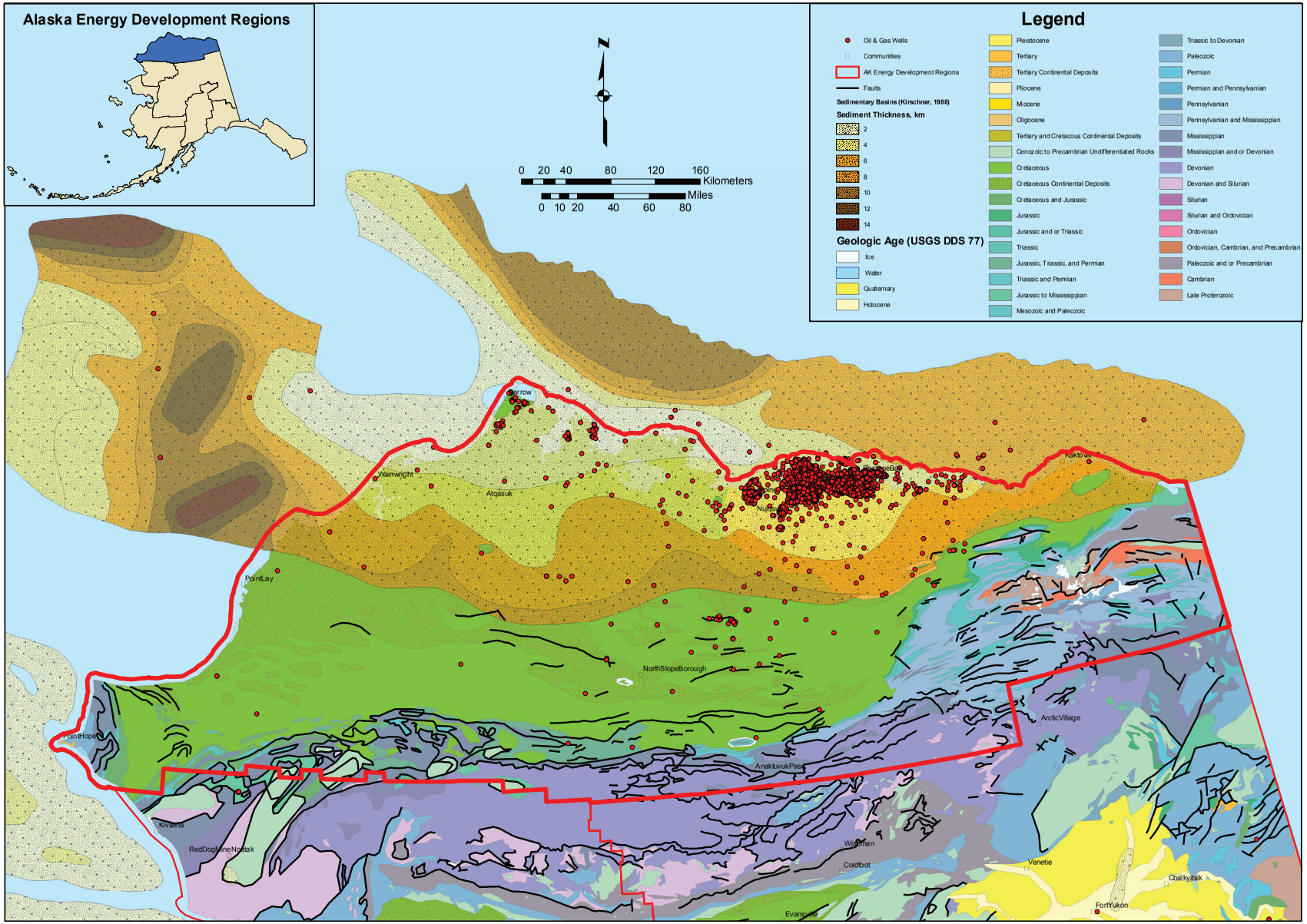
Geology of the North Slope Energy Region, Alaska



North Slope

SUMMARY OF FOSSIL FUEL AND GEOTHERMAL RESOURCE POTENTIAL IN THE NORTH SLOPE ENERGY REGION

by Marwan A. Wartes

INTRODUCTION

Purpose of this report

Economic growth and stability in Alaska's rural and urban areas hinges partially, if not primarily, on the availability of affordable and sustainable energy supplies. Recent price increases in oil and gas commodities have created severe economic hardship in many areas of the state that are dependent on diesel and heating oil as their primary source of energy. All sectors of Alaska's economy rely on affordable energy sources with limited price volatility, highlighting the need to diversify the energy portfolio by developing locally available and sustainable resources that are not tied to the global market. Unfortunately, all areas are not created equal in energy accessibility; the resources available for local exploitation vary widely across the state. It is critical that funding decisions for expensive programs to reduce the dependence on diesel for heat and electricity take into account information concerning the entire suite of natural resources that exist in a given area.

This report draws from existing information to provide community and state leaders an objective summary of our current knowledge concerning the potential of locally exploitable fossil fuel and geothermal energy resources in the North Slope energy region (fig. H1), one of 11 regions recognized by the Alaska Energy Authority in their Energy Plan (AEA, 2009). The potential geologically hosted energy resources considered here include exploitable coal, conventional and unconventional oil and gas, and geothermal resources. This report concludes with recommendations as to what additional data or strategies, if any, would provide the most leveraging in helping to develop new energy resources in the region.

Readers without geological training are encouraged to peruse the geologic summaries of fossil fuel resources and geothermal energy in chapter A. They provide an overview of the geologic elements that must be present in an area to economically develop coal, conventional oil and gas, unconventional oil and gas, and geothermal resources. These summaries will provide the necessary background to more fully understand the information presented in this chapter.

Geographic and geologic setting

The North Slope Energy Region includes the largest borough in the state and is extremely remote, even by Alaska standards. Eight villages are located in the region (sheet 1); in descending order of population these include Barrow, Point Hope, Wainwright, Nuiqsut, Kaktovik, Anaktuvuk Pass, Point Lay, and Atqasuk. Barrow is notably larger than other communities with a population of more than 4,000 (all others have between 220 and 700 residents). The region can be subdivided into three main physiographic provinces—the Brooks Range in the south, which transitions northward into rolling foothills and finally into the low-relief coastal plain.

The geologic evolution of northern Alaska is recorded by the development of two main stratigraphic packages (megasequences) that include sediments derived from

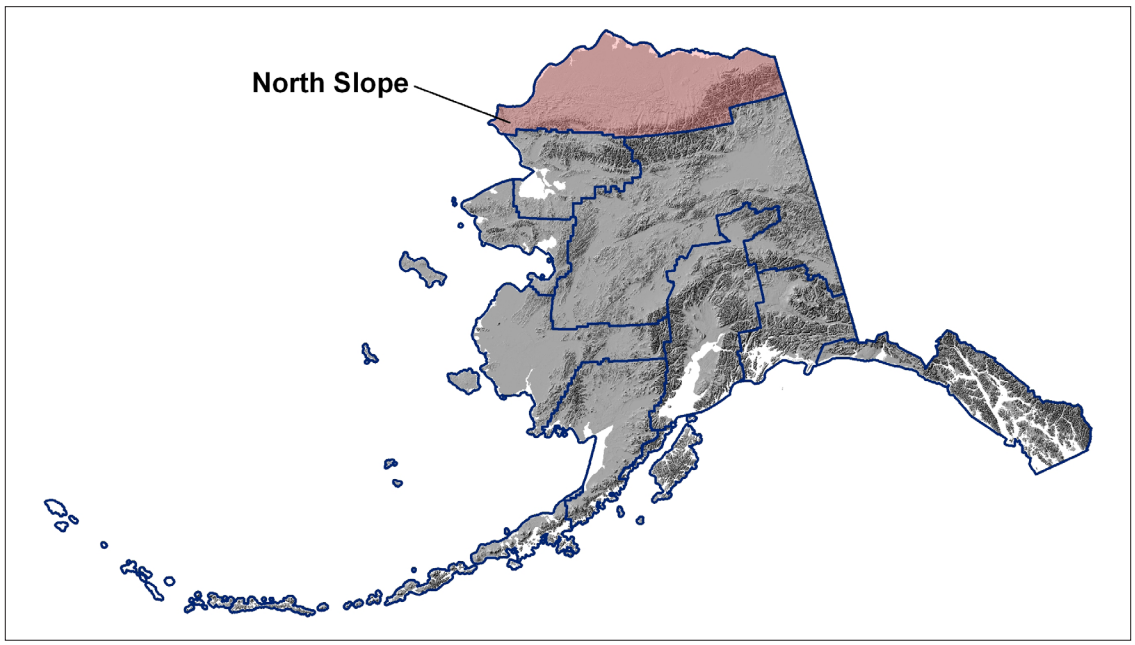


Figure H1. Location map of North Slope Energy Region.

distinctly different source areas (Moore and others, 1994). The older units include a wide variety of rock types that were generally derived from the north between about 360 and 120 million years ago and record marine deposition in progressively deeper water to the south (toward the present-day Brooks Range). The younger unit (~120 Ma to present) is dominated by sandstone and shale derived from the Brooks Range that progressively filled the large Colville basin from the southwest to the northeast. This change in sedimentation patterns, and the subsiding basin itself (a foreland basin developed in front of the growing mountain belt), formed in response to the tectonic collision that gave rise to the ancestral Brooks Range mountain belt.

The long geologic history of northern Alaska has endowed the region with an unusually rich collection of natural resources including coal, oil, and gas. To date, the North Slope has produced about 15 billion barrels of oil and represents one of the most prolific petroleum provinces in North America. Recent estimates by federal agencies suggest the region includes vast undiscovered resources (Houseknecht and Bird, 2006) and will likely continue to be the site of significant domestic exploration and production.

GEOLOGIC ENERGY RESOURCE POTENTIAL IN THE NORTH SLOPE ENERGY REGION

Mineable coal resource potential

As explained in the discussion of requirements for mineable coal (see Chapter A), several factors must be considered when evaluating whether a coal deposit is exploitable. The most important factors include the maturity of the coal (rank), seam thickness, amount of impurities (ash and sulfur content), amount of overburden, and the degree of structural complications (steeply dipping seam, folds, faults, etc.). The higher the coal rank, the higher its energy content by weight. Coal rank also influences the minimum seam thickness worth exploiting. Low ash and sulfur contents are highly desirable, as ash reduces the amount of combustible material in a seam and sulfur combines on combustion to form environmentally damaging compounds.

The Colville basin includes a staggering volume of coal in both Cretaceous and Cenozoic rocks, perhaps one-third of the known coal resource in all of the United States. Although estimates of the total reserves vary depending on the vintage of the assessment and the methodology used, studies have concluded the North Slope may contain as much as 3.2 trillion short tons of coal in the Cretaceous alone (Sable and Stricker, 1987) that is bituminous to subbituminous in rank (fig. H2). The Cretaceous coals of the western North Slope are most relevant to discussions of rural energy due to their superior quality, rank, and proximity to villages (fig. H2). Despite this vast resource, the history of coal mining in the region is limited to local use at select Eskimo villages and their hunting and fishing camps (Sanford and Pierce, 1946), seasonal mining along the Chukchi Sea coast to fuel whaling ships around the turn of the century, and brief mining ventures in the 1940s to support local needs (Flores and others, 2004).

The village of Wainwright overlies thick, coal-bearing strata of the Cretaceous Nanushuk Formation (Martin and Callahan, 1978), and near-surface coals are known from a number of nearby localities bordering Peard Bay and along the Kugrua and Kuk rivers (fig. H3; Sanford and Pierce, 1946). Several coal beds from 5 to 10 feet thick are recognized; Kaiser Engineers, Inc. (1977) deemed these coals to have high potential for surface mining based on characteristics such as rank (high-volatile subbituminous B and C), high coal quality (low ash and low sulfur), limited overburden, and shallow dip. The proximity of this resource to Wainwright (7–20 miles) suggests coal would be a viable alternative source of energy in this rural community.

Atqasuk similarly overlies coal-rich rock of the Cretaceous Nanushuk Formation, and surface exposures have been recognized in a number of locations along the Meade River (fig. H3). A modest mining effort was undertaken beginning in the mid 1940s to alleviate acute shortages in the community of Barrow approximately 60 miles to the north (Sanford and Pierce, 1946). The characteristics of these coals are very similar to the Wainwright occurrences noted above (5–6 feet thick, subbituminous, moderately low ash), suggesting extraction of this resource could be a reasonable source of local energy in Atqasuk.

Point Lay lies adjacent to a moderately well studied, high-quality coal province and has long been considered for possible commercial development. A number of private, government, and Native organizations have undertaken geological and exploratory drilling programs aimed at delineating this resource (Kaiser Engineers, Inc., 1977; Clough and others, 1995). The Corwin Mine, south of the community of Point Lay near Corwin Bluffs (fig. H4), was a producer of bituminous coal for steamships from 1880 to 1923 with about 2,600 short tons of coal reportedly mined (Plangraphics, 1983). Smith and Mertie (1930) indicate there were four mines on the bluff and two mines up the nearby creek. Most recently, the Arctic Slope Regional Corporation was working closely with BHP Billiton on a coal exploration program in the region to the east of Corwin Bluffs, although recent reports indicate they will not proceed further (R. Kirkham, Alaska Division of Mining, Land and Water, written commun.). This long-standing interest stems from the outstanding resource base in the region. The abundant coals are found in the Cretaceous Nanushuk Formation, similar to the above examples, although deeper burial to the south has given rise to higher maturity (high-volatile bituminous) and excellent heating values up to 13,000 Btu/lb (Clough and others, 1995). The exposures of coal nearest the village of Point Lay appear to be along the Kukpowruk and Kokolik rivers (fig. H4), where Eskimos historically mined small amounts for local use (Plangraphics, Inc., 1983). Coal has

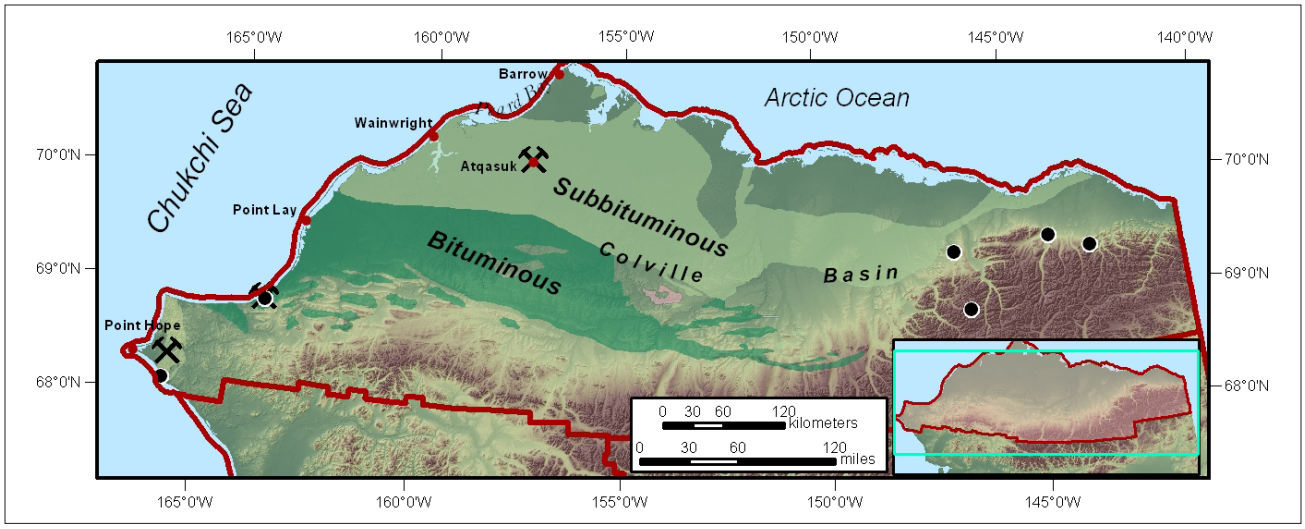


Figure H2. Location map of the North Slope Energy Region, showing extensive distribution of rocks bearing bituminous and subbituminous coal. Black dots indicate additional, more isolated reported coal occurrences.

been noted on the Kukpowruk River as close as 5 miles from the mouth, although the best candidate for development appears to be about 40 miles farther upstream, where a 15-foot-thick coal seam dips gently at river level (Toenges and Jolley, 1947). Less data exist for the Kukpuk River locality, although local Natives reported a 10-foot-thick seam approximately 15 miles east of the village (Toenges and Jolley, 1947). The quality and abundance of coal in the vicinity of Point Lay suggest it could reasonably supply energy for local use.

Point Hope is near some of the oldest coal beds known in Alaska, found in the early Mississippian age Kapaloak Formation (Tailleur, 1966). These coals crop out intermittently along the western side of the Lisburne Hills from Cape Thompson to Cape Dyer and along the Kukpuk River and various other drainages in the area (fig. H4) (Clough and others, 1995). Although Eskimos had reportedly long collected coal along the beaches for local use, explorers in the region first observed these coals 1831; the convenient location along the sea cliffs led to extensive use by passing whaling ships and revenue cutters in the late 1800s and early 1900s (Collier, 1906). These coals are reportedly low-sulfur, low-volatile bituminous to semi-anthracite and possess very high heating quality (11,457–14,731 Btu/lb) (Conwell and Triplehorn, 1976; Clough and others, 1995). Unlike the Cretaceous coals to the north, the rocks in the Lisburne Hills were significantly affected by the development of the Brooks Range and are complexly folded and faulted (Clough and others, 1995). This deformation complicates subsurface prediction and estimation of reserves, resulting in higher exploration and mining risk. Nevertheless, the proximity of this resource to Point Hope and the high heating quality of the coal suggest it could potentially be utilized to satisfy local energy needs.

Conventional oil and gas resource potential

As explained in the discussion of requirements for exploitable oil and gas resources (see Chapter A), functioning petroleum systems occur in thick sedimentary basins, and consist of three basic elements: Effective source rocks, reservoirs, and traps. Each of the elements must be in existence and connected at the time hydrocarbons are generated. This section considers each of these necessary elements of petroleum systems in turn to evaluate whether conventional oil and gas resources may exist as an exploitable resource near any of the communities in the North Slope Energy Region.

Overview of sedimentary basins. Sheet 2 illustrates the broad distribution of Cretaceous and Tertiary sediments of the Colville basin (after Kirschner, 1988), which spans the North Slope region and represents the largest onshore sedimentary basin in Alaska. Beneath these Brooks-Range-derived sediments is a thick package of Mississippian through Cretaceous rocks derived from an enigmatic source to the north (Moore and others, 1994). The most intensive exploratory drilling (sheet 2) highlights the most prospective portion of the basin along the Barrow arch, a relative subsurface high along the north flank of the basin where source and reservoir rocks were not buried too deeply and subtle uplift generated favorable trapping relationships (Houseknecht and Bird, 2006).

Source rocks. Alaska's North Slope is endowed with several excellent oil and gas source rocks in the Triassic, Jurassic, and Cretaceous (Magoon and Claypool, 1985) and this parameter is generally not a limiting factor in most exploration targets. The total depth of burial is often a more important issue, particularly when considering regions south of the Barrow arch, such as near the community of Point Lay, where many of the source rocks are very deeply

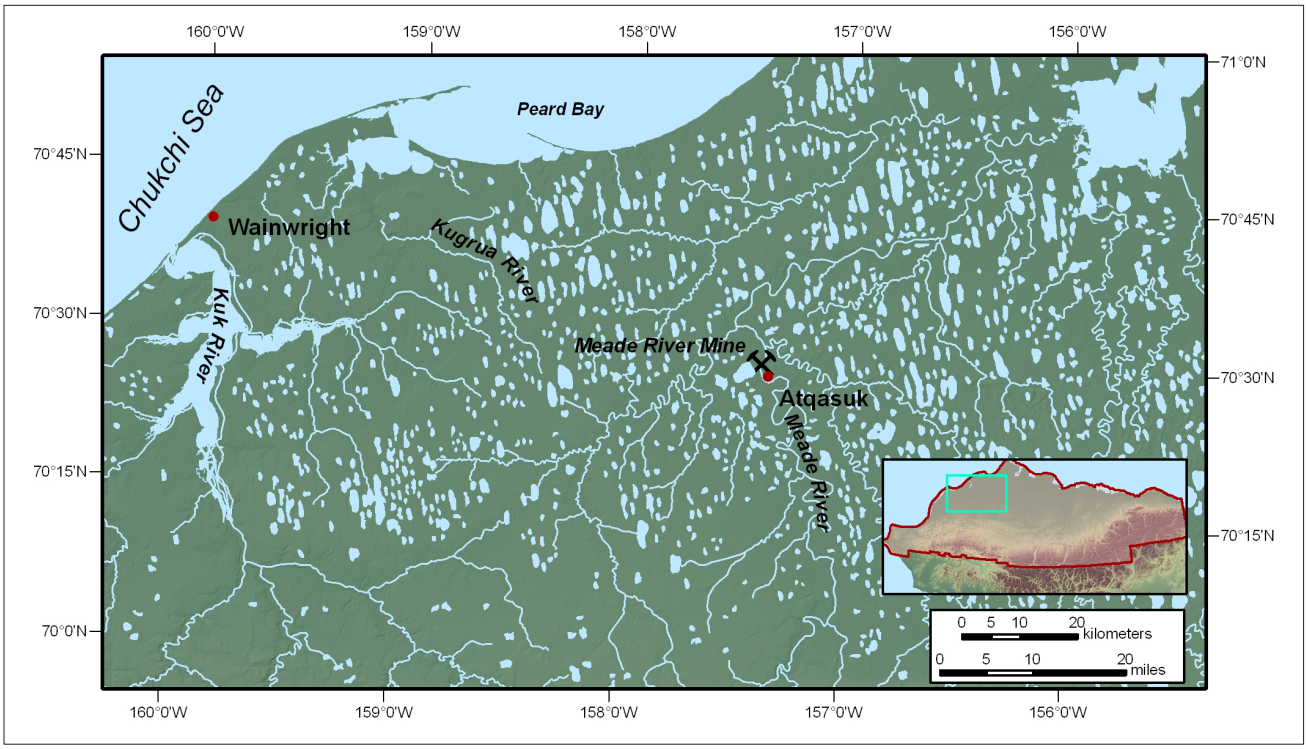


Figure H3. Map marking coal localities near Wainright, and the Meade River Mine near the village of Atqasuk. The pick-axe symbol marks the location of the historic coal mine.

buried beneath sediments shed from erosion of the Brooks Range and are likely no longer oil prone. Gas shows in a number of exploration wells support the contention that the central and western North Slope contains a number of gas-prone source rock horizons, although their quality decreases west of the Meade arch, a subtle subsurface high (Magoon and Bird, 1988). This north–south-trending arch runs east of Atqasuk and two wells indicate the region possesses an unusually high geothermal gradient (Claypool and Magoon, 1988). The Meade No. 1 well (MAP) is recognized as a noncommercial gas discovery with poorly constrained reserves of approximately 20 bcf (Kumar and others, 2002). Although this well is considerably south of Atqasuk, it demonstrates the viability of a gas charge in the general region. More salient and encouraging data come from several methane gas seeps observed in small lakes near the community; government and academic researchers are currently evaluating the source of this gas, which emits nearly 140 m^3/day (Ruppel and others, 2009). Less data are available for the Kaktovik area due to restrictions on exploration within the Arctic National Wildlife Refuge and the proprietary nature of the one well drilled near the community. Nevertheless, the presence of nearby oil seeps and regional assessments suggest the settlement likely overlies excellent Cretaceous oil and gas source rocks noted in the producing fields to the west (Bird, 1999). The communities of Point Hope and Anaktuvuk Pass are part of the Brooks Range Mountain belt where source rocks are generally mature to overmature or have already been uplifted and eroded away (Johnsson and others, 1996).

Reservoir rocks. The most prospective reservoir unit of interest for Point Lay, Wainwright, and Atqasuk is the Cretaceous Nanushuk Formation. Regional porosity and permeability data (Bartsch-Winkler and Huffman, 1988) indicate reservoir quality in this unit is more favorable in the coastal plain than in the foothills, although reported values are locally adequate for gas even near Point Lay. Results from a recent shallow coalbed methane well drilled at Wainwright indicate that thick sandstones deposited in ancient river channels possess good reservoir quality with measured porosity locally exceeding 25 percent (K. Helmold, written commun.). In the Kaktovik area, the most prospective reservoir rocks are likely within Cenozoic strata of the Canning and Sagavanirktok Formations, both of which are locally oil-stained at the surface or tested significant hydrocarbons in regional drilling (Bird, 1999). Conventional reservoirs beneath Point Hope and Anaktuvuk Pass are likely very limited, due to deep burial, thorough cementation, and complex deformation during creation of the Brooks Range.

Traps. A number of stratigraphic traps might occur in the Nanushuk Formation where isolated sandstone bodies are encased in impermeable mudstone (Houseknecht, 2003). However, in the vicinity of Wainwright, Atqasuk, and Point Lay, these settings are likely very difficult to predict or document without the benefit of high-resolution three-

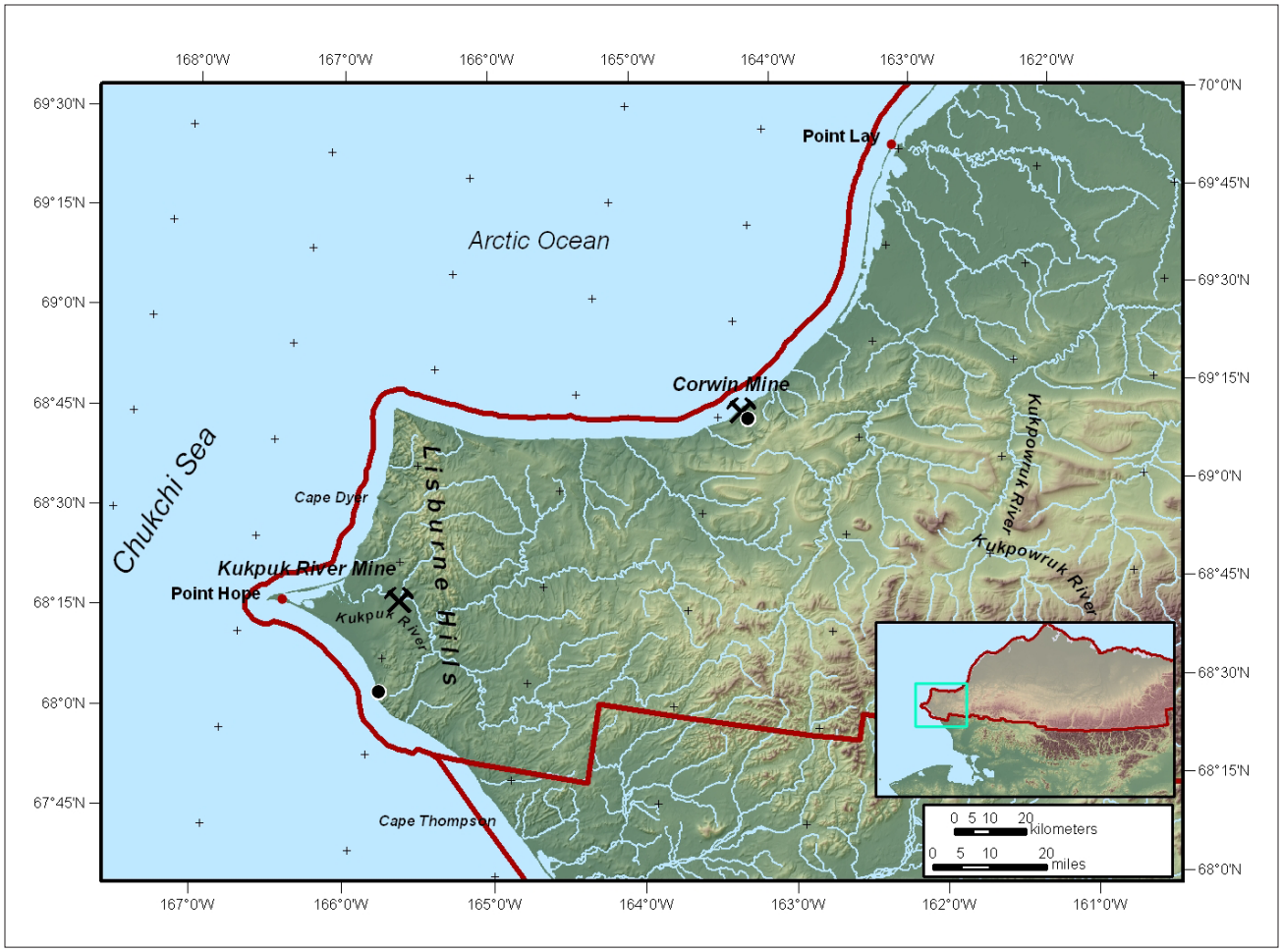


Figure H4. Map of the westernmost Brooks Range and Point Hope and Point Lay areas, showing select geographic references noted in the text. The pick-axe symbol indicates the location of the historic Kukpuk River and Corwin coal mine; black dots mark additional reported coal occurrences.

dimensional (3-D) seismic data. Anticlinal structural traps are also possible in the Point Lay area, although significant risk exists regarding the timing of folding relative to hydrocarbon generation (Potter and Moore, 2003). Assessment of Native lands near Kaktovik suggests a number of possible trapping configurations including stratigraphic traps involving marine and nonmarine Cenozoic sediments (Houseknecht and Schenk, 1998), and structural traps associated with both contractional and extensional folds and faults (Perry and others, 1998). The intense and complex structural deformation associated with the Brooks Range presents a significant challenge to exploration in the Point Hope and Anaktuvuk areas and any structural traps are likely to be small gas accumulations.

Summary of conventional oil and gas resource potential. Much of the North Slope Energy Region north of the Brooks Range is underlain by several rich source rocks that have contributed hydrocarbons to several functioning petroleum systems. These source rocks tend to be more deeply buried in the west-central and southwestern North Slope and, consequently, are likely gas-prone. Communities near or close to the Barrow arch in the north-central and western North Slope may be favorably situated for discovery of nearby conventional gas accumulations similar to accumulations near Barrow. Less data are available for the Kaktovik area, given restrictions on exploration in the Arctic National Wildlife Refuge. The presence of nearby oil seeps and likely excellent oil and gas source rocks at depth suggests this area may be located near oil and gas accumulations that could be utilized by Kaktovik residents.

Unconventional oil and gas resource potential

Coalbed methane. The Cretaceous Nanushuk Formation of the North Slope Energy Region possesses abundant bituminous and subbituminous coal (fig. H2), which is the default required ingredient for this resource. Recent assessments suggest these coals in the central and western North Slope contain an estimated mean of 15 tcf of

undiscovered coalbed gas (Roberts and others, 2008). This extremely large number reflects the broad, laterally continuous distribution of thick coal beds of the appropriate rank and burial depth as well as documented gas shows associated with coals penetrated in regional exploration wells (Roberts, 2008). Wainwright, Atqasuk, and Point Lay all lie within this prospective "fairway" for coalbed methane accumulations (Tyler and others, 2000; Roberts, 2008). In fact, the village of Wainwright was selected as a test site for coalbed methane shallow coring in the Arctic, resulting in the successful drilling to a depth of 1,613 feet and documentation of more than 20 total feet of methane-bearing coals beneath the permafrost (Clark and others, 2007; Clark and others, 2010). Preliminary data indicate that the coals are fully saturated with gas (average of 140 asf gas/ton coal) and conservative estimates indicate this resource could serve village energy needs for 10 to 100 years, depending on the number of seams that are tapped and the total area of extraction (Petroleum News, 2007). Testing is continuing from additional monitoring and delineation wells, although a number of economic and engineering hurdles remain. Ongoing studies of the gas seeps near Atqasuk may help establish whether or not the methane is derived from shallow coalbed methane sources. Regardless, the village has good potential for this resource. Similarly, the abundant coal beneath Point Lay has modest coalbed methane potential, possibly assisted by fold-related traps (Roberts, 2008). Although high-quality, mature coals are recognized in the vicinity of Point Hope, the degree of structural disruption suggests coalbed methane accumulations are unlikely (Smith, 1995).

Tight gas sands. The Colville basin contains the two most important features for tight gas accumulations: Abundant gas-prone source rocks and thick, low-permeability reservoir units. The potential for this resource is best developed in the Brooks Range foothills, where geologically rapid and deep burial has matured probable Jurassic and Cretaceous source rocks beneath and adjacent to deep-water sandstones of the Torok Formation. Evidence suggesting tight gas resources may be present largely comes from exploration wells, many of which indicate gas charge, overpressure, and undercompaction within potential tight gas sandstone units (Nelson and others, 2006). Point Lay, Atqasuk, and Wainwright each have some potential for tight gas, although Point Lay is the best situated of the three due to its location above the thicker, deeper parts of the Colville basin.

Shale gas. The presence of organic-rich, gas-prone shales within the Brooks Range and Colville basin suggest there is significant potential for shale gas in northern Alaska. The only exploration for this resource to date is in the western Brooks Range (Northwest Arctic region), where organic-rich Mississippian-age mudstones are recognized to contain gas trapped within a self-sourcing system. Although preliminary results from shale gas exploration around Red Dog have been promising, it is unclear how extensive this resource might be. Similar rocks are known in the Lisburne Hills east of Point Hope, but complex folding and faulting indicate exploration would be a very high risk. As part of the Colville basin, Point Lay, Wainwright, Atqasuk, and Kaktovik all overlie several possible shale gas targets, although too little is known to reliably assess their potential.

Gas hydrates. Gas hydrates are found in a narrow range of modern environments and only occur within specific temperature and pressure conditions. Presently, the North Slope appears to be the only onshore region in Alaska with sufficient permafrost to preserve significant methane hydrate. Recent evaluations point to a vast amount of gas hydrate in the region; the mean estimate of more than 85 tcf exceeds that of all other sources of conventional and unconventional gas (Collet and others, 2008). Recovering this gas presents a number engineering and development challenges, although ongoing research in northern Alaska and Canada suggests that gas can be produced with existing technology (Collet, 2009). Wainwright and Kaktovik are in the critical gas hydrate stability zone (Atqasuk may also be, although the elevated geothermal gradient associated with the Meade arch limits the thickness of critical permafrost). As our understanding of this resource improves, this gas may eventually prove to be viable source of local energy.

Geothermal resource potential

There are only two recognized thermal springs in the North Slope region, both in the northeastern Brooks Range (sheet 2). The temperatures reported for these springs are relatively low (84°F and 120°F [29°C and 49°C]) and flow rates have not been measured (Motyka and others, 1983). Neither of these is close enough to Kaktovik to be an exploitable energy resource.

RECOMMENDATIONS

Conventional oil and gas resource recommendations

Alaska's North Slope remains the most prospective onshore conventional hydrocarbon province remaining in North America. Despite this recognized potential, large parts of the region remain underexplored due to the remoteness and hostile climate that results in unusually high exploration and development costs. In this context, the economics surrounding pursuing conventional oil and gas for rural energy alone are extremely challenging. Rural energy success stories such as Barrow and Nuiqsut depended originally upon third-party investment in commercial-led exploration. Any future exploration (or pipelines) in the vicinity of other villages in the region should similarly attempt to secure agreements for local distribution. The vigorous gas seeps near Atqasuk deserve further research to determine the source and nature of the methane (biogenic vs. thermogenic). It remains possible these seeps are leaking from an exploitable

conventional accumulation that could be harnessed for local use. If so, engineering and economic studies would also be critical in assessing whether this potential resource is competitive with present energy sources.

Coal resource recommendations

The western part of the North Slope Energy Region contains abundant subbituminous and bituminous coal reserves that might benefit the following communities: Point Hope, Point Lay, Wainwright, and Atqasuk (fig H2). Of these communities, our understanding of the high-quality coal resources near Point Lay is the most mature due to recent exploration efforts. Local energy needs could be supplied by these coals, particularly if a local use agreement is planned into future commercial-scale development. If commercial development proceeded, there is a sufficient resource base to support a power plant feeding other communities along the western Arctic coast. The modest historic mining near Point Hope, Wainwright, and Atqasuk demonstrates the feasibility of further exploitation. In these three communities, a logical next step would be improved geologic characterization, particularly shallow drilling near Wainwright and Atqasuk, where surface exposures are limited in the coastal plain. Exploration risk associated with mining the coals in the Point Hope area could be reduced through the execution of detailed geologic mapping and stratigraphic work to characterize the local and regional structural relationships. Remaining villages in the region are either not in need of additional local energy sources (Barrow and Nuiqsut), or are not situated near any mineable coals (Kaktovik and Anaktuvuk Pass). It should be noted that the development of any of these coal resources would need to overcome nontrivial difficulties associated with the extreme climate, including plans for reclamation in sensitive permafrost environments. Additionally, the National Petroleum Reserve Alaska is closed to mineral development, which includes coal mining. Any coal mining in the NPRA would require a change in the regulations for mineral development near the affected villages.

Unconventional oil and gas resource recommendations

Coalbed methane. The abundance of subbituminous to bituminous coal and gas-prone source rocks near the communities of Wainwright, Atqasuk, and Point Lay suggest the overall potential for coalbed methane is fair to good. However, coalbed methane production techniques are unproven in rural Arctic Alaska and it remains unclear if any of these could be developed in a cost-effective manner. The results of coalbed methane test drilling at Wainwright are encouraging, although a number of engineering challenges remain, including effective water disposal and production in permafrost settings. Nevertheless, depending on the results of ongoing studies and sustained investment in the project, this unconventional resource may ultimately provide Wainwright with local energy and serve as a critical benchmark for future exploration elsewhere in rural Alaska. The nature and source of gas seeps in the Atqasuk area remain poorly known and deserve further study. The results of ongoing studies by academic and government researchers should provide preliminary constraints and assist in evaluations of whether or not this gas might represent a viable source of energy for the community.

Tight gas sands and shale gas. The ultimate potential of tight gas sands and shale gas in rural Alaska remains unknown; given the abundance of gas-prone source rocks across the North Slope, future assessment of these resources is warranted, perhaps including detailed analysis of existing well data and new sample analyses.

Gas hydrates. Although the estimated volume of gas hydrate resource on the North Slope is enormous, long-term production is unproven and its application in rural settings must await further government- and industry-led research.

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