NORTHERN ALASKA PROVINCE (001)

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INTRODUCTION

The Northern Alaska Province has a common boundary with the Central Alaska province that approximates the southern margin of the Brooks Range (Dolton and others, 1993). The Northern Alaska Province extends 670 mi from the Chukchi Sea on the west to the Alaska-Yukon Territory border on the east and, at its widest, 300 mi from the Beaufort Sea on the north to the southern edge of the Brooks Range. Total province area of about 130,00 sq mi includes the Brooks Range, Foothills, and Coastal Plain Physiographic Provinces and extends offshore to the national 3-mile territorial limit.

A wide variety of potential hydrocarbon reservoirs occur in the Province. They include Proterozoic and Paleozoic carbonate rocks, and sandstones of Mississippian to Tertiary age. These rocks are found in a number of tectonic settings that include stable platform, foreland basin, fold and thrust belt, and rifted margin. Most petroleum prospective rocks in the province are Mississippian and younger and overlie metamorphosed basement rocks. Proterozoic and early Paleozoic carbonate rocks may, under favorable circumstances, also locally be petroleum bearing. Rich source rocks for oil range in age from Triassic to Cretaceous. Gas-prone source rocks are also abundant and range from Mississippian to Tertiary in age. More than thirty oil and gas accumulations are known in the province, but only five are producing. Oil is produced from Mississippian, Triassic, and Cretaceous sandstone and Mississippian and Pennsylvanian carbonate reservoirs. Gas production is not commercially viable in this province, primarily for lack of a transportation system, but some gas is used locally.

Eleven plays in the Northern Alaska Province are defined for this assessment. The seven confirmed plays are: Topset (0101), Turbidite (0102), Barrow Arch Beaufortian (0103), Barrow Arch Ellesmerian (0104), Ellesmerian-Beaufortian Clastics (0105), Fold Belt (0109), and Eastern Thrust Belt (0111). The four hypothetical plays are: Lisburne (0106), Lisburne Unconformity (0107), Endicott (0108), and Western Thrust Belt (0110). Oil production is limited to the Topset (0101), Turbidite (0102), Barrow Arch Beaufortian (0103), and Barrow Arch Ellesmerian (0104) plays. Most plays lie north of the Brooks Range, beneath the North Slope and State offshore. Two plays extend as far south as the northern part of the Brooks Range, but the oil and gas potential even in these plays is believed to be greatest north of the range. This is because the thermal history is such that preservation of oil and gas can reasonably be discounted. Approximately 65 percent of the province or 84,000 sq mi, is encompassed by the plays.

The earliest drilling operations in the Northern Alaska Province occurred in 1944 when the U.S. Navy began the exploration of Naval Petroleum Reserve No. 4 (now known as the NPRA, National Petroleum Reserve in Alaska) and nearby areas. During this 10-year exploration program, three oil fields and five

gas fields were discovered. Although all were noncommercial, most of them exceed the minimum threshold size of one million barrels of oil-equivalent (1 MMBOE) used in this assessment. Industry drilling operations began in this province in 1963. As of the end of 1993, the total number of exploratory wells (including core holes) drilled is about 300, an average of less than one well per 400 sq mi in the province as a whole. The largest commercial accumulation, Prudhoe Bay (12 billion barrels of oil, or 12 BBO, ultimate recovery according to State of Alaska, 1993) was discovered in 1968. Since then, more than 20 additional discoveries have been made, the most recent being in 1990. Because of the economics of oil production in the province, only five fields are producing. Production from the province peaked at 2.0 million barrels per day (2.0 MMBOPD) in 1988 and since then has declined to 1.6 MMBOPD in 1993. By the end of 1993, cumulative production stood at about 9.9 BBO and condensate, and reserves were estimated at about 6.1 BBO and 26.5 TCFG (State of Alaska, 1994).

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CONVENTIONAL PLAYS

0101. TOPSET PLAY

This confirmed conventional oil and gas play consists of stratigraphic and structural (fault) traps in sedimentary reservoirs of Cretaceous and Tertiary age. It includes those rocks represented on seismic records in the topset position of a clinoform sequence. The rocks consist of marine and nonmarine deltaic sandstone, siltstone, shale, conglomerate, and coal assigned to the Lower, Middle and Upper Brookian sequences encompassing the Nanushuk Group and Sagavanirktok Formations and the uppermost parts of the Torok and Canning Formations. These are the youngest petroleum-prospective rocks in the province. Their total maximum thickness, about 9,000 ft, is also the maximum drilling depth in the play area. The play is limited to the area of relatively flat-lying strata north of the fold and thrust belt that generally corresponds to the Coastal Plain Physiographic Province. The play covers an area of about 26,400 sq mi.

Reservoirs: Potential reservoir rocks consist of sandstone and conglomerate and may constitute as much as half of the total thickness of the play interval, even though individual beds thicknesses seldom exceed 50 ft. Stacked shoreline sandstones may be present in areas where basin subsidence equaled sedimentation for prolonged periods of time; this is manifest on seismic records as an abrupt stratigraphic rise in the base of the topset reflectors. Fair to good reservoir continuity is expected parallel to depositional strike (northwesterly), but marked changes may occur over short distances perpendicular to strike. Porosity is expected to increase, from 10 to 20 percent in the western part of the play to better than 20 percent in the eastern part.

Source rocks: Within the play interval, deltaic shales and mudstones are thermally immature and probably gas-prone. Directly beneath the play interval, marine foreset and bottomset shales (Torok and Canning Formations) are poor to fair oil source rocks that are immature to marginally mature in the play area. Deeper in the section, rich oil source rocks of the Hue Shale, an underlying informally designated pebble-shale unit, the Kingak Shale, and the Shublik Formation are mature beneath most of the play area. Multiple oil sources for the play are indicated by the presence of both the high-sulphur Barrow-Prudhoe-type oil and the low-sulphur Simpson-Umiat-type oil.

Timing and migration: Basin reconstructions and burial-history calculations show that source rocks reached maturity as a result of burial by rocks of this play. Maturity was achieved in the Late Cretaceous in the western part of the play and in the late Tertiary in the easternmost part. Migration pathways along faults and along clinoform bedding are indicated. In the Prudhoe Bay and Kuparuk River area, vertical migration along the Eileen Fault Zone is postulated for the West Sak and Ugnu accumulations whereas in the northeastern part of the NPRA, lateral migration west or southwest, upward along clinoforms is postulated for the Fish Creek and Simpson oil fields.

Traps: Postulated traps are mostly stratigraphic and are related to facies changes or by cut and fill features; structural traps are formed by small-displacement normal faults. The faults and interbedded shales are expected to provide only fair to poor seals, therefore hydrocarbon accumulations will probably consist of oil rather than gas. However, large volumes of natural gas (37-44 TCF) in the form of gas hydrates are reported to occur in these rocks in the Prudhoe Bay and Kuparuk River areas (Collett, 1993). Neither hydrate gas nor hydrate-associated free gas are considered in the assessment of this play.

Exploration Status: The single-well Fish Creek oil accumulation was discovered in 1949. This accumulation of Prudhoe-type oil of unknown size occurs in Nanushuk Group sandstone at a depth of about 2,900 ft. The Simpson oil field, having a low-sulphur Simpson-Umiat-type oil, was discovered in 1950 by drilling on surface oil seeps. An estimated 12 MMBO occurs in Nanushuk sandstones at a depth of 100 m or less, trapped against the side of a shale-filled submarine canyon, Simpson canyon. The Schrader Bluff pool of the Milne Point field, discovered in 1969, is the only productive oil field in the play. The Schrader Bluff pool is actually the deepest and most down-dip portion of the giant multi-billion barrel West Sak heavy oil accumulation. This portion of the West Sak is reported to consist of five separate fault-bounded accumulations, each with its own oil-water contact and pressure regime (Thomas and others, 1993, p. A32). Because of the pool's marginal economic value, oil production did not begin here until 1990. At year-end 1993, about 2.9 MMBO have been produced and reserves (combined with the deeper Kuparuk River pool--a part of the Barrow Arch Beaufortian play-0103)--are reported at 81 MMBO (State of Alaska, 1994). The West Sak and overlying Ugnu heavy oil and tar accumulations were discovered in 1969 just west of the Prudhoe Bay field; although not currently productive, the State carries reserves for the West Sak accumulation of 149 MMBO (State of Alaska, 1994). Thousands of wells (exploratory and development) have penetrated the rocks of the play, but relatively few have been drilled for prospects within this play area. A total of about 250 exploratory wells have penetrated this play.

Resource potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered good.

0102. TURBIDITE PLAY

This play consists of stratigraphically trapped deep-marine sandstone reservoirs of Cretaceous and Tertiary age and includes those rocks represented by the foreset and bottomset seismic reflectors in the clinoform sequence north of the fold and thrust belt. The play includes Lower, Middle, and Upper Brookian turbidites assigned to the Torok and Canning Formations. Rock types in this play are predominantly marine shale and siltstone with minor amounts of sandstone. The maximum play interval thickness is about 6,500 ft, and drilling depths range from near the surface in the Barrow area to a maximum depth of about 18,000 ft. Total area of the play is 30,500 sq mi.

Reservoirs: Reservoir rocks may occur anywhere within the play interval, but they are most frequently encountered in the lower half of the play interval as toe-of-slope or basin-plain turbidites. Individual sandstone bodies are expected to be thin and laterally discontinuous; aggregate reservoir thickness may occasionally reach 100 ft or more. Reservoir porosity is expected to vary from 5 to 30 percent. Abnormally high fluid pressures are present in the easternmost part of the play and, as a result, porosities should be better than normally expected for rocks at these depths.

Source rocks: Source rocks include the marine shale of the Torok and Canning Formations, which are expected to be relatively gas-prone. The Hue Shale is the richest oil-prone source rock known in the play interval and lies directly beneath the turbidites. Other oil-prone source rocks beneath this play include the pebble shale unit, the Kingak Shale, and the Shublik Formation. Throughout most of the play, the top of the thermal zone of oil generation lies within or just below the lower part of the play interval.

Timing and migration: The turbidite reservoir sandstones in this play are the deep-water equivalents of the deltaic deposits of the overlying Topset play. Thus thermal maturation of the source rocks was the result of burial by rocks of this and the overlying play. The timing relative to stratigraphic-trap formation is judged to be ideal, and migration distances relatively short because some turbidites rest directly on the Hue Shale.

Traps: Postulated traps are stratigraphic and are related to facies changes, or they are traps formed against small-displacement normal faults. Mounded turbidites are interpreted on some seismic records in the NPRA (Stuart, 1990). Faults and the surrounding thick marine shales are expected to provide fair to good seals.

Exploration Status: More than 200 exploratory wells and 2,000 development wells have penetrated this play; but relatively few have been targeted for deposits within the play. Four oil accumulations have been discovered (Flaxman Island, Badami, Stump Island pool of Point McIntyre field, and Colville Delta). Sizes of these accumulations have not been reported. The Stump Island pool is currently producing along with production from deeper Kuparuk Formation reservoirs. Oil has been recovered from turbidite reservoirs in numerous exploratory wells in the play.

Resource Potential: Prospects for additional discoveries are judged to be excellent.

0103. BARROW ARCH BEAUFORTIAN PLAY

This confirmed conventional oil and gas play consists of combined structural and stratigraphic traps involving Jurassic and Early Cretaceous sandstone reservoirs (the Beaufortian sequence) that are found along the Barrow Arch. Locally, pre-Mississippian basement rocks directly overlain by Beaufortian sandstones are included in this play. The stratigraphic interval encompassed by the play includes the Kingak Shale (and equivalent Miluveach Formation), the Kuparuk Formation, and the pebble shale unit

(and equivalent Kalubik Formation). The play occupies a relatively narrow strip along the northern coast of Alaska. Its northern and western border is the national offshore territorial boundary. The southern border is arbitrarily selected as the downdip limit (on the south flank of the Barrow Arch) of the characteristic structural-stratigraphic traps. Play interval thickness varies from as little as 100-200 ft in areas where only the pebble shale unit is present, to nearly 2,000 ft in areas where the entire stratigraphic section is preserved. The total area of the play is about 6,000 sq mi.

Reservoirs: Potential reservoir rocks include the Put River Sandstone and its equivalents, the informally named Barrow sand, and other unnamed Jurassic sandstones. However, the most important reservoir rock is the shallow-marine sandstone of the Kuparuk Formation, which is present only in areas where the entire Kingak Shale is preserved—between long. 148¡ and 151.5¡ W. Elsewhere, sandstones overlying the regional Lower Cretaceous unconformity (such as the Thomson sand, which is the main reservoir of the Point Thomson field) may provide important reservoirs. In the Point Thomson area, the Thomson sand overlies pre-Mississippian basement rocks, which also have some porosity and contain hydrocarbons. In situations such as this, the basement rocks are assigned to the play. Porosity in the sandstone reservoirs is expected to average about 20 percent. All potential reservoirs have oil and gas shows or are oil productive. Drilling depths range from 1,500 ft at the western end of the play to about 15,000 ft at the eastern end.

Source rocks: Potential source rocks include marine shales of Triassic to Early Cretaceous age in the Kavik Member of the Ivishak Formation, the Shublik Formation, the Kingak Shale, the pebble shale unit, and the Hue Shale. Lacustrine shale, mudstone, and coal of Mississippian age below the play interval may also serve as source rocks. All potential source rocks are marginally thermally mature within the play area, mature to overmature south of the play area, and, where present, overmature to the north.

Timing and migration: Basin reconstructions and burial-history calculations show that source rocks reached thermal maturity as a result of burial by Cretaceous and Tertiary foreland basin fill. Maturity was achieved in the Late Cretaceous in areas adjacent to the western part of the play and in the early to middle Tertiary in areas adjacent to the easternmost part of the play. Migration direction would have been generally north or northeastward.

Traps: Traps are mostly combinations of structure and stratigraphy. Closure is generally achieved by faulting and partial truncation of the reservoir in broad, gentle anticlines. Truncation is usually the result of a regionally prevalent Lower Cretaceous unconformity, and sealing is accomplished by the overlying pebble shale unit and younger marine shales.

Exploration status: This is one of the most intensely explored play on the North Slope, with about 200 exploratory wells, some of which date from the beginning of North Slope drilling in 1946. Four producing oil fields are in this play: Kuparuk River (2,200 MMBO ultimate recovery), Milne Point (115 MMBO

ultimate recovery), Point McIntyre (358 MMBO ultimate recovery), and Niakuk (55 MMBO ultimate recovery). Two producing gas fields are South Barrow, East Barrow. Currently non-producing oil and gas accumulations include Point Thomson (200 MMBO and 3,000 BCF), Sikulik, and the recently discovered Colville Delta field (size not announced).

Resource Potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered very good.

0104. BARROW ARCH ELLESMERIAN PLAY

This confirmed conventional oil and gas play consists of combined structural and stratigraphic traps involving Mississippian to Triassic sandstone reservoirs and Mississippian and Pennsylvanian carbonate reservoirs (the Ellesmerian sequence) that are found along the Barrow Arch. The stratigraphic interval encompassed by the play includes the Endicott, Lisburne, and Sadlerochit Groups as well as the Shublik Formation and Sag River Sandstone. The play occupies a relatively narrow strip along the northern coast of Alaska. Its northern and western border is the national offshore territorial boundary. The southern border is arbitrarily selected as the downdip limit (on the south flank of the Barrow Arch) of the characteristic structural-stratigraphic traps. Play interval thickness varies from a zero truncation edge to nearly 5,000 ft in areas where the entire stratigraphic section is preserved. The total area of the play is about 4,700 sq mi.

Reservoirs: Potential reservoirs include both sandstone and carbonate rocks. Sandstone reservoirs (Kekiktuk Conglomerate, Sadlerochit Group, and Sag River Sandstone) predominate over carbonate reservoirs (Lisburne Group and Shublik Formation). The most important reservoir is expected to be the nonmarine to shallow-marine Ivishak Sandstone of the Sadlerochit Group. Porosity in sandstone reservoirs is expected to average better than 20 percent; limestone porosity is expected to be less than 5 percent and dolomite porosity is variable but potentially as high as 25 percent. All potential reservoirs have oil shows or are oil productive. Drilling depths range from 2,200 ft to 15,300 ft.

Source rocks: Potential source rocks include marine shales of Triassic to Early Cretaceous age including the Kavik Member of the Ivishak Formation, the Shublik Formation, the Kingak Shale, the pebble shale unit, and the Hue Shale. Lacustrine shale, mudstone, and coal of Mississippian age in the lower part of the play interval may also serve as source rocks. All potential source rocks are marginally thermally mature within the play area, but are mature to overmature south of the play area.

Timing and migration: Basin reconstructions and burial-history calculations show that source rocks reached thermal maturity as a result of burial by Cretaceous and Tertiary foreland basin fill. Maturity was achieved in the Late Cretaceous in areas adjacent to the western part of the play and early to middle Tertiary in areas adjacent to the easternmost part. The migration direction would have been generally north or northeastward.

Traps: Traps are mostly combinations of structure and stratigraphy. Closure is generally achieved by faulting and partial truncation of the reservoir in broad, gentle anticlines. Truncation is usually the result of a regionally prevalent Lower Cretaceous unconformity, and sealing is accomplished by the overlying pebble shale unit and younger marine shales.

Exploration Status: This is another very intensely explored play on the North Slope, with about 200 exploratory wells. The three producing fields are in this play are Prudhoe Bay, Sadlerochit pool (12 BBO ultimate recovery); Prudhoe Bay, Lisburne pool (181 MMBO ultimate recovery); and Endicott (497 MMBO ultimate recovery). Undeveloped oil and gas accumulations include Gwydyr Bay, North Prudhoe Bay, Seal Island, Sandpiper, and Tern Island. The State of Alaska (1994) reports reserves from these undeveloped fields total about 180 MMBO.

Resource Potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered very good.

0105. ELLESMERIAN-BEAUFORTIAN CLASTICS PLAY

This confirmed conventional oil and gas play consists of combined stratigraphic and structural traps of sandstone reservoirs in the gently south-dipping Permian to Early Cretaceous section, above the Lisburne Group. The play interval consists mostly of siltstone and shale with as much as 10-percent sandstone. The northern boundary of the play is the southern boundary of the Barrow Arch Ellesmerian and Barrow Arch Beaufortian plays, where the play interval may be as thin as 400 ft. The southern play boundary lies beneath the Foothills Physiographic Province, where the play interval rocks become involved in Brooks Range compressional structures. The boundary shown in figure 9 is the 26,000 ft deep to the base of rocks in the play. Along this southern boundary, the play interval may be as thick as 6,000 ft. The total area of the play is about 35,000 sq mi.

Reservoirs: Potential reservoirs include sandstone in the Echooka and Ivishak Formations, the Sag River Sandstone, several unnamed sandstone units in the Kingak Shale, Kuparuk Formation, and stratigraphic equivalents of the Kemik Sandstone. These sandstones were deposited primarily in shallow-marine environments; minor amounts of fluvial sandstone are present in the northernmost areas of the play (Ivishak Formation) and turbidite sandstone of northern derivation (such as the Early Cretaceous unnamed gas-bearing sandstone in the Tunalik well) is present in the southernmost areas of the play. Porosities may reach 25 percent in the northern parts of the play area, but are anticipated to decrease to less than 10 percent in the southern parts. Drilling depths range from as little as 2,000 ft in the north to a maximum of 26,000 ft at the southern play boundary. Most reservoirs, particularly those with the best porosity, are expected to occur beneath the Coastal Plain Physiographic Province, where drilling depths are generally less than 15,000 ft.

Source rocks: The play interval contains many of the richest source rocks on the North Slope, including the Kavik Shale, the Shublik Formation, the Kingak Shale, the pebble shale unit, and the Hue Shale. These shales range from marginally thermally mature in the northernmost parts of the play to overmature in the

southern parts. At the top of the play interval, the (R_O) 0.6 percent value lies just north of and parallel to the -10,000 ft contour and the R_O 2.0 percent value approximates the -20,000 ft contour.

Timing and migration: Basin reconstructions and burial-history calculations show that source rocks reached maturity as a result of burial by Cretaceous and Tertiary foreland basin fill. Maturity was achieved in the Late Cretaceous in the western part of the play and the early to middle Tertiary in the easternmost part. The migration direction would have been generally northward.

Traps: Because of the homoclinal southerly dip of strata in this play and the rarity of structural reversals, oil and gas accumulations are expected to be trapped in stratigraphic or a combination of fault and stratigraphic traps. Shales within the play interval are expected to provide adequate seals.

Exploration status: The Walakpa gas field was discovered in 1977 by the NPRA program. Since then, the field was turned over to the North Slope Borough, and eight development wells have been drilled to supply the town of Barrow. Although the size of the field is undetermined, an estimate of 60 BCF is entirely justified and an upper size limit of 1-4 TCFG is possible if the reservoir is widely distributed (Richard Glenn, personal communication, 1994). Oil and gas shows are reported in several wells in this play; good gas shows have been encountered in the South Simpson and Tunalik wells. A few dozen exploratory wells have penetrated this play, only a few of which were drilled for prospects in the play interval.

Resource potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered good.

0106. LISBURNE PLAY (HYPOTHETICAL)

(This hypothetical play consists of structurally and stratigraphically trapped carbonate or clastic reservoirs in the gently south-dipping Lisburne Group. The northern play boundary is the Lisburne onlap limit west of long 154i W.; east of this longitude, it is the southern boundary of the Barrow Arch Ellesmerian play. The Lisburne Play extends southward to the area beneath the northern Brooks Range at depths greater than 26,000 ft. Only autochthonous Lisburne rocks, those not involved in Brooks Range deformation, are included in this play. The play-interval thickness may vary from zero at the onlap edge to as much as 4,000 ft in areas such as the Ikpikpuk-Umiat Basin. Total area of the play is about 57,000 sq mi.

Reservoirs: Potential reservoir rocks include dolomite, limestone, and sandstone. Dolomite, the most important reservoir with porosity occasionally as high as 25 percent, is expected to occur most abundantly in the late Mississippian part of the Lisburne Group, as in the Prudhoe Bay area. Dolomite of this age is not expected in the northernmost or western part of the NPRA because Lisburne rocks of this age are missing by onlap. Limestone porosity in the Lisburne is expected to average less than 5 percent, similar to that in the Lisburne oil field (in the Barrow Arch Ellesmerian Play). Sandstone, which may be common along the northern onlap edge in the NPRA, may be partially to completely cemented with calcite and, thus, may serve as a marginal reservoir. Depth to the top of the Lisburne in the play ranges from 10,000 ft along the northern play boundary to greater than 26,000 ft in the south.

Source rocks: Potential source rocks include marine shale in the overlying Sadlerochit Group, marine shale and limestone within the Lisburne, and marine to lacustrine shale and coal in the underlying Endicott Group. Where truncated by the regional Lower Cretaceous unconformity at the easternmost part of the play, the pebble shale unit and the Hue Shale overlying the unconformity may be important source rocks. Limited geochemical data suggest that all except the pebble shale unit and Hue Shale are fair to poor, gas-prone source rocks that are thermally mature in the northern part of the play and supermature in the southern part. R_O values of 2.0 percent generally coincide with the -12,000 ft structure contour. Oil residue is often encountered in porous dolomite in the Lisburne Group, and hydrogen sulfide gas was encountered in interbedded limestone and shale near the Lisburne-Endicott Group boundary at a depth of about 17,500 ft in the Inigok-1 well.

Timing and migration: Burial-history analysis indicates that hydrocarbons may have been generated as early as Permian time in the Ikpikpuk-Umiat basin; elsewhere, generation did not occur until Early Cretaceous burial by the Colville Basin fill. Because the reservoir traps formed relatively early, the postulated timing of thermal maturity and migration for this play are regarded as favorable. In general, maturation would have occurred earlier in the southern and western parts of the play and the migration direction would have been from south to north.

Traps: Stratigraphic traps related to the Lisburne Group onlap edge and facies changes are expected in the northern part of the play area. Numerous low-relief (<200 ft) structural traps, noses, and faults are seismically mapped in the NPRA, apparently the result of folding and faulting during Mississippian, Pennsylvanian, and Permian(?) time. In the northwestern part of the NPRA, numerous seismic anomalies have been mapped; these may be carbonate buildups (reefs) and may constitute yet another potential trap type. Sealing rocks are expected to be interbedded shale and impermeable limestone.

Exploration status:: Less than a dozen exploratory wells have been drilled for prospects in this play; no hydrocarbon accumulations are known.

Resource potential: Available data suggests limited resource potential, probably all natural gas. Because of the relatively few wells and large area covered by this play, there are many geologic uncertainties. Chief among these are the distribution, continuity, and thickness of reservoirs, size and integrity of traps (adequacy of seals), and the richness of source rocks.

0107. LISBURNE UNCONFORMITY PLAY (HYPOTHETICAL)

The Lisburne Unconformity Play consists of stratigraphic traps developed as a result of differential erosion on the regional Permian or Lower Cretaceous unconformities that lie at the top of the Lisburne Group. The play is hypothetical because the amount of differential erosion on the unconformities is largely unknown and the coincidence of relief with porous carbonate rocks is also unknown. Evidence for relief on the Permian unconformity is known from outcrops in the eastern Shublik Mountains of the Arctic National Wildlife Refuge (ANWR), where conglomerate-filled channels cut into the uppermost part of the Lisburne Group.

The play encompasses the entire area of Lisburne Group beneath the Permian and Lower Cretaceous Unconformities, including that area overlying the Barrow Arch. The Barrow Arch area is included in this play because the size distribution of oil and gas accumulations in the play is likely to be significantly different from that in the Barrow Arch Ellesmerian Play. The southern limit of the play coincides with the southern limit of the Lisburne Play. Total area of the play is about 60,3500 sq mi.

Reservoirs: Reservoir rocks are expected to be porous dolomite and limestone, similar to that in the Lisburne Play. Depth to the Permian unconformity in the play area ranges from about 8,000 ft to greater than 26,000 ft.

Source rocks: Potential source rocks are mostly gas-prone marine and nonmarine shale. Oil-prone source rocks younger than the Lisburne Group may be in fault contact with Lisburne rocks along the Barrow Arch.

Timing and migration: Timing and migration are considered good because the traps would have formed early.

Traps: Postulated traps are envisioned to consist of erosional scarps and remnants of porous Lisburne Group carbonates sealed by the overlying Sadlerochit Group. These traps are analogous to those that trap most Mississippian oil and gas accumulations beneath the plains of Alberta.

Exploration status: As many as 50 exploratory wells may have penetrated this play, but few, if any, were drilled for prospects.

Resource potential: Because of the small probability for traps and favorable reservoir, the chance for hydrocarbon accumulations greater than the minimum size used in this assessment is considered remote.

0108. ENDICOTT PLAY (HYPOTHETICAL)

This hypothetical play consists of combined structural and stratigraphic traps in sandstone reservoirs in the Mississippian Kekiktuk Conglomerate, and sandstone or dolomite reservoirs in the overlying Kayak Shale, both formations belong to the Endicott Group). The northern boundary of the play west of long 155¡ W. is the onlap edge of the Endicott Group; east of this longitude, it is the southern boundary of the Barrow Arch Ellesmerian Play. The Endicott Play extends southward to the area beneath the northern Brooks Range at depths greater than 24,000 ft. Only autochthonous rocks, those not involved in Brooks Range deformation, are included in this play. Thickness of the Endicott Group is generally 100—1,000 ft but locally may be as much as 10,000 ft. Total area of the play is about 57,500 sq mi.

Reservoirs: Potential reservoir rocks consist primarily of fluvial to shallow-marine(?) quartzose sandstone and conglomerate within the Kekiktuk Conglomerate. Minor amounts of shallow-marine dolomite and sandstone are present in the overlying Kayak Shale. Porosity is expected to be less than 10 percent because of extreme burial depths; about 90-percent of the play lies at depths greater than 12,000 ft. and half of the play at depths greater than 24,000 ft.

Source rocks: Potential source rocks include coal and lacustrine shale in the Kekiktuk and marine shale in the Kayak. Limited geochemical data suggest that all are poor to fair, gas-prone source rocks that are thermally mature in the northern part of the play and supermature in the southern part. R_o values of 2.0 percent generally coincide with the -12,000 ft structure contour. Hydrogen sulfide gas was encountered in interbedded limestone and shale near the Lisburne-Endicott Group boundary at a depth of about 17,500 ft in the Inigok-1 well.

Timing and migration: Burial-history analysis indicates that hydrocarbons may have been generated as early as Permian time in the Ikpikpuk-Umiat basin; elsewhere, generation did not occur until Early Cretaceous burial by Colville basin fill. Because the reservoir traps formed relatively early, the postulated

timing of thermal maturity and migration for this play is regarded as favorable. In general, maturation would have occurred earlier in the southern and western parts of the play and the migration direction would have been from south to north.

Traps: Traps are expected to be structural folds and faults that were developed during the formation of Endicott Group basins in Mississippian, Pennsylvanian, and Permian(?) time. Numerous low-relief (<200 ft) structural traps, noses, and faults are seismically mapped in the NPRA at the Lisburne Group level, apparently the result of folding and faulting during Mississippian, Pennsylvanian, and Permian(?). Interbedded Kekiktuk Conglomerate shale and the overlying Kayak Shale are probable seal rocks.

Exploration status: Less than a dozen exploratory wells have been drilled for prospects in this play; no hydrocarbon accumulations are known.

Resource potential: Available data suggests limited resource potential, probably all natural gas. Because of the relatively few wells and large area covered by this play, there are many geologic uncertainties. Chief among these are the distribution, continuity, and thickness of reservoirs, size and integrity of traps (adequacy of seals), and the richness of source rocks.

0109. FOLD BELT PLAY

This confirmed conventional oil and gas play consists primarily of anticlinal traps in Cretaceous and Tertiary sandstone reservoirs in the northern part of the Brooks Range fold and thrust belt. The Fold Belt Play is situated north of the Western Thrust Belt Play and south of the Topset Play; its western border is the offshore national 3-mile territorial limit in the Chukchi Sea, and its eastern border the same offshore limit in the Beaufort Sea. The Fold Belt play encompasses the Nanushuk Group; the Torok, Sagavanirktok, and Canning Formations; the Hue Shale, the pebble shale unit, and the Kemik-equivalent sandstones. Even older strata may be included in the play along its southern border. Total area of the play is about 36,500 sq mi.

Reservoirs: Potential reservoirs are sandstones representing deltaic, shallow-marine, and turbidite environments. Porosity is expected to range from 5 to 30 percent and to improve eastward across the play. Drilling depths range from the near-surface to greater than 20,000 ft.

Source rocks: Potential source rocks include generally gas-prone shales of the Nanushuk Group and the Sagavanirktok, Torok and Canning Formations and the underlying more oil-prone shales of the Hue Shale, pebble shale unit, Kingak Shale, and Shublik Formation. Gas-prone source rocks within this play range from thermally immature to mature, whereas most oil-prone source rocks range from mature to overmature. The eastern part of the play is considered more oil prospective than the western part because of greater thicknesses of the oil-prone Hue Shale in the east. Oil seeps and oil-stained sandstones are numerous.

Timing and migration: The coincidence of maturity isograds with structures along the Dalton Highway suggests that maturity was reached prior to structural deformation and that the isograds were deformed along with the rocks. Thus, hydrocarbon migration would initially have been controlled by depositional geometries (such as clinoforms and onlap relations). Migration directions along clinoforms would have been generally southwestward. Hydrocarbons that were trapped during this time may have re-migrated into anticlinal traps following deformation. The time lag between maturation and structural deformation is not known; within the eastern NPRA area, Bird (1994) suggests lag of at least 7 m.y. (maximum burial at about 85 Ma where rocks as young as 78 Ma are involved in folding and faulting). At least two phases of deformation are indicated in the ANWR portion of this play.

Traps: Traps are faulted anticlines related to Brooks Range deformation. In addition, all of the stratigraphic trapping possibilities in the Topset, Turbidite, and Ellesmerian-Beaufortian Clastics Plays should also exist within this play. Shales within the play are expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing.

Exploration status: Both oil and gas seeps are known in the play and six non-economic accumulations have been discovered: Umiat oil field (about 70 MMBO), Gubik gas field (about 295 BCF), East Umiat gas field (size unknown), Wolf Creek gas field (size unknown), Square Lake gas field (about 58 BCF), and Meade gas field (about 20 BCF). Approximately 50 exploratory and delineation wells have tested 30 structures in this play. The number of untested structures may be more than 100.

Resource potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered good.

0110. WESTERN THRUST BELT PLAY (HYPOTHETICAL)

This hypothetical conventional oil and gas play consists primarily of structural traps in Mississippian and Pennsylvanian carbonate reservoirs in the Brooks Range fold- and thrust belt. The northern boundary of the play, guided by seismic reflection data within the NPRA, is drawn far enough north to encompass all of the estimated occurrences of thrust sheets of Lisburne Group carbonates. The southern boundary is arbitrarily placed about 30 mi into the Brooks Range; the area farther south is expected to have negligible petroleum potential based on the observed southward increase in the level of thermal maturity. The western play boundary is the offshore national 3-mile territorial limit in the Chukchi Sea. The eastern boundary, a short distance east of the Trans Alaska Pipeline, is where the structural style changes from that of the Brooks Range to the east. Greatest potential for petroleum in the Western Thrust Belt Play is expected to be along the immediate range front and foothills to the north. The thickness of rocks in the play may exceed 35,000 ft. The total area of the play is about 16,000 sq mi.

Reservoirs: Lisburne Group carbonate rocks are the primary reservoir rock. Other potential reservoir rocks include graywacke sandstone of Jurassic and Cretaceous age and fractured chert and siliceous shale of Mississippian to Jurassic age. The structural style of potential prospects and physical nature of potential reservoir rocks is exemplified by the Lisburne-1 well, which encountered five thrust repetitions of the Lisburne Group. Each repetition is about 1,200-ft thick. Drilling depths range from near-surface to greater than 35,000 ft.

Source rocks: Potential source rocks include marine shale of Mississippian to Cretaceous age. Oil shales of Mississippian, Triassic, and Jurassic ages are known to occur within this play, but they are considered representative of local occurrences and not characteristic of the entire play. Preliminary data from the Lisburne-1 well indicate that Jurassic-Triassic rocks are fair to good oil source rocks. Most source rocks are expected to be thermally mature to overmature, although the data are sparse and the geologic relationships complex. The western part of the play displays higher maturity than the eastern part. Bitumen in pores and fractures was encountered in the Lisburne-1 well along with minor indications of gas. Veins of bitumen are known from outcrop localities.

Timing and migration: Analysis of paleothermal indicators in the Lisburne-1 well and in the western Brooks Range suggests that thermal maturity results from tectonic burial. A favorable aspect of this situation is that hydrocarbon migration would have been directly into early-formed structural traps. An unfavorable aspect is the duration of deformation, which lasted from Early Cretaceous to early Tertiary time and may have been episodic or quasi-continuous, thus compromising trap integrity.

Traps: Traps in the play are large anticlinal structures composed of multiple thrust sheets of carbonate rocks. Shales within the play are expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing.

Exploration status: Only four exploratory wells have been drilled in this play, and information on three of the four remains proprietary. Large, untested structures remaining in the play may number in the dozens.

Resource potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered fair.

0111. EASTERN THRUST BELT PLAY

This confirmed conventional oil and gas play consists primarily of structural traps in carbonate and clastic reservoirs of Beaufortian, Ellesmerian, and Franklinian sequences in the Brooks Range fold- and thrust belt. The northern boundary of the play, guided by seismic reflection data within the ANWR, is drawn far enough north to encompass all of the estimated occurrences of thrust blocks of these rocks. The southern boundary is arbitrarily placed about 30 mi into the Brooks Range; the area farther south is

expected to have negligible petroleum potential based on the observed southward increase in the level of thermal maturity. The eastern part of the play extends offshore to the national territorial limit in the Beaufort Sea. The western boundary lies a short distance east of the Trans Alaska Pipeline where the structural style changes from that of the Brooks Range to the west. The Thrust Belt East Play lies structurally beneath the Fold Belt Play. Greatest potential for petroleum in the Eastern Thrust Belt Play is expected to be north of the Brooks Range front, beneath the foothills and coastal plain of the ANWR and the area to the west. The total area of the play is about 8,200 sq mi.

Reservoirs: Potential reservoirs include sandstones (Kemik Sandstone and Kuparuk Formation equivalents, Sag River Sandstone, Ivishak and Echooka Formations, and Kekiktuk Conglomerate) and carbonate rocks (Shublik Formation, Lisburne Group, Nanook Limestone and Katakturuk Dolomite). The most important reservoir rocks are expected to be Lisburne Group, Ivishak Formation, and Kuparuk-equivalent rocks. Some or all of the Ellesmerian sequence may be missing from structures in the northernmost part of the play because of erosional truncation by the regional Lower Cretaceous unconformity. Drilling depths range from about 2,000 ft to greater than 24,000 ft.

Source rocks: Potential source rocks include a continuous section of oil-prone marine shale that ranges in age from Middle Triassic to Late Cretaceous (Shublik Formation, Kingak Shale, pebble shale unit, and Hue Shale). Gas-prone source rocks are represented by Triassic and Mississippian marine shales. Thermal maturity decreases northeastward across the play, ranging from overmature in the southwest to mature in the northeast. Minor oil staining in sandstone and carbonate rock is known from wells and outcrop in this play.

Timing and migration: Basin reconstructions and burial-history calculations show that source rocks reached thermal maturity as a result of burial by Cretaceous and Tertiary foreland basin fill. Maturity was accomplished by the Late Cretaceous in the southwestern part of the play and the middle Tertiary in the easternmost part of the play. Apatite fission-track analysis (O'Sullivan and others, 1993), suggests that maturation was achieved prior to uplift and cooling that is equated to deformation and development of structural traps. Thus migration would have been generally northward into stratigraphic and structural traps that predated Brooks Range deformation. Structural traps formed by Brooks Range deformation would have had to rely on late-stage or secondary migration of hydrocarbons. At least two phases of Tertiary deformation are suggested by the presence of an unconformity that beveled deformed rocks that, in turn, was itself deformed.

Traps: Traps are broad, thrust-faulted anticlinal structures that involve Beaufortian, Ellesmerian, and Franklinian rocks and typically produce only a single repetition of the stratigraphic section. Stratigraphic traps may also be present. Shales within the play, as well as shale in the basal Brookian sequence, are

expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing.

Exploration status: The Kavik and Kemik (dry) gas fields were discovered by drilling anticlinal structures in this play within a few years after the discovery of the Prudhoe Bay oil field in 1968. Reservoir rocks in these fields are the Triassic Sag River Sandstone, the Shublik Formation, and the Ivishak Formation. Although these fields undoubtedly exceed 6 BCFG, their actual sizes are not reported. About 80-percent of the play lies within the ANWR, an area off limits to exploratory drilling. Ten exploratory wells have tested eight structures, located mostly in the area west of the ANWR; at least several dozen structures remain to be tested.

Resource potential: The potential for undiscovered oil and gas resources greater than the minimum size used in this assessment is considered very good.

UNCONVENTIONAL PLAYS

There are no unconventional plays described in this province report. However, unconventional plays listed in the surrounding provinces may include parts of this province. Individual unconventional plays are usually discussed under the province in which the play is principally located.

REFERENCES

Bird, K.J., 1994, The Ellesmerian(!) petroleum system, North Slope of Alaska, USA, *in* Magoon, L.B., and Dow, W., eds., The petroleum system—From source to trap: American Association of Petroleum Geologists Memoir 60, p. 339-358.

Collett, T.S., 1993, Natural gas hydrates of the Prudhoe Bay and Kuparuk River area, North Slope, Alaska: American Association of Petroleum Geologists Bulletin, v. 77, no. 5, p. 793-812.

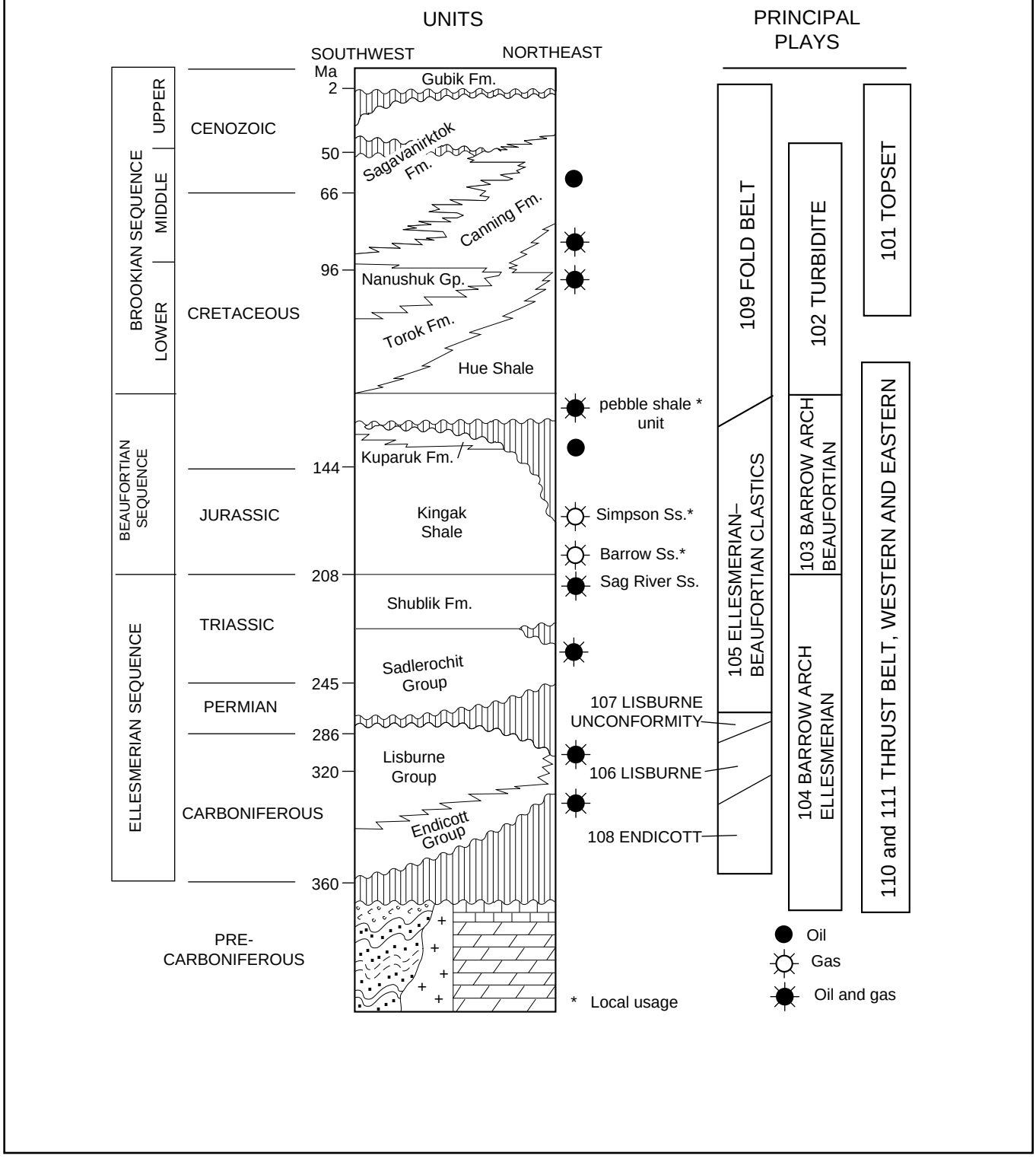
Dolton, G.L., Bird, K.J., Varnes, K.L., and Gautier, D.L., 1993, Onshore oil and gas resource assessment areas—Alaska: U.S. Geological Survey Open-File Report 93-331, 1 sheet, scale 1:5,000,000.

O'Sullivan, P.B., Green, P.F., Bergman, S.C., Decker, J., Duddy, I.R., Gleadow, A.J.W., and Turner, D.L., 1993a, Multiple phases of Tertiary uplift in the Arctic National Wildlife Refuge, Alaska, based on apatite fission track analysis: American Association of Petroleum Geologists Bulletin, v. 77, no. 3, p. 359-385.

State of Alaska, 1994, State of Alaska historical and projected oil and gas consumption: Anchorage, Alaska, Department of Natural Resources, 61 p.

Stuart, C.J., 1990, Seismic sequences and facies of siliciclastic deep-water deposits with application to hydrocarbon exploration, in Deep Marine Sedimentation: Pacific Section SEPM Field Trip Book 66, p. 71-122.

Thomas, C.P., Allaire, R.B., Doughty, T.C., Faulder, D.D., Irving, J.S., Jamion, H.C., and White, G.J., 1993, Alaska North Slope national energy strategy initiative: Analysis of five undeveloped fields: U.S. Department of Energy, DOE/ID/01570-T164.


UNITS
PRINCIPAL PLAYS
SOUTHWEST
NORTHEAST
Ma
2
50
66
96
144
208
245
286
320
360
BROOKIAN SEQUENCE
UPPER
MIDDLE
LOWER
BEAUFORTIAN SEQUENCE
ELLESMERIAN SEQUENCE
CENOZOIC
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
PRE-CARBONIFEROUS
Gubik Fm.
Sagavanirktok Fm.
Canning Fm.
Nanushuk Gp.
Torok Fm.
Hue Shale
Kuparuk Fm.
Kingak Shale
Shublik Fm.
Sadlerochit Group
Lisburne Group
Endicott Group
pebble shale * unit
Simpson Ss.*
Barrow Ss.*
Sag River Ss.
107 LISBURNE UNCONFORMITY
106 LISBURNE
108 ENDICOTT
* Local usage
109 FOLD BELT
105 ELLESMERIAN–BEAUFORTIAN CLASTICS
102 TURBIDITE
103 BARROW ARCH BEAUFORTIAN
104 BARROW ARCH ELLESMERIAN
101 TOPSET
110 and 111 THRUST BELT, WESTERN AND EASTERN
Oil
Gas
Oil and gas