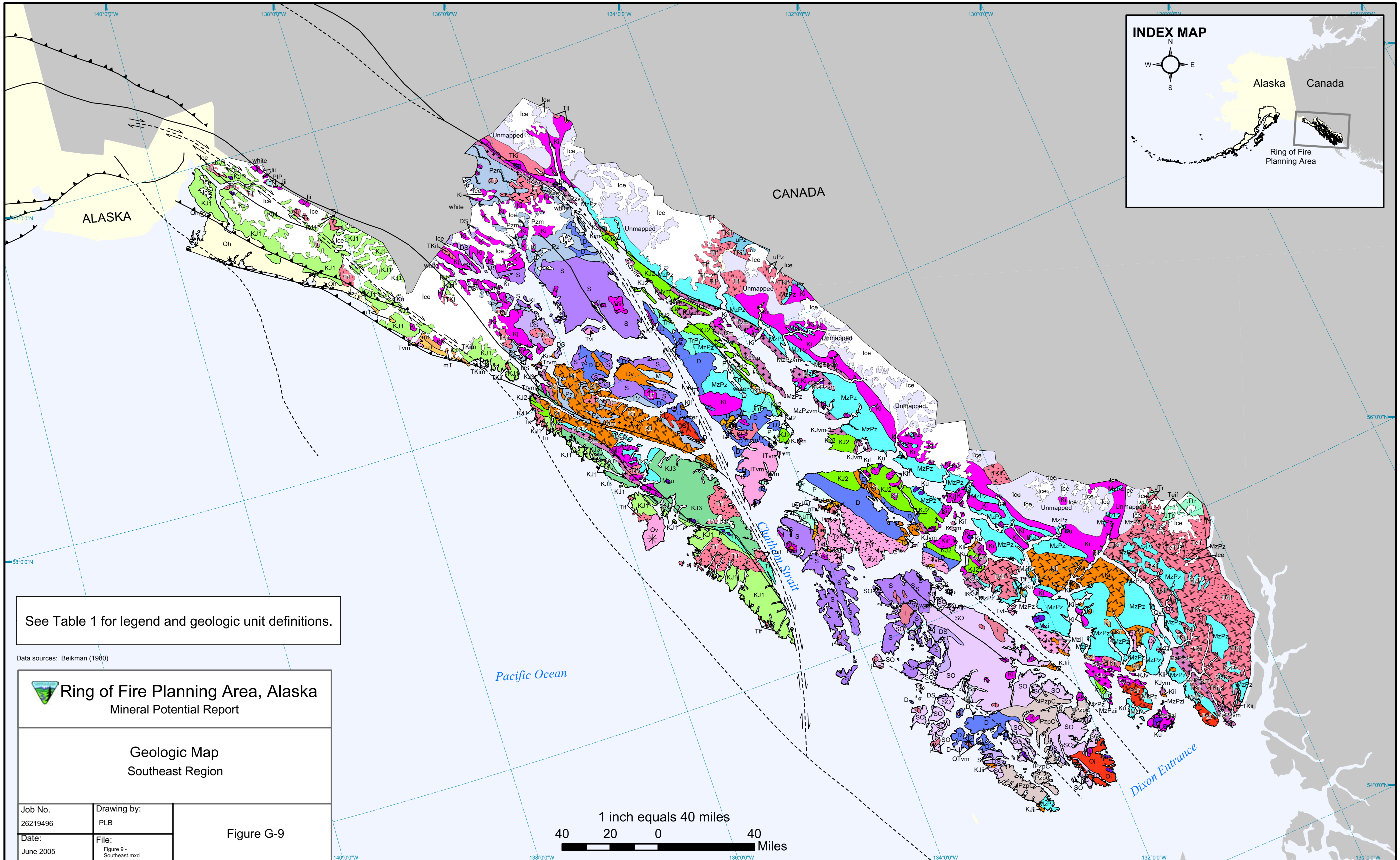
U.S. Geological Survey

Figure G-7, Geologic Map of the Alaska Peninsula and Kodiak Island



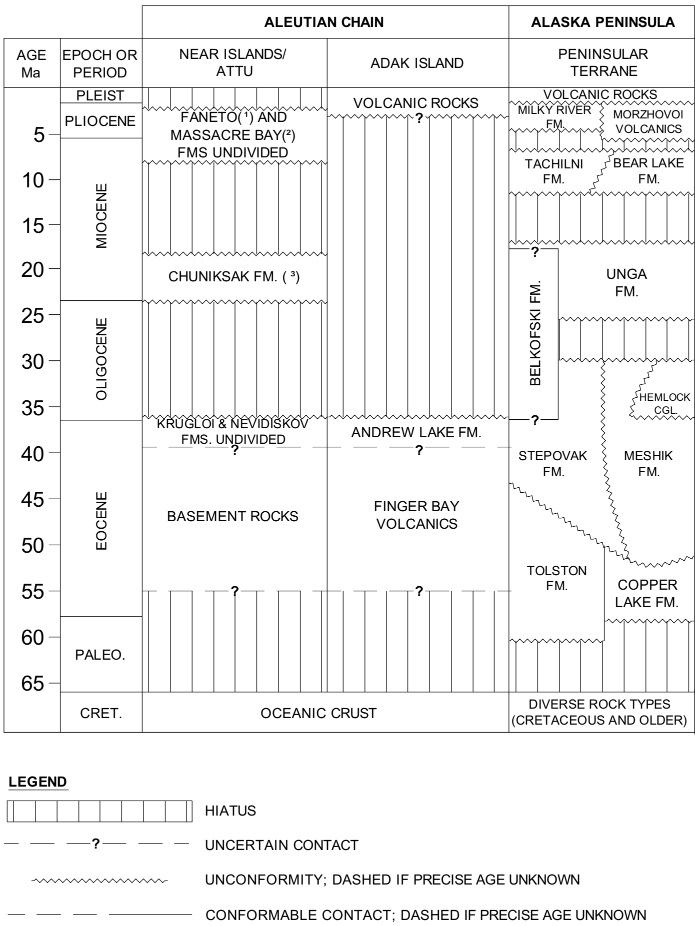
U.S. Geological Survey

Figure G-8, Geologic Map of the Southcentral Region

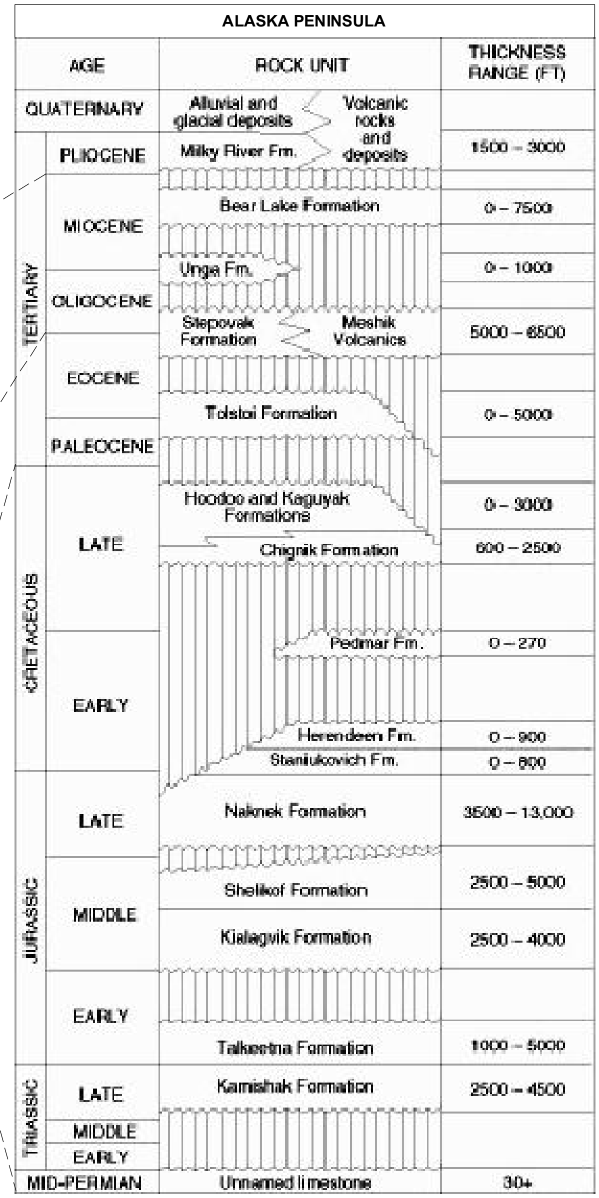


U.S. Geological Survey

Figure G-9, Geologic Map of the Southeast Region



A. CORRELATION CHART OF ALEUTIAN RIDGE AND ALASKA PENINSULA STRATIGRAPHIC UNITS, MODIFIED FROM VALLIER ET AL. (1994)



B. MESOZOIC AND TERTIARY STRATIGRAPHY OF THE ALASKA PENINSULA, FROM MOLENAAR (1996)

Ring of Fire Planning Area, Alaska
Mineral Potential Report

Stratigraphic Columns
Aleutian Chain and Alaskan Peninsula

Job No.	Drawing by:	
26219496	ARN	Figure G-10
Date:	File:	
June 2004	Figs.dwg	

Figure G-10, Stratigraphic Columns, Aleutian Chain and Alaskan Peninsula

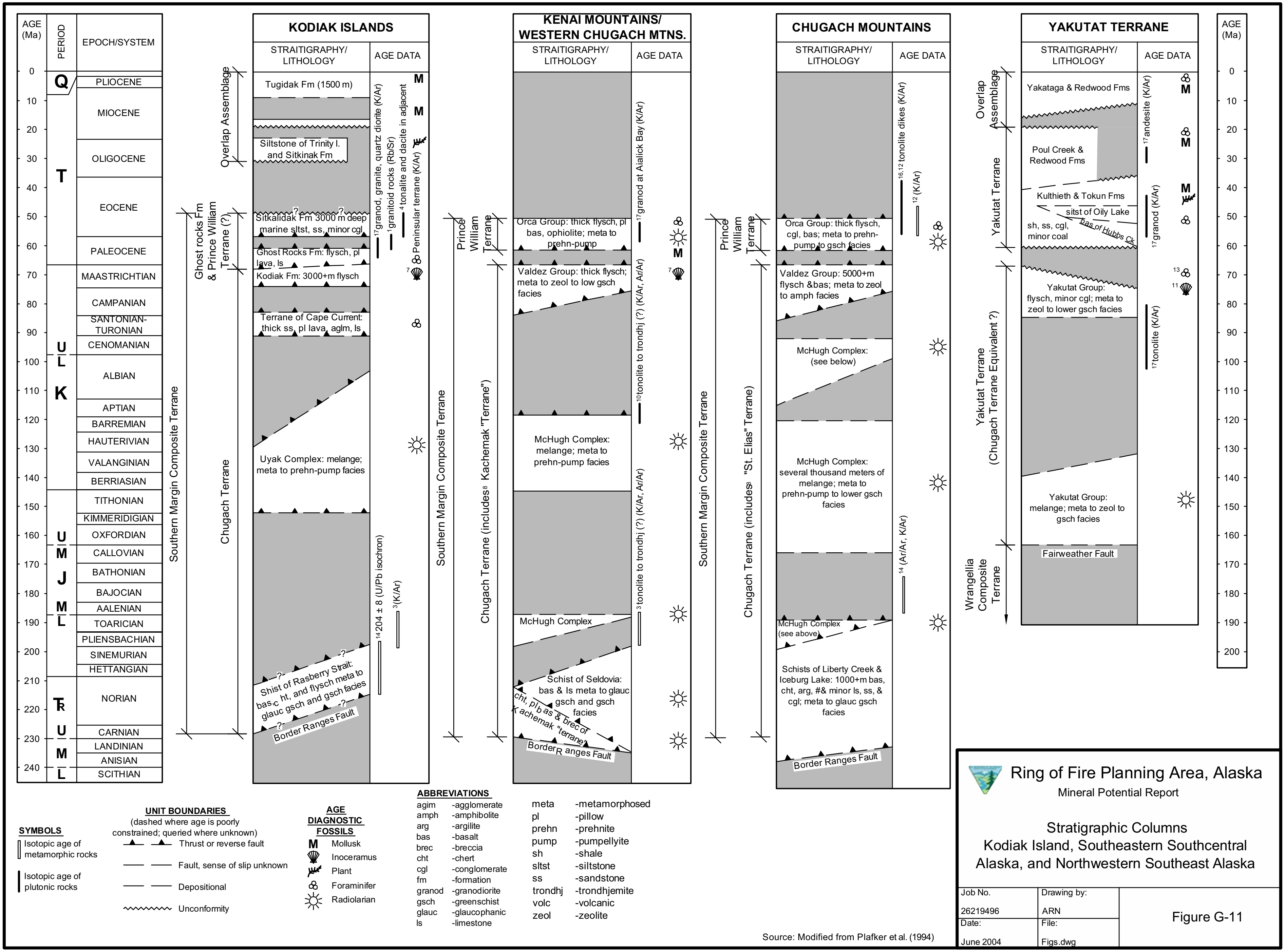
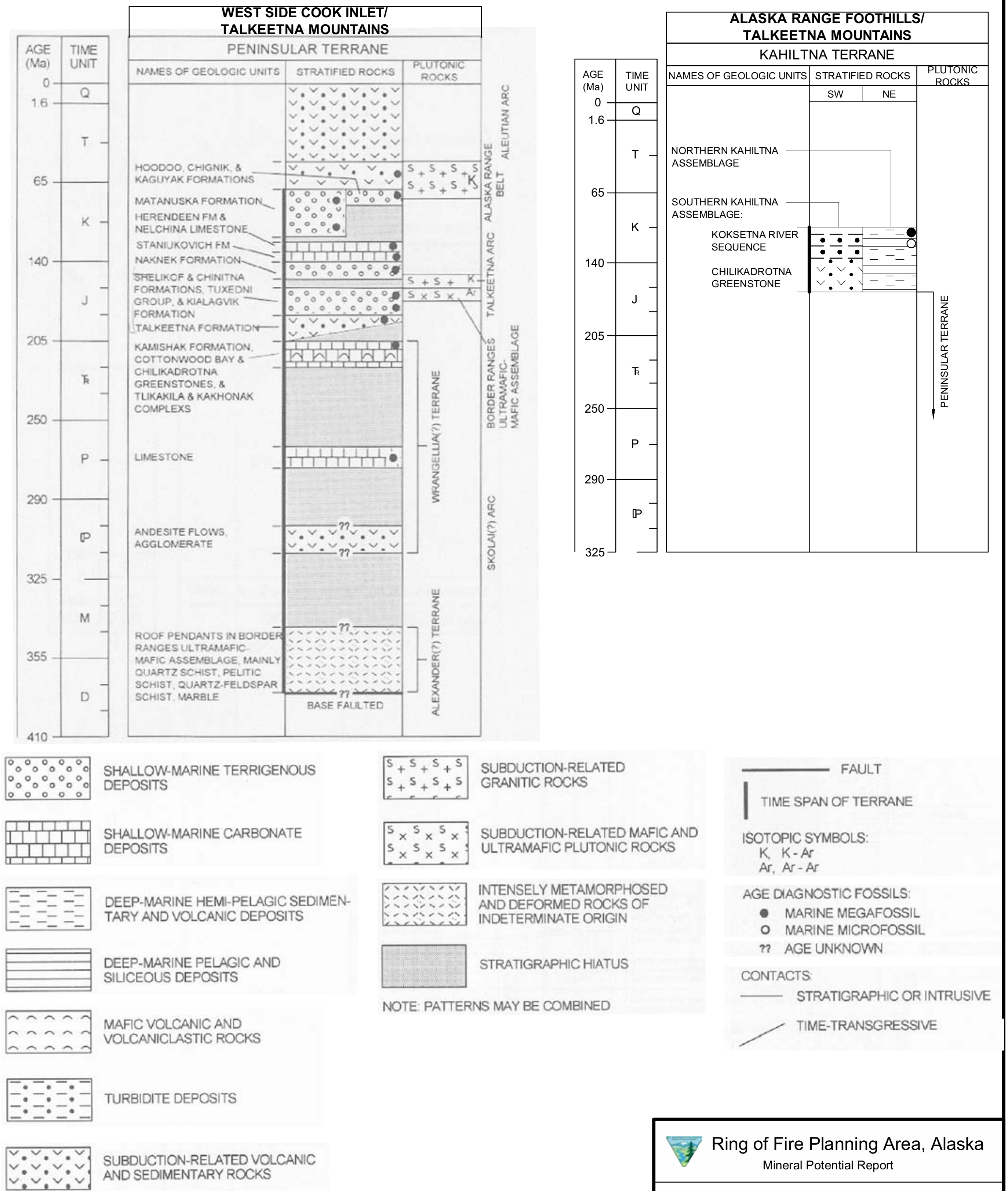


Figure G-11, Stratigraphic Columns, Kodiak Island, Southeastern Southcentral Alaska, and Northwestern Southeast Alaska

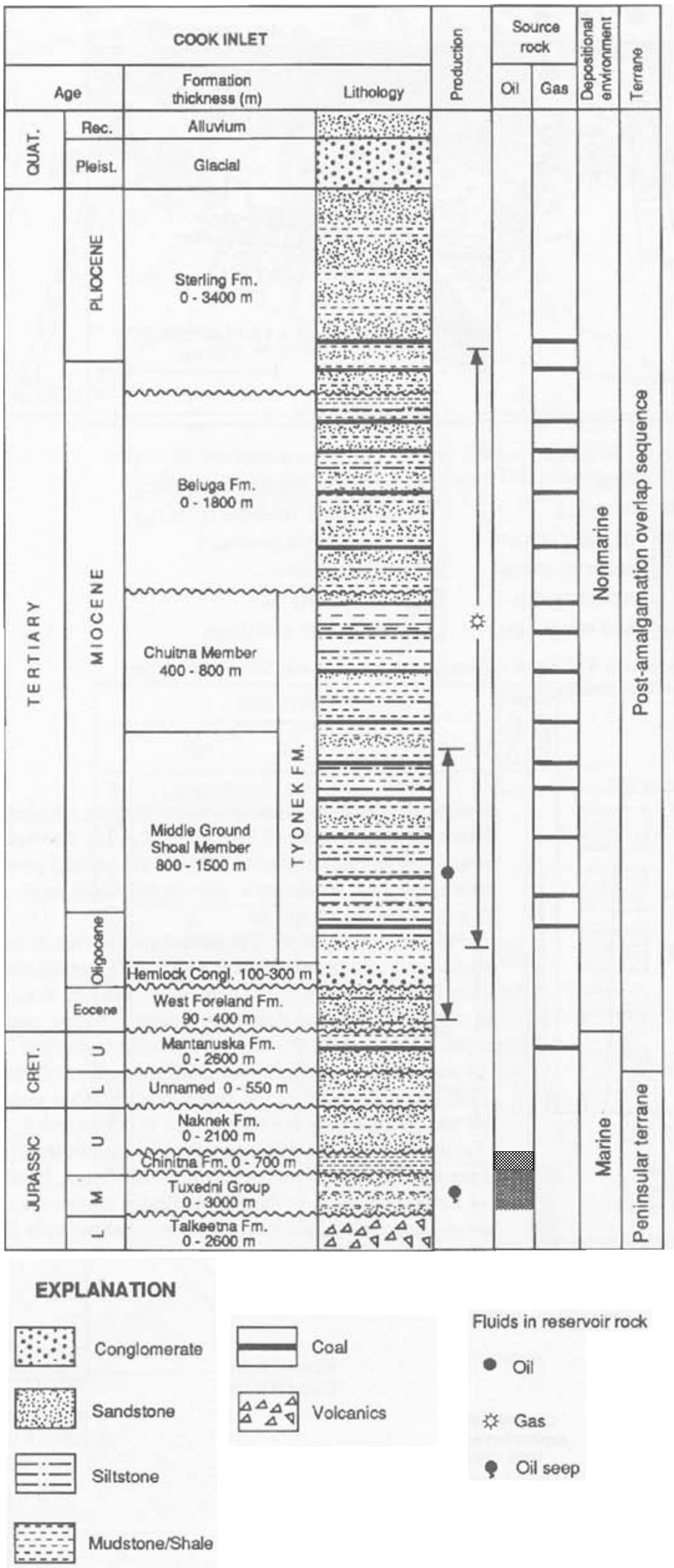


Ring of Fire Planning Area, Alaska
Mineral Potential Report

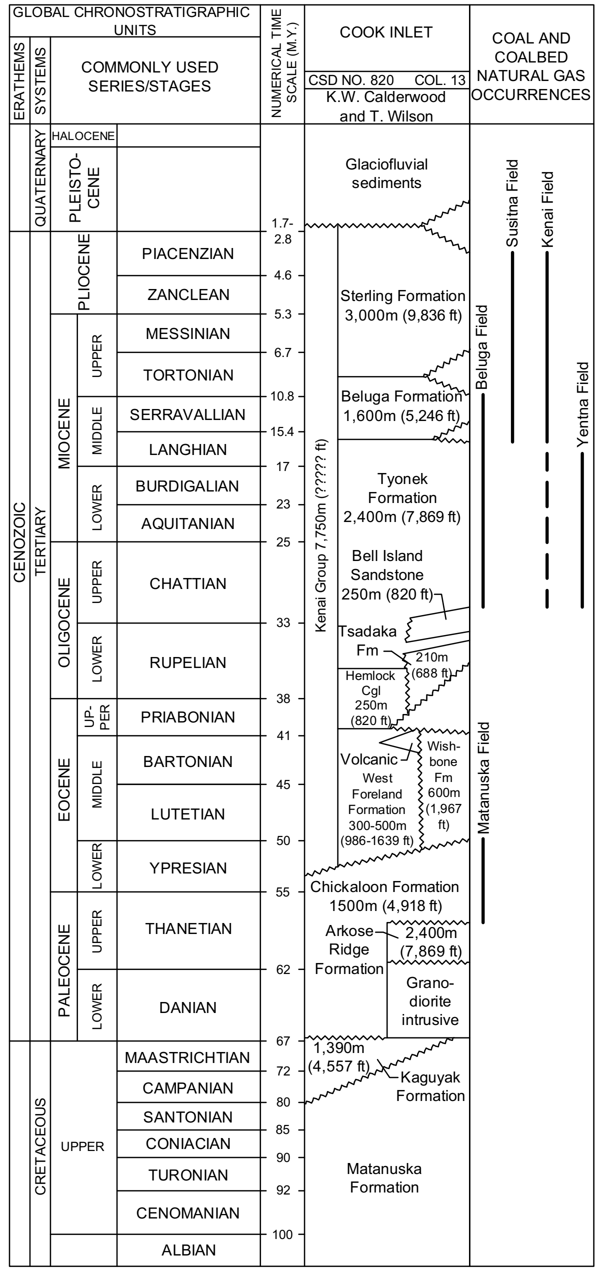
Stratigraphic Columns
Western and Northern Southcentral Alaska

Job No.	Drawing by:	
26219496	ARN	Figure G-12
Date:	File:	
June 2004	Figs.dwg	

Figure G-12, Stratigraphic Columns, Western and Northern Southcentral Alaska



A. Generalized stratigraphic column for Cook Inlet showing petroleum in reservoir rocks and source rock intervals. See Table 2 for oil and gas field names. Modified from Magoon (1994,1996a)



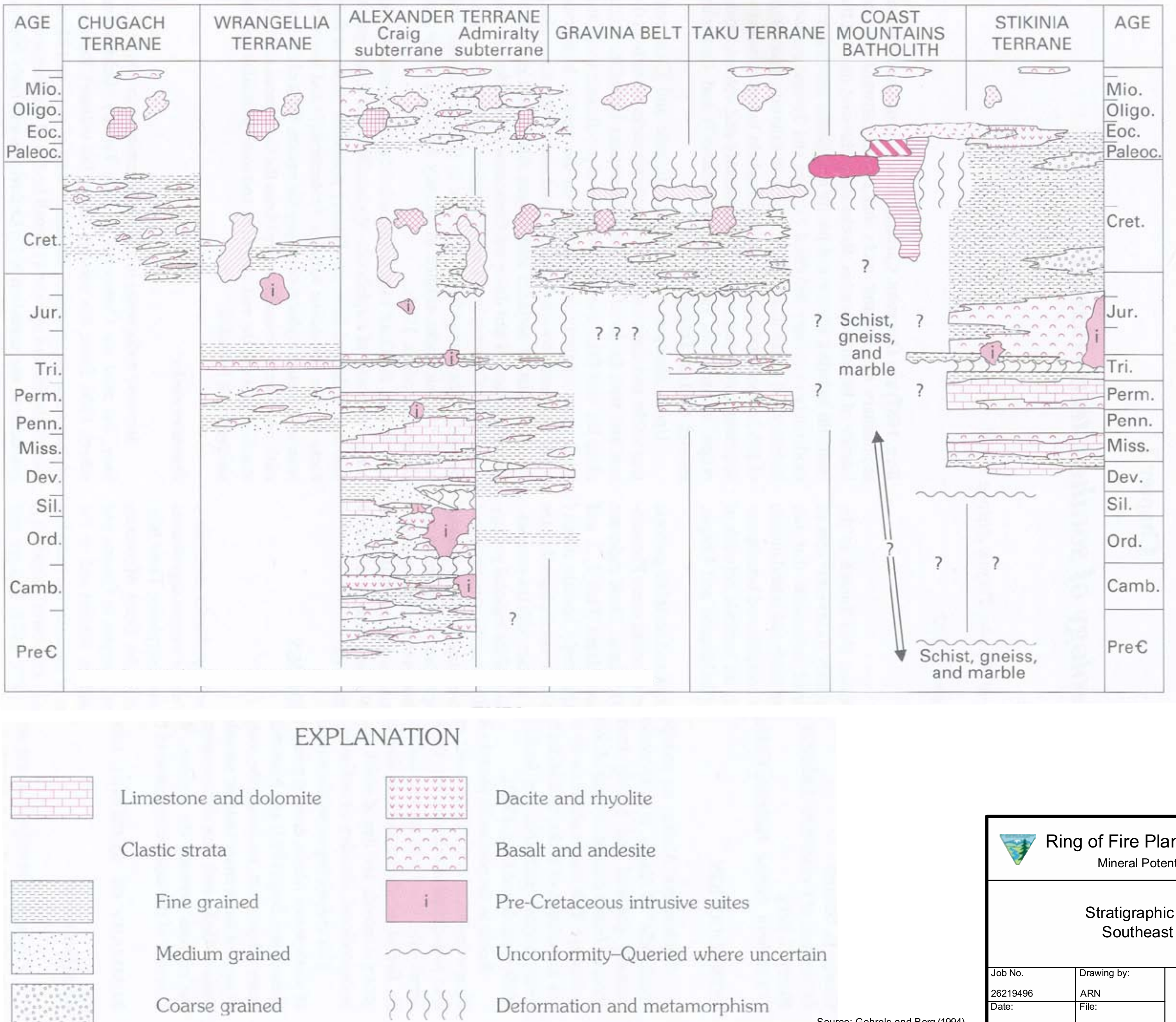
B. Stratigraphic column of Cook Inlet-Susitna basin showing coal and coalbed natural gas occurrences and fields. Modified from Wahrhaftig (1994) and Merritt and Hawley (1986)

Ring of Fire Planning Area, Alaska
Mineral Potential Report

Stratigraphic Columns
Cook Inlet-Susitna Basin

Job No.	Drawing by:	
26219496	ARN	Figure G-13
Date:	File:	
June 2004	Figs.dwg	

Figure G-13, Stratigraphic Columns, Cook Inlet-Susitna Basin



Source: Gehrels and Berg (1994)

Ring of Fire Planning Area, Alaska

Mineral Potential Report

Stratigraphic Columns
Southeast Alaska

Job No.	Drawing by:	
26219496	ARN	Figure G-14
Date:	File:	
June 2004	Figs.dwg	

Figure G-14, Stratigraphic Columns, Southeast Alaska

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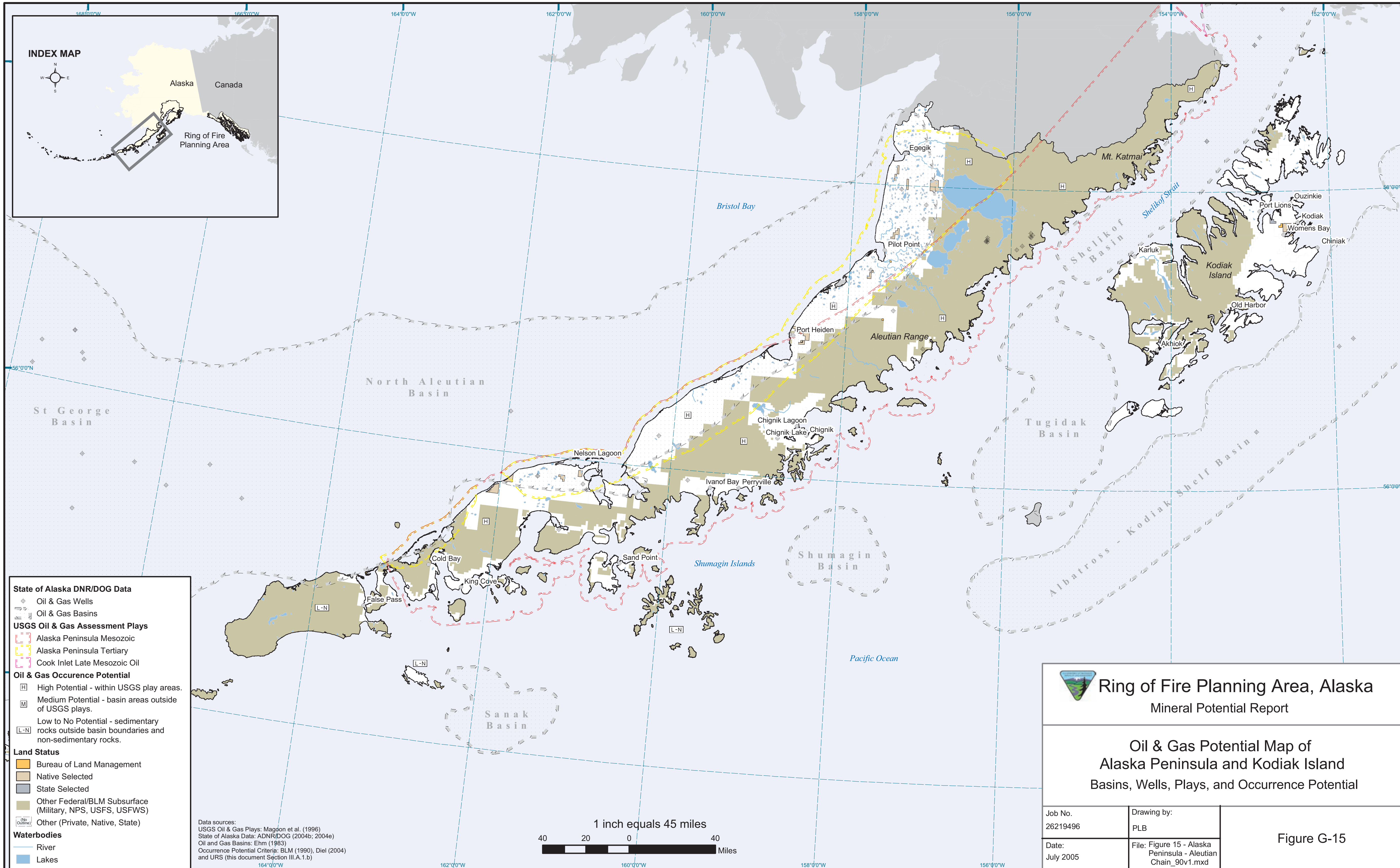

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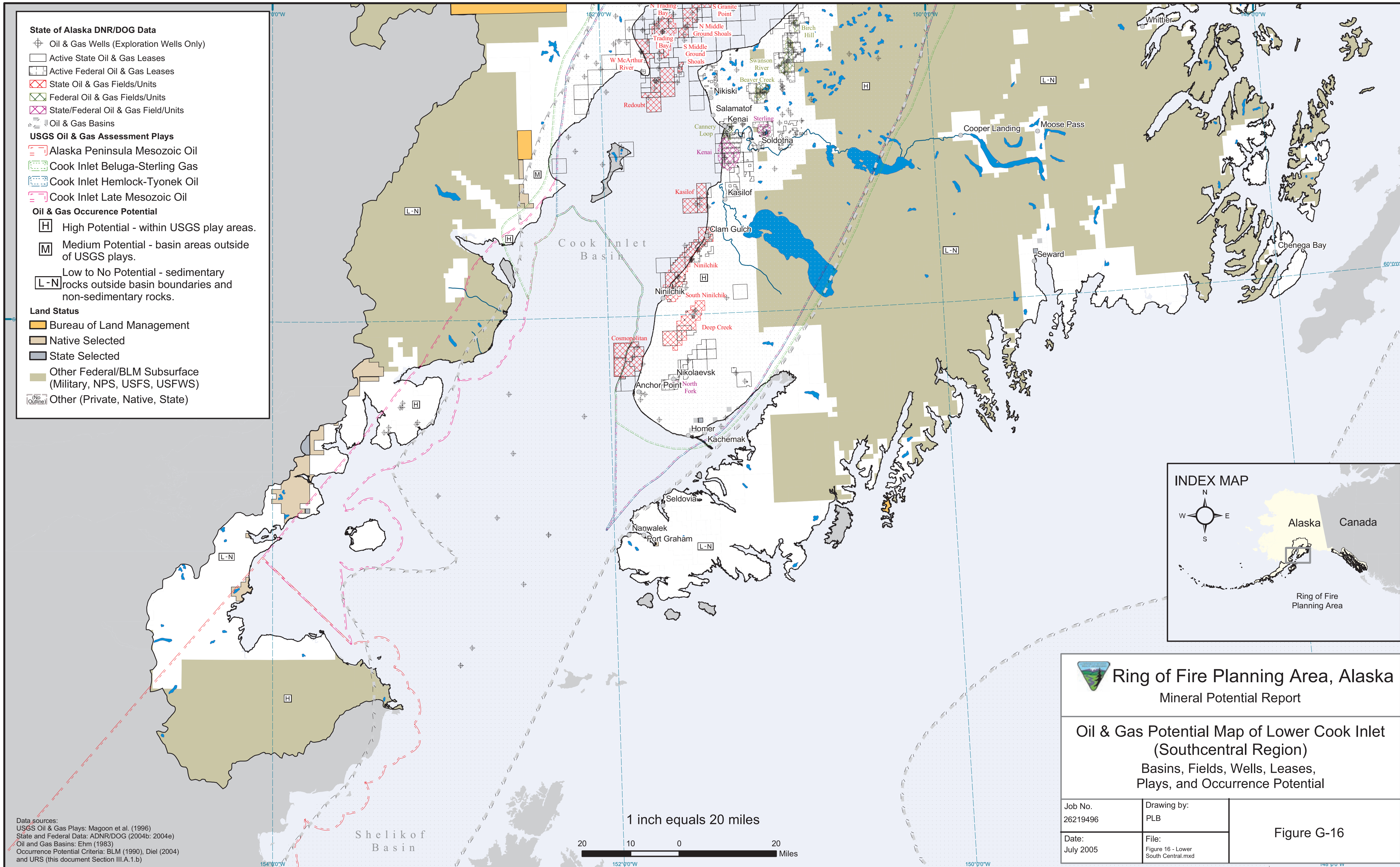
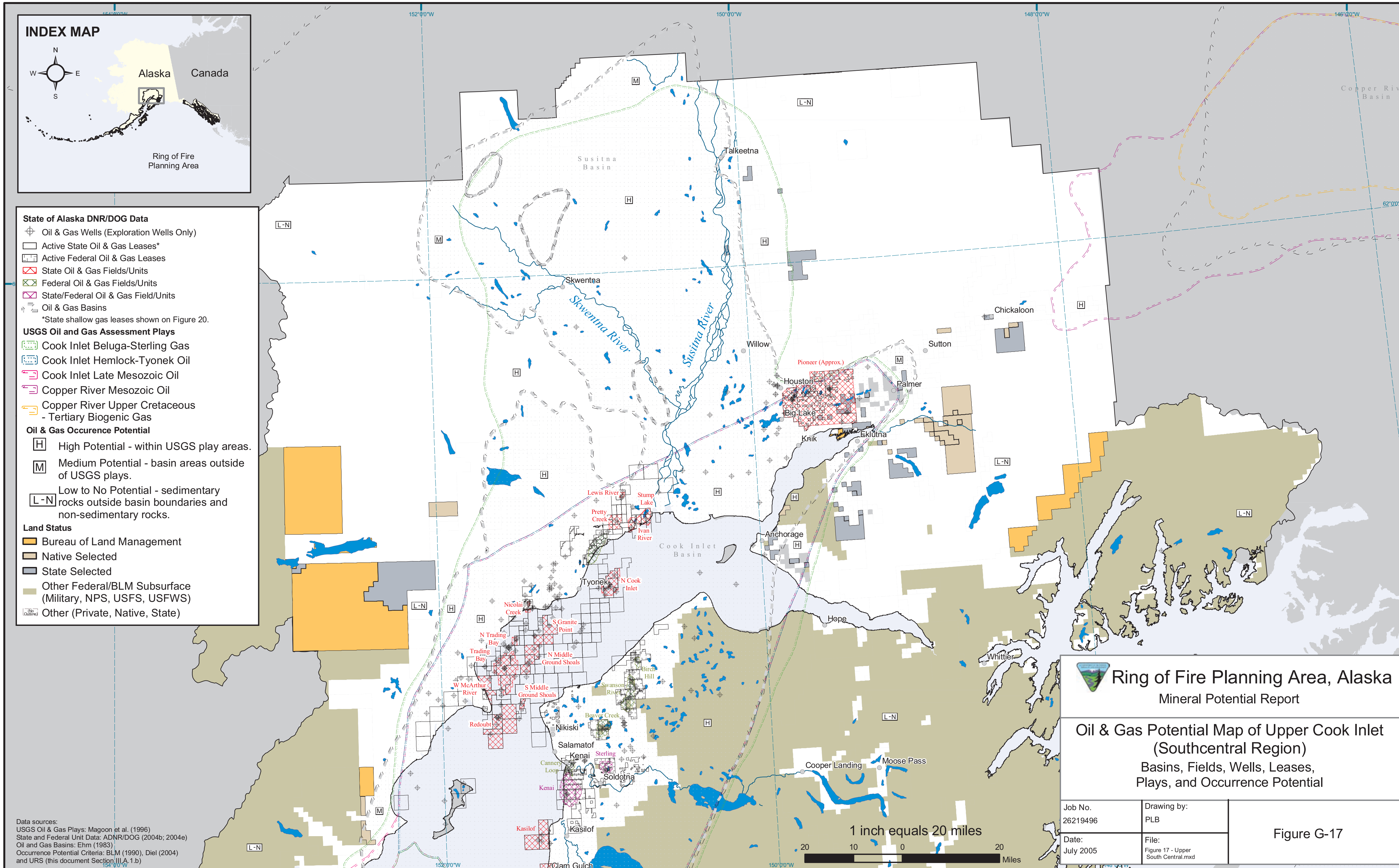
Figure G-15, Oil & Gas Potential Map of Alaska Peninsula and Kodiak Island



Bureau of Land Management

Figure G-16, Oil & Gas Potential Map of Lower Cook Inlet (Southcentral Region)

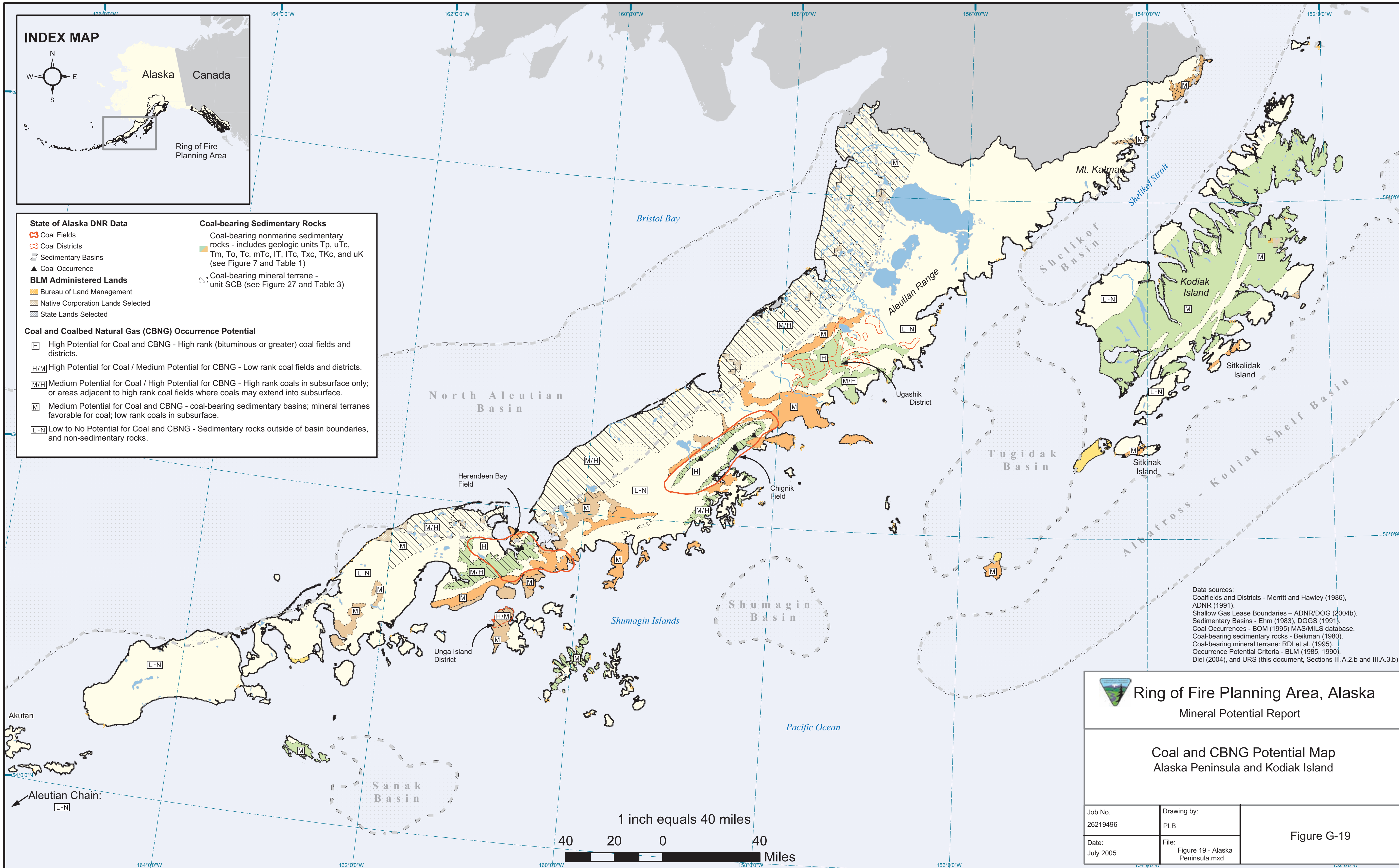


Bureau of Land Management

Figure G-17, Oil & Gas Potential Map of Upper Cook Inlet (Southcentral Region)

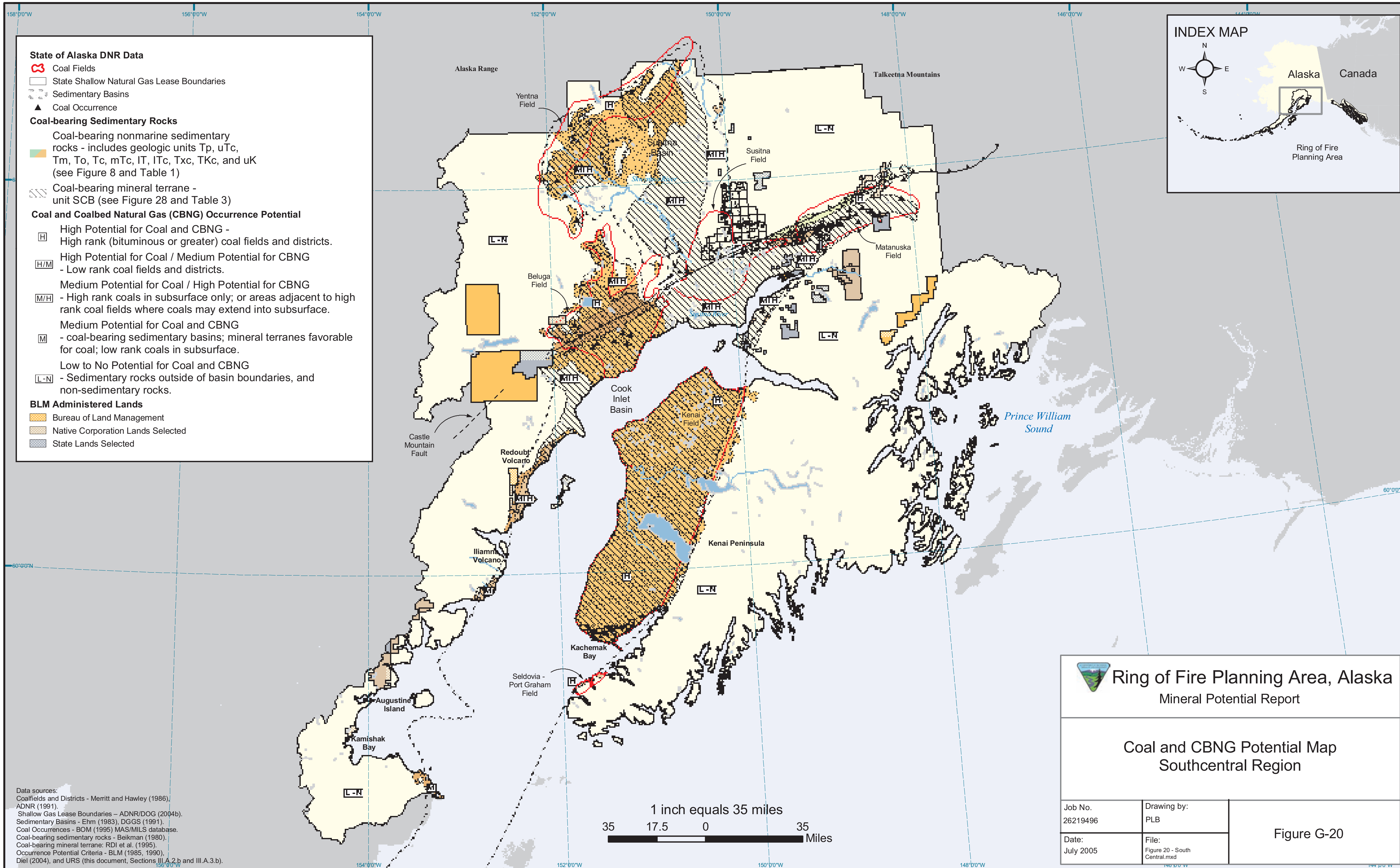
Bureau of Land Management

Figure G-18, Oil and Gas Potential Map of the Southeast Region



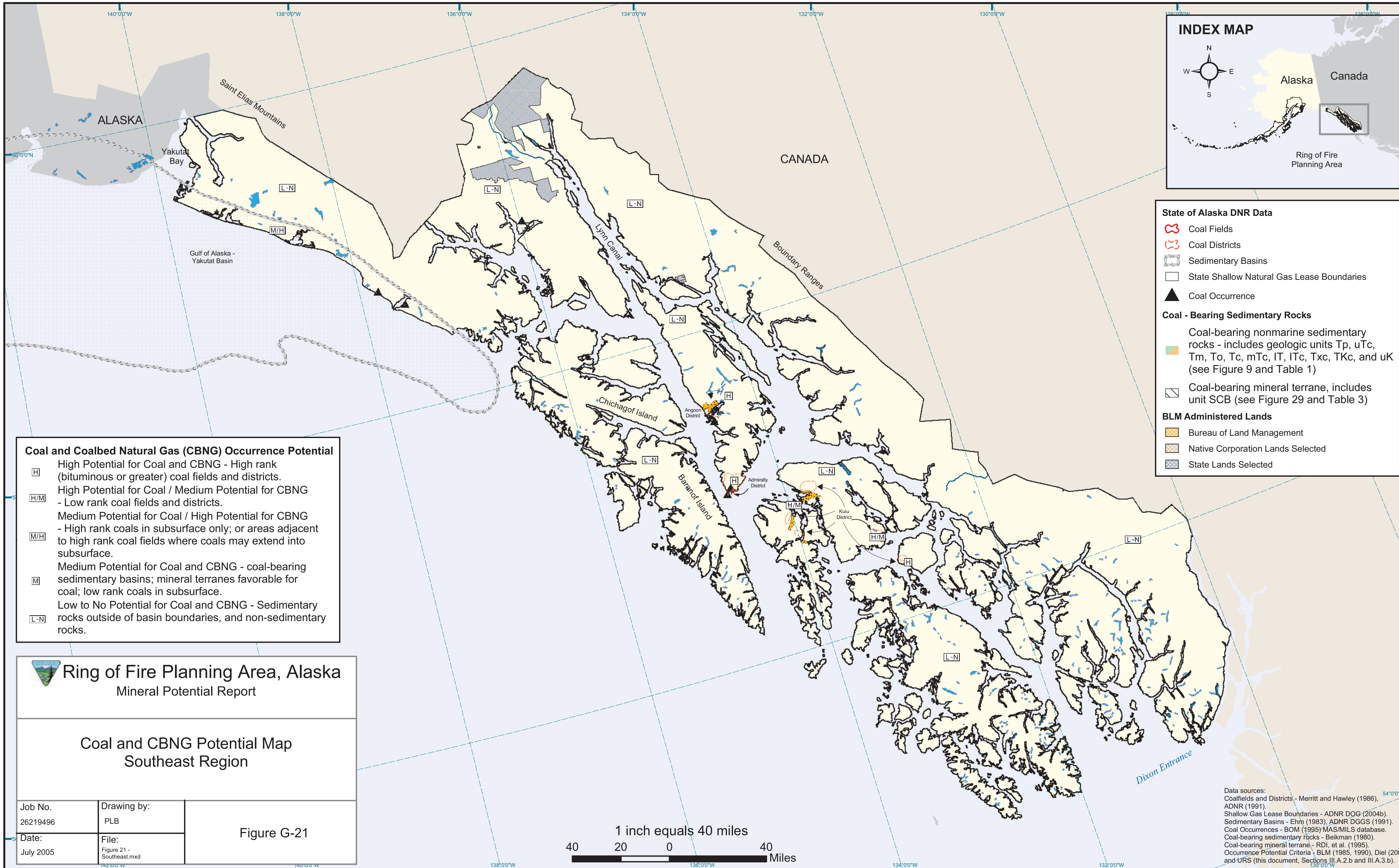
Bureau of Land Management

Figure G-19, Coal and CBNG Potential Map of Alaska Peninsula and Kodiak Island



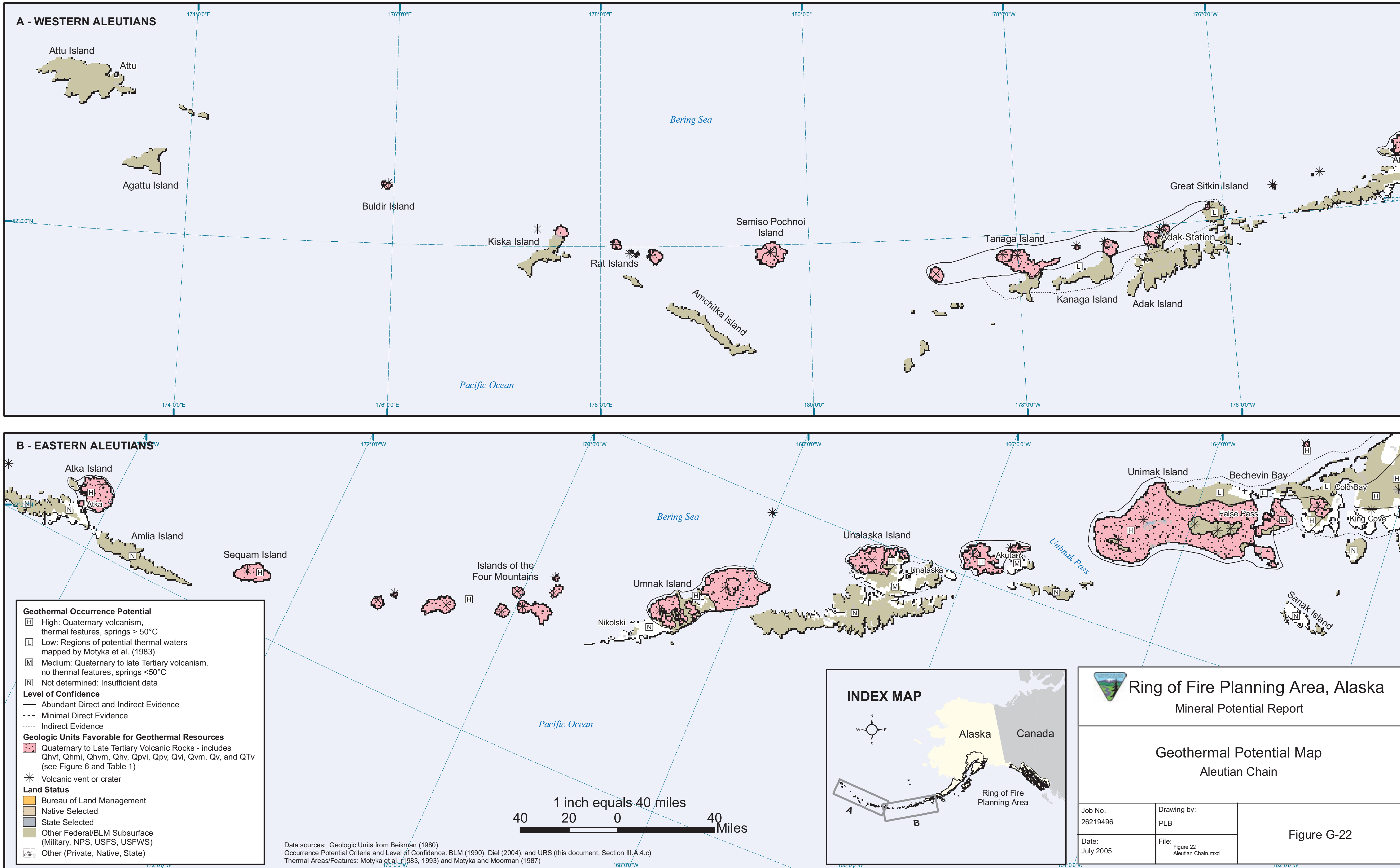
Bureau of Land Management

Figure G-20, Coal and CBNG Potential Map, Southcentral Region



Bureau of Land Management

Figure G-21, Coal and CBNG Potential Map, Southeast Region



Bureau of Land Management

Figure G-22, Geothermal Potential Map, Aleutian Chain

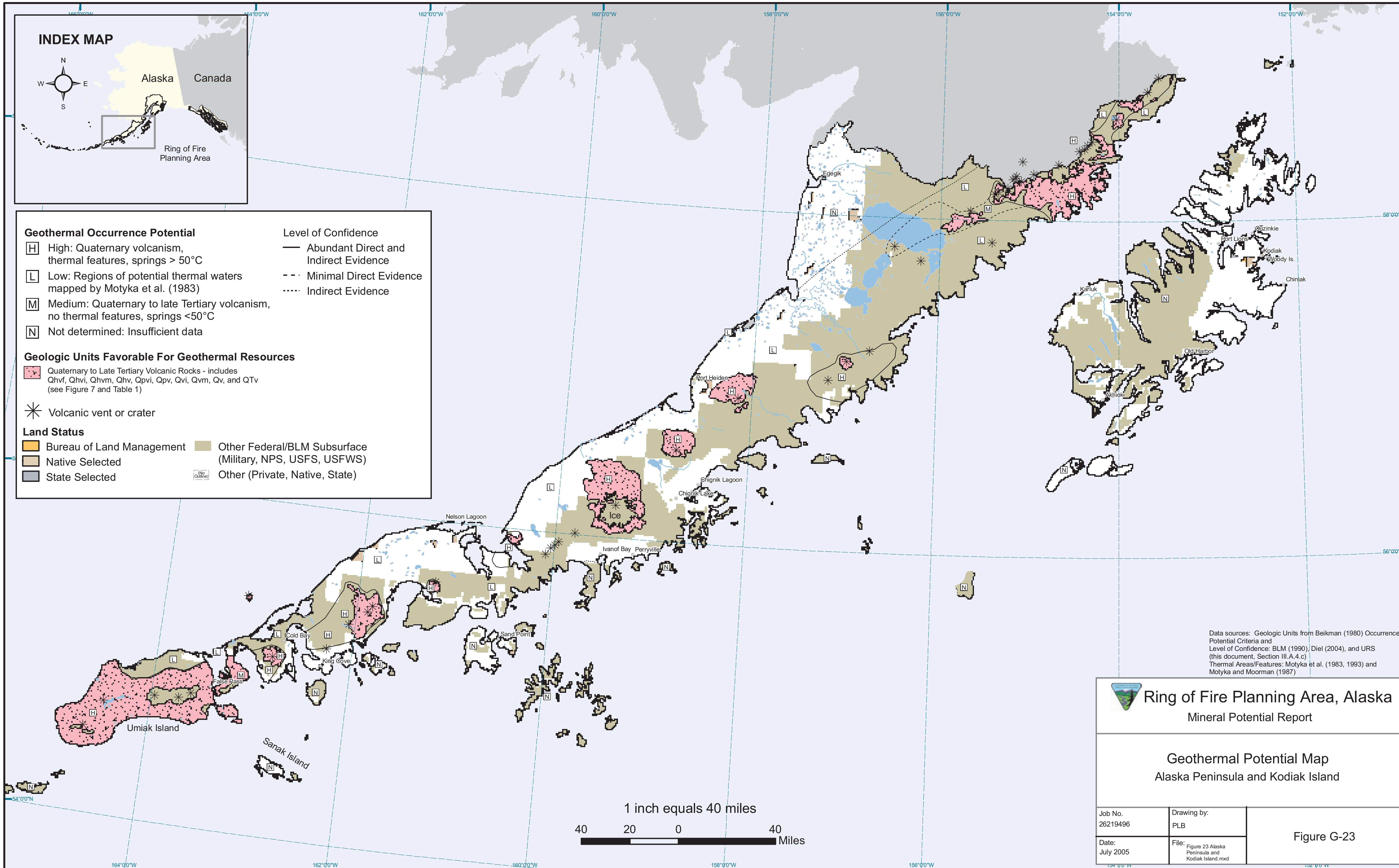


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Figure G-23, Geothermal Potential Map, Alaska Peninsula and Kodiak Island

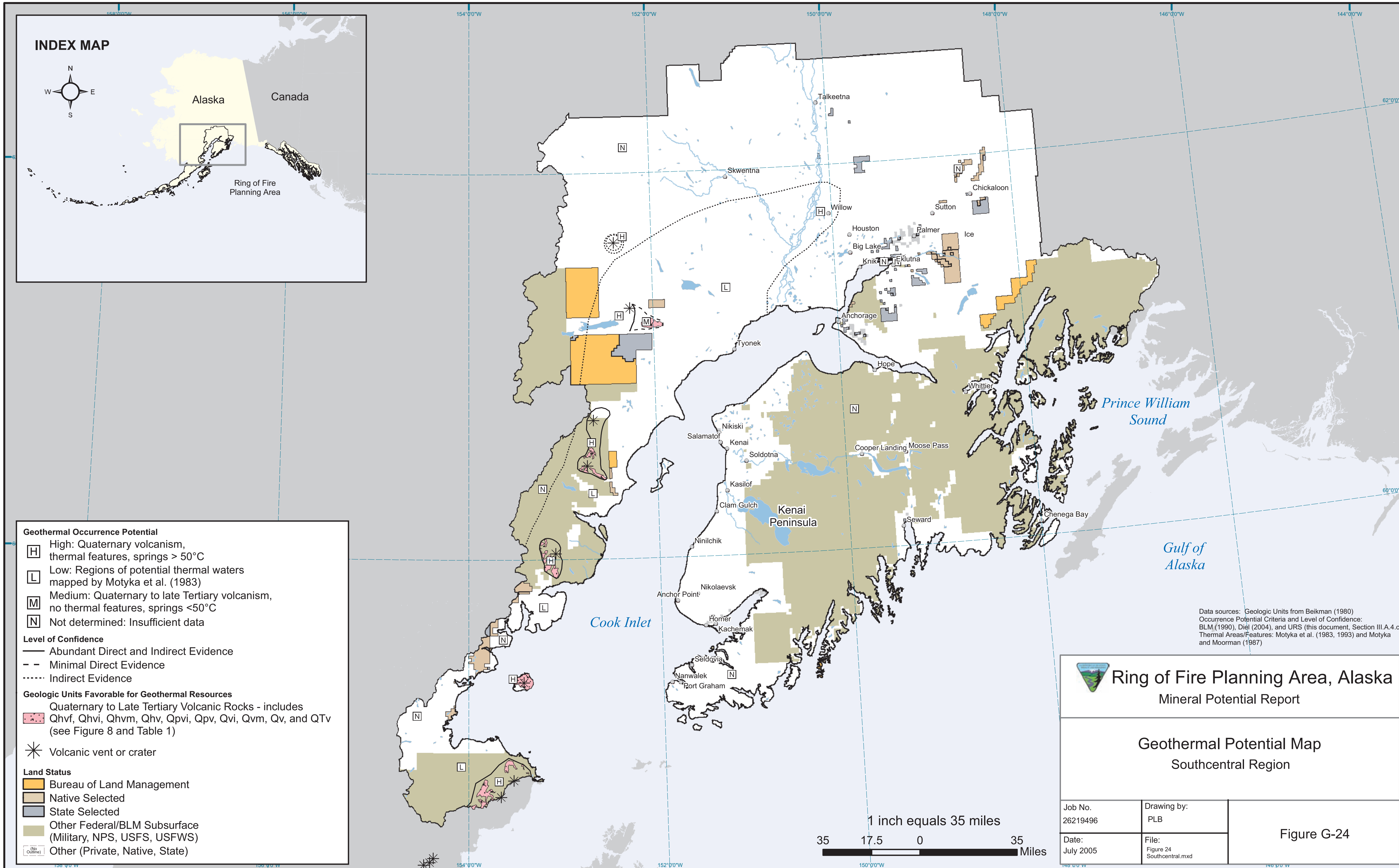

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Figure G-24, Geothermal Potential Map, Southcentral Region

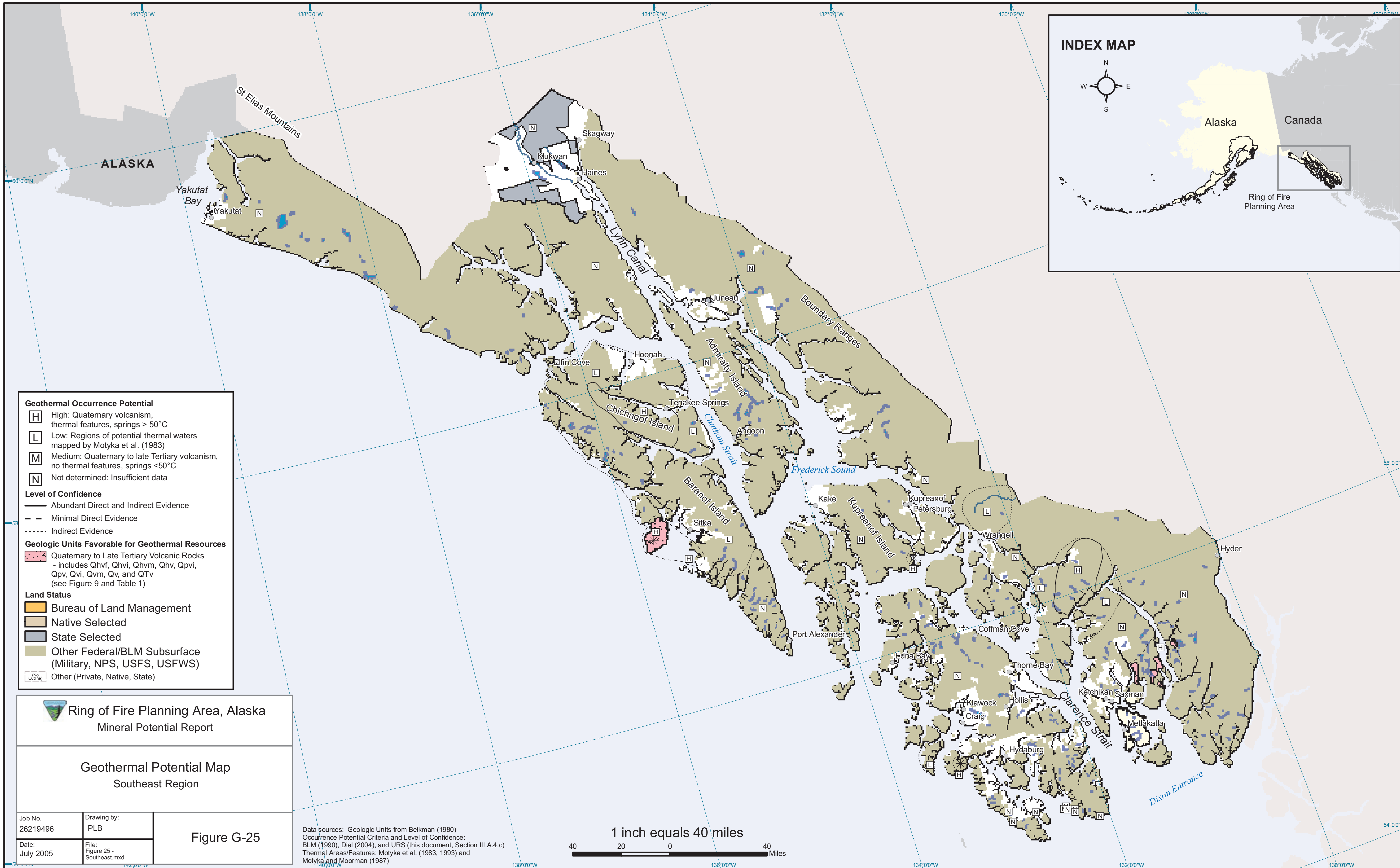

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Figure G-25, Geothermal Potential Map, Southeast Region

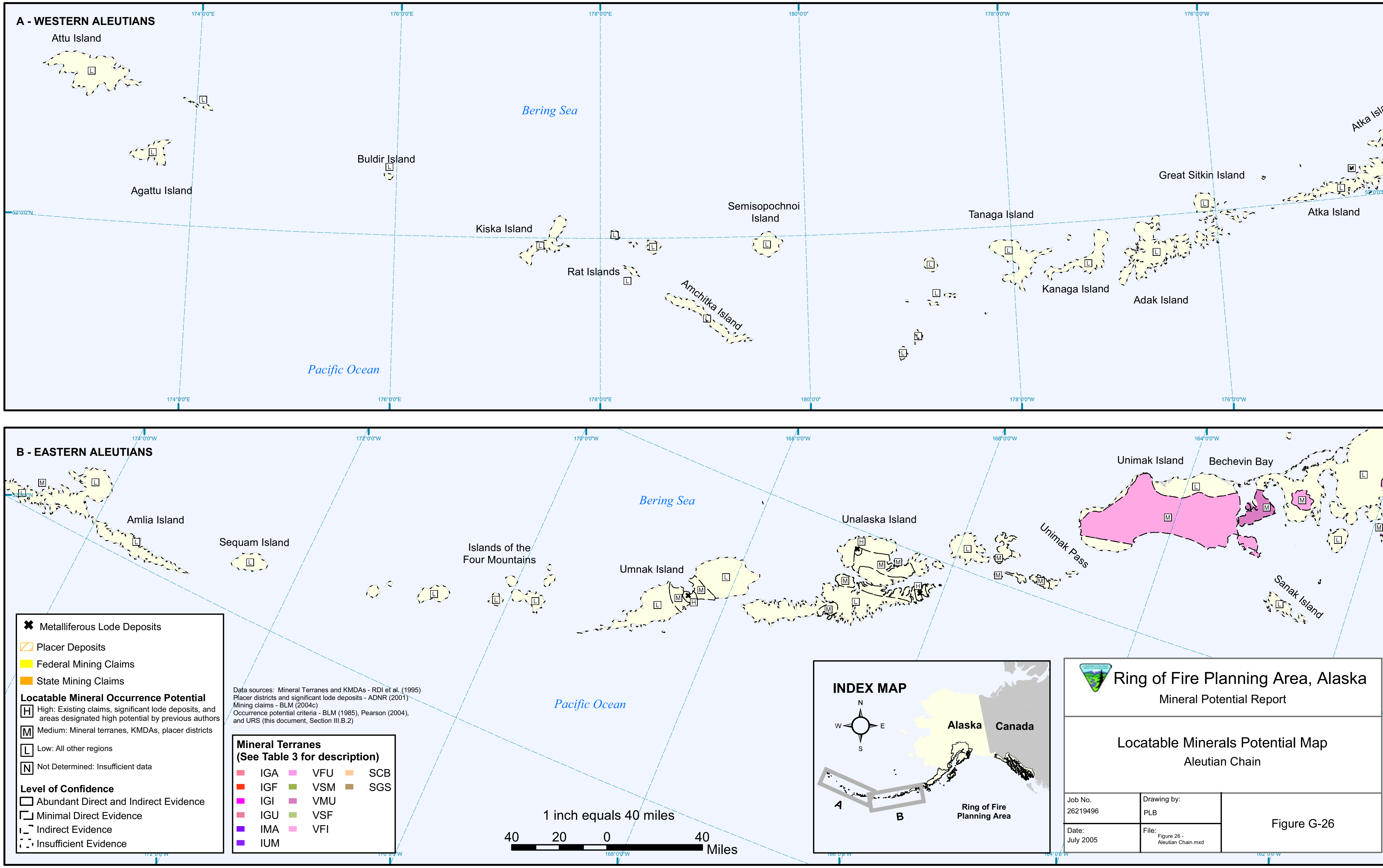

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Figure G-26, Locatable Minerals Potential Map, Aleutian Chain

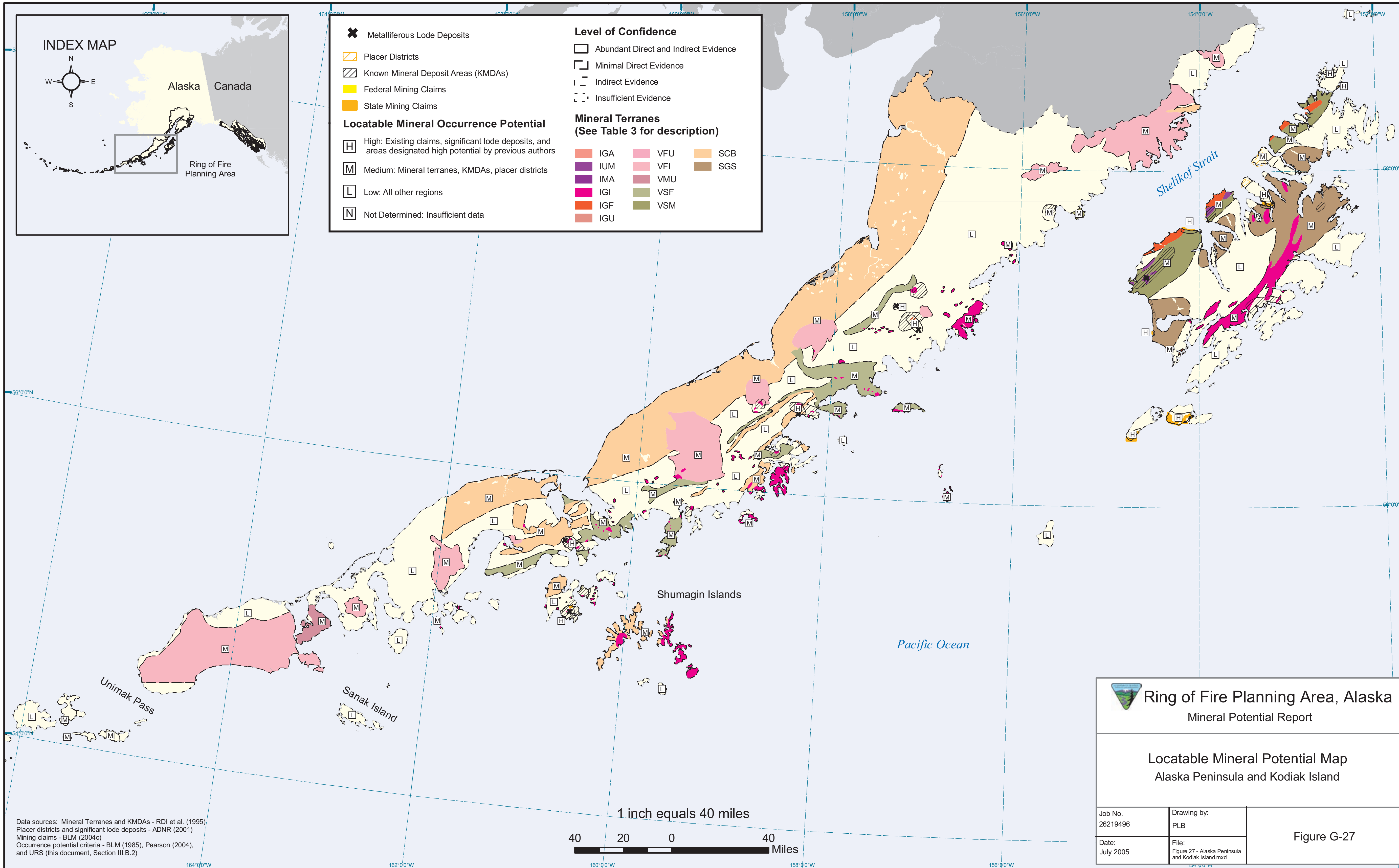

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Figure G-27, Locatable Mineral Potential Map, Alaska Peninsula and Kodiak Island

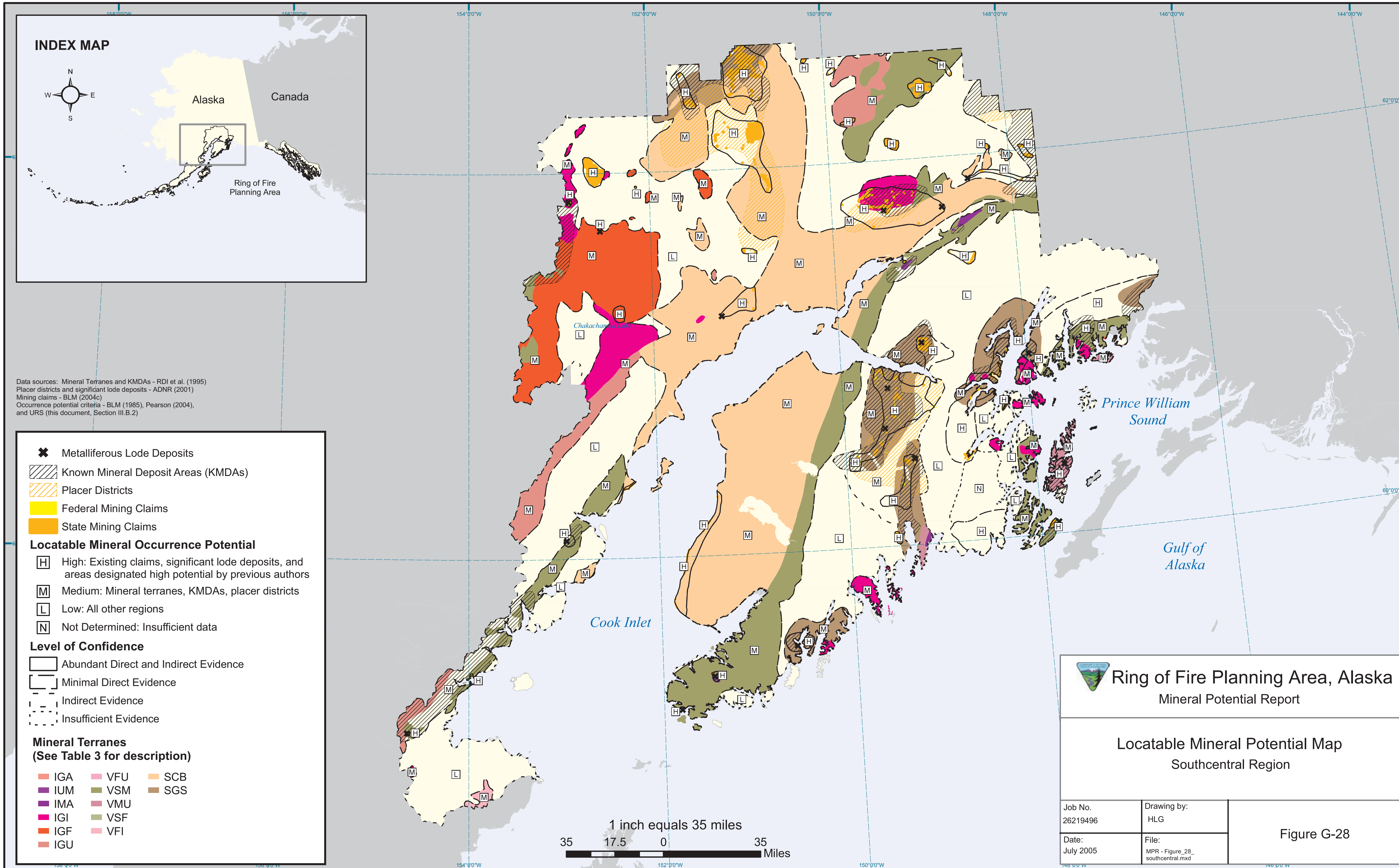

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Figure G-28, Locatable Mineral Potential Map, Southcentral Region

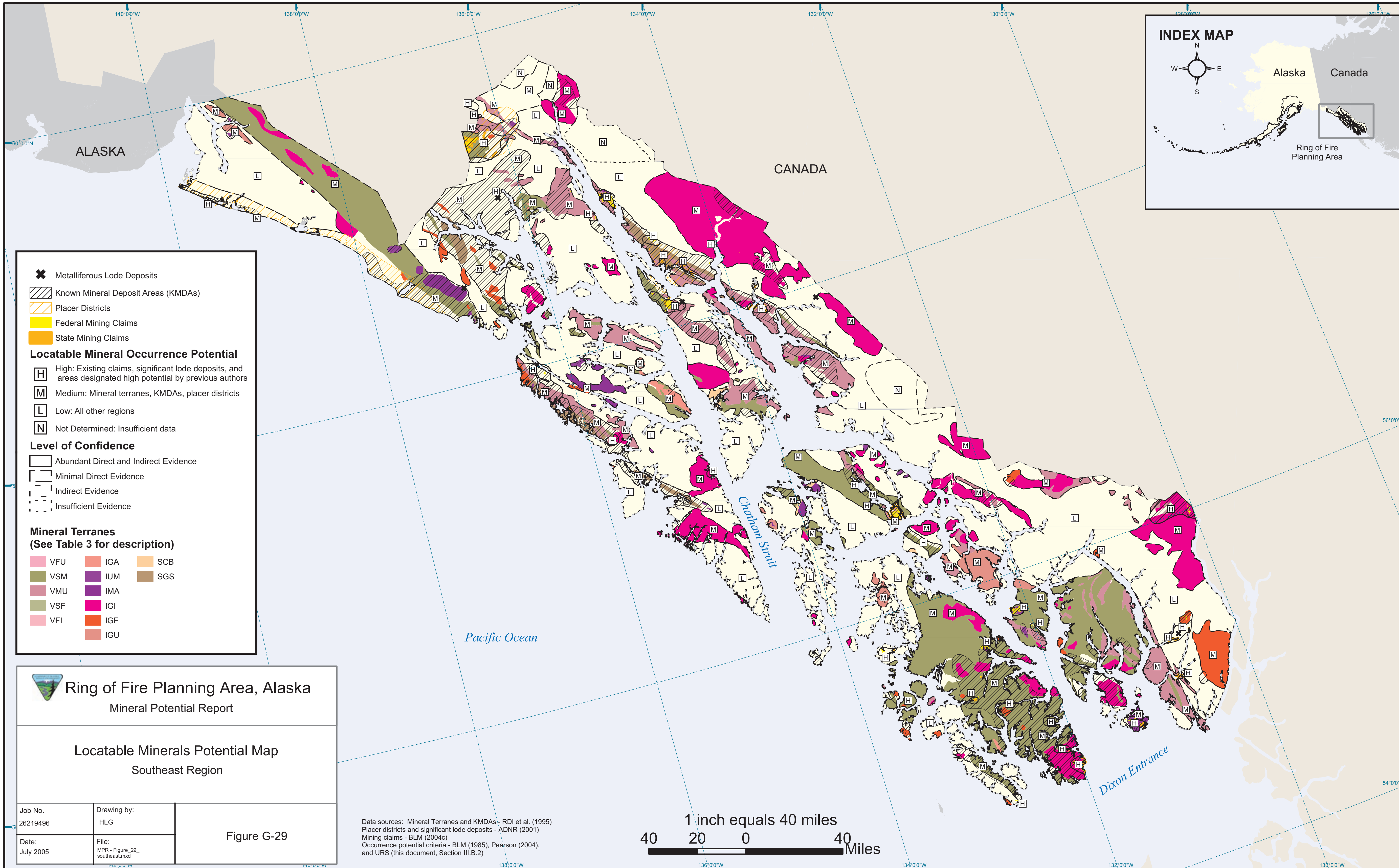

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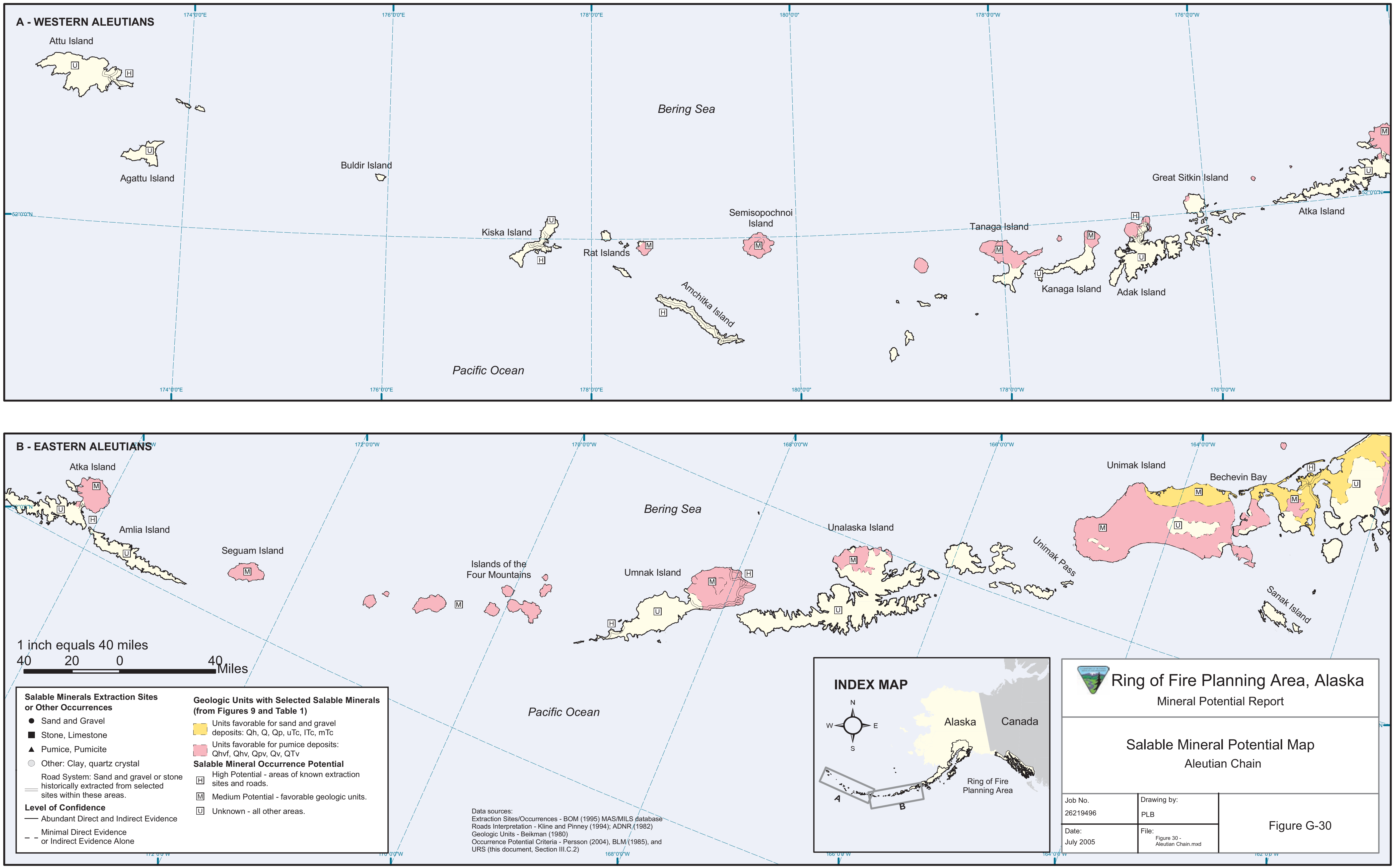
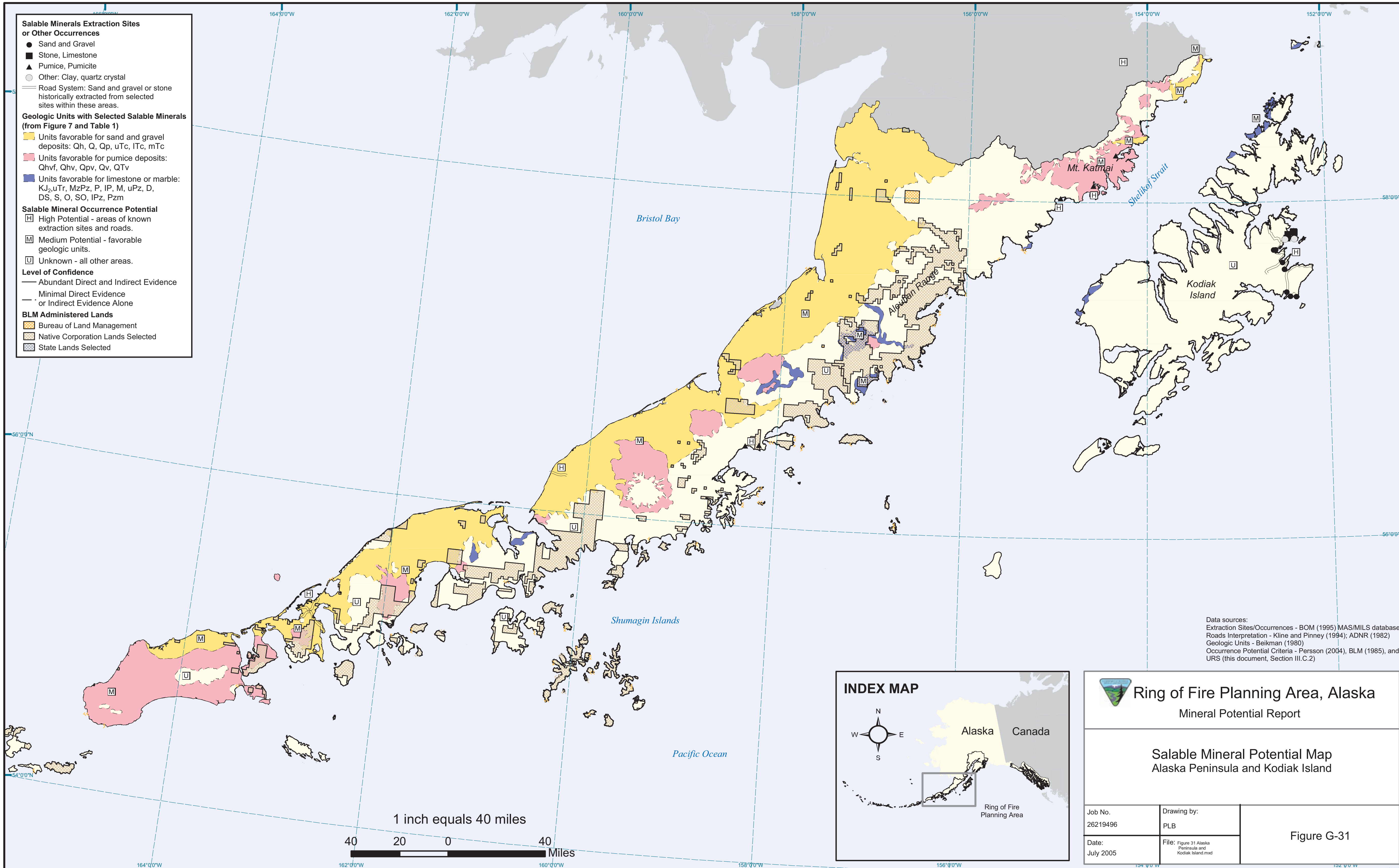
Figure G-29, Locatable Minerals Potential Map, Southeast Region



Bureau of Land Management

Figure G-30, Salable Mineral Potential Map, Aleutian Chain



Bureau of Land Management

Figure G-31, Salable Mineral Potential Map, Alaska Peninsula and Kodiak Island

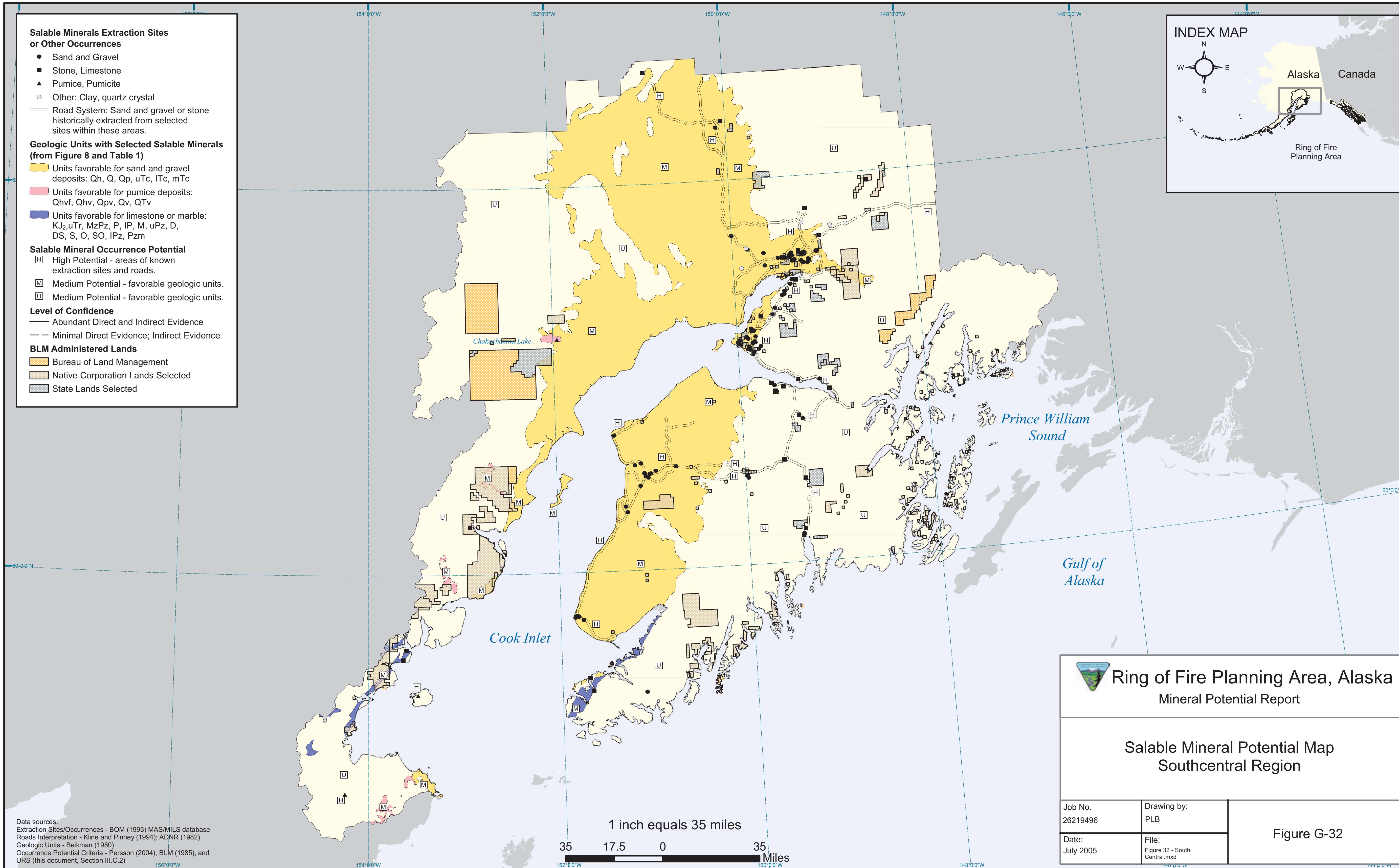


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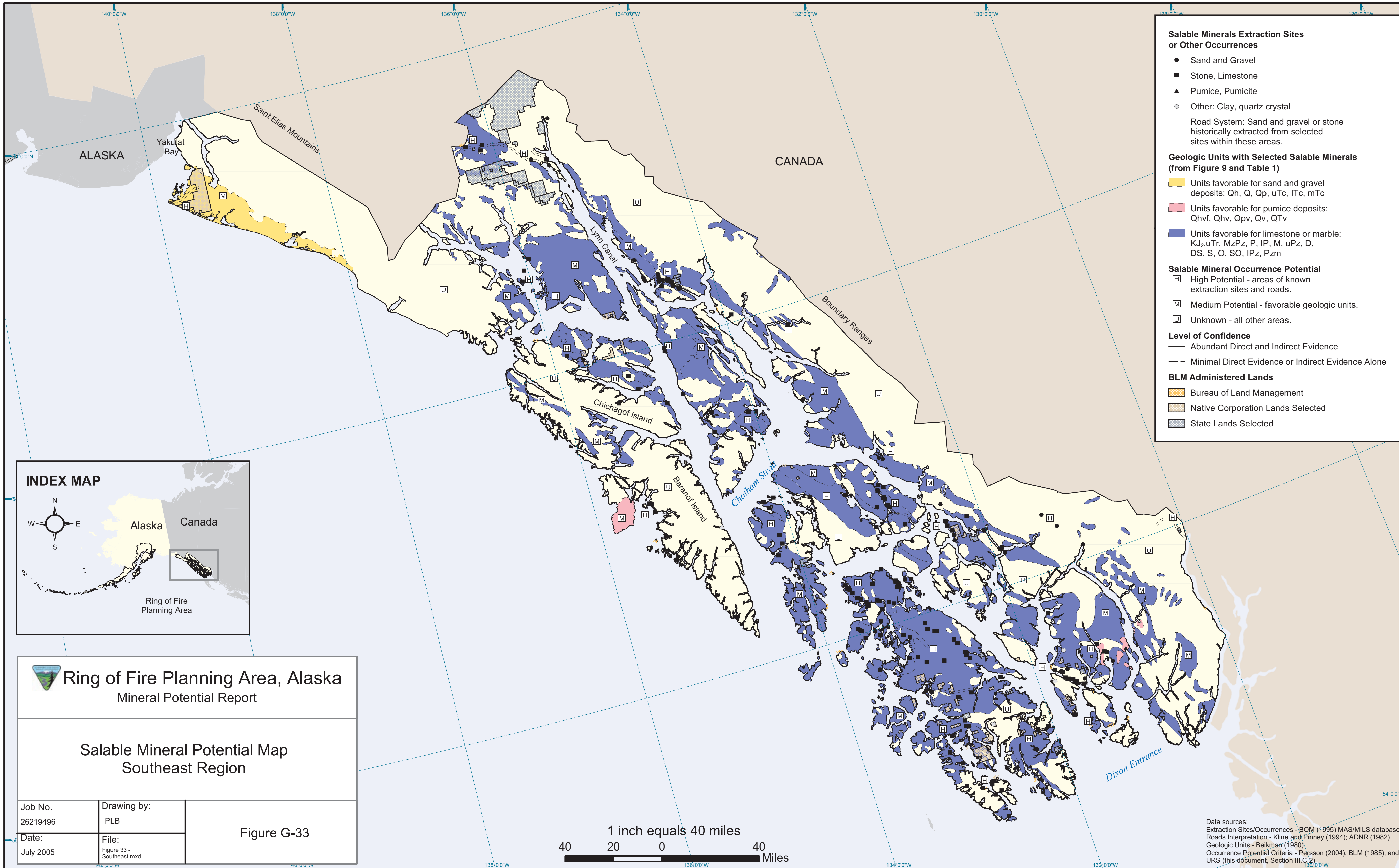
Figure G-32, Salable Mineral Potential Map, Southcentral Region



Bureau of Land Management

Figure G-33, Salable Mineral Potential Map, Southeast Region