Petroleum Resource Assessment of the Old Crow Basin, Yukon Territory, Canada

by
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FOREWORD

On November 19, 1998, the Government of Canada transferred to the Government of Yukon the administrative legislative powers and responsibilities of managing onshore oil and gas resources. Yukon oil and gas resources are now governed under the Yukon *Oil and Gas Act*.

A study of the petroleum resources of the Old Crow Basin in the Yukon Territory was undertaken by Geological Survey of Canada (GSC) in response to a request from the Government of Yukon. Assessment of petroleum resource potential is important for forming regulatory policies for these resources and for providing a basis for planning and issuing exploration rights.

EXECUTIVE SUMMARY

This study was undertaken by the Geological Survey of Canada on behalf of the Yukon Government as part of its ongoing oil and gas resources management program. The objective of this study was to investigate the hydrocarbon resource potential of the Old Crow Basin in the Yukon. A quantitative analysis was utilized to derive a numerical estimate of resources that may exist in the basin. Due to the absence of defined pools with established reserves, probability distributions of reservoir parameters and marginal risk factors are employed to generate a range of hydrocarbon potential estimates which disclose the uncertainties involved in the analysis of frontier conceptual plays.

There is a large structural and physiographic depression in northern Yukon called the Old Crow-Babbage Depression. Sedimentary rocks occupying this depression range in age from Proterozoic to Early Cretaceous. The Old Crow-Babbage Depression consists of a complex association of structural highs and lows partly buried by Tertiary and Quaternary nonmarine deposits in Old Crow Plain. Seismic interpretation reveals a Tertiary depocentre that defines the Old Crow Basin proper, which overlies Mesozoic and older strata at a major unconformity. No evidence exists for an underlying Mesozoic depocentre. Two minor basins, the Bluefish and Driftwood basins, are preserved in an arcuate zone of structural discontinuity south of Old Crow plain. Outcrops in these basins indicate a thin Cretaceous succession overlying Lower Paleozoic rocks occurring beneath a Quaternary fluviatile cover.

The hydrocarbon potential volumes were derived using the Geological Survey of Canada's PETRIMES assessment methodology system. This resource study embraced analyses of three conceptual plays, each of which incorporated the estimation of field size parameters, numbers of prospects and exploration risks. Three speculative exploration plays were also defined but are described qualitatively due to insufficient information. The median estimate for total gas potential for all Old Crow plays is 29 billion m^3 of in-place gas. There are no discovered reserves in the Old Crow region, but three gas fields greater than 3,000 million m^3 (100 BCF) are expected. Even though geological risk factors are substantial, significant gas potential is predicted for the Kekiktuk conglomerate and Upper Paleozoic carbonate plays. Geochemical evidence indicates that there is little, if any, oil potential in the study area.

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INTRODUCTION

This study was undertaken by the Geological Survey of Canada on behalf of the Yukon Territorial Government as part of its ongoing oil and gas resource management program. The objective of this study was to investigate the hydrocarbon resource potential of the Old Crow Basin in the Yukon Territory (Figs. 1, 2). A quantitative analysis was employed to derive a numerical estimate of resources that may exist in the basin. Due to the absence of defined pools with established reserves, probability distributions of reservoir parameters and marginal risk factors were utilized to generate a range of hydrocarbon potential estimates indicative of the uncertainties involved in the analysis of frontier conceptual plays.

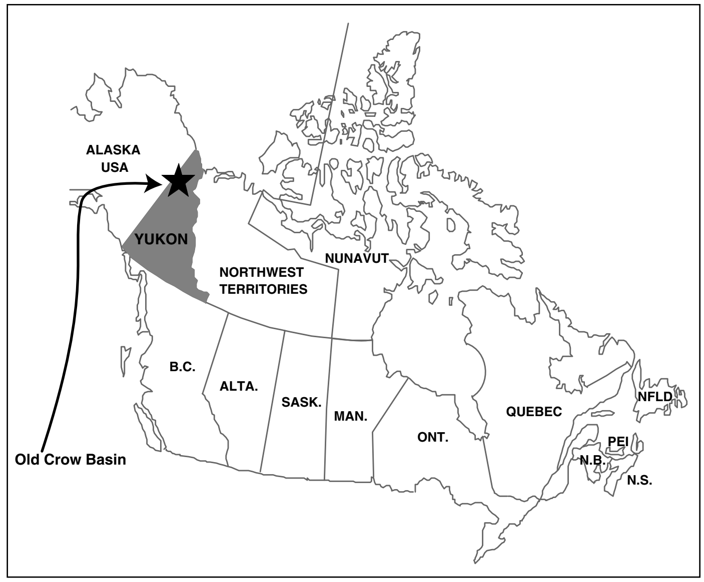


Figure 1. *Old Crow Basin location map.*

Regional petroleum resource assessments have been prepared periodically for numerous sedimentary basins in Canada by the Geological Survey of Canada. These studies incorporate systematic basin analysis with subsequent statistical resource evaluations (Podruski e*t al.*, 1988; Wade e*t al.*, 1989; Sinclair e*t al.*, 1992; Reinson e*t al.*, 1993; Bird e*t al.*, 1994; Dixon e*t al.*, 1994; Hannigan e*t al.*, 1998, 1999; Hannigan, in press (a) and (b)).

This report provides an overview of the petroleum geology of the Old Crow region and presents quantitative estimates of the oil and gas resources contained therein. The geological and resource framework for the region will assist government agencies in evaluating land-use and moratorium issues and petroleum industry companies in pursuing future exploration opportunities.

ACKNOWLEDGEMENTS

The author would like to acknowledge staff at GSC-Calgary for their insight and geological expertise on this area, specifically, J. Dixon, L.S. Lane, and K.G. Osadetz. Giles Morrell of DIAND provided astute appraisals with respect to play definition and reservoir parameter input.

TERMINOLOGY

The terminology and procedures used in this report follow those outlined in Reinson e*t al.* (1993) and are summarized below.

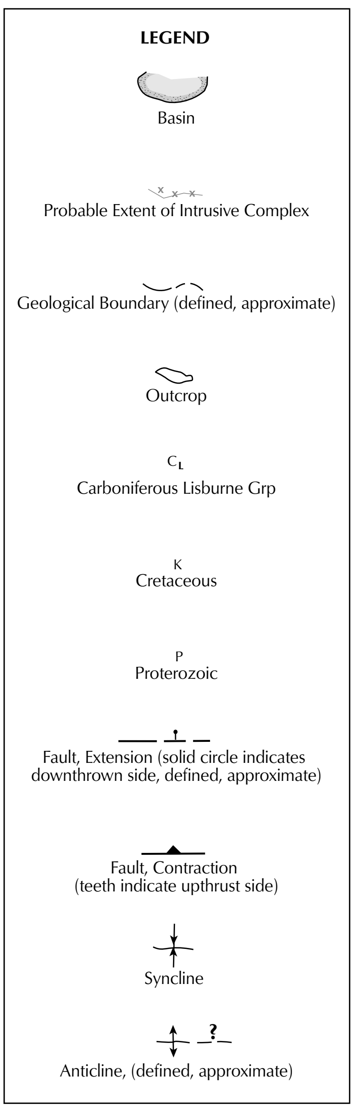
Oil is defined as any naturally occurring liquid that, at the conditions under which it is measured or estimated, is primarily composed of hydrocarbon molecules and is readily producible from a borehole.

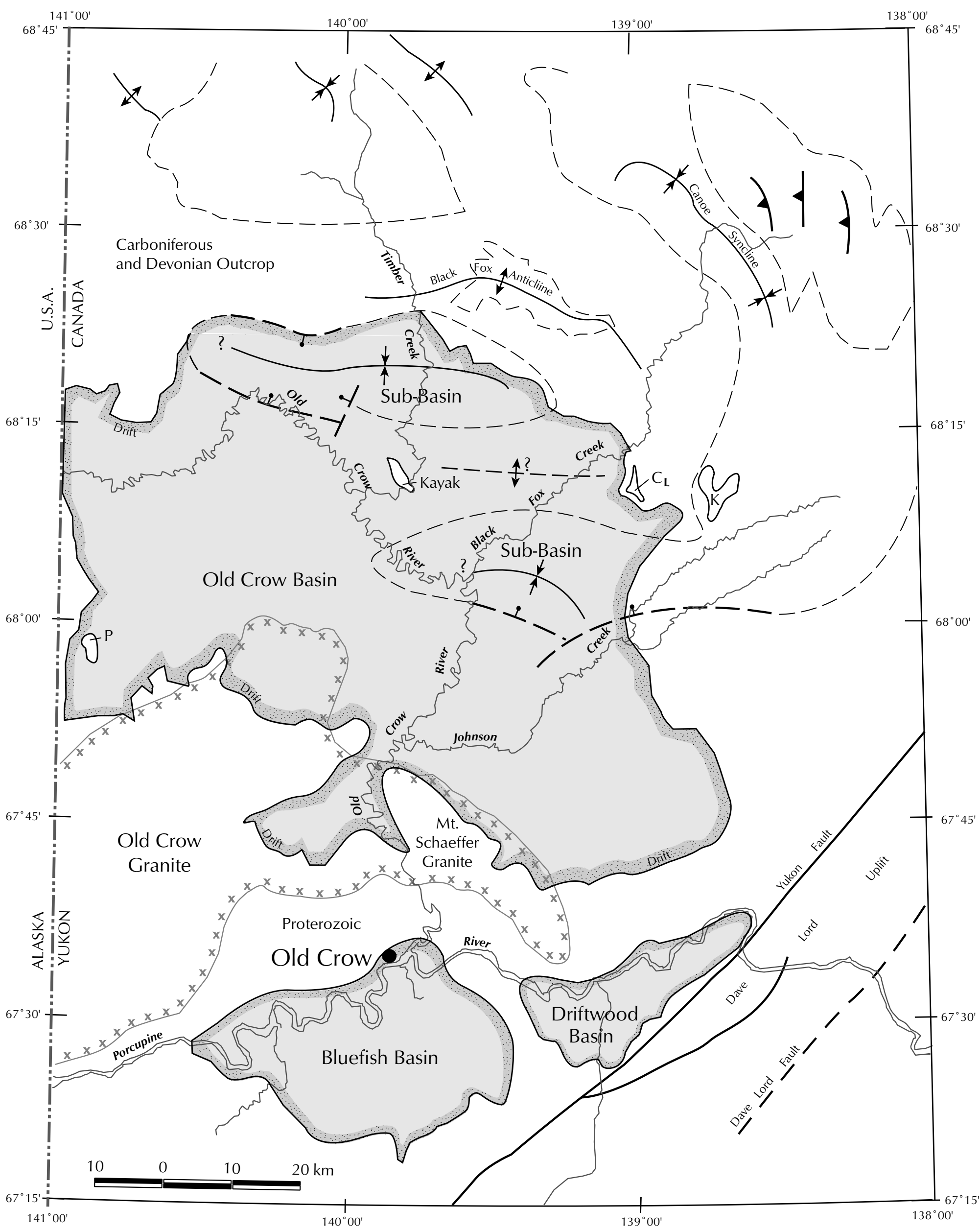
Natural gas is defined as any gas (at standard pressure and temperature, 101.33 kPa and 15°C) of natural origin comprised mostly of hydrocarbon molecules producible from a borehole (Potential Gas Committee, 1990). Natural gas may contain significant amounts of non-hydrocarbon gas such as H_2S, CO_2 or He. In this study, non-hydrocarbon gas was not considered due to lack of information on gas compositions in these basins.

Raw gas is unprocessed natural gas, containing methane, inert and acid gases, impurities and other hydrocarbons, some of which can be recovered as liquids. *Non-associated gas* is natural gas that is not in contact with oil in a reservoir. *Associated gas* is natural gas that occurs in oil reservoirs as free gas. *Solution gas* is natural gas that is dissolved in crude oil in reservoirs. In this report, insufficient information is available in order to differentiate non-associated, associated, and solution gas. All gas figures reported represent initial raw gas volumes.

Resource indicates all hydrocarbon accumulations known or inferred to exist. *Resource, resource endowment* and *endowment* are synonymous and can be used interchangeably. *Reserves* are that portion of the resource that has been discovered, while *potential* represents the portion of the resource that is not discovered but is inferred to exist.

Figure 2. *Area of the Old Crow Basin showing major geological features. Quaternary fluviatile sands and gravel cover delineates the Tertiary the Old Crow Basin and the Cretaceous Bluefish and Driftwood basins. Note that Kaltag Fault previously inferred as extending from Alaska northeastward into northern Yukon (as in Norris, 1981b) is now interpreted as not projecting into northern Yukon due to recent potential field data (Lane, 1992, 1998).*





(After Morrell & Dietrich, 1993)

The terms *potential* and *undiscovered resources* are synonymous and may be used interchangeably.

Gas-in-place indicates the gas volume found in the ground, regardless of what portion is recoverable. *Initial in-place volume* is the gross volume of raw gas, before production. *Recoverable in-place volume* represents the volume expected to be recovered using current technology and costs. These definitions can be applied to oil volumes as well.

A *prospect* is defined as an untested exploration target within a single stratigraphic interval; it may or may not contain hydrocarbons. A prospect is not synonymous with an undiscovered pool. An undiscovered pool is a prospect that contains hydrocarbons but has not been tested as yet. A *pool* is defined as a discovered accumulation of oil or gas, typically within a single stratigraphic interval, that is separate, hydrodynamically or otherwise, from another hydrocarbon accumulation. A *field* consists of one or more oil and/or gas pools within a single structure or trap. Similar to most frontier regions, the assessment of petroleum resources in the Old Crow Basin is based on estimates of field rather than pool sizes. A *play* is defined as a family of pools and/or prospects that share a common history of hydrocarbon generation, migration, reservoir development and trap configuration.

Plays are grouped into two categories: *established* and *conceptual* plays. *Established plays* are demonstrated to exist due to the discovery of pools with established reserves. *Conceptual plays* are those that have no discoveries or reserves, but which geological analyses indicate may exist. Established plays are categorized further into *mature* and *immature* plays depending on the adequacy of play data for statistical analysis. Mature plays are those plays that have sufficient numbers of discoveries within the discovery sequence so that the *discovery process model* of the PETRIMES assessment procedure is of practical use (Lee and Tzeng, 1989; Lee and Wang, 1990; Lee, 1993). Immature plays do not have a sufficient number of discoveries with established reserves to properly apply the model. Conceptual play analysis was applied exclusively in this study due to the lack of any discovered pools with established reserves.

Speculative plays are a type of conceptual play that have insufficient geological information for quantitative analyses. Therefore, these plays are only described qualitatively. Often, there is some doubt whether these plays actually exist in the area of interest.

METHOD AND CONTENT

This report incorporates two essential components; geological basin analysis and statistical assessment. Basin analysis fundamentally describes and characterizes the exploration play. Fields and prospects in a play form a natural geological population that can be delimited areally. Once a play is properly defined, a numerical and statistical resource assessment is undertaken using relevant geological data and information for that specific play.

RESOURCE ASSESSMENT PROCEDURE

The analysis of the Old Crow basin area began with the compilation and synthesis of information on regional geology and hydrocarbon occurrence. This included a survey of National Energy Board (NEB) public files and a search of pertinent publications. The NEB files contain information submitted as exploration agreements, and they often contain relevant geophysical information, notably seismic lines and maps.

The aim of this data compilation was to initiate basin analysis in order to provide background for the definition of hydrocarbon occurrence models. Play models in the study area were developed by examining the hydrocarbon systems and, when possible, using analogues to extrapolate certain parameters.

Play definition and estimation of reservoir parameters formed the input for a systematic statistical analysis which allowed a quantitative analysis of the undiscovered resource.

GEOLOGICAL PLAY DEFINITION

Definitions of play type and area are essential components in geological basin analysis preceding any numerical resource evaluation procedure. A properly defined play will possess a single population of pools and/or prospects that satisfies the assumption that geological parameters within a play can be approximated by a family of lognormal distributions. Mixed populations derived from improperly defined plays add uncertainty to the resource estimate. Pools and/or prospects in a specific play form a natural geological population characterized by one or more of the following: age, depositional model, structural style, trapping mechanism, geometry, and diagenesis. Prospects or areas within a basin or region can be assigned to specific plays on the basis of a commonality of some or all of these geological elements.

COMPILATION OF PLAY DATA

Since conceptual plays have no defined pools or discoveries, probability distributions of reservoir parameters such as prospect area, reservoir thickness, porosity, trap fill, and hydrocarbon fraction are needed. Prospect size can then be calculated using the standard “pool”-size equation. Seismic, well, and outcrop data prove particularly useful in identifying the limits for sizes of prospect area and reservoir thickness as well as porosity limits. Geochemical data are useful in identifying prospective areas as well as the composition of the hydrocarbon accumulations, i.e. oil-vs.-gas proneness. Research of similar hydrocarbon-bearing basins is also important in order to provide reasonable constraints on reservoir parameters as well as contributing further information on other aspects of petroleum geology that may prove useful in the study.

CONCEPTUAL PLAY ANALYSIS

There are several methods for estimating the quantity of hydrocarbons that may exist in a play, region or basin (White and Gehman, 1979; Masters, 1984; Rice, 1986; Lee, 1993). Petroleum assessments undertaken by the Geological Survey of Canada are currently based on probabilistic methods (Lee and Wang, 1990) that are developed in the Petroleum Exploration and Resource Evaluation System, PETRIMES (Lee and Tzeng, 1989). The conceptual hydrocarbon plays defined in the Old Crow region were analysed by applying a subjective probability approach to the various reservoir parameters. The lognormal option in PETRIMES was used since experience indicates that geological populations of pool parameters can adequately be represented by lognormal distributions.

Conceptual resource assessments in frontier regions use field-size estimates rather than pool-size predictions as derived from mature and immature play analysis. A field consists of one or more oil/gas pools or prospects in a single structure or trap. Probability distributions of oil and gas field sizes are computed by combining probability distributions of reservoir parameters, including prospect area, reservoir thickness, porosity, trap fill, hydrocarbon fraction, oil shrinkage, and gas expansion.

Probability distributions of oil and gas field sizes are then combined with estimates of numbers of prospects (from seismic and play area mapping) and exploration risks to calculate play potential and to estimate sizes of undiscovered fields.

Exploration risks at a play or prospect level are determined on the basis of the presence or adequacy of geological factors necessary for the formation of petroleum accumulations. Essential factors are reservoir, seal, source rock, timing of hydrocarbon generation, trap closure and preservation. Appropriate marginal probabilities are assigned for each geological parameter to obtain risk factors. The Old Crow conceptual plays are expected to exist (the low play-level risk of 1.0 was assigned to each play). Within each play, certain prospect-level risks are high and these are assigned appropriate risk factors. Exploration risk is an estimate, incorporating all risk factors, of the percentage of prospects within a play that are expected to contain hydrocarbon accumulations.

Uncertainties in oil and gas play potential and pool-size estimates for a given range of probabilities are necessarily greater than the ranges derived by discovery process analysis used for assessing mature plays. This is due to the nature of conceptual assessment results and because no discovered pool sizes are available to constrain sizes of undiscovered accumulations.

REGIONAL GEOLOGY

Two distinct structural and genetic regional geological regimes are present in northern Yukon. The vast majority of this area occupies the northern portion of the Cordilleran Orogen. An area in the extreme northeastern corner of the Yukon occupies a portion of the ancestral North American craton where little Phanerozoic deformation has taken place. This area of ancestral North America is known as the Interior Platform.

There are two major geological components, separated by the northwest-trending Tintina fault, within the Cordilleran Orogen of northern Yukon. The southwestern area represents the amalgamated and accreted geological terranes and contains younger, more complex assemblages of varying rock-types. The northeastern region, which is part of the morphogeological Frontal Belt, is comprised of a thick assemblage of older sedimentary rocks deposited on the relatively stable ancient North America margin (Hart, 1999).

The western edge of the ancient North America craton extended far out into the ancient Pacific Ocean. This submerged continental shelf of crystalline basement rock is at least 1.7 billion years old and is present throughout northern Yukon beneath both the Interior Platform and the Cordilleran Orogen. These rocks, in part, provided the stable continental platform, upon which sediments, dominantly limestone and sandstone, were deposited over a period of a billion years (Hart, 1999). Shale, sandstone and chert accumulated in basinal regions of deeper water. Thus, the two depositional environments (platform and basin) gave rise to distinct sedimentary packages, dominated by limestone and shale, respectively. These shale and limestone packages are now in fault contact with each other. The Interior Platform amassed thicknesses between 5 and 25 km of dominant limestone and sandstone. Limestone accumulated during quiescent times in warm, shallow and clear water. The sandstone consists of detritus eroded from the Canadian Shield.

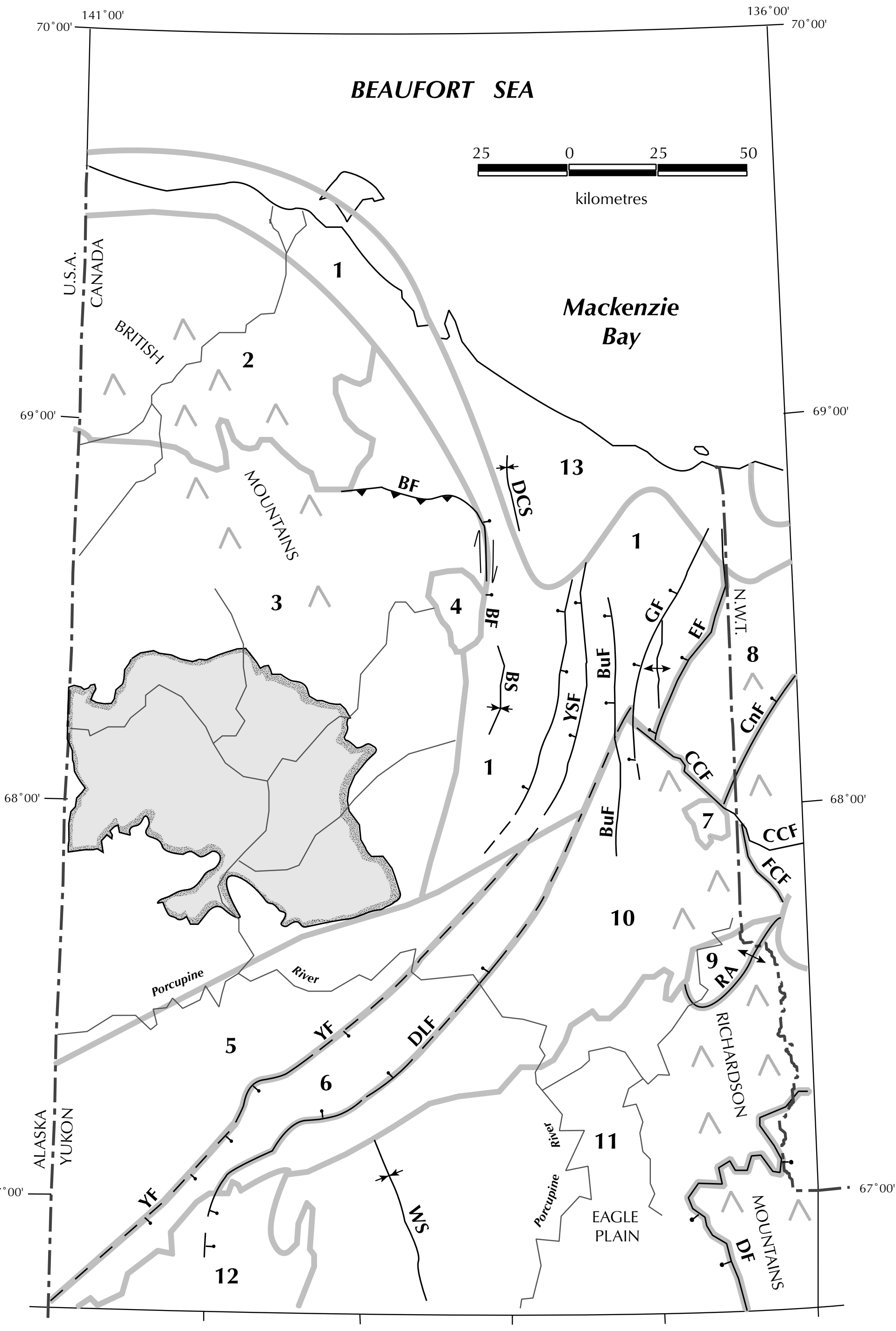
Figure 3 shows the principal tectonic elements and structures in northern Yukon (Norris, 1997b). In northwestern Yukon within the Frontal morphogeological belt north of Tintina Fault, there is a large structural and physiographic depression known as the Old Crow-Babbage Depression. Lying on the north flank of the Brooks Range Geanticline, the Depression is bounded to the north by the Romanzof Uplift, the east by the Rapid Depression and Barn Uplift, and the south by the Aklavik Arch Complex (Norris, 1997b). These bounding tectonic elements were uplifted by the Laramide Orogeny. Surface mapping by Norris (1981a, 1981b) indicates that sedimentary rocks occupying this depression range in age from Proterozoic to Early Cretaceous. The Old Crow-Babbage Depression consists of a complex association of structural highs and lows partly buried by Tertiary and Quaternary nonmarine deposits in the Old Crow Basin (Norris, 1997b). Seismic interpretation by Morrell and Dietrich (1993) infers the Tertiary depocentre defining the Old Crow Basin proper overlies Mesozoic and older strata at a major unconformity. No evidence exists for an underlying Mesozoic depocentre (Morrell and Dietrich, 1993). Two minor basins, the Bluefish and Driftwood basins, are preserved in an arcuate zone of structural discontinuity south of Old Crow plain (Fig. 2). Outcrop in these basins reveal a thin Cretaceous cover directly overlying Lower Paleozoic rocks (Norris, 1981b).

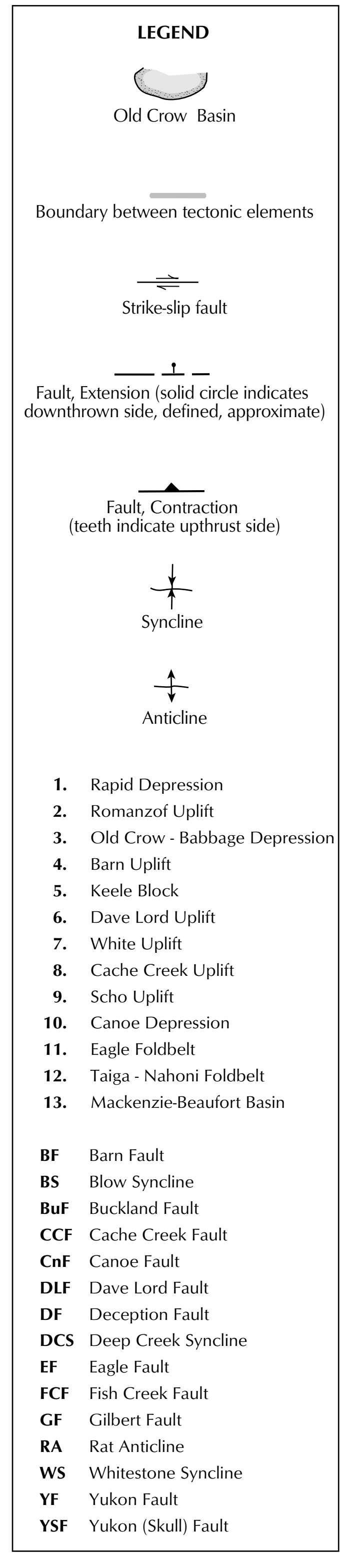
There are intensely folded and faulted Ellesmerian carbonates and clastics on the north and east flanks of the Depression. There is also a single Paleozoic outcrop of Carboniferous Kayak shale exposed in the middle of the Old Crow Basin (Fig. 2) (Norris, 1981a). If these potential hydrocarbon source and reservoir rocks are folded and sealed beneath this plain, then there may be significant hydrocarbon potential beneath the Old Crow Basin. The age, name and lithology of potential reservoir and source rocks found in the study area are indicated in Fig. 4 and discussed below.

STRATIGRAPHY AND DEPOSITIONAL SETTING

It is unknown whether sedimentation was continuous throughout Phanerozoic time in the Old Crow region. There were at least two orogenic episodes that produced periods of uplift and erosion in this area. There is no evidence of Early Triassic deposition within surrounding positive tectonic elements neighbouring the Old Crow Basin and no major half-graben is interpreted to have formed in the area comparable to the thick coarse clastic development on the Alaska North Slope.

Figure 3. Location map for principal elements and structures in northern Yukon (adapted from Norris, 1997b).





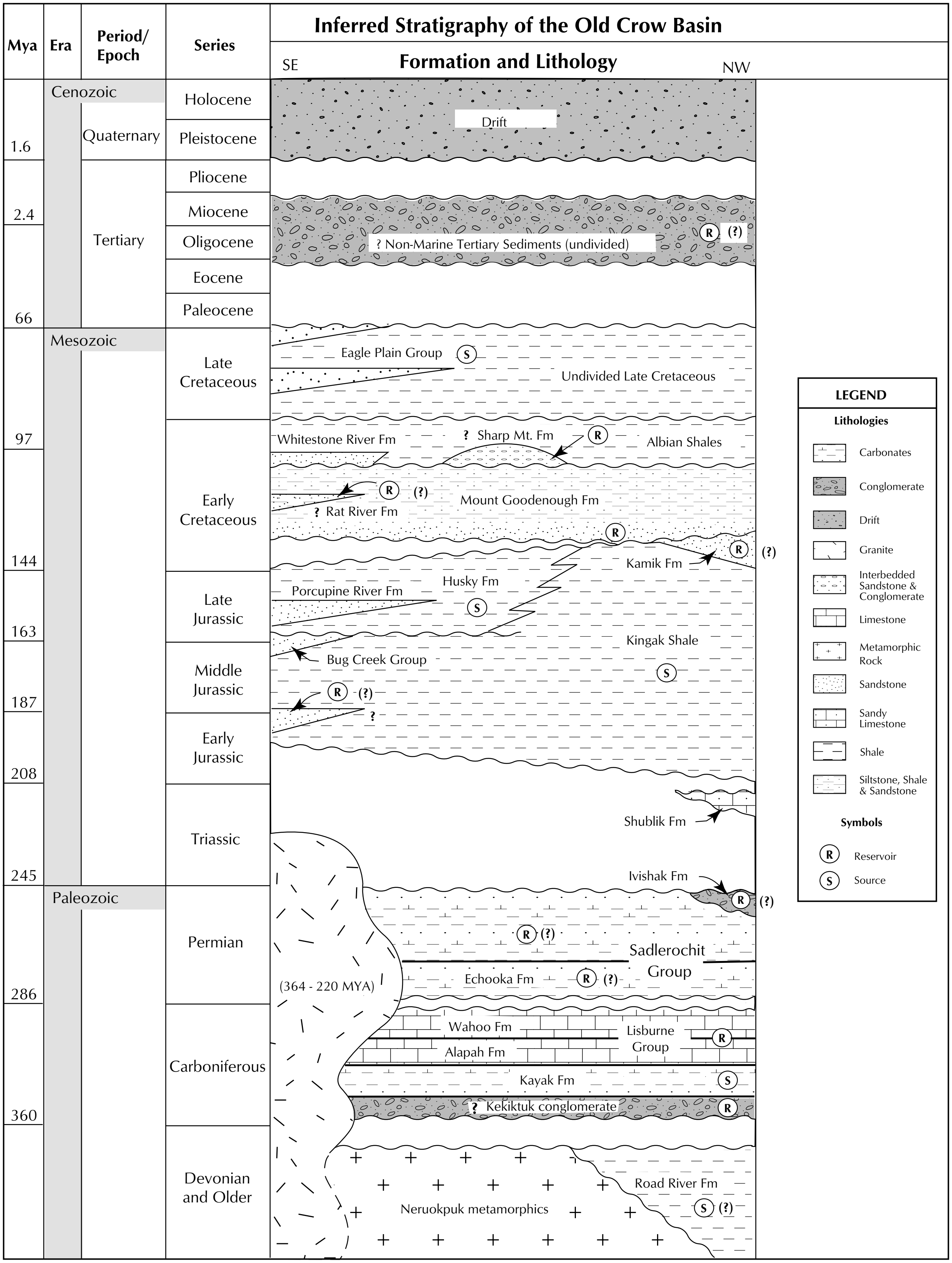
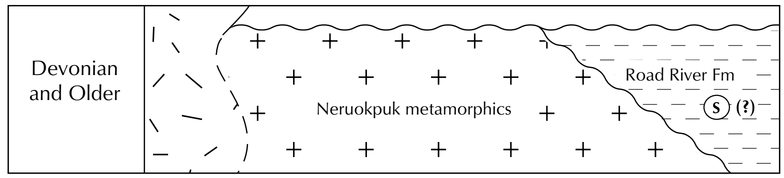


Figure 4. *Inferred stratigraphy of the Old Crow Basin (adapted from Morrell and Dietrich, 1993).*

PRECAMBRIAN

Limestones and quartzites of the Proterozoic Neruokpuk Formation are exposed in the core of the Black Fox Anticline north of the Old Crow Basin (Fig. 2). Numerous outcrops of ?Helikian quartzites, argillites and dolomites have been observed in the southwestern portion of the study area adjacent to the Old Crow granite complex (Norris, 1981b). These sediments have undergone metamorphism and represent the effective economic basement in the area.

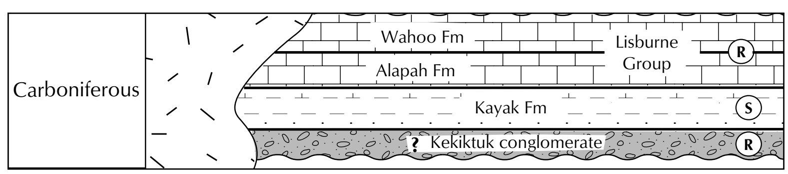


LOWER PALEOZOIC

The Porcupine Platform contains a succession of Lower Paleozoic carbonate rocks about 2.3 to 3 km thick lying unconformably on metasedimentary Proterozoic rocks (Norris, 1984; Lane, 1998). The platform is almost entirely surrounded by early Paleozoic deep-water shale facies. The Silurian to Early Devonian transition from shelf carbonates to deep water shale facies occurs just south of the Old Crow Basin within the Keele Range. Norris (1981b) mapped marine limestones of the Ogilvie Formation in the Keele Range. Bluefish and Driftwood basins are underlain by carbonate facies and likely overlie potential reservoir strata. The presence of Lower Paleozoic carbonate facies under the Old Crow Basin, however, is unlikely (Pugh, 1983; Morrow, 1989; Morrell and Dietrich, 1993). Instead, a thick succession of marine shale and argillaceous limestone of the Road River Group is interpreted to occur beneath the Old Crow Basin (Pugh, 1983; Morrow, 1989). Lower Paleozoic Road River strata are probably overmature but may retain some potential as a source rock for gas.

CARBONIFEROUS

At Black Fox Anticline immediately to the north of the Old Crow Basin, the Proterozoic to Early Paleozoic Neruokpuk metasediments are overlain by Carboniferous strata at a major unconformity. The lowermost Carboniferous sediments are chert conglomerates of the Kekiktuk Formation (Fig. 4). Chert, quartz and quartzite clasts are encased in a tight siliceous matrix. The unit is probably preserved throughout the Old Crow Basin varying in thickness from one to 50 m, averaging about 25 m (Richards e*t al.*, 1997). Porosity development in the subsurface is unknown but surface exposures indicate that primary porosity is generally poor. Secondary porosity development may be significant but patchy. Leaching has produced an important Kekiktuk reservoir beneath the Alaskan North Slope, namely the Endicott Field (Craig e*t al.*, 1985).

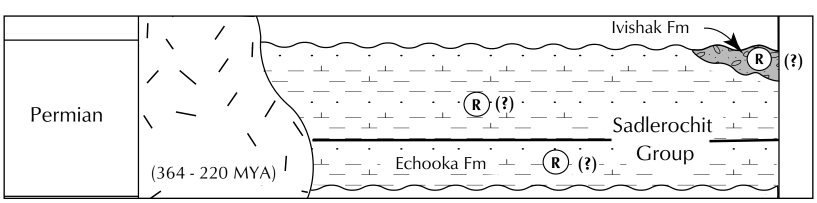


Near the junction of Timber Creek and Old Crow River at Timber Ridge, there lies an isolated outcrop of Carboniferous Kayak Formation (Fig. 2). Bamber and Waterhouse (1971) describe this outcrop as skeletal and micritic limestone, but Kayak strata in the surrounding area are dominated by shales. The Kayak Formation consists of a basal sandstone unit, a middle shale-dominated unit and an upper unit containing shale and minor limestone. Thicknesses vary from 220 to 375 m (Richards e*t al.*, 1997). Terrestrial plant remains and coal seams ranging up to 5.5 m in thickness have been observed in these rocks. The Kayak Formation records a transgressive deepening-upward depositional episode. Coal-bearing siliciclastics deposited in shoreline and coastal plain settings of the basal Kayak are succeeded by shales and carbonates likely deposited in shallow neritic and intertidal environments (Richards *et al.*, 1997). Coeval Carboniferous shales in Eagle Plain to the southeast are described as fair to good source rocks for gas with some oil potential (Link *et al.*, 1989). It would be reasonable to infer that comparable shales in the Old Crow Basin have at least fair gas-generating potential if maturity is similar. These rocks do, however, exhibit high maturity to the north and east of the Old Crow Basin and are probably well beyond the oil window beneath the basin itself.

Conformably overlying the Kayak Formation in the Old Crow region is a widespread Carboniferous carbonate succession consisting of the Alapah and Wahoo formations of the Lisburne Group. These rocks are equivalent to the Hart River and Ettrain limestones to the south and southeast in Eagle Plain. The Alapah Formation is the thickest and most extensively preserved carbonate unit in northern Yukon. It is more than 1300 m thick in the western British Mountains and thins to the northeast (Richards *et al.*, 1997). Lower Alapah carbonates in the British Mountains consist of lime mudstones and wackestones, while skeletal lime grainstones and packstones dominate the upper part. Lower Alapah carbonates were deposited in restricted to protected shelf environments while upper Alapah rocks were laid down in a shelf margin environment. Immediately overlying Alapah carbonates is another carbonate unit called the Wahoo Formation. This formation ranges in thickness from 130 to 225 m in the British Mountains (Richards *et al.*, 1997). Lime grainstones and packstones dominate this cyclic succession. Deposition probably occurred on protected shelf to shelf margin marine environments. Carboniferous carbonates have been identified as eminent potential reservoir units in the Alaskan North Slope and in Eagle Plain. Dolomites within the Lisburne Group carbonate succession contain significant reserves of hydrocarbons at Prudhoe Bay.

PERMIAN

An unconformity separates Carboniferous strata from overlying Permian sediments. In the British Mountains, north of the Old Crow Basin, there is a thin (~200 m), poorly known succession called the Sadlerochit Group that was deposited in a Permian basin that developed north of the Ancestral Aklavik Arch (Fig. 4; Richards *et al.*, 1997). Local erosional remnants have been preserved in the British Mountains. Shales, sandstone and minor carbonates of the Lower Permian Echooka Formation of the Sadlerochit Group may have been deposited in the Old Crow region. The Echooka Formation may be coeval with the Permian Jungle Creek Formation south of the study area. Both of these units likely contain a shallow marine facies, including shelf sandstones which may encompass potential reservoir horizons. The potential of Echooka sands in the Alaskan North Slope is considered to be poor due to inadequate reservoir permeability (Craig *et al.*, 1985). However, Jungle Creek sandstones do contain pooled reservoirs in southern Eagle Plain (Hamblin, 1990).



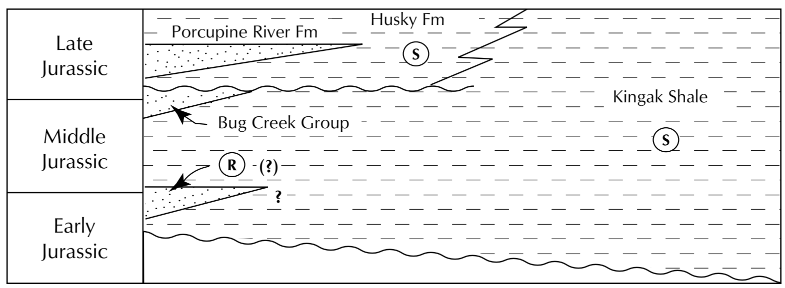
TRIASSIC

The Lower Triassic Ivishak Formation of the Sadlerochit Group comprises the principal reservoir in the Prudhoe Bay Field (Craig *et al.*, 1985). However, Ivishak conglomerates probably do not occur beneath the Old Crow Basin. Isopach trends of Ivishak Formation show a distinct depositional thinning to the southeast from the Alaskan North Slope into northwestern Yukon. This apparent lack of Early Triassic strata in outcrop areas surrounding Old Crow region suggests that the area was uplifted during this period. The subsequent Mesozoic history consists of episodic but overall southerly overstepping of marine facies as sea level rose (Morrell and Dietrich, 1993).

The initial transgression is represented by the Upper Triassic Shublik Formation, locally preserved only in extreme northwestern Yukon. Although Shublik strata are postulated to be a major source of oil at Prudhoe Bay, the carbonate facies in northwestern Yukon is unlikely to be a source rock of equivalent quality.

JURASSIC

Jurassic sediments, well exposed to the east of the Old Crow region, are a shallow marine clastic succession typical of an inner shelf facies. To the northwest, the clastics pass laterally into outer shelf facies shales of the Brooks-Mackenzie basin. Rocks of the Bug Creek Group may have reservoir potential but these sandstones are likely present only in the eastern extremities of the Old Crow region. Jurassic rocks beneath most of the Old Crow Basin are likely fine-grained deep-water shales and siltstones of the Kingak Formation. Poulton (1997) believes that Jurassic rocks in northern Yukon are craton-derived from the east and southeast.

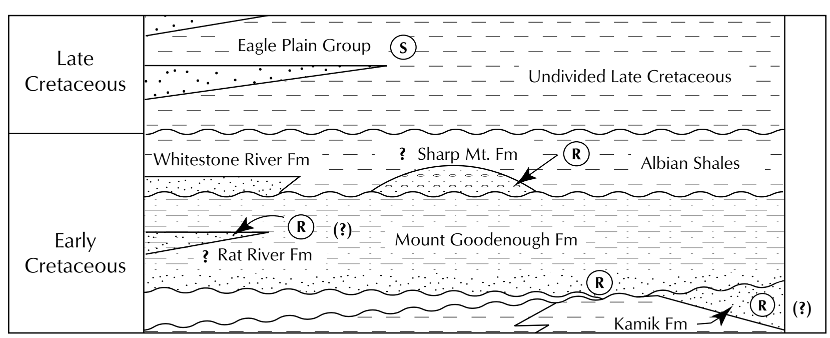


The Upper Jurassic marine sandstones of the Porcupine River Formation also pass laterally into shales of the Kingak Formation to the northwest. To a large extent the paleogeography of these units is similar to the Bug Creek and equivalent strata. Therefore, facies in the subsurface of the Old Crow Basin are likely distal shelf or deep-water clastics (Morrell and Dietrich, 1993). Porcupine River sands outcropping east of the Old Crow Basin generally consist of fine-grained sandstones. Prospects for significant reservoir thicknesses and porosity appear negligible.

Jurassic Husky and Kingak shales have been recognized as potential source rocks in Beaufort-Mackenzie Basin and the Alaskan North Slope. Davies and Poulton (1989) report elevated Thermal Alteration Indices (T.A.I.) and vitrinite reflectance values from outcrops in the western Richardson Mountains. If these rocks are present beneath the Old Crow Basin, their maturity may be comparable given the additional depth of burial. These source rocks have passed through the oil window and the generation of dry gas may still be taking place.

CRETACEOUS

Paleogeographic reconstructions indicate that deposition in the Old Crow Basin during Late Jurassic to Early Cretaceous time occurred within an inner to outer shelf environment, generally distal to a northwesterly tract of transitional facies (Dixon, 1986). Two coarsening-upwards sequences observed in northern Richardson



Mountains to the east are singularly represented in the Old Crow basin area as distal Husky shales. Lower Cretaceous Kamik sands are acknowledged in northern Yukon and the Beaufort-Mackenzie Basin as containing excellent reservoirs due to deposition as a major deltaic progradational sequence. However, Kamik sandstones are absent in Keele Range directly south of the basin and by inference, are not thought to exist beneath the Old Crow Basin.

Unconformably overlying Neocomian strata is the Upper Hauterivian to Barremian Mount Goodenough Formation. The Mount Goodenough Formation is also truncated by an Early Albian unconformity. This Lower Cretaceous succession consists of marine siltstones, shales and very fine-grained sandstones. Potential reservoir horizons may be present in a fairly persistent thin basal sandstone with local lenses of coarser grained material. The Rat River Formation which represents a regressive pulse of shallow marine sandstones may also contain porous horizons (Fig. 4). A general shale-out to the northwest and drastic Early Albian erosion across the Old Crow basin area curtails the prospects for reservoir development.

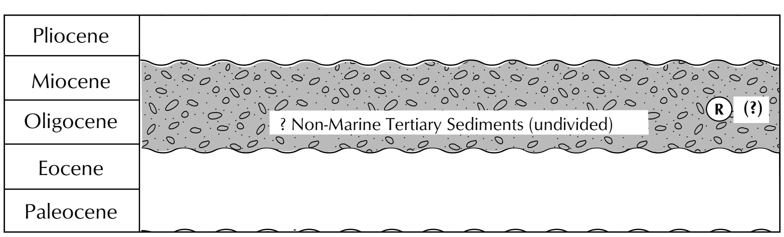
During Albian time, widespread deposition of deep-water, fine-grained sediments took place. To the southeast in Eagle Plain, the Lower Cretaceous Whitestone River Formation consists of shale interbedded with very fine-grained sandstone and siltstone. In the Old Crow region, equivalent strata were deposited in the outer shelf and slope facies.

A coarse clastic unit occurring at the base of the Albian is designated the Sharp Mountain Formation. It has been mapped in the Keele Range southeast of Old Crow Plain where 600 to 1000 m of interbedded sandstones and conglomerates are present. These rocks may be present beneath the Old Crow Basin as well. Dixon (1986) believes that these coarse deposits are gravity flow deposits derived from the northwestern flank of the Keele-Kandik Trough and transported into deeper parts of the basin. These potential reservoirs lie beneath a thick seal of Albian shale.

Upper Cretaceous strata in the area consist of a thick succession of interfingered marine shales and sandstones known as the Eagle Plain Group. These rocks are fair to excellent gas source strata in Eagle Plain, although immature (Link and Bustin, 1989; Link *et al.*, 1989).

TERTIARY

Tertiary outcrop occurrences are limited to Eocene and younger deposits which are coal-bearing and non-marine. These rocks unconformably overlie Cretaceous shales and sandstones (see Fig. 6 for outcrop location; Hopkins and Norris, 1974). The Tertiary rocks present in the Old Crow Basin are likely to be non-marine fluviatile or lacustrine in origin. Coal laminae are interbedded with poorly consolidated clastic sediments. The continental nature of these sediments suggests that potential hydrocarbon source rock is gas-prone and immature. Biogenic gas is a possible hydrocarbon product that may have been generated within this succession.



STRUCTURAL GEOLOGY

An extensive gravity survey was undertaken by Gulf Oil Canada Ltd. in 1973 in the Old Crow region (Overland Exploration Services (1969) Ltd., 1973) (about 2000 line-kilometres, 3 kilometre line spacing). Gulf concluded that the gravity anomalies indicated irregular basement topography containing fault-bounded sub-basins accommodating about 1.8 to 4.0 km of post-Paleozoic strata. Reinterpretation of the Bouguer Gravity map by Morrell and Dietrich (1993) (Fig. 5) suggest that two east-west trending lows set apart by a gravity high may in fact represent two synclines separated by an anticlinal ridge. The wavelengths of these interpreted folds correspond with wavelengths observed in surrounding outcrop. It is possible, however, that these interpreted anticlines are also fault-bounded. It is also reasonable to assume that Carboniferous rocks subcrop beneath Quaternary cover under the gravity high interpreted as an anticlinal structure due to the presence of Kayak shale and Lisburne carbonate outcrops along its axis (Fig. 2).

The northern sub-basin shows a slightly larger gravity anomaly magnitude which implies greater thickness of less dense sediment (Fig. 5). Cenozoic sediments in the area are thought to be a low density succession providing sufficient contrast with Mesozoic and Paleozoic rocks.

Figure 6 depicts seismic coverage in the Old Crow region. Approximately 2000 line-km of reconnaissance seismic was shot between 1969 and 1972. Interpreted seismic sections reproduced in this study (Figs. 7, 8, 9 and 10) are derived from Morrell and Dietrich (1993). The stratigraphic units differentiated in these sections are Tertiary (T), Mesozoic (M), Paleozoic (P), and Proterozoic (Pr). Seismic reflection character and velocities of these stratigraphic units were obtained from wells in Eagle Plain and the Alaskan North Slope. Limited outcrop exposure was also used to identify these units.

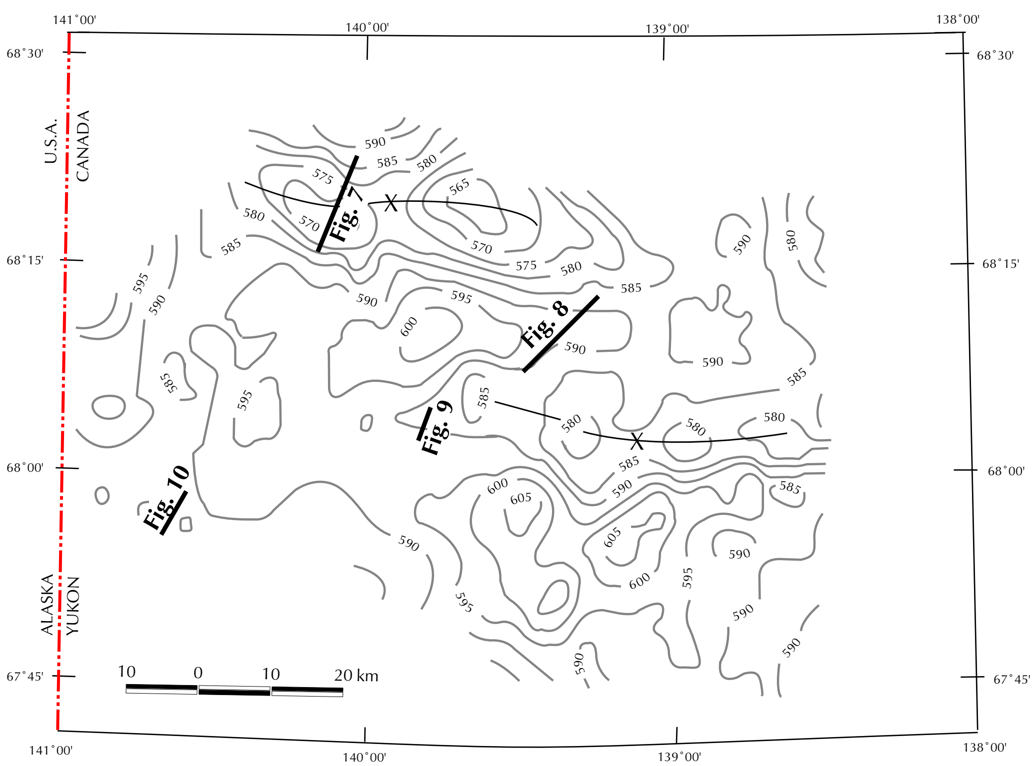


Figure 5. *Interpretation of Bouguer gravity anomalies for the Old Crow Basin (interpretation by Morrell and Dietrich, 1993; survey by Overland Exploration Services (1969) Ltd., 1973).*

LEGEND

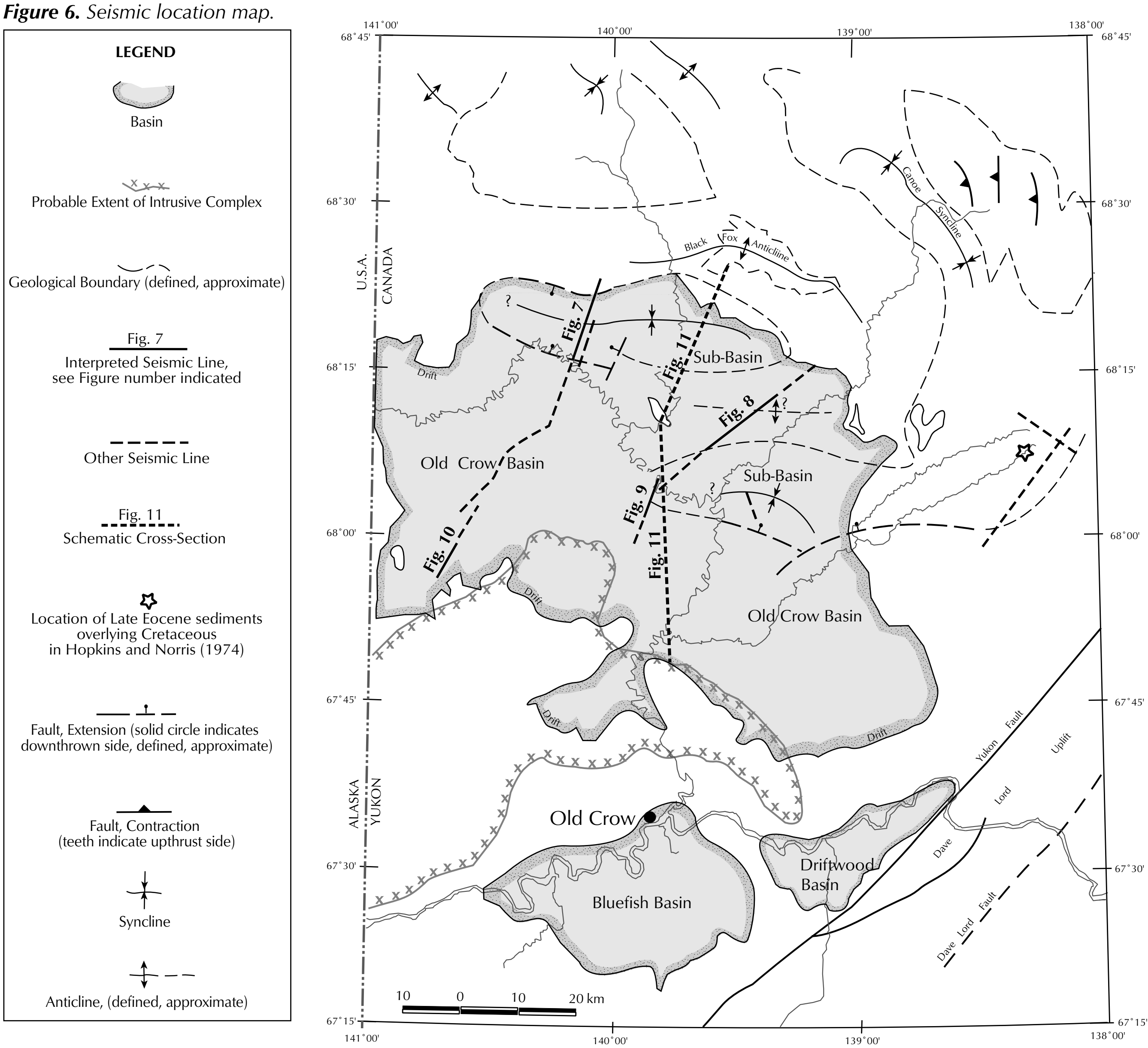
Sub-basin

Fig. 7
Interpreted Seismic Line, see Figure number indicated

Note: gravity contours are shown in mgals

The seismic section in Figure 7 crosses the entire width of the northern sub-basin (Figs. 5, 6). The sub-basin is interpreted to be an asymmetric syncline consisting of coherent and continuous reflections representing Tertiary sediments overlying less continuous reflections in underlying Mesozoic and Paleozoic strata. The synclinal axis corresponds closely with the gravity low. The sub-basin is up to 0.75 s or approximately 800 m deep and the floor appears to be an angular unconformity where underlying reflections are truncated and overlying reflections onlap the boundary. A small normal fault occurs within the upper part of the section. Directly north of the northern terminus of this section, Paleozoic rocks outcrop. Paleozoic rocks most likely underlie the northern flank of the sub-basin. The poor reflection patterns of these rocks seem to indicate steep dips and complex structure similar to outcroppings north of the basin. North-dipping rocks below the southern flank of the sub-basin have dips slightly or markedly steeper than the overlying unconformity. Below the unconformity on the southern flank, is 300 to 500 m of clastic Mesozoic strata, which in turn unconformably overlie Paleozoic carbonates or highly compacted clastics (Fig. 7).

Figure 6. *Seismic location map.*



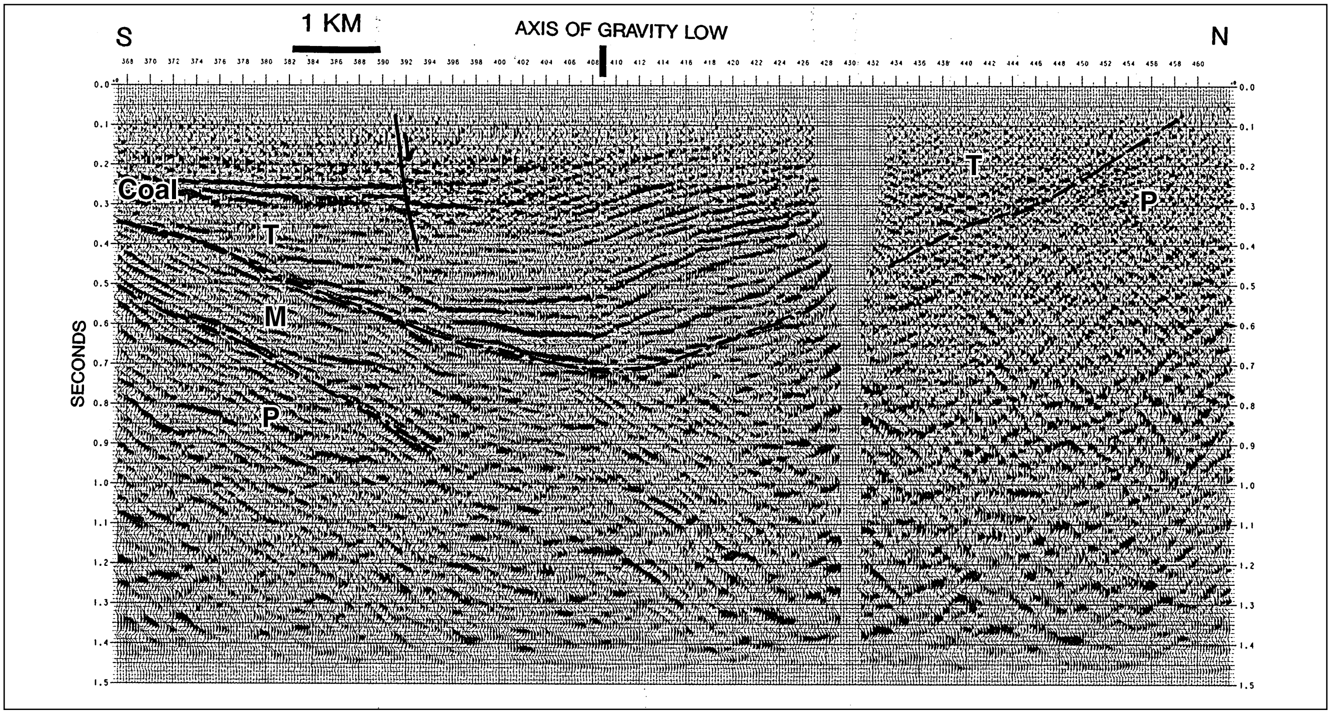


Figure 7. *Migrated seismic section across the northern sub-basin (location in Fig. 6). Probable coal-bearing Tertiary strata (T) are up to 800 m thick (0.75 s) in the centre of the sub-basin and unconformably overlie ?Mesozoic and ?Paleozoic strata (from Morrell and Dietrich, 1993).*

The seismic section in Figure 8 spans part of the anticline separating the northern and southern sub-basins (Figs. 5, 6). The axis of the gravity high coincides with the crest of the anticline outlined by the seismic reflections. It is not possible to differentiate Mesozoic and Paleozoic strata in this section. However, the reflections from Mesozoic and/or Paleozoic rocks suggest up to 600 to 700 m (0.3 s) of relief with younger strata being partially or wholly truncated on the crest of the structure (Morrell and Dietrich, 1993).

The seismic section in Figure 9 occurs on the southern flank of the southern sub-basin (Figs. 5, 6). Thick, coal-bearing Tertiary sediments (630 - 730 m) unconformably cover both Mesozoic and Paleozoic strata. Faults with reverse throw offset lower Tertiary and older strata.

The last seismic section, shown in Figure 10, intersects the southwestern corner of the Old Crow Basin (Figs. 5, 6). Proterozoic outcrops to the west preclude the likely occurrence of Mesozoic and Paleozoic strata below the pre-

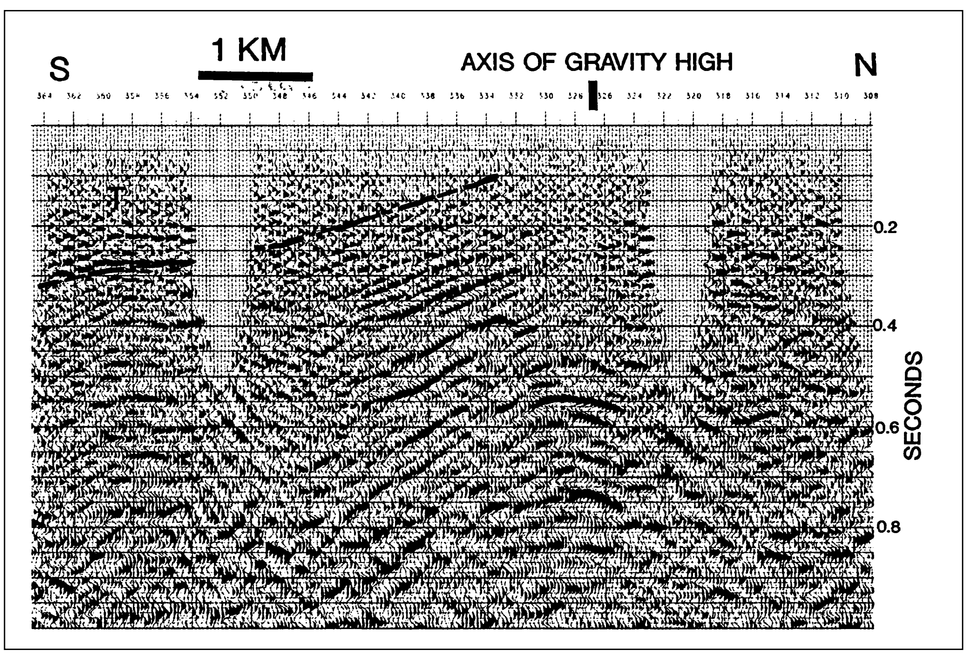


Figure 8. *Migrated seismic section across an anticline between the northern and southern sub-basins (location in Fig. 6). Folded ?Mesozoic and Paleozoic strata display up to 700 m (0.3 s) of vertical relief (from Morrell and Dietrich, 1993).*

Figure 9. *Structure stack seismic section on the flank of the southern sub-basin (location in Fig. 6). 630 to 730 m (0.6 to 0.7 s) of coal-bearing Tertiary strata unconformably overlie ?Mesozoic (M) and ?Paleozoic (P) strata. The lower sub-basinal sediments and underlying rocks are disrupted by a small offset (?reverse) fault (from Morrell and Dietrich, 1993).*

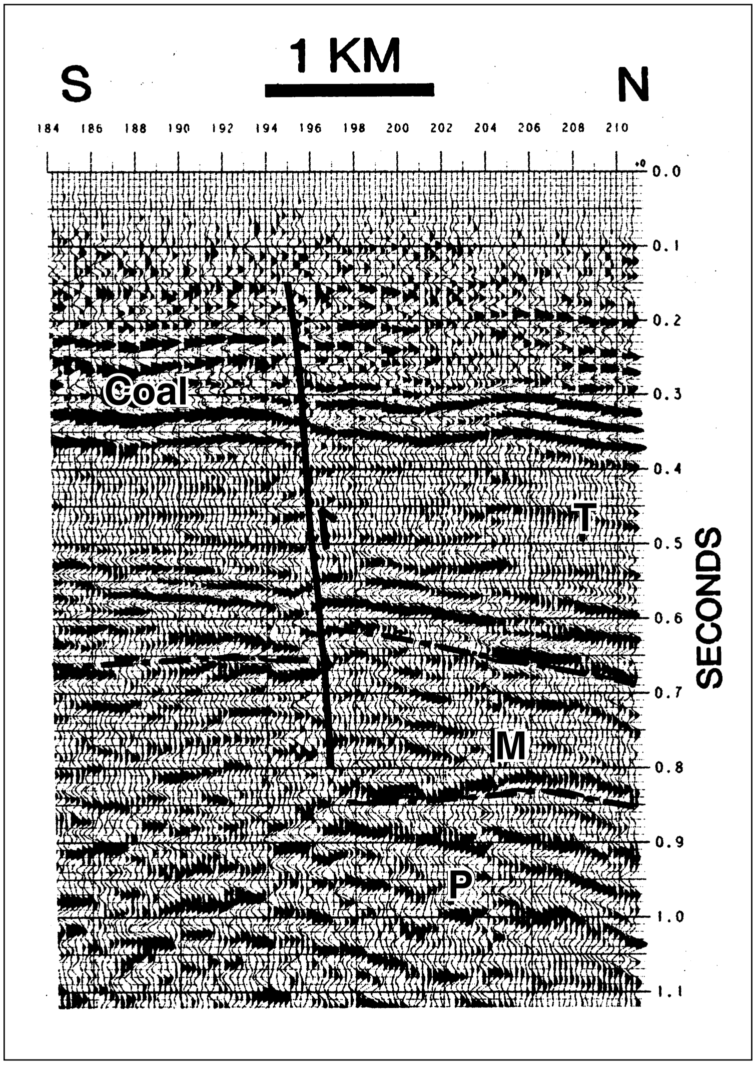
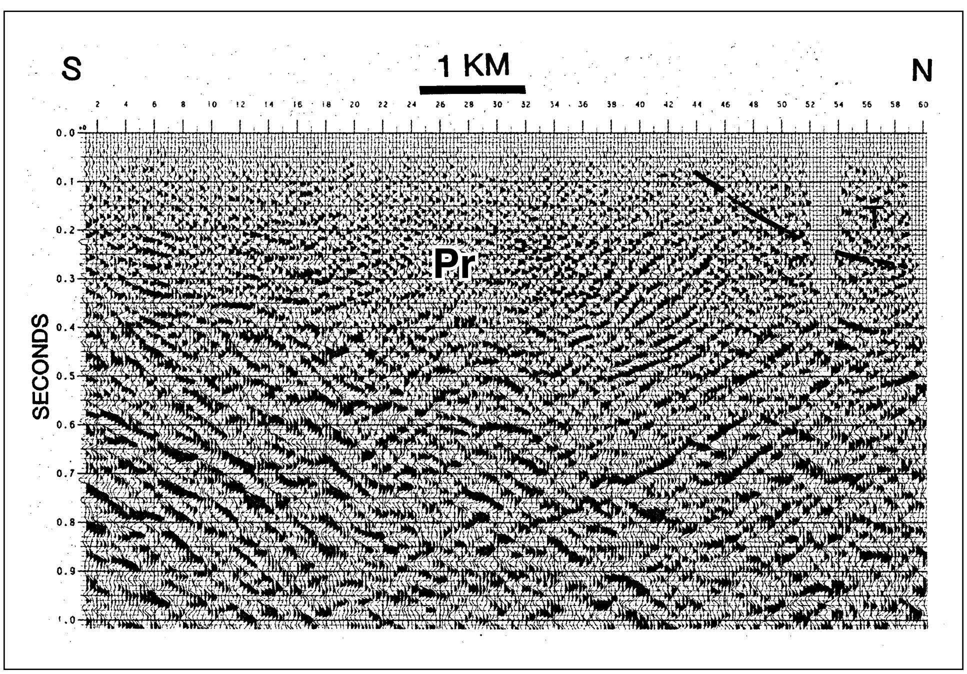


Figure 10. *Migrated seismic section near the southwestern margin of the Old Crow Basin (location in Fig. 6). Reflection patterns indicate that ?Proterozoic (Pr) metasedimentary rocks beneath the basin are intensely deformed and possibly thrust faulted (from Morrell and Dietrich, 1993).*



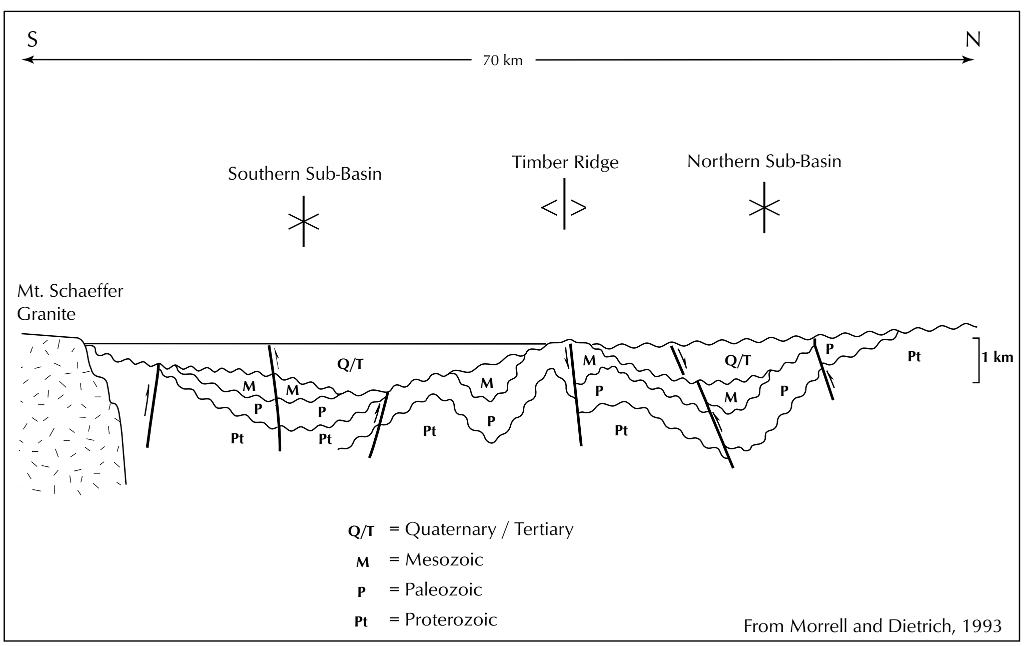
Tertiary unconformity. It is speculated that intensively deformed Proterozoic metasediments directly underlie a thin Tertiary/Quaternary succession. Variable reflection dips and cutoff patterns in Proterozoic strata may indicate a thrust-faulted terrain.

The gravity and seismic geophysical evidence indicates that two Tertiary depositional sub-basins may be present beneath Quaternary cover in the Old Crow region. The east-west trends of these sub-basins parallel fold axes in the mountains to the north and probably represent synclinal structures. The gravity anomalies within these sub-basins indicate thickening of low-density Cenozoic sediments.

It is believed that Mesozoic deposition in the Old Crow Basin probably took place in a mildly extensional structural regime prior to a major compressional folding episode in the early Tertiary. If this is true, then no systematic correlation is expected between Mesozoic deposition and the location of the younger Tertiary sub-basins. Mesozoic strata may have escaped truncation by overlying Cenozoic unconformities within the sub-basins but not across intervening anticlines. Figure 11 is a schematic cross-section illustrating the speculated stratigraphic relationships among Tertiary, Mesozoic and Paleozoic strata across the two Tertiary sub-basins. There appears to be a periodic repetition of large amplitude structures beneath the Old Crow Basin that are parallel to folds exposed in mountains immediately to the north of the basin. These folds are cored by Proterozoic and Paleozoic rocks overlain by variably preserved Mesozoic strata (Fig. 11; Morrell and Dietrich, 1993). The Mesozoic succession is, in turn, overlain by a relatively flat Tertiary succession at a major truncating unconformity. This unconformity is also locally folded. The sub-basins created by the synclinal axes of folds were filled by Tertiary sediments during subsidence of the basin subsequent to uplift and erosion of Mesozoic strata. Hopkins and Norris (1974) identified Late Eocene sediments unconformably overlying Mesozoic rocks east of the Old Crow Basin (Fig. 6). This relationship is consistent with a widespread Middle Eocene unconformity separating Tertiary basin fill from older rocks.

Rocks in the Old Crow region were deformed by two major orogenic episodes: an Early Devonian compressional tectonic event represented by acutely folded and thrust-faulted Ellesmerian strata, and a latest Cretaceous to Tertiary Laramide compressional deformational episode. Evidence indicates that early Carboniferous deformation is present to the east of the Old Crow basin area. Outcrop strata surrounding the Old Crow Basin have been folded and thrust-faulted. The Late Jurassic and Early Cretaceous Brookian orogenic episode characterized by an extensional collapse of the orogen seems to have little affected the rocks in the Old Crow region.

Figure 11. *Schematic cross-section from north to south across the Old Crow Basin.*



PETROLEUM GEOLOGY

EXPLORATION HISTORY

Petroleum exploration in the Old Crow Basin has been quite limited. About 200 km of reconnaissance seismic was shot in the basin between 1969 and 1972 and no wells have been drilled in the area (Northern Oil and Gas Directorate, 1995). The nearest well is the Socony Mobil-W.M. Molar P-34 well drilled in northern Eagle Plain, 50 kilometres to the southeast. Exploration in the Old Crow Basin area has been suspended since 1973 because of environmental concerns.

Two 1:250,000 geological maps (Blow River and Davidson Mountains map-sheet: NTS 117 A & B and Old Crow map-sheet: NTS 116N, E1/2 & 116O) were compiled by D.K. Norris, the coordinator of the regional Geological Survey of Canada mapping project, 'Operation Porcupine' (Norris, 1981a,b). Norris also published a regional geological map for northern Yukon and northwestern District of Mackenzie at a scale of 1:500,000 (Norris, 1984).

RESERVOIRS

LOWER PALEOZOIC

The Lower Paleozoic carbonate shelf/basinal facies transition occurs immediately south of the Old Crow Basin (Norford, 1997; Lane, 1998). Potential reservoir horizons may occur in unnamed dolomites described by Norford (1997) north of Bluefish Lake on the Porcupine Platform. These Lower Paleozoic carbonates outcrop further north in the Old Crow map-sheet (Norris, 1981b) and appear to underlie both Bluefish and Driftwood basins. The dolomites near Bluefish Lake are reported to be about 180 m thick in this area and are Early Silurian in the basal part (Norford, 1997). The Lower to Middle Devonian Ogilvie Formation outcrops in the Keele Range south of Bluefish and Driftwood basins (Norris, 1981b). A.W. Norris (1997a) speculates, according to paleogeographic reconstructions, that an Upper Emsian dolomite lithofacies was deposited to the south of Porcupine River, constituting part of a Lower Devonian marine carbonate succession on the Yukon Stable Block. Further north, under the Old Crow Basin, a Lower Paleozoic basinal facies occurs, containing minimal reservoir potential. The presence of Lower Paleozoic carbonate shelf facies beneath the Old Crow Basin is unlikely.

CARBONIFEROUS

Carboniferous strata in the Old Crow basin area consist of a potential reservoir facies basal conglomerate (Kekiktuk Formation), the recessive Kayak shale and undivided argillaceous limestones of the Lisburne Group which may have patchy porous intervals (Fig. 4). The Kekiktuk Conglomerate, containing quartz, chert, quartzite and granitic clasts, generally occurs in a tight siliceous matrix. Even though porosity development in this unit is frequently poor in the subsurface, leaching has produced significant reservoirs in Alaska, specifically at the Endicott Field (Craig e*t al.*, 1985). Primary porosity is very low or absent, but secondary, patchy porosity likely has been developed.

Dolomitized facies and leached zones adjacent to unconformities are porous horizons occurring in marine Upper Carboniferous Alapah and Wahoo carbonate formations of the Lisburne Group. It is possible that these Lisburne carbonates are absent from the Old Crow Basin and may instead be represented by a shale facies. There have been discoveries of hydrocarbons in equivalent rocks on the Alaskan North Slope, in southern Eagle Plain (Hamblin, 1990) and in the Unak L-28 well in the Mackenzie Delta.

PERMO-TRIASSIC

Permian and Lower Triassic potential reservoir strata represented by Echooka sandstones of the Sadlerochit Group and conglomeratic Ivishak Formation, respectively, exhibit good porosity development in equivalent rocks of the Eagle Plain and the Alaskan North Slope. Paleogeographic reconstructions (Bamber and Waterhouse, 1971), however, indicate that these reservoir units may not occur beneath the Old Crow Basin.

JURA-CRETACEOUS

Marine sands of Jurassic age, specifically Bug Creek Group and Porcupine River Formation, have reservoir potential in some instances but paleogeographic reconstructions (e.g. Poulton e*t al.,* 1982) place these coarser grained reservoir units outside the Old Crow Basin. Similarly, Hauterivian Kamik and late Barremian to Aptian Rat River sands, interpreted as regressive pulses and containing excellent potential reservoir horizons in surrounding areas, do not appear to underlie the Old Crow Basin. Fine-grained shales and siltstones of Kingak and Husky formations beneath the basin provide very limited reservoir potential.

Potential Lower Cretaceous reservoir horizons beneath the Old Crow Basin are the Upper Hauterivian to Barremian Mount Goodenough Formation, a basal succession of marine siltstones, shales and fine-grained sandstones, and an Albian coarse clastic unit called the Sharp Mountain Formation (Fig. 4). The Sharp Mountain succession consists of interbedded sandstones and small-pebble conglomerates (Dixon, 1986). These Sharp Mountain sands may have significant reservoir potential beneath the Old Crow Basin.

There is little or no reservoir potential in Upper Cretaceous strata. The Eagle Plain Group, consisting of a thick succession of interfingered marine shales and sandstones, exhibits poor reservoir quality in Eagle Plain and is likely to have similar qualities if present beneath the Old Crow Basin.

Generally, there is great uncertainty with respect to the depositional extent of Jurassic and Cretaceous sandstones that exhibit favourable reservoir properties in the Old Crow Basin.

TERTIARY

Reservoirs in poorly consolidated Eocene and younger sediments may occur as porous lenses within the succession. These fluviatile and lacustrine sediments may contain small accumulations of biogenic gas. Gas hydrates may be trapped beneath permafrost in the methane-hydrate stability zone.

SEALS

In Lower Paleozoic carbonate reservoirs, top seal is likely supplied by overlying Carboniferous shales. Overlying Paleozoic shale successions, such as Carboniferous Kayak shales and shaly intervals in the Permian Sadlerochit Group, provide very good seal for the Kekiktuk reservoir interval. This seal is so efficient that it may isolate this reservoir from overlying potential source rock. Jurassic and Upper Cretaceous shales have good seal potential for Upper Paleozoic carbonates, Upper Paleozoic and Lower Triassic clastics and Mesozoic clastics, especially above Mesozoic sands at the base of sequences (Fig. 4). Intraformational shales form local top and lateral seals for Tertiary reservoirs.

TRAPS

A variety of structural, stratigraphic and combination traps occur within Phanerozoic sedimentary strata throughout the region. Pre-Laramide traps are more favourable for accumulating hydrocarbons since the primary episode of hydrocarbon generation probably took place in Mesozoic and Tertiary time when maximum load was imposed. Structural folds and unconformity-related traps are likely present in Lower Paleozoic carbonates. Anticlines, faulted anticlines, unconformity related traps and up-dip porosity pinchouts are present within the Carboniferous succession. Fault-related and structural-stratigraphic combination traps likely occur in Mesozoic sediments. Stratigraphic porosity pinchouts probably represent the single most important trap-type in Cenozoic rocks.

SOURCE ROCKS

Potential source rocks in the Old Crow Basin area are locally organic-rich Lower Paleozoic Road River Formation shales. Link *et al.*, (1989), however, rated the overall source rock potential of this formation in northern Yukon as poor. Conodont alteration indices (CAI's) levels in Road River-equivalent strata vary from 4.5 to 5.5, indicating overmaturity. Another potential gas source occurs within Upper Devonian Imperial shales. Imperial shales have been identified in the area directly west of the Black Fox Anticline (Norris, 1981a). Lower Paleozoic strata in this area are probably overmature but may retain some potential for gas.

Carboniferous shales are reported to be an important source rock in surrounding areas, specifically beneath the Alaskan North Slope and in Eagle Plain (Craig *et al.*, 1985; Link *et al.*, 1989; Utting, 1989). In the Alaskan North Slope area, Kayak Formation shales are lean and gas-prone with some potential for oil generation. In Eagle Plain, these equivalent Carboniferous shales are characterized to be fair to good source rocks for gas with some oil potential (Link *et al.*, 1989). Comparable shales found in the Old Crow basin area, therefore, are expected to have at least fair potential to generate gas if maturities are equivalent. Thermal maturities of these rocks at the northern and eastern flanks of the Old Crow Basin are high and probably well beyond the oil window. No Kayak samples have reported vitrinite reflectance values of less than 2.5% and Thermal Alteration Indices (TAI's) range from 3+ to 5 (Cameron *et al.*, 1986; Utting, 1989).

Although the Late Triassic Shublik Formation is considered to be a significant oil source at Prudhoe Bay (Claypool and Magoon, 1985), the high-energy carbonate facies, occurring only in extreme northwestern Yukon, is unlikely to be a source rock of comparable quality.

Potential source rocks have been identified in Jurassic shale, specifically in the Kingak Formation beneath the Alaskan North Slope and in the Husky Formation in the Beaufort-Mackenzie Basin. Kingak shales are thought to be a rich oil source in Alaska (Claypool and Magoon, 1985) and Husky shales are believed to have generated significant quantities of gas and condensate in the Beaufort-Mackenzie area (Langhus, 1980). Reported TAI's of 2+ to 3- and vitrinite reflectance values of 1.5 to 4% in Jurassic shales from western Richardson Mountains (Davies and Poulton, 1989), indicate overmaturity. If these rocks are present beneath the Old Crow Basin, maturities should be comparable.

Jurassic strata have passed through the oil window and generation of dry gas is likely continuing, but at a low rate.

The Upper Cretaceous Eagle Plain Group in Eagle Plain contains excellent to fair gas source rocks (Link *et al.*, 1989), although immature (Link and Bustin, 1989). If these rocks are present beneath the Old Crow Basin, they will most likely occur in shallow strata and thus, occupy unfavourable positions for charging older rocks, unless juxtaposed across extension faults with large throws (Morrell and Dietrich, 1993).

Tertiary sediments are organic-rich in parts with interbedded coal seams within the unconsolidated sedimentary succession. The continental nature of these rocks suggests that these source rocks are gas-prone but immature for production of significant thermogenic gas due to the shallow depth of burial. Biogenic gas, however, does have significant potential within Tertiary strata, either occurring as conventional hydrocarbon accumulations or unconventional methane hydrate buildups below permafrost.

TIMING OF HYDROCARBON GENERATION

Modelling by Link and Bustin (1989) of Paleozoic source rocks in the northern Yukon indicate that they passed through the ‘oil window’ before the end of Mesozoic time. This implies that the probable most effective trapping configurations are structures formed previous to Tertiary time during the period of active oil migration. Seeking Paleozoic targets based on Laramide anticlinal structures may not represent the most efficient exploration strategy for this region. Post-Mesozoic traps likely gathered relatively minor amounts of gas created in the later stages of the main hydrocarbon generation episode. Therefore, pre-Tertiary traps and reservoirs are more favourable sites for accumulation of hydrocarbons during late Paleozoic to Mesozoic times. Rocks in the Old Crow region underwent two and possibly three major compressive tectonic episodes: an Early Devonian episode, the Late Cretaceous/Tertiary Laramide orogeny, and a possible early Carboniferous deformation. Pre-Laramide stratigraphic/structural traps are favourable configurations for trapping hydrocarbons. The pre-Upper Devonian source rocks do not generate oil at the present day, but gas continues to be generated. Carboniferous and Mesozoic source rocks, if buried deep enough, can generate thermogenic gas that can be trapped in Laramide-related folds.

HYDROCARBON SHOWS

The most direct indication of hydrocarbon potential in a frontier area is the presence of hydrocarbon shows. Limited exploration activity in the Old Crow Basin and its environs have revealed no such shows as yet. Coal seams in Tertiary strata are direct indications of coal potential in the area. Coal seams may also contribute as a free gas source for Tertiary reservoir strata, in addition to methane hydrate accumulations under permafrost.

HYDROCARBON ASSESSMENT

The Old Crow Basin petroleum resource assessment was undertaken in order to provide quantitative estimates of total oil and gas potential and possible sizes of undiscovered fields in the region. Hydrocarbon assessments of basins or regions are usually based on analyses of a number of exploration plays. In the Old Crow basin area, six exploration plays were defined based on petroleum geological considerations such as structural style, dominant reservoir lithology and thermal maturity. Three conceptual gas plays and three speculative gas plays were identified in the Old Crow Basin study area. The conceptual plays had sufficient information to attempt a statistical analysis to obtain estimates of resource potential and sizes of undiscovered fields (Table 1). The speculative plays had insufficient information for statistical analysis and thus, are described qualitatively.

Table 1. *Hydrocarbon potential in the Old Crow Basin, Yukon Territory.*

Play name	Expected no. of fields (mean) (million m^3)	Median play potential (in-place) (million m^3)	Mean play potential (in-place) (million m^3)	Median of largest field size (in-place)
Gas plays				
Kekiktuk conglomerate	5	9,786	11,956	4,246
Upper Paleozoic carbonate	5	14,049	19,439	6,976
Mesozoic clastic	0.6	N/A	1,160	N/A
Total Old Crow Basin*	**10**	**29,029**	**33,485**	

* The totals are statistically derived. They are retrieved from the basin empirical distribution in Appendix 2. The median total of basin potential is the value at 50%.

KEKIKTUK CONGLOMERATE GAS PLAY

CONCEPTUAL HYDROCARBON PLAY

Play definition

This play encompasses all gas prospects occupying structural and stratigraphic traps involving reservoirs of the Lower Carboniferous Kekiktuk conglomerate unit. This stratigraphic unit is most likely preserved throughout most of the Old Crow Basin, covering an area of about 6,200 sq. km. (Figs. 11, 12). The play area is limited by the Quaternary/Tertiary fluvial and lacustrine cover providing sealing strata above subcropping Carboniferous units (Fig. 12).

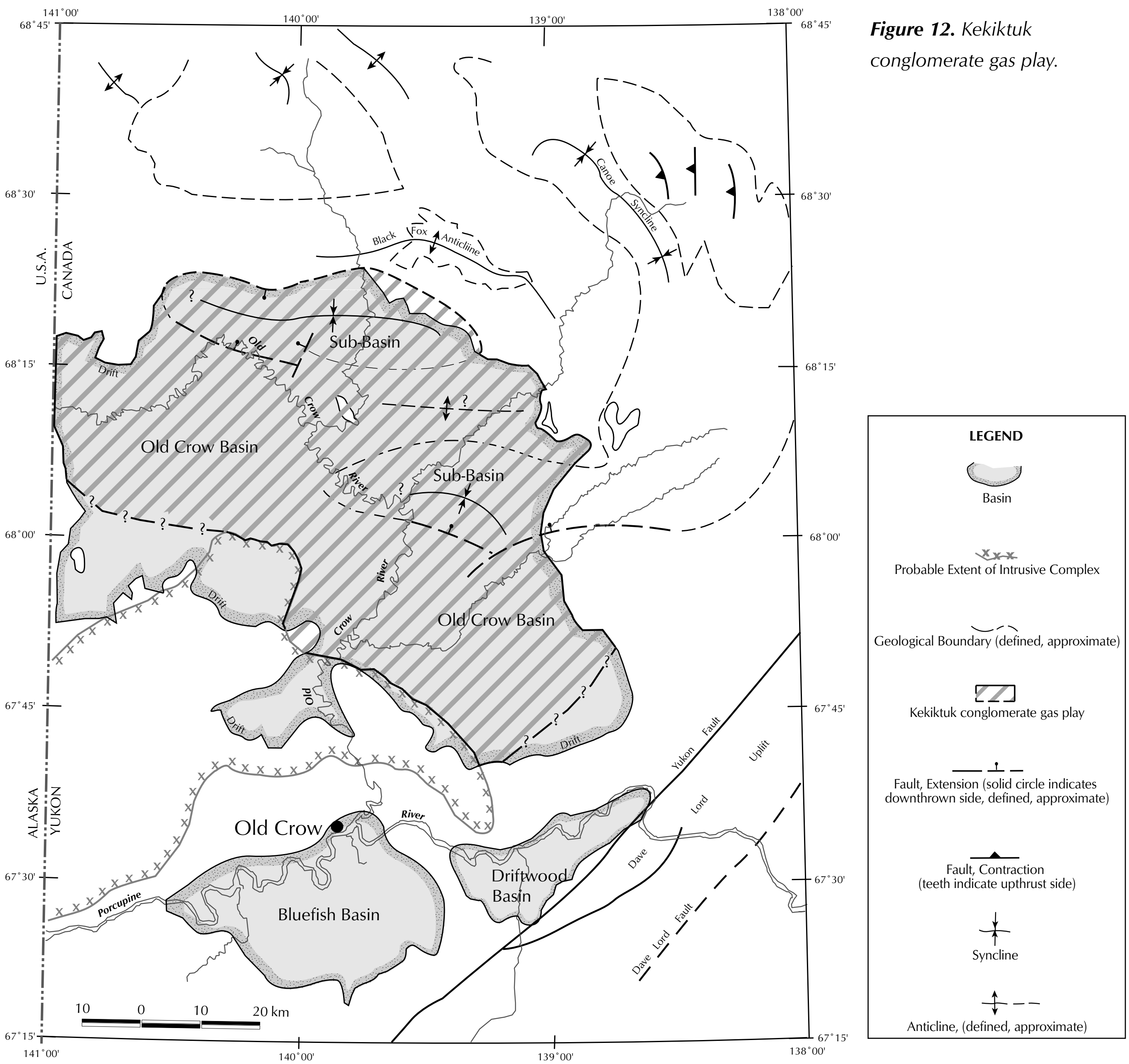


Figure 12. *Kekiktuk conglomerate gas play.*

Geology

The Kekiktuk conglomerate formation is a poorly exposed terrestrial unit at the base of the Carboniferous succession. This formation which fines upward overall contains subunits resembling channel fills. Regional relationships indicate deposition in braided stream and alluvial fan to fan delta settings landward of coastal plain and marine lithofacies characteristic of the overlying Kayak Formation (Richards e*t al.*, 1997). The thickness of this prospect succession ranges from one to 50 m, averaging about 25 m. This prospective unit is directly overlain by potential source rock for gas — specifically marine shales of the Kayak Formation (Fig. 4). Also, gas migrating from subcropping Lower Paleozoic carbonate and shale successions may have accumulated in the Kekiktuk Formation. Overlying Paleozoic shales provide excellent seal potential. This seal may isolate certain Kekiktuk reservoirs from gas sources, especially from Mesozoic strata, unless juxtaposed across faults with large throws. These "large-throw" faults, however, have not been identified in the area as yet.

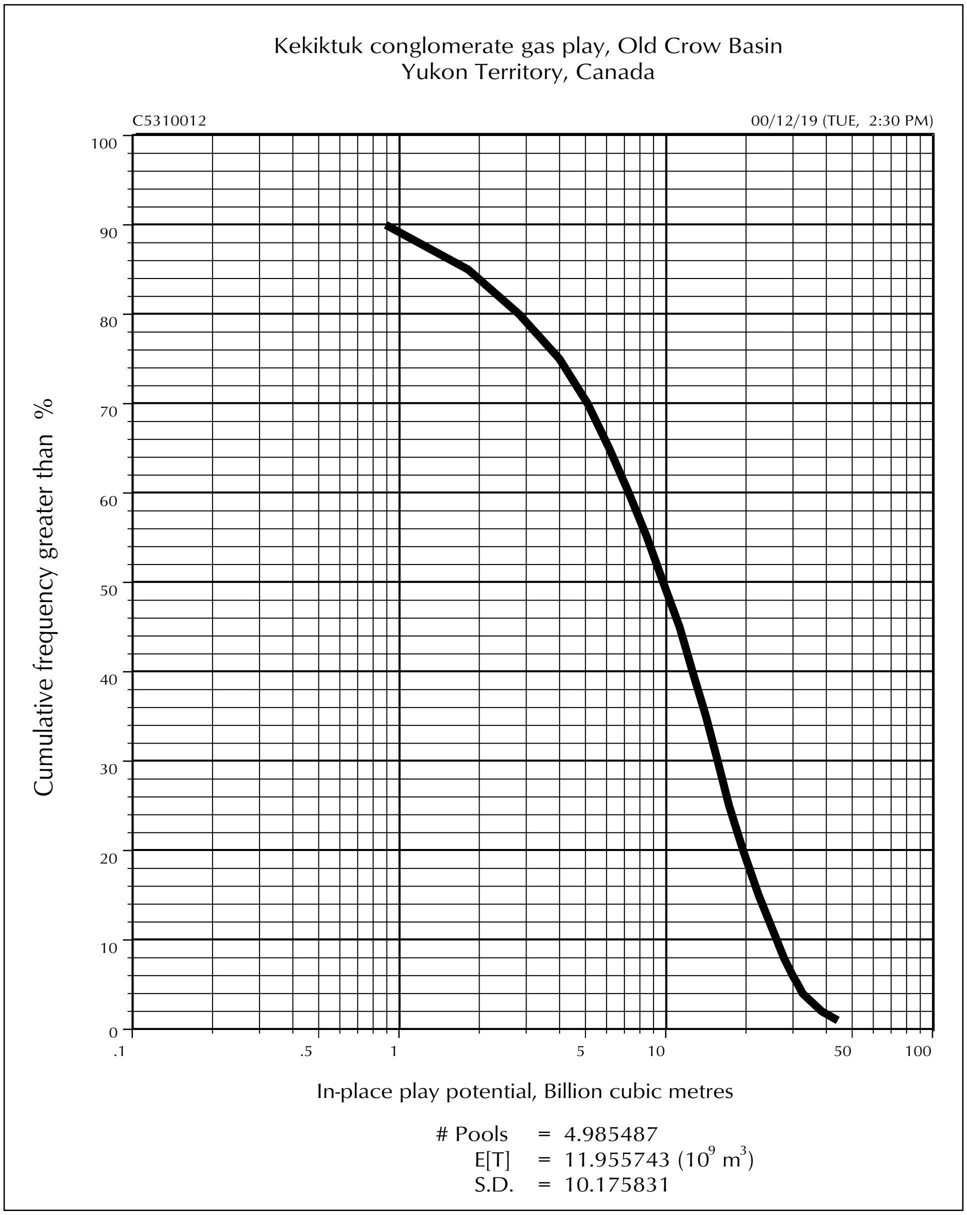


Figure 13. *Estimate of in-place gas potential of the Kekiktuk conglomerate gas play. Median value of probabilistic assessment is 9,786 million m*^{3} *of in-place gas distributed in 5 fields.*

The development of porous strata is generally poor in the Kekiktuk, although secondary porosity development, where present, is likely to be patchy. Early Carboniferous deformation has occurred to the east of the Old Crow Basin (Lane, pers. comm., 2000) so these rocks may have undergone two compressive orogenic episodes, one during Early Carboniferous time contemporaneous with deposition and the other during the well-established Late Cretaceous-Tertiary Laramide event. The main episode of gas generation likely occurred in Mesozoic and Tertiary time when maximum load was imposed. Some structures, at least, were formed before this hydrocarbon generation was complete. Trap types in this play may be structural such as anticlinal or fault-related or stratigraphic such as unconformity-related or topographic traps. Porosity occlusion may also produce diagenetic trapping configurations.

Similar exploration plays are the Endicott play on the Alaskan North Slope (Bird, 1996) and Tuttle sandstone play in Eagle Plain (National Energy Board, 1994). These plays were considered to be suitable analogues for the purpose of establishing probability distributions used in the computations of field size and number of field distributions (Appendices 1, 2).

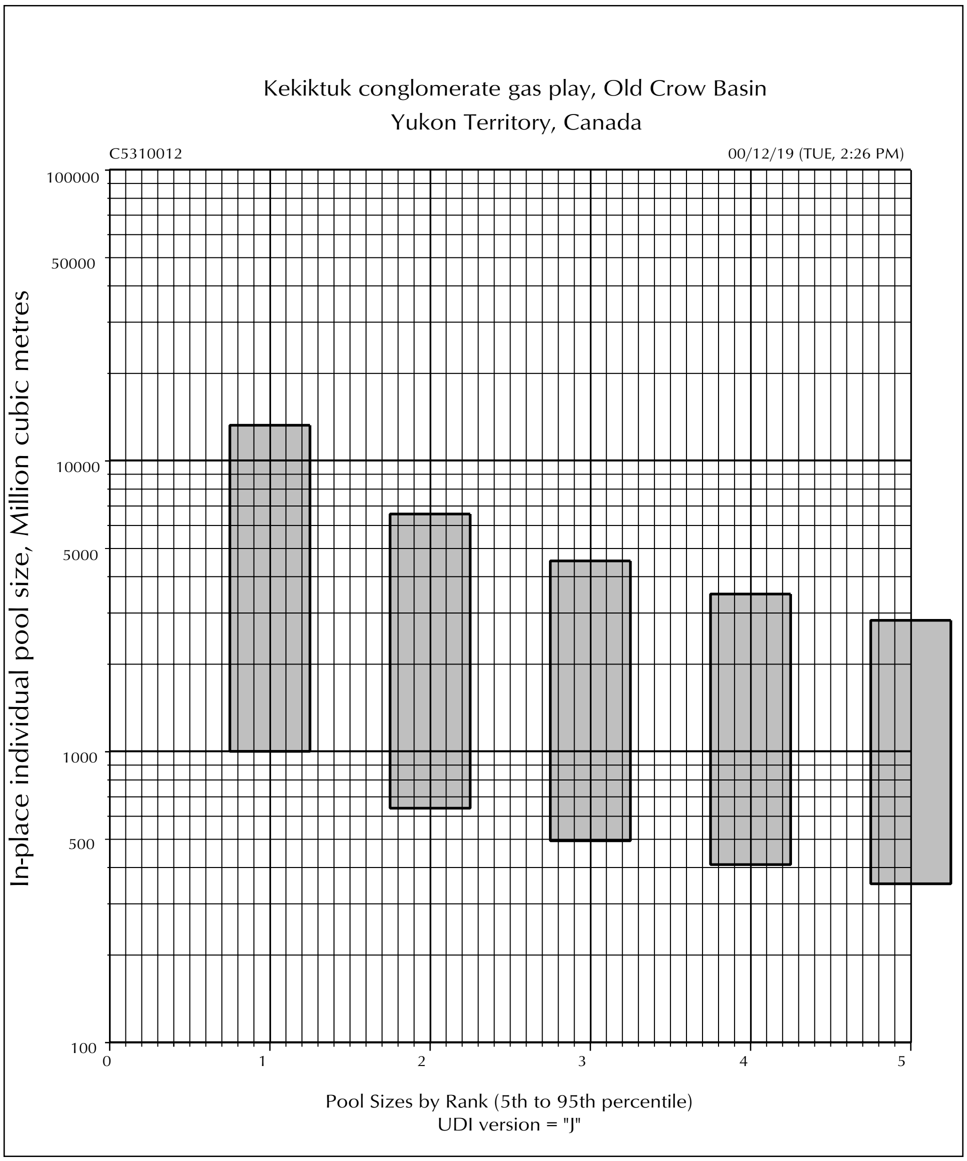


Figure 14. *Field-size-by-rank plot of the Kekiktuk conglomerate gas play. Median value of the largest predicted field size is 4,246 million m*^{3} *of in-place gas.*

Exploration risks

All of the Old Crow conceptual plays are assumed to exist (implicated by a play-level marginal probability of 1.0). However, within each play, geological risk factors associated with individual prospects are evaluated in order to derive the exploration risk for the entire play. Significant prospect-level risks interpreted in this play are the presence of reservoir facies and closure (Appendix 1). Primary porosity was reported to be poor in the Endicott play in Alaska but secondary leaching produced sufficient patchy porosity for gas accumulations to be present in the Endicott Field (Craig *et al.*, 1985). Some structures may be breached by erosion which produces the high risk associated with adequate closure. On the other hand, low risk, or high marginal probability, was assigned to preservation, source rock and the adequacy of seal (Appendix 1). The sedimentary unit is low in the stratigraphic succession so the chances of its preservation are quite good. There is potential source rock for gas in underlying Lower Paleozoic strata and overlying Carboniferous shales. The overlying shales also provide excellent top seal for traps. An intermediate risk was assigned to adequate timing since some structures may have developed before the main episode of gas generation was complete.

Play potential

The Kekiktuk conglomerate play has an estimated in-place median gas potential of 9.8 billion m^3 in the Old Crow Basin (50 percentile value in Fig.13, Table 1). If the 90 and 10 upper percentiles representing the range of expected potential are specified, then there is an 80% chance that the resource potential resides within the range of 0.9 to 26.1 billion m^3 in-place. The mean value of the number of predicted fields is 5 for the play. The largest undiscovered field is expected to contain 4.2 billion m^3 of gas (median value) (Fig. 14, Table 1). One field with a volume greater than three billion m^3 of gas is predicted to occur in this clastic play (median value in first box in Fig. 14). (See Appendix 2 for computation outputs.) Three billion m^3 (100 BCF) is an arbitrary in-place gas volume defined as a minimum individual field size required in order to foster interest among explorationists to pursue exploration activities in a specified play in a frontier region of Canada.

UPPER PALEOZOIC CARBONATE GAS PLAY

CONCEPTUAL HYDROCARBON PLAY

Play definition

This exploration play contains all structures and prospects occurring in Upper Carboniferous Lisburne Group carbonates in the Old Crow Basin (Fig. 15). The play area occurs beneath Quaternary/Tertiary cover in the Old Crow region. It is bounded to the southwest by subcrops of Proterozoic metasediments and to the south of the basin by the Old Crow intrusive complex. The play is absent in the north-central part of the basin west of the plunging anticlinal axis, where older Kayak shales outcrop (Fig. 15). Lisburne carbonates outcrop along the inferred anticlinal axis to the east (Fig 2).

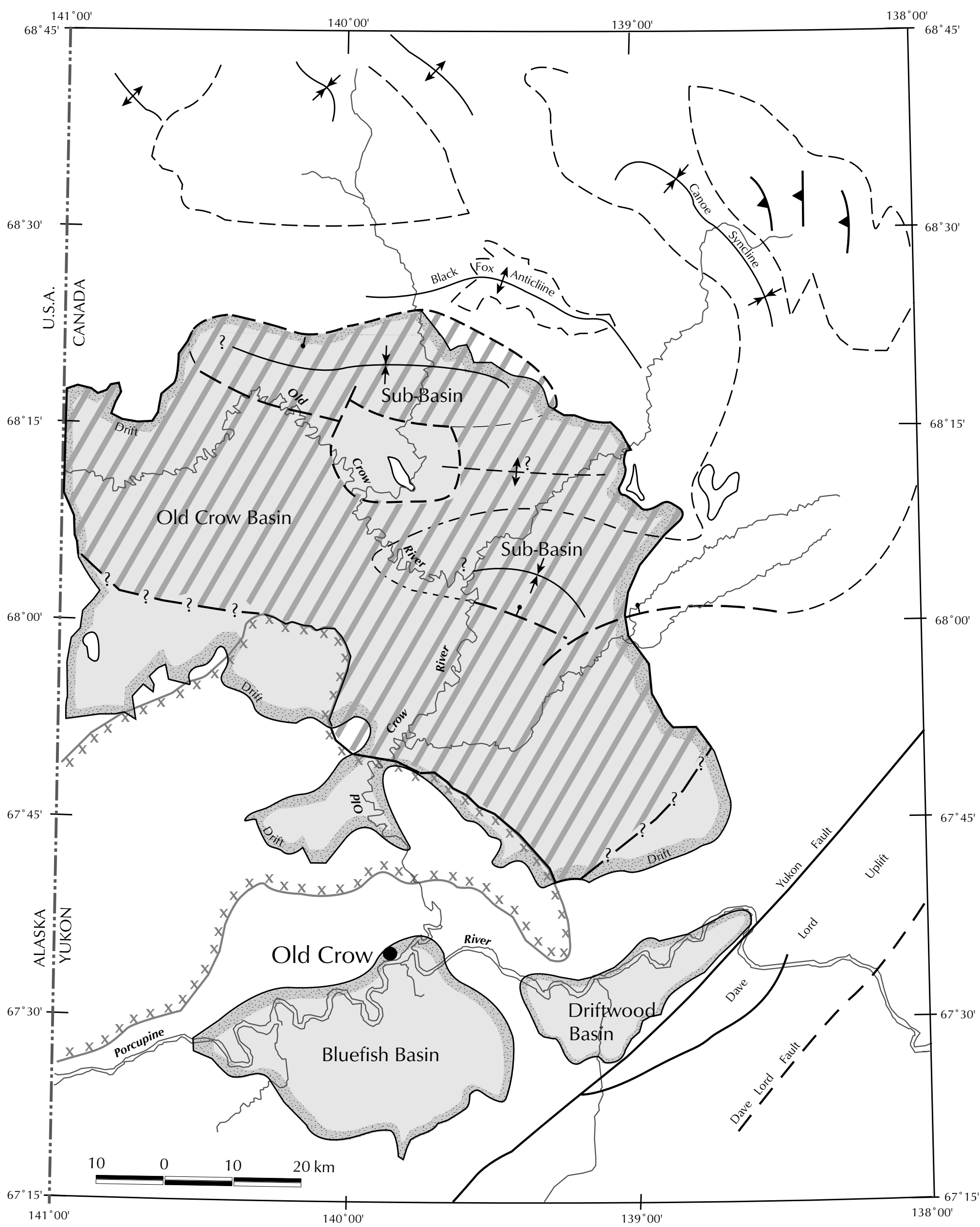
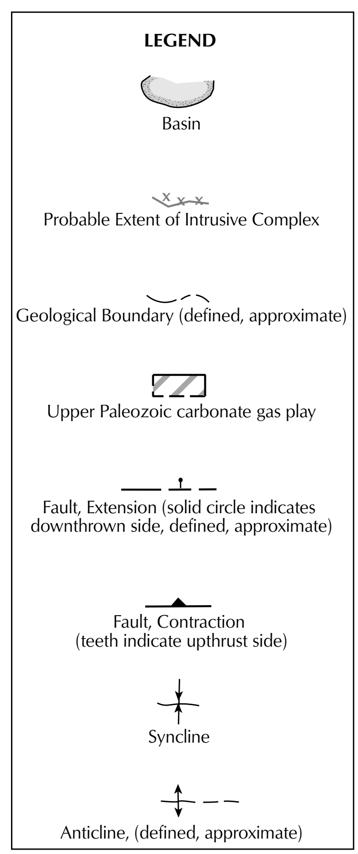


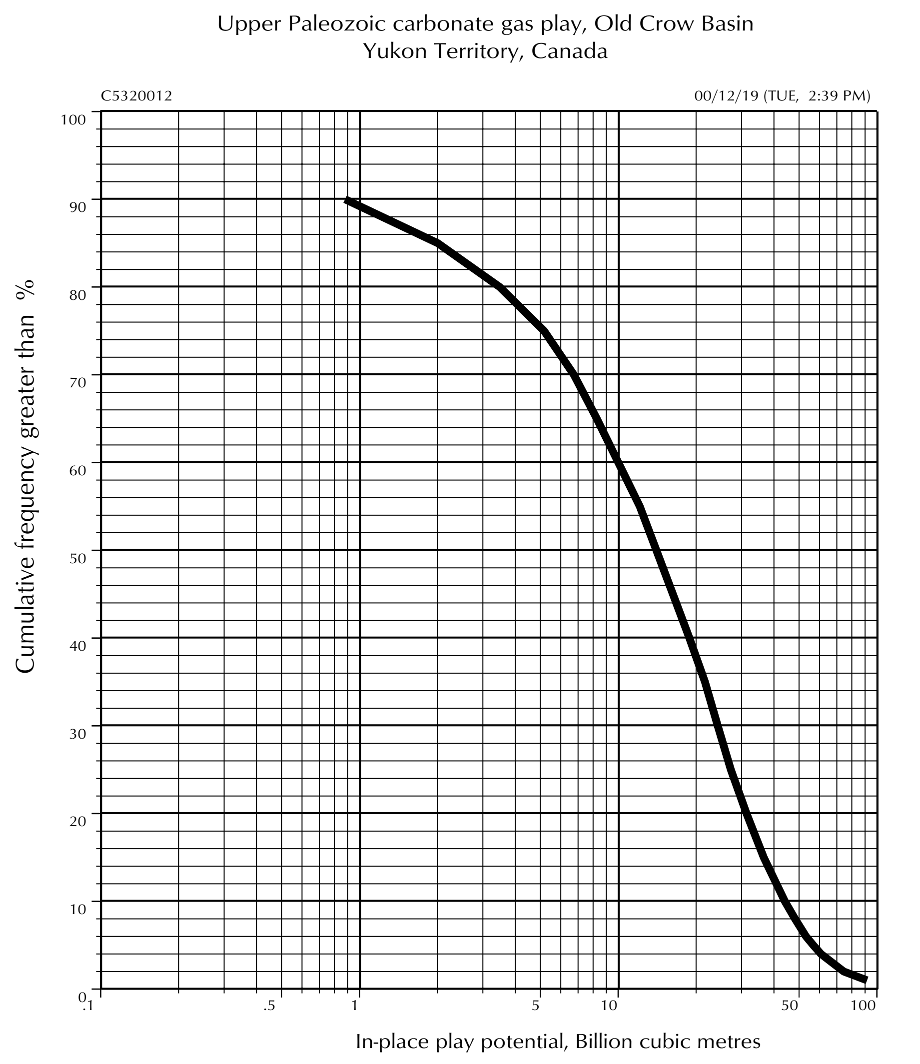
Figure 15. *Upper Paleozoic carbonate gas play.*



Geology

Prospective targets in this Upper Carboniferous succession are dolomitic facies and leached zones adjacent to unconformities within marine limestones of the Lisburne Group. The thickness of the prospect succession ranges up to 800 m and it occurs at depths varying from 700 to 3,000 m. Underlying shales of the Kayak Formation are probable gas source rocks although these rocks are overmature. The overlying Mesozoic shales, also containing probable gas source rocks as well as possible overmature oil source rocks, may have charged these reservoirs. These Mesozoic shales additionally provide a very good seal for traps. An important trap-type is fault-bounded structures, often including a diagenetic component to trapping, specifically, development of dolomitic facies or leached zones adjacent to unconformities critical to the trapping arrangement. Anticlines, unconformity-related traps and up-dip porosity pinchouts may also occur. The main episode of gas hydrocarbon generation probably occurred during Mesozoic and Tertiary time when maximum load was imposed. These rocks underwent

Figure 16. *Estimate of in-place gas potential of the Upper Paleozoic carbonate gas play. Median value of probabilistic assessment is 14,049 million m³ of in-place gas distributed in 5 fields.*



# Pools = 4.985488
E[T] = 19.438950 ($10^9 m^3$)
S.D. = 20.095131

Laramide compression so some structures, at least, were formed contemporaneously with the primary episode of hydrocarbon generation. Analogous plays on the Alaskan North Slope and Eagle Plain are the Lisburne and Ettrain carbonate plays, respectively (Bird, 1996; National Energy Board, 1994).

Exploration risks

Heightened risk factors integrated in the analysis of this exploration play are presence of reservoir facies and closure and adequacy of timing (Appendix 1). Porosity development seems to be limited and discoveries in carbonates of this age at Prudhoe Bay and southern Eagle Plain generally have poor reservoir quality. Closure integrity may be affected by erosion and breaching of some of the structures. Some structures may have formed in the latter part of the Laramide orogeny thereby preventing these structures from accumulating gas produced during the main generation episode. Adequate seal and source are expected for most prospects in this play.

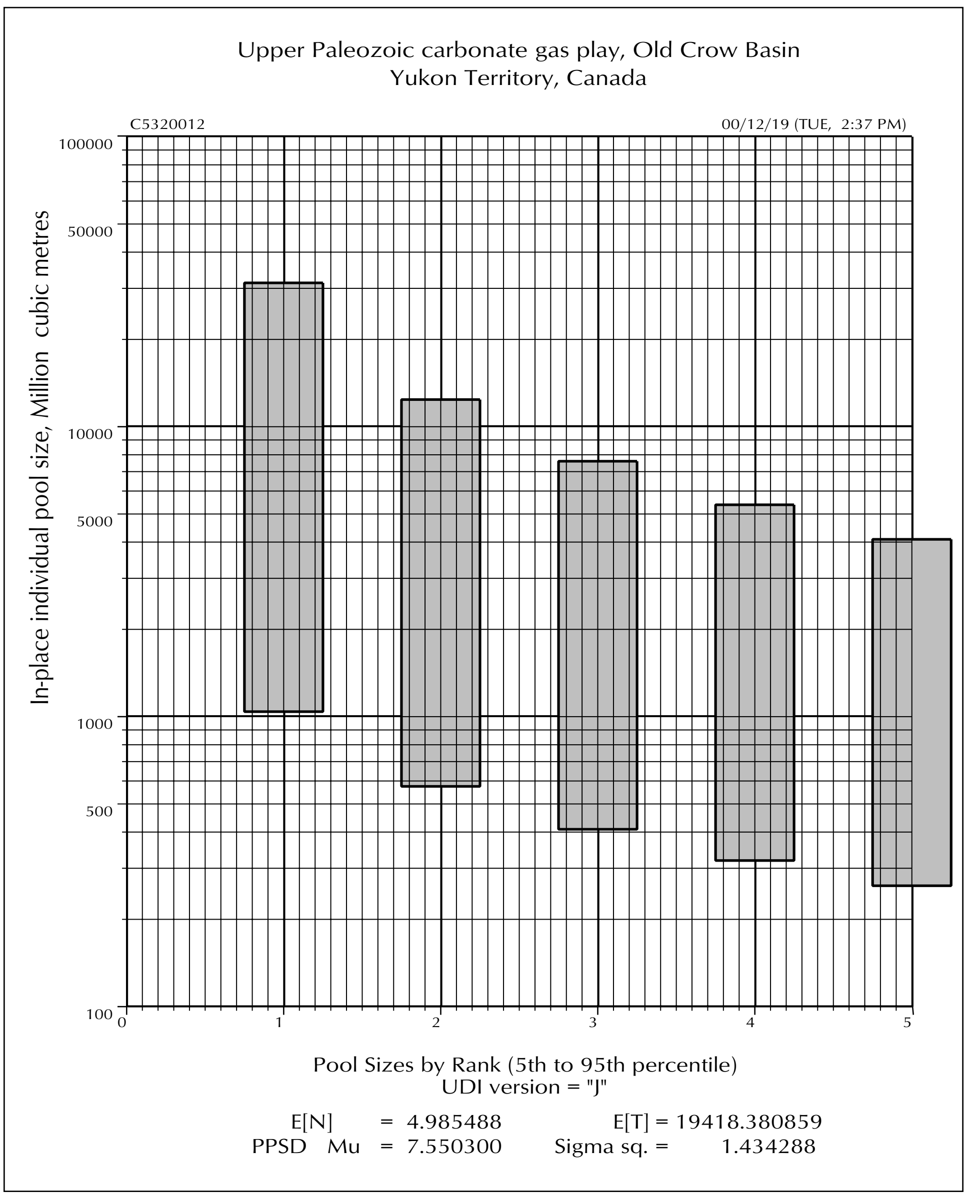


Figure 17. *Field-size-by-rank plot of the Upper Paleozoic carbonate gas play. Median value of the largest predicted field size is 6,976 million m³ of in-place gas.*

Play potential

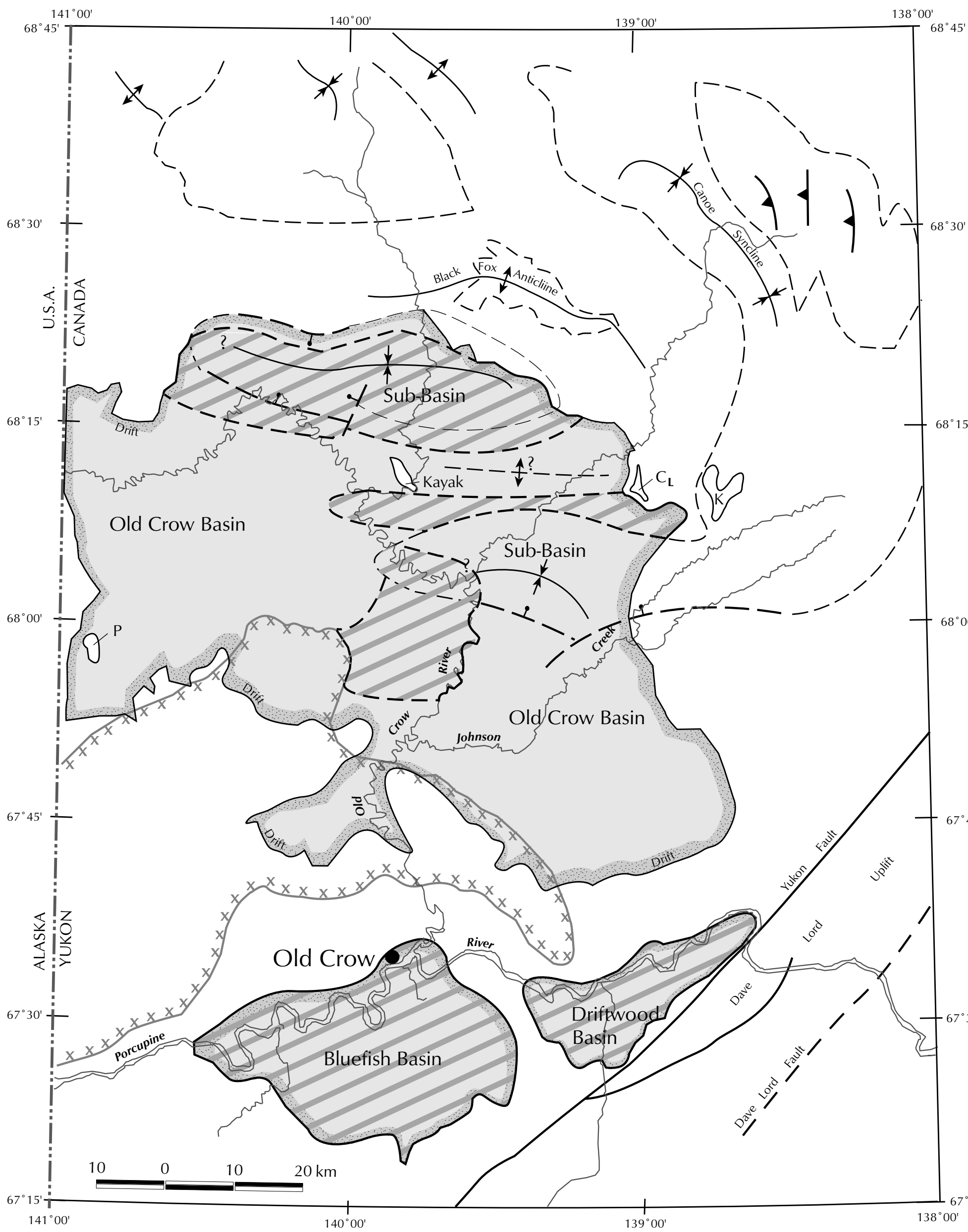
This play has an estimated median resource potential of 14.0 billion m^3 of in-place natural gas (Fig. 16; Table 1). The range of estimates for resource potential is 3.5 to 44.1 billion m^3 in-place. The expected number of gas fields in the play is 5 (mean value) with the largest field having a volume of 7.0 billion m^3 (Fig. 17; Table 1). Two fields are expected with volumes greater than 3 billion m^3 in this play (Appendix 2).

MESOZOIC CLASTIC GAS PLAY

CONCEPTUAL HYDROCARBON PLAY

Play definition

The Mesozoic clastic gas play includes all Jurassic and Cretaceous gas prospects present in marine regressive sand pulses in the dominantly deep-water fine-grained succession (Fig. 4). As noted previously, most Jurassic and Cretaceous sand-dominated successions probably do not occur beneath the Old Crow Basin, including the Bug Creek Group sands, Porcupine River Formation, Kamik Formation and Rat River Formation. Mount Goodenough and Sharp Mountain sands and conglomerates are expected to occur within the basin, however. Mesozoic rocks are likely to occur locally beneath the Tertiary sub-basins. Paleozoic rocks subcrop at the basal Tertiary unconformity in certain



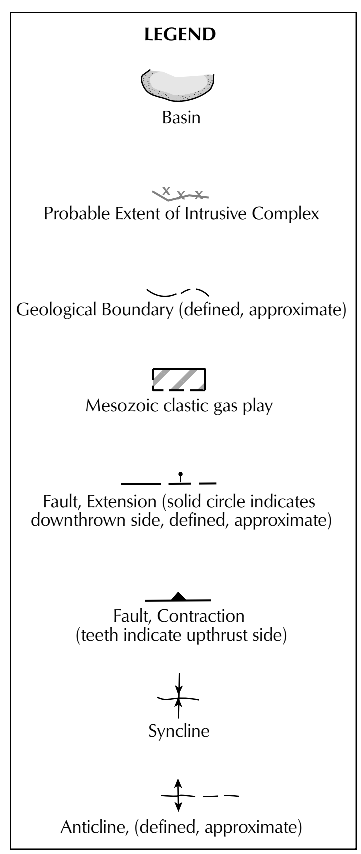


Figure 18. *Mesozoic clastic gas play.*

areas (Figs. 7, 11). Also, Mesozoic rocks are probably missing over the anticlinal axes. Uncertainty regarding the extent of this play is an important risk but it is believed that restricted areas of the basin contain Mesozoic sediments (Fig. 18). Norris (1981b) mapped sparse Cretaceous outcrop in the Bluefish and Driftwood basin areas; thus Mesozoic clastics are expected to underlie these basins (Fig. 18).

Geology

Coarse-grained clastic horizons within Jurassic and Cretaceous marine sediments are prospective targets in this play. These potential reservoir strata are interbedded and encased within fine-grained shale and siltstone deep-water successions. Jurassic and Upper Cretaceous shales are potential gas sources and seals, particularly for fining-upward base of sequence horizons such as the Sharp Mountain and Mount Goodenough formations. Expected trap-types are fault-related structural configurations as well as structural-stratigraphic combination traps. Thickness of the prospect succession is only

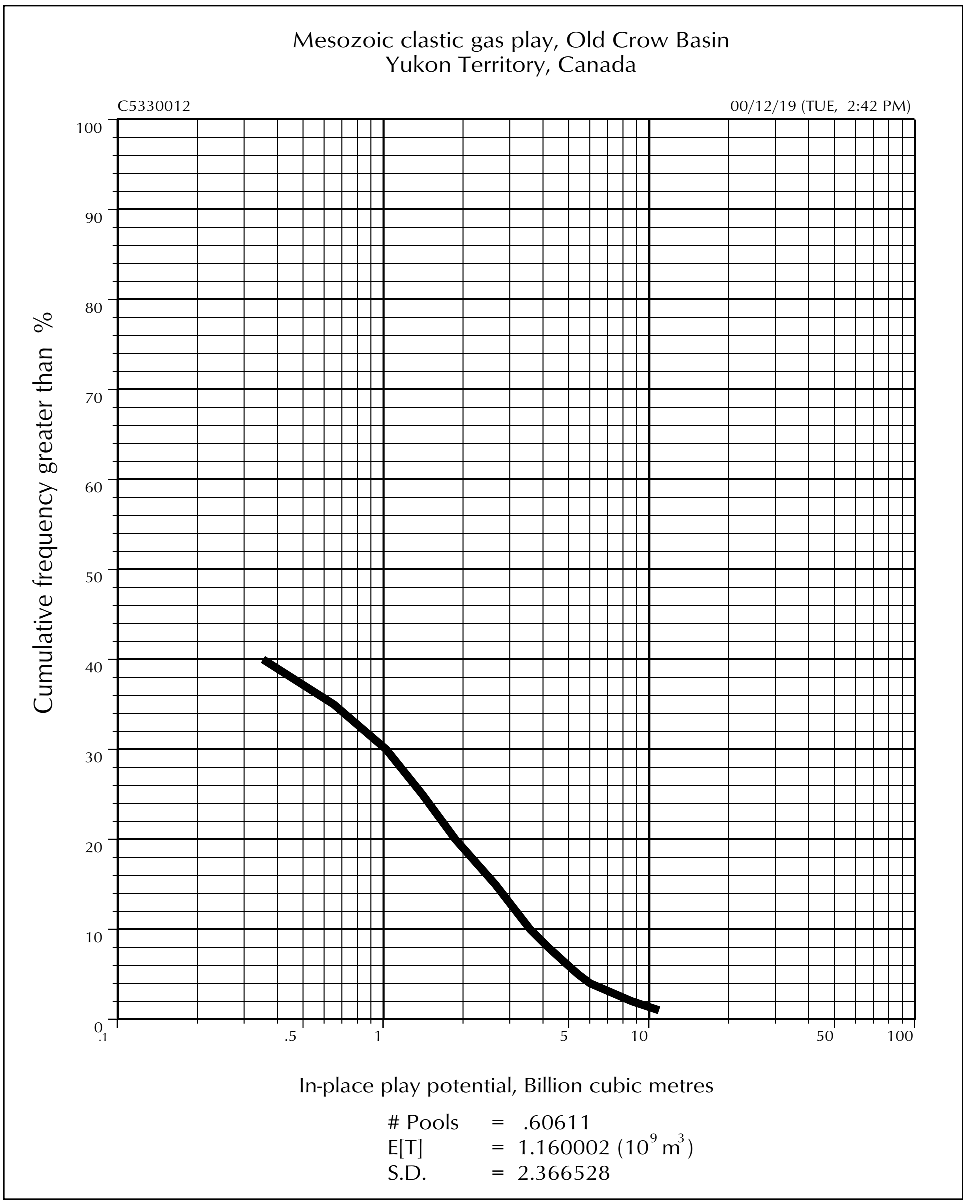


Figure 19. *Estimate of in-place gas potential of the Mesozoic clastic gas play. Mean value of probabilistic assessment is 1,160 million m^3 of in-place gas. This model predicts no fields are expected in this play.*

about 300 to 500 m thick and it ranges in depth from near-surface to 1800 m. The Cretaceous sands underwent deformation during the Laramide orogeny so structures were formed almost simultaneously with hydrocarbon generation during Mesozoic and Tertiary time when maximum load was imposed.

Exploration risks

Significant risk factors attributed to the Mesozoic clastic play are the presence of reservoir facies as well as closure and adequate timing (Appendix 1). The depositional extent of Jurassic and Cretaceous sandstones with reservoir potential is questionable. Truncation of Mesozoic rocks over anticlinal axes makes presence of trap closure on certain structures uncertain. Peak hydrocarbon generation, occurring during Mesozoic and Tertiary time when maximum load was imposed, took place contemporaneously with Laramide tectonics. Intermediate prospect-level risk factors of 0.7 were assigned to adequate seal and preservation. Seal quality of overlying and lateral shales is generally good. The Mesozoic succession is present near the top of the sedimentary fill so preservation may be compromised in some cases as a result of erosion. Flushing of meteoric waters through reservoirs may add further risk to the adequate preservation of hydrocarbons. Jurassic and Upper Cretaceous shales are potential gas sources.

Play potential

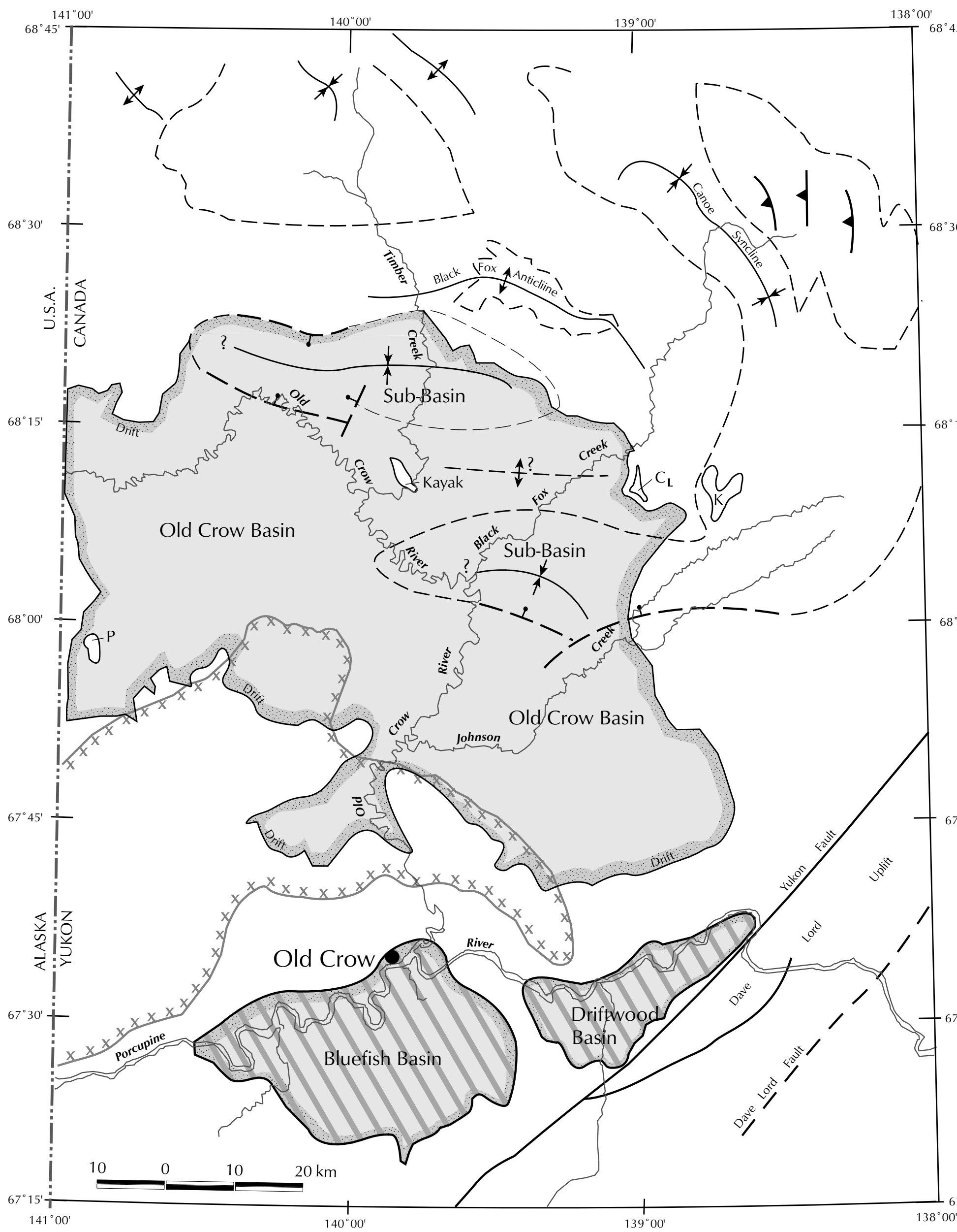
Estimates of potential for the Mesozoic clastic gas play indicate a mean in-place volume of 1.2 billion m^3 (Fig. 19; Table 1). No median for gas potential was predicted in this model; i.e., no cumulative frequency of 50% was retrieved for this curve (see Fig. 19). The mean value of the number of predicted fields is 0.6. This estimate (<one field) for expected number of fields indicates that there is a good chance (40%) that there are no fields present in this play. Therefore, the largest undiscovered gas field (median value) generated by PETRIMES is meaningless (it was predicted to be larger than the play's mean resource potential) (Appendix 2), and thus no value for the largest field size was listed in Table 1.

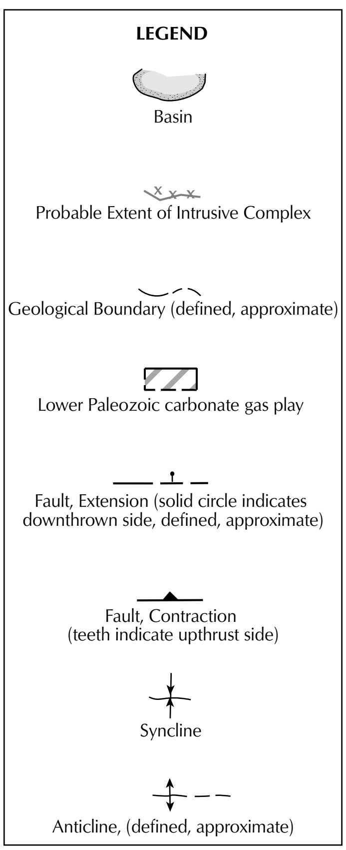
SPECULATIVE HYDROCARBON PLAYS

There are three exploration plays that may be present in the Old Crow Basin area but insufficient information is available to properly determine their hydrocarbon resource potential quantitatively.

The Silurian-Devonian carbonate shelf facies delineated by the Porcupine Platform occurs south of the Old Crow Basin, probably underlying Bluefish and Driftwood basins south of Porcupine River. The speculative Lower Paleozoic carbonate gas play is comprised of rocks which may contain diagenetically enhanced porous horizons (Fig. 20). Equivalent Road River shales and argillaceous limestones are believed to underlie the Old Crow Basin to the north according to paleogeographic reconstructions (Morrow, 1989; Lane, 1998). These shales may retain some potential as a source of gas for laterally equivalent carbonates, although they are probably overmature. Road River shaly strata may provide

Figure 20. *Lower Paleozoic carbonate gas play.*





lateral seal. Overlying Carboniferous shales may provide source for gas and act as top-seal for potential hydrocarbon accumulations. Trap types are likely structural and unconformity-related where enhanced leaching generates secondary diagenetic porosity development. Significant play-level risks are lack of reservoir and overmaturity of coeval hydrocarbon sources. Migration routes from younger source rocks (e.g. Mesozoic shales) are severely limited. No numerical assessment was attempted for this play because of the very high risk of absence of reservoir and the lack of available seismic coverage over prospective areas to properly assign appropriate reservoir parameters for field-size calculations.

A second speculative gas play with very high risk associated with adequate reservoir facies and preserved succession is the Upper Paleozoic and Lower Triassic clastic play. Mesozoic unconformities indicate probable erosion of these rocks beneath the Old Crow Basin. Erosional remnants are difficult to locate within the basin, even in the sub-basinal

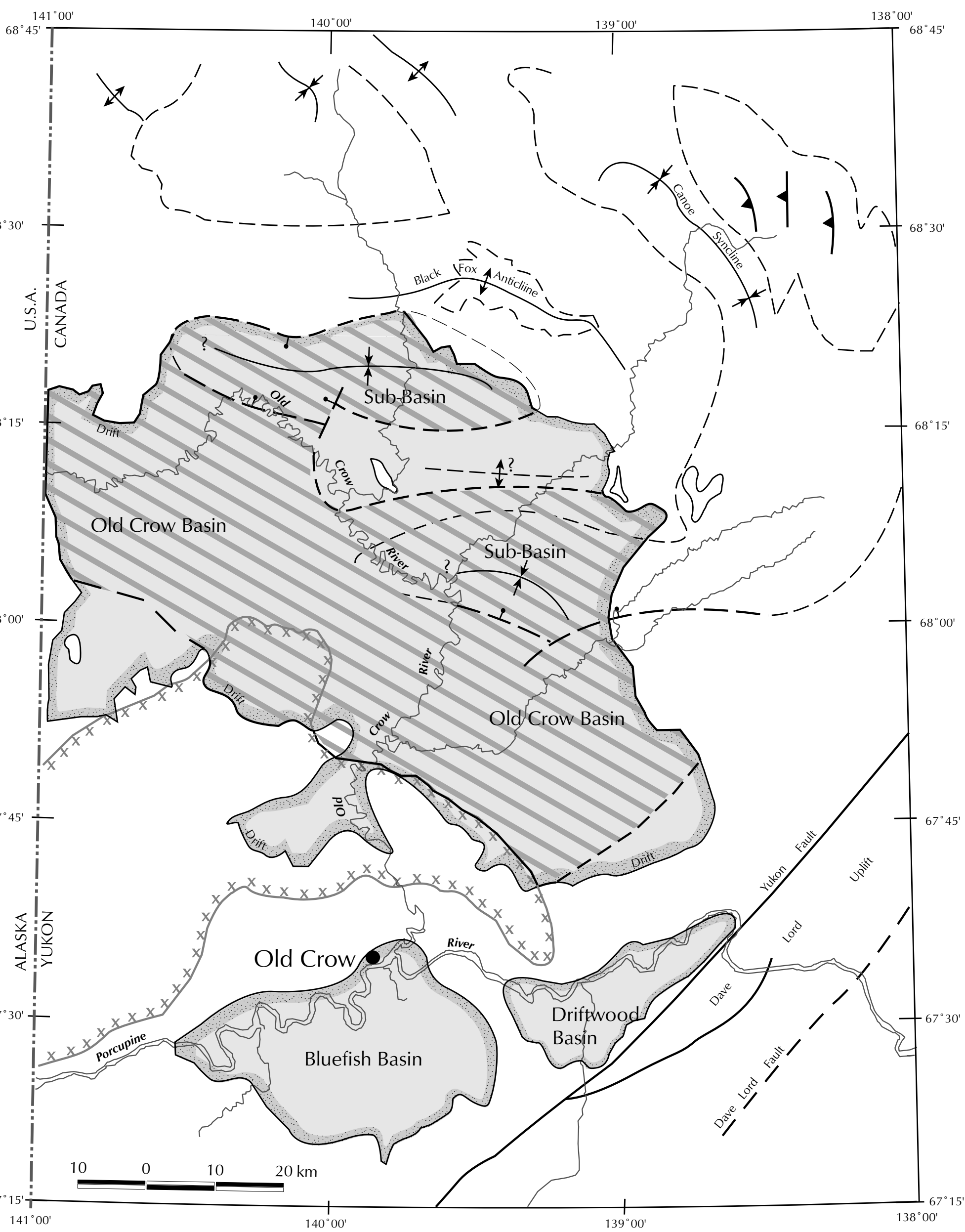
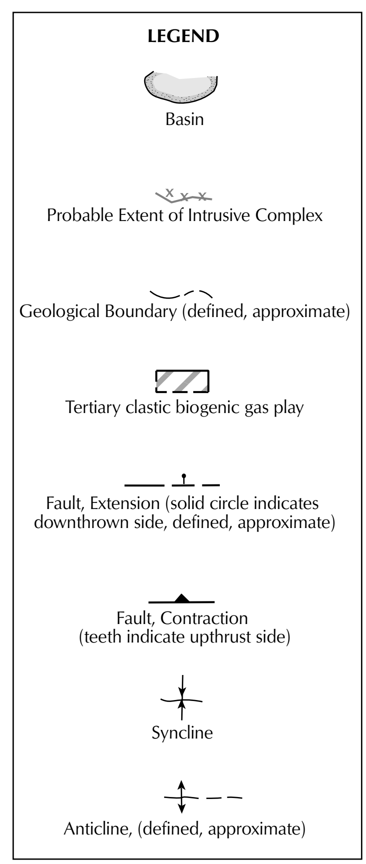


Figure 21. Tertiary clastic biogenic gas play.



syncline areas, since folding post-dated the episode of peneplanation. Paleogeographic reconstructions indicate units exhibiting reservoir potential, such as Jungle Creek and equivalent Echooka formations and Ivishak sand, may not have been deposited at all in the Old Crow basin area (Bamber and Waterhouse, 1971). Insufficient information regarding the depositional extent of potential sands prevents the delineation of play boundaries so no play map has been depicted in this study. Potential traps include a variety of structural and sub-unconformity configurations. A potential gas source is present in overlying Jurassic and Cretaceous shales. These may also act as good seal.

Another speculative play in the Old Crow region is the Tertiary clastic biogenic gas play. It is quite widespread, covering most of the Old Crow Basin except in areas where Paleozoic and Proterozoic rocks subcrop the Quaternary cover (Fig. 21). Ages of potential reservoirs are speculated to range from Oligocene to Miocene with thicknesses varying up to 750 m. Stratigraphic trapping configurations such as porosity pinchouts in these continental deposits are prospective trap types. The continental nature of these deposits suggests gas-proneness. Abundant coal laminae interpreted from seismic sections (Figs. 7, 9) provide plentiful organic matter for gas generation. This organic material is probably insufficiently mature given the shallow depth of burial for thermogenic gas production. However, biogenic gas generation is feasible in this play. In addition to conventional biogenic gas, gas hydrates may have been formed in the area and trapped under the continuous permafrost layer.

DISCUSSION OF ASSESSMENT RESULTS

RESOURCE POTENTIAL

The median estimate of total hydrocarbon potential for the Old Crow region (including all conceptual plays) is 29 billion m^3 (1.0 TCF) of in-place gas (Table 1; Fig. 22). (Note that the total median estimate for the Old Crow Basin is not arithmetically derived by summing the hydrocarbon potentials of individual plays. This number is derived using statistical techniques). High confidence (95% probability) and speculative (5% probability) estimates of total gas potential are 5.8 and 75 billion m^3 (0.2 and 2.6 TCF), respectively (Fig. 22). Individual field-size estimates in each play display similar probability-dependent variations. The wide range of estimates of total potential and field sizes are typical of frontier region assessments and reflect the geological uncertainties in quantifying lightly explored or conceptual exploration plays.

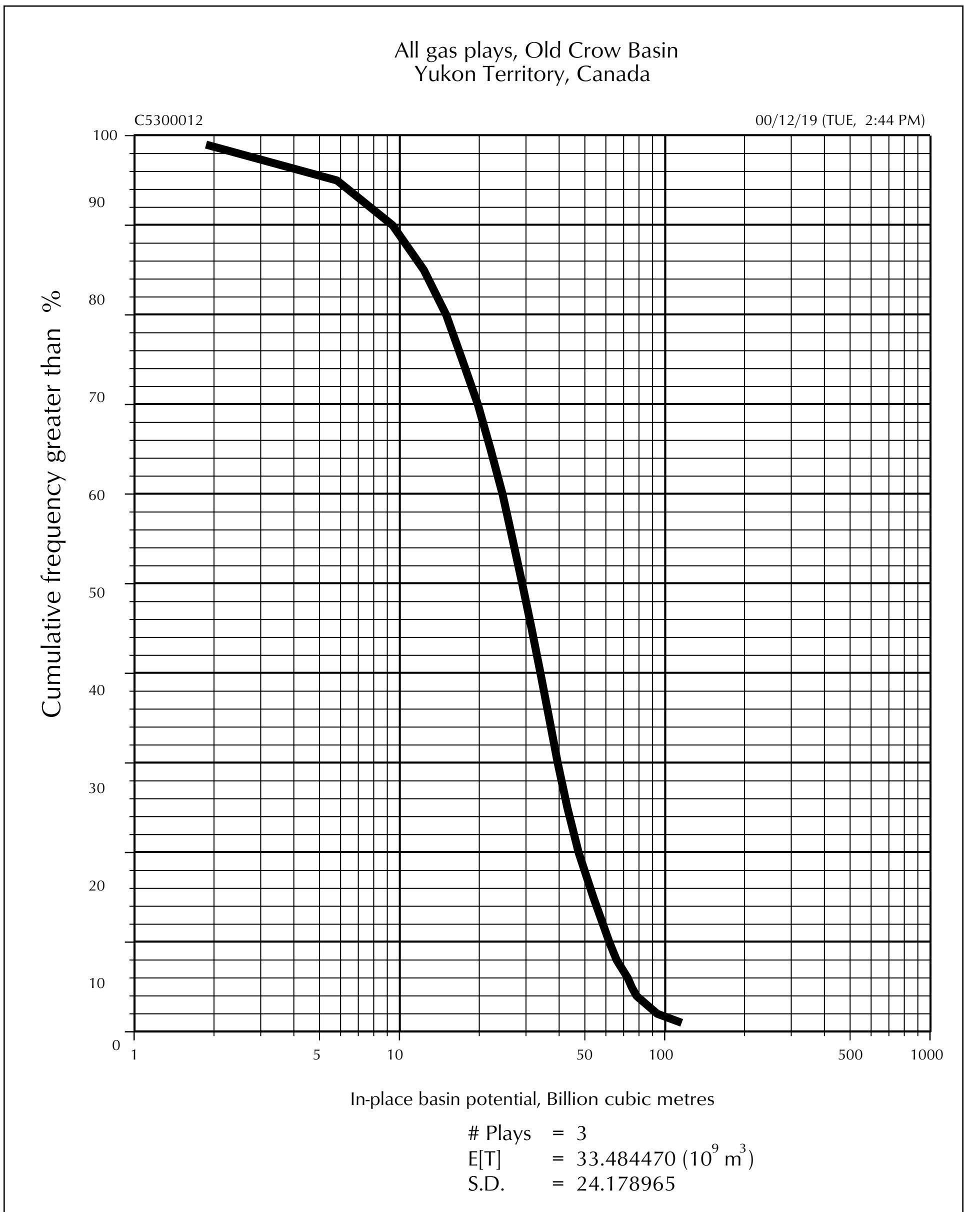


Figure 22. *Estimate of total gas potential for the Old Crow Basin area. Median value of probabilistic assessment is 29,029 million m^3 of in-place gas.*

RESOURCE DISTRIBUTIONS

The greatest gas potential volume occurs in the Lower Paleozoic carbonate/shale facies transition play (Table 1). The largest individual gas field is expected to occur in the same play, having a median-size estimate of 6.7 billion m^3 (236 BCF) of in-place gas.

The assessment results indicate the Lower Paleozoic carbonate/shale facies transition play is expected to contain about 67% of the basin's total gas resource volume and the 6 largest fields, a concentration reflecting the greater number of reservoir horizons within the thick Lower Paleozoic succession as well as the greater likelihood of significant volumes of hydrocarbons accumulating in pre-Laramide traps derived from the main episode of hydrocarbon generation. In contrast, gas resource distributions in younger Cretaceous/Tertiary clastic rocks, where small fields are predicted, indicate minor volumes of gas may occur as a result of less significant secondary hydrocarbon generation.

ASSESSMENT RESULTS AND EXPLORATION HISTORY

The exploration risks estimated in this assessment suggest success rates for exploratory drilling in the Old Crow basin area would average about one in 10 when seeking Paleozoic targets. This predicted success rate seems to be reasonably comparable to other frontier regions in northern Yukon (Hannigan et al., 1999; Hannigan, in press (a) and (b)). The reconnaissance nature of the seismic data and the lack of wells, along with the inherent difficulty in estimating numbers of prospects associated with stratigraphic traps, makes the presumption of the number of prospects quite arbitrary. The use of probability distributions from analogous plays, with appropriate adjustments compensating for differences in play area, was the only method available for approximating the probability distribution of the number of prospects. Incorporating relevant future exploration data such as improved and more dense seismic survey coverage or exploration drilling, will provide a greater degree of confidence in hydrocarbon potential estimates.

CONCLUSIONS

The hydrocarbon resource potential of the Old Crow Basin area has been evaluated through regional hydrocarbon play assessments. The quantitative assessments were derived using the Geological Survey of Canada's (PETRIMES) assessment methodology system. The Old Crow Basin is a shallow depression of Paleogene origin. Thick Tertiary fill accumulated in two sub-basins interpreted as occupying synclinal structures. These Cenozoic strata are likely too immature and sparingly structured to have significant hydrocarbon potential. There is some potential, however, for biogenic gas. It is believed that Mesozoic and Late Paleozoic strata subcrop the Tertiary the Old Crow Basin beneath a major Middle Eocene unconformity. These rocks do have some potential for reservoir and gas source, but the highly variable nature of preservation of these rocks argues for applying appropriate marginal risk factors to play-estimate calculations. Geophysical interpretation reveals no evidence for the presence of a Mesozoic depocentre in the area corresponding with the overlying Tertiary basin. A Mesozoic depocentre may improve potential by preserving a greater diversity of strata and increase the probability of developing favourable reservoir horizons. Regarding Lower Paleozoic strata, carbonate shelf strata which may host significant hydrocarbon occurrences elsewhere in northern Yukon, does not appear to exist under the Old Crow Basin. The Old Crow basin area is interpreted to be distal to the platform, thereby containing deep-water basinal facies not suitable for reservoir development and hydrocarbon accumulation.

The petroleum resource assessments includes analyses of three conceptual plays, each of which incorporated the calculation or estimation of field size parameters, numbers of prospects and exploration risks. Hydrocarbon volumes reported for these conceptual plays are total statistical estimates of the resource present 'in the ground', not the volumes that are economically producible. Individual field-size determinations are important in identifying which plays are attractive for future exploration programs.

The potential for significant hydrocarbon accumulations in the Old Crow assessment region is derived by the combined presence of numerous and diverse trapping configurations, good to excellent petroleum source rocks in favourable stratal positions and reservoir-quality strata in some portions of the stratigraphic succession. However, significant risks associated with lack of porosity development in Paleozoic and Mesozoic strata, freshwater flushing of Mesozoic and Tertiary reservoirs, and thermal maturity considerations reduce overall hydrocarbon potential. Thermal maturity studies indicate that insignificant oil potential is expected in the area. Significant gas potential is predicted for the Upper Paleozoic carbonate play in the Old Crow Basin. The complex geology and anticipated high exploration risks associated with all defined exploration plays in the region suggest that considerable seismic survey work and exploration drilling are required to properly evaluate the Old Crow basin's hydrocarbon potential.

The median estimate for total gas potential for all the Old Crow Basin plays is 29 billion m^3 of in-place gas (Fig. 22; Table 1). Three fields with median sizes greater than three billion m^3 of in-place gas are expected in two plays; two in the Upper Paleozoic carbonate play and the other in the Kekiktuk conglomerate play.

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APPENDIX 1

INPUT DATA FOR THE OLD CROW BASIN HYDROCARBON ASSESSMENTS

The following tables present the probability distributions of reservoir parameters, number of prospects, and marginal probabilities of geological risk factors used as input for the various conceptual statistical analyses discussed in this paper. These estimates are based on subjective opinion, partly constrained by reservoir data and information from analogous hydrocarbon-bearing basins.

1. KEKIKTUK CONGLOMERATE GAS PLAY

Table 1.1a. Probability distributions of reservoir parameters

Geological variable	Unit of measurement	Probability in upper percentiles 1.00	Probability in upper percentiles 0.50	Probability in upper percentiles 0.01	Probability in upper percentiles 0.00
Area of closure	km^2	0.4	5	40	100
Formation thickness	m	1	25	50	60
Porosity	decimal fraction	0.05	0.09	0.2	0.3
Trap fill	decimal fraction	0.2	0.2	0.2	0.2
Gas saturation	decimal fraction	0.6	0.8	0.9	0.95
Gas compressibility factor	decimal fraction	0.804	0.82	0.836	0.85
Reservoir temperature	Celsius	39	39	39	39
Reservoir pressure	kPa	28,150	28,150	28,150	28,150

Table 1.1b. Marginal probabilities of geological risk factors

Geological factors	Marginal probability	Play level	Prospect level
Presence of closure	0.6		x
Presence of reservoir facies	0.40		x
Adequate seal	0.8		x
Adequate timing	0.7		x
Adequate source	0.8		x
Adequate preservation	0.9		x

Table 1.1c. Probability distribution for number of prospects

Geological variable	Probability in upper percentiles 0.99	Probability in upper percentiles 0.5	Probability in upper percentiles 0.00
Number of prospects	5	50	100

2. UPPER PALEOZOIC CARBONATE GAS PLAY

Table 1.2a. Probability distributions of reservoir parameters

Geological variable	Unit of measurement	Probability in upper percentiles 1.00	Probability in upper percentiles 0.50	Probability in upper percentiles 0.01	Probability in upper percentiles 0.00
Area of closure	km^2	0.4	5	40	100
Formation thickness	m	1	60	600	1300
Porosity	decimal fraction	0.05	0.09	0.2	0.3
Trap fill	decimal fraction	0.1	0.1	0.1	0.1
Gas saturation	decimal fraction	0.6	0.8	0.9	0.95
Gas compressibility factor	decimal fraction	0.804	0.82	0.836	0.85
Reservoir temperature	Celsius	39	39	39	39
Reservoir pressure	kPa	28,150	28,150	28,150	28,150

Table 1.2b. Marginal probabilities of geological risk factors

Geological factors	Marginal probability	Play level	Prospect level
Presence of closure	0.6		x
Presence of reservoir facies	0.60		x
Adequate seal	0.8		x
Adequate timing	0.6		x
Adequate source	0.8		x
Adequate preservation	0.7		x

Table 1.2c. Probability distribution for number of prospects

Geological variable	Probability in upper percentiles 0.99	Probability in upper percentiles 0.5	Probability in upper percentiles 0.00
Number of prospects	5	50	100

3. MESOZOIC CLASTIC GAS PLAY

Table 1.3a. Probability distributions of reservoir parameters

Geological variable	Unit of measurement	Probability in upper percentiles 1.00	Probability in upper percentiles 0.50	Probability in upper percentiles 0.01	Probability in upper percentiles 0.00
Area of closure	km^2	0.1	5	50	140
Net pay	m	0.4	10	20	30
Porosity	decimal fraction	0.03	0.09	0.15	0.2
Gas saturation	decimal fraction	0.55	0.75	0.9	0.95
Gas compressibility factor	decimal fraction	0.8	0.9	0.95	0.96
Reservoir temperature	Celsius	18	18	18	18
Reservoir pressure	kPa	5,460	5,460	5,460	5,460

Table 1.3b. Marginal probabilities of geological risk factors

Geological factors	Marginal probability	Play level	Prospect level
Presence of closure	0.6		x
Presence of reservoir facies	0.3		x
Adequate seal	0.7		x
Adequate timing	0.5		x
Adequate source	0.8		x
Adequate preservation	0.7		x

Table 1.3c. Probability distribution for number of prospects

Geological variable	Probability in upper percentiles 0.99	Probability in upper percentiles 0.5	Probability in upper percentiles 0.00
Number of prospects	2	15	35

APPENDIX 2

OUTPUT FOR OLD CROW HYDROCARBON ASSESSMENTS

The following text presents the output generated by the PETRIMES hydrocarbon assessment program using the conceptual play analysis procedure. For each play, the MPRO, PSRK and PSUM modules are presented. MPRO generates the number of pools distribution and risks for the play. PSRK gives the individual pool sizes by rank and PSUM indicates the Monte Carlo simulation for the pool size distribution. (Note: In text, field sizes are indicated rather than pools. In frontier conceptual plays, insufficient geological and engineering information is available to define individual pool accumulations in single structures). A PSUM module for total gas potential on a basin-scale is also presented.

PETRIMES MODULE MPRO

NO. OF POOLS DISTRIBUTION AND RISKS
****

```
UAI        C5310012
PLAY       Kekiktuk conglomerate gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   THU, DEC 14, 2000,  9:51 AM
```

USER SUPPLIED PARAMETERS

```
-----------------------
   DO YOU WANT TO STORE ON DB?          >    Y
   OIL (O) OR GAS (G) ?                 >    G
```

A) Risks

	GEOLOGICAL FACTOR		MARGINAL PROBABILITY
PLAY LEVEL	Overall Play Level Risk	=	1.00
PROSPECT LEVEL	Presence of Closure	(1)	.60
	Presence of Reservoir Facies	(2)	.40
	Adequate Seal	(4)	.80
	Adequate Timing	(5)	.70
	Adequate Source	(6)	.80
	Adequate Preservation	(8)	.90
	Overall Prospect Level Risk	=	.10
EXPLORATION RISK:		=	.10

B) No. of Prospects Distribution

Minimum	=	5
Maximum	=	100
Mean	=	51.52
S.D.	=	27.69

Frequency	No. of Prospects
99.00	5
95	9
90	14
80	23
75	28
60	41
50	50
40	60
25	75
20	80
10	90
5	95
1	99
0	100

C) No. of Pools Distribution

Minimum	=	0
Maximum	=	24
Mean	=	4.99
S.D.	=	3.42

Frequency	No. of Pools
93.29	0
90	1
80	2
75	2
60	4
50	5
40	6
25	7
20	8
10	10
5	11
1	14
0	24

Note: The no. of pools distribution is saved in the database with UDI= 6201GB4
PETRIMES MODULE PSRK

INDIVIDUAL POOL SIZES BY RANK

```
WHERE N IS A RANDOM VARIABLE
****************************

UAI        C5310012
PLAY       Kekiktuk conglomerate gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   THU, DEC 14, 2000, 12:15 PM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE ON DB ?          > Y
   DO YOU WANT TO USE MPRO OUTPUT?       > Y
   MIN. AND MAX. POOL RANKS?             >      1    11
   DO YOU USE LOGNORNAL ASSUMPTION?      > Y
   DO YOU WANT TO USE PPSD OUTPUT?       > Y

A) Basic Information
   -----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) Lognormal Pool Size Distribution
   -------------------------------
   Summary      mu     = 7.3680     MEAN   = 2393.1
   Statistics   sig. sq= .82470     S.D.   = 2708.7

   Upper        99.99% = 54.089     60.00% = 1258.8     15.00% = 4061.0
   Percentiles  99.00% = 191.59     55.00% = 1413.6     10.00% = 5073.5
                95.00% = 355.75     50.00% = 1584.4      8.00% = 5675.8
                90.00% = 494.80     45.00% = 1776.0      6.00% = 6502.3
                85.00% = 618.17     40.00% = 1994.3      5.00% = 7056.6
                80.00% = 737.80     35.00% = 2248.2      4.00% = 7768.5
                75.00% = 858.73     30.00% = 2550.9      2.00% = 10230.
                70.00% = 984.13     25.00% = 2923.4      1.00% = 13103.
                65.00% = 1116.6     20.00% = 3402.6       .01% = 46413.

C) No. of Pools Distribution
   ------------------------
   Lower Support     =   0
   Upper Support     =  24
   Expectation       =   4.99
   Standard Deviation=   3.42

D) Pool Sizes By Rank
   ------------------

   Pool Rank                   Distribution

        1     MEAN   = 5344.6     S.D.   = 4461.8     P(N>=r)= .93294
              99%    = 448.95     75%    = 2563.1     10%    = 10247.
              95%    = 1003.3     50%    = 4245.8      5%    = 13265.
              90%    = 1479.7     25%    = 6745.9      1%    = 22005.

        2     MEAN   = 2950.3     S.D.   = 1947.8     P(N>=r)= .82972
              99%    = 310.25     75%    = 1580.9     10%    = 5395.4
              95%    = 639.64     50%    = 2563.2      5%    = 6569.2
              90%    = 922.75     25%    = 3851.4      1%    = 9503.4
```

3	MEAN	= 2112.4	S.D.	= 1296.3	P(N>=r)	= .71946
	99%	= 252.36	75%	= 1169.8	10%	= 3796.3
	95%	= 494.13	50%	= 1878.3	5%	= 4531.9
	90%	= 696.89	25%	= 2777.8	1%	= 6258.2
4	MEAN	= 1654.4	S.D.	= 979.50	P(N>=r)	= .61035
	99%	= 216.92	75%	= 932.30	10%	= 2946.3
	95%	= 409.33	50%	= 1483.6	5%	= 3486.0
	90%	= 566.77	25%	= 2178.8	1%	= 4709.7
5	MEAN	= 1357.8	S.D.	= 786.22	P(N>=r)	= .50478
	99%	= 191.78	75%	= 774.58	10%	= 2403.6
	95%	= 351.67	50%	= 1221.7	5%	= 2831.0
	90%	= 479.66	25%	= 1786.7	1%	= 3779.9
6	MEAN	= 1148.3	S.D.	= 654.13	P(N>=r)	= .40487
	99%	= 172.67	75%	= 661.87	10%	= 2022.8
	95%	= 309.36	50%	= 1034.5	5%	= 2376.6
	90%	= 416.70	25%	= 1508.0	1%	= 3151.5
7	MEAN	= 992.55	S.D.	= 557.66	P(N>=r)	= .31316
	99%	= 157.61	75%	= 577.78	10%	= 1740.5
	95%	= 276.99	50%	= 894.94	5%	= 2041.8
	90%	= 369.17	25%	= 1300.0	1%	= 2696.1
8	MEAN	= 873.09	S.D.	= 484.17	P(N>=r)	= .23229
	99%	= 145.51	75%	= 513.30	10%	= 1523.6
	95%	= 251.62	50%	= 787.89	5%	= 1785.4
	90%	= 332.34	25%	= 1140.0	1%	= 2350.9
9	MEAN	= 779.38	S.D.	= 426.55	P(N>=r)	= .16444
	99%	= 135.66	75%	= 462.90	10%	= 1352.9
	95%	= 231.40	50%	= 704.19	5%	= 1583.9
	90%	= 303.26	25%	= 1014.4	1%	= 2080.9
10	MEAN	= 704.63	S.D.	= 380.45	P(N>=r)	= .11065
	99%	= 127.55	75%	= 422.86	10%	= 1216.3
	95%	= 215.05	50%	= 637.72	5%	= 1422.5
	90%	= 279.96	25%	= 914.09	1%	= 1865.0
11	MEAN	= 644.14	S.D.	= 342.96	P(N>=r)	= .70567E-01
	99%	= 120.81	75%	= 390.57	10%	= 1105.3
	95%	= 201.66	50%	= 584.18	5%	= 1291.1
	90%	= 261.01	25%	= 832.98	1%	= 1689.4

E) The mean of the potential = 11879.

PETRIMES MODULE PSUM

```
MONTE CARLO SUM SIMULATION
POOL SIZE DISTRIBUTION
**************************

UAI        C5310012
PLAY       Kekiktuk conglomerate gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   THU, DEC 14, 2000, 12:19 PM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE IN DATA BASE ?   >    Y
   OIL (O) OR GAS (G) ?                  >    G
   BRITISH OR S.I. UNIT OF MEASUREMENT?  >   SI
   RECOVERABLE RESOURCES?                >    N
   DO YOU WANT TO USE MPRO OUTPUT?       >    Y
   DO YOU ASSUME LOGNORMAL DISTRIBUTION? >    Y
   DO YOU WANT TO USE PPSD OUTPUT?       >    Y
   DO YOU COMPUTE CONDITIONAL POTENTIAL? >    N

A) Basic Information
   -----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) Lognormal Pool Size Distribution
   --------------------------------
   Summary      mu     = 7.3680     MEAN   = 2393.1
   Statistics   sig. sq= .82470     S.D.   = 2708.7

   Upper        99.99% = 54.089     60.00% = 1258.8     15.00% = 4061.0
   Percentiles  99.00% = 191.59     55.00% = 1413.6     10.00% = 5073.5
                95.00% = 355.75     50.00% = 1584.4      8.00% = 5675.8
                90.00% = 494.80     45.00% = 1776.0      6.00% = 6502.3
                85.00% = 618.17     40.00% = 1994.3      5.00% = 7056.6
                80.00% = 737.80     35.00% = 2248.2      4.00% = 7768.5
                75.00% = 858.73     30.00% = 2550.9      2.00% = 10230.
                70.00% = 984.13     25.00% = 2923.4      1.00% = 13103.
                65.00% = 1116.6     20.00% = 3402.6       .01% = 46413.

C) NO. OF POOLS DISTRIBUTION
   ------------------------------
   Lower Support     =    0
   Upper Support     =   24
   Expectation       =      4.98549
   Standard Deviation=      3.41837
```

```
D) Summary Statistics for 4000 Simulations
   ---------------------------------------

   Play Resource:    (  B cu m    )
   ------------------------------
     Minimum     = .0000000E+00Maximum           = 80.33903
     Expectation = 11.95574    Standard Deviation= 10.17583

   EMPERICAL DISTRIBUTION:
   ----------------------
     Greater than    Play
     Percentage      Potential
     ------------    -----------
        100.00          .00000E+00
         90.00          .89195
         85.00          1.8166
         80.00          2.8213
         75.00          3.9978
         70.00          5.0955
         65.00          6.1386
         60.00          7.2754
         55.00          8.5181
         50.00          9.7857
         45.00          11.271
         40.00          12.609
         35.00          14.154
         30.00          15.662
         25.00          17.282
         20.00          19.512
         15.00          22.303
         10.00          26.068
          8.00          27.721
          6.00          29.941
          5.00          31.317
          4.00          32.612
          2.00          38.450
          1.00          44.143
           .01          74.143
           .00          79.719
```

PETRIMES MODULE MPRO

```
NO. OF POOLS DISTRIBUTION AND RISKS
***********************************

UAI        C5320012
PLAY       Upper Paleozoic carbonate gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   MON, DEC 18, 2000,  9:26 AM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE ON DB?           >    Y
   OIL (O) OR GAS (G) ?                  >    G


A) Risks
   -----

               GEOLOGICAL FACTOR              MARGINAL PROBABILITY
               -----------------              --------------------

   PLAY LEVEL     Overall Play Level Risk        =       1.00

   PROSPECT LEVEL Presence of Closure         ( 1)        .60
                  Presence of Reservoir Facies ( 2)       .60
                  Adequate Seal               ( 4)        .80
                  Adequate Timing             ( 5)        .60
                  Adequate Source             ( 6)        .80
                  Adequate Preservation       ( 8)        .70
                  ---------------------------------------------------
                  Overall Prospect Level Risk    =        .10

   EXPLORATION RISK:                             =        .10
```

```
B) No. of Prospects Distribution
   -----------------------------

   Minimum       =     5
   Maximum       =   100
   Mean          =   51.52
   S.D.          =   27.69

   Frequency   No. of Prospects
   ---------   ----------------

     99.00           5
       95            9
       90           14
       80           23
       75           28
       60           41
       50           50
       40           60
       25           75
       20           80
       10           90
        5           95
        1           99
        0          100
```

```
C) No. of Pools Distribution
   -------------------------

   Minimum       =     0
   Maximum       =    24
   Mean          =    4.99
   S.D.          =    3.42

   Frequency   No. of Pools
   ---------   ------------

     93.29          0
       90           1
       80           2
       75           2
       60           4
       50           5
       40           6
       25           7
       20           8
       10          10
        5          11
        1          14
        0          24
```

```
Note: The no. of pools
distribution is saved in the
database with UDI= 6201GB4
```

PETRIMES MODULE PSRK

```
INDIVIDUAL POOL SIZES BY RANK
WHERE N IS A RANDOM VARIABLE
*****************************

UAI        C5320012
PLAY       Upper Paleozoic carbonate gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   MON, DEC 18, 2000,  4:24 PM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE ON DB ?          > Y
   DO YOU WANT TO USE MPRO OUTPUT?       > Y
   MIN. AND MAX. POOL RANKS?             >      1    11
   DO YOU USE LOGNORNAL ASSUMPTION?      > Y
   DO YOU WANT TO USE PPSD OUTPUT?       > Y

A) Basic Information
   -----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) Lognormal Pool Size Distribution
   -------------------------------
   Summary      mu      = 7.5503     MEAN   = 3895.0
   Statistics   sig. sq= 1.4343      S.D.   = 6963.9

   Upper        99.99% = 22.117      60.00% = 1403.7     15.00% = 6578.4
   Percentiles  99.00% = 117.24      55.00% = 1635.7     10.00% = 8822.9
                95.00% = 265.18      50.00% = 1901.3      8.00% = 10230.
                90.00% = 409.73      45.00% = 2210.1      6.00% = 12238.
                85.00% = 549.52      40.00% = 2575.3      5.00% = 13632.
                80.00% = 693.92      35.00% = 3016.2      4.00% = 15475.
                75.00% = 847.69      30.00% = 3562.9      2.00% = 22246.
                70.00% = 1014.6      25.00% = 4264.5      1.00% = 30834.
                65.00% = 1198.5      20.00% = 5209.5       .01% = .16345E+06

C) No. of Pools Distribution
   ------------------------
   Lower Support     =   0
   Upper Support     =  24
   Expectation       =   4.99
   Standard Deviation=   3.42

D) Pool Sizes By Rank
   -----------------

   Pool Rank                     Distribution

        1      MEAN   = 10562.     S.D.   = 13124.     P(N>=r)= .93294
               99%    = 360.41     75%    = 3585.5     10%    = 22295.
               95%    = 1040.7     50%    = 6976.0      5%    = 31339.
               90%    = 1737.4     25%    = 12846.      1%    = 61087.

        2      MEAN   = 4675.9     S.D.   = 4210.9     P(N>=r)= .82972
               99%    = 221.39     75%    = 1895.7     10%    = 9568.4
               95%    = 574.84     50%    = 3585.6      5%    = 12405.
               90%    = 932.01     25%    = 6134.3      1%    = 20187.
```

```
 3     MEAN   = 2984.3     S.D.   = 2447.2     P(N>=r)= .71946
       99%    = 168.60     75%    = 1274.4     10%    = 6018.9
       95%    = 408.99     50%    = 2379.5      5%    = 7602.4
       90%    = 643.63     25%    = 3986.7      1%    = 11636.

 4     MEAN   = 2153.4     S.D.   = 1691.3     P(N>=r)= .61035
       99%    = 138.10     75%    = 944.75     10%    = 4308.6
       95%    = 319.06     50%    = 1743.4      5%    = 5378.8
       90%    = 490.08     25%    = 2894.1      1%    = 7998.3

 5     MEAN   = 1655.2     S.D.   = 1268.1     P(N>=r)= .50478
       99%    = 117.39     75%    = 739.90     10%    = 3294.1
       95%    = 261.17     50%    = 1349.4      5%    = 4087.7
       90%    = 393.27     25%    = 2227.8      1%    = 5984.6

 6     MEAN   = 1324.4     S.D.   = 997.60     P(N>=r)= .40487
       99%    = 102.22     75%    = 601.32     10%    = 2624.0
       95%    = 220.55     50%    = 1083.7      5%    = 3245.5
       90%    = 326.66     25%    = 1781.2      1%    = 4708.7

 7     MEAN   = 1091.0     S.D.   = 810.74     P(N>=r)= .31316
       99%    = 90.626     75%    = 502.67     10%    = 2152.0
       95%    = 190.64     50%    = 895.15      5%    = 2656.5
       90%    = 278.45     25%    = 1464.6      1%    = 3832.8

 8     MEAN   = 919.83     S.D.   = 675.08     P(N>=r)= .23229
       99%    = 81.564     75%    = 430.05     10%    = 1805.6
       95%    = 167.96     50%    = 756.71      5%    = 2225.7
       90%    = 242.41     25%    = 1231.7      1%    = 3199.1

 9     MEAN   = 790.74     S.D.   = 573.14     P(N>=r)= .16444
       99%    = 74.363     75%    = 375.25     10%    = 1543.8
       95%    = 150.39     50%    = 652.54      5%    = 1900.5
       90%    = 214.84     25%    = 1055.9      1%    = 2723.8

10     MEAN   = 691.25     S.D.   = 494.59     P(N>=r)= .11065
       99%    = 68.561     75%    = 333.05     10%    = 1341.6
       95%    = 136.53     50%    = 572.56      5%    = 1649.3
       90%    = 193.34     25%    = 920.50      1%    = 2357.4

11     MEAN   = 613.15     S.D.   = 432.84     P(N>=r)= .70567E-01
       99%    = 63.823     75%    = 299.93     10%    = 1182.5
       95%    = 125.44     50%    = 510.04      5%    = 1451.4
       90%    = 176.27     25%    = 814.34      1%    = 2069.1
```

E) The mean of the potential = 19372.

PETRIMES MODULE PSUM

```
MONTE CARLO SUM SIMULATION
POOL SIZE DISTRIBUTION
**************************

UAI        C5320012
PLAY       Upper Paleozoic carbonate gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   MON, DEC 18, 2000,  4:33 PM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE IN DATA BASE ?   >    Y
   OIL (O) OR GAS (G) ?                  >    G
   BRITISH OR S.I. UNIT OF MEASUREMENT?  >   SI
   RECOVERABLE RESOURCES?                >    N
   DO YOU WANT TO USE MPRO OUTPUT?       >    Y
   DO YOU ASSUME LOGNORMAL DISTRIBUTION? >    Y
   DO YOU WANT TO USE PPSD OUTPUT?       >    Y
   DO YOU COMPUTE CONDITIONAL POTENTIAL? >    N

A) Basic Information
   -----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) Lognormal Pool Size Distribution
   -------------------------------
   Summary      mu     = 7.5503     MEAN   = 3895.0
   Statistics   sig. sq= 1.4343     S.D.   = 6963.9

   Upper        99.99% = 22.117     60.00% = 1403.7     15.00% = 6578.4
   Percentiles  99.00% = 117.24     55.00% = 1635.7     10.00% = 8822.9
                95.00% = 265.18     50.00% = 1901.3      8.00% = 10230.
                90.00% = 409.73     45.00% = 2210.1      6.00% = 12238.
                85.00% = 549.52     40.00% = 2575.3      5.00% = 13632.
                80.00% = 693.92     35.00% = 3016.2      4.00% = 15475.
                75.00% = 847.69     30.00% = 3562.9      2.00% = 22246.
                70.00% = 1014.6     25.00% = 4264.5      1.00% = 30834.
                65.00% = 1198.5     20.00% = 5209.5       .01% = .16345E+06

C) NO. OF POOLS DISTRIBUTION
   -----------------------------
   Lower Support     =    0
   Upper Support     =   24
   Expectation       =      4.98549
   Standard Deviation=      3.41837
```

D) Summary Statistics for 4000 Simulations

```
Play Resource:    (  B cu m    )
------------------------------
  Minimum     = .0000000E+00Maximum           = 227.0266
  Expectation = 19.43895    Standard Deviation= 20.09513

EMPERICAL DISTRIBUTION:
----------------------
```

Greater than Percentage	Play Potential
100.00	.00000E+00
90.00	.87989
85.00	2.0066
80.00	3.4842
75.00	5.1732
70.00	6.7426
65.00	8.2662
60.00	10.013
55.00	12.122
50.00	14.049
45.00	16.277
40.00	18.851
35.00	21.649
30.00	24.251
25.00	27.266
20.00	31.340
15.00	36.523
10.00	44.086
8.00	48.248
6.00	53.211
5.00	56.783
4.00	60.813
2.00	74.473
1.00	91.603
.01	210.88
.00	225.41

PETRIMES MODULE MPRO

```
NO. OF POOLS DISTRIBUTION AND RISKS
***********************************

UAI         C5330012
PLAY        Mesozoic clastic gas play
Assessor    Peter Hannigan
Geologist   Peter Hannigan
Remarks     Old Crow Hydrocarbon Assessment Project
Run date    THU, DEC 14, 2000, 11:26 AM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE ON DB?           >    Y
   OIL (O) OR GAS (G) ?                  >    G


A) Risks
   -----

               GEOLOGICAL FACTOR              MARGINAL PROBABILITY
               -----------------              --------------------

   PLAY LEVEL     Overall Play Level Risk        =       1.00

   PROSPECT LEVEL Presence of Closure          ( 1)       .60
               Presence of Reservoir Facies ( 2)       .30
               Adequate Seal                ( 4)       .70
               Adequate Timing              ( 5)       .50
               Adequate Source              ( 6)       .80
               Adequate Preservation        ( 8)       .70
               ---------------------------------------------------
               Overall Prospect Level Risk    =        .04

   EXPLORATION RISK:                          =        .04


B) No. of Prospects Distribution
   -----------------------------

   Minimum       =     2
   Maximum       =    35
   Mean          =   17.18
   S.D.          =    9.65

   Frequency   No. of Prospects
   ---------   ----------------

     99.00           2
       95            4
       90            5
       80            8
       75            9
       60           13
       50           15
       40           19
       25           25
       20           27
       10           31
        5           33
        1           35
        0           35


C) No. of Pools Distribution
   ------------------------

   Minimum       =     0
   Maximum       =     8
   Mean          =     .61
   S.D.          =     .84

   Frequency   No. of Pools
   ---------   ------------

     42.84          0
       40           1
       25           1
       20           1
       10           2
        5           2
        1           3
        0           8

Note: The no. of pools
distribution is saved in the
database with UDI= 6201GB4
```

PETRIMES MODULE PSRK

```
INDIVIDUAL POOL SIZES BY RANK
WHERE N IS A RANDOM VARIABLE
*****************************

UAI        C5330012
PLAY       Mesozoic clastic gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   THU, DEC 14, 2000, 11:28 AM

USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE ON DB ?          > Y
   DO YOU WANT TO USE MPRO OUTPUT?       > Y
   MIN. AND MAX. POOL RANKS?             >      1     2
   DO YOU USE LOGNORNAL ASSUMPTION?      > Y
   DO YOU WANT TO USE PPSD OUTPUT?       > Y

A) Basic Information
   -----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) Lognormal Pool Size Distribution
   -------------------------------
   Summary      mu     = 7.0366     MEAN   = 1807.3
   Statistics   sig. sq= .92605     S.D.   = 2231.6

   Upper        99.99% = 31.745     60.00% = 891.40     15.00% = 3083.9
   Percentiles  99.00% = 121.26     55.00% = 1007.9     10.00% = 3904.3
                95.00% = 233.63     50.00% = 1137.5      8.00% = 4397.1
                90.00% = 331.40     45.00% = 1283.7      6.00% = 5078.5
                85.00% = 419.56     40.00% = 1451.6      5.00% = 5538.4
                80.00% = 506.07     35.00% = 1648.1      4.00% = 6132.1
                75.00% = 594.38     30.00% = 1884.1      2.00% = 8208.6
                70.00% = 686.74     25.00% = 2176.9      1.00% = 10671.
                65.00% = 785.08     20.00% = 2556.8       .01% = 40760.

C) No. of Pools Distribution
   ------------------------
   Lower Support     =   0
   Upper Support     =   8
   Expectation       =    .61
   Standard Deviation=    .84

D) Pool Sizes By Rank
   ------------------
   Pool Rank                      Distribution

        1     MEAN   = 2156.8     S.D.   = 2516.2     P(N>=r)= .42843
              99%    = 139.19     75%    = 735.31     10%    = 4619.3
              95%    = 277.21     50%    = 1412.8      5%    = 6438.3
              90%    = 400.51     25%    = 2650.2      1%    = 12052.

        2     MEAN   = 1049.3     S.D.   = 908.55     P(N>=r)= .13476
              99%    = 105.35     75%    = 456.28     10%    = 2113.9
              95%    = 195.53     50%    = 795.73      5%    = 2748.2
              90%    = 270.01     25%    = 1346.4      1%    = 4452.4

E) The mean of the potential =  1065.4
```

PETRIMES MODULE PSUM

```
MONTE CARLO SUM SIMULATION
POOL SIZE DISTRIBUTION
**************************

UAI        C5330012
PLAY       Mesozoic clastic gas play
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   THU, DEC 14, 2000, 11:30 AM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE IN DATA BASE ?   >    Y
   OIL (O) OR GAS (G) ?                  >    G
   BRITISH OR S.I. UNIT OF MEASUREMENT?  >   SI
   RECOVERABLE RESOURCES?                >    N
   DO YOU WANT TO USE MPRO OUTPUT?       >    Y
   DO YOU ASSUME LOGNORMAL DISTRIBUTION? >    Y
   DO YOU WANT TO USE PPSD OUTPUT?       >    Y
   DO YOU COMPUTE CONDITIONAL POTENTIAL? >    N

A) Basic Information
   ----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) Lognormal Pool Size Distribution
   -------------------------------
   Summary      mu      = 7.0366     MEAN   = 1807.3
   Statistics   sig. sq= .92605      S.D.   = 2231.6

   Upper        99.99% = 31.745     60.00% = 891.40     15.00% = 3083.9
   Percentiles  99.00% = 121.26     55.00% = 1007.9     10.00% = 3904.3
                95.00% = 233.63     50.00% = 1137.5      8.00% = 4397.1
                90.00% = 331.40     45.00% = 1283.7      6.00% = 5078.5
                85.00% = 419.56     40.00% = 1451.6      5.00% = 5538.4
                80.00% = 506.07     35.00% = 1648.1      4.00% = 6132.1
                75.00% = 594.38     30.00% = 1884.1      2.00% = 8208.6
                70.00% = 686.74     25.00% = 2176.9      1.00% = 10671.
                65.00% = 785.08     20.00% = 2556.8       .01% = 40760.

C) NO. OF POOLS DISTRIBUTION
   ----------------------------
   Lower Support     =    0
   Upper Support     =    8
   Expectation       =       .60611
   Standard Deviation=       .83709
```

```
D) Summary Statistics for 4000 Simulations
   --------------------------------------

   Play Resource:    (  B cu m    )
   ------------------------------
     Minimum     = .0000000E+00Maximum           = 36.09216
     Expectation = 1.160002    Standard Deviation= 2.366528

   EMPERICAL DISTRIBUTION:
   ----------------------
     Greater than    Play
     Percentage      Potential
     ------------    -----------
        100.00          .00000E+00
         40.00          .35324
         35.00          .65255
         30.00          1.0278
         25.00          1.4055
         20.00          1.8725
         15.00          2.6436
         10.00          3.5766
          8.00          4.1821
          6.00          4.9659
          5.00          5.4226
          4.00          6.0097
          2.00          8.6371
          1.00          10.931
           .01          31.717
           .00          35.654
```

PETRIMES MODULE PSUM

```
MONTE CARLO SUM SIMULATION
POOL SIZE DISTRIBUTION
**************************

UAI        C5300012
PLAY       All gas plays
Assessor   Peter Hannigan
Geologist  Peter Hannigan
Remarks    Old Crow Hydrocarbon Assessment Project
Run date   MON, DEC 18, 2000,  4:36 PM


USER SUPPLIED PARAMETERS
------------------------
   DO YOU WANT TO STORE IN DATA BASE ?   >    Y
   OIL (O) OR GAS (G) ?                  >    G
   BRITISH OR S.I. UNIT OF MEASUREMENT?  >   SI
   RECOVERABLE RESOURCES?                >    N
   DO YOU COMPUTE CONDITIONAL POTENTIAL? >    N

A) Basic Information
   ----------------
   TYPE OF RESOURCE      =Gas In-place
   SYSTEM OF MEASUREMENT =S.I.
   UNIT OF MEASUREMENT   =M cu m  (19)

B) PLAY POTENTIAL DISTRIBUTION
   ------------------------------


   Summary      MEAN   = 11.956     S.D.   = 10.176
   Statistics   B cu m

   Upper       100.00% = .00000E+00 50.00% = 9.7857      8.00% = 27.721
   Percentiles  90.00% = .89195     45.00% = 11.271      6.00% = 29.941
                85.00% = 1.8166     40.00% = 12.609      5.00% = 31.317
                80.00% = 2.8213     35.00% = 14.154      4.00% = 32.612
                75.00% = 3.9978     30.00% = 15.662      2.00% = 38.450
                70.00% = 5.0955     25.00% = 17.282      1.00% = 44.143
                65.00% = 6.1386     20.00% = 19.512       .01% = 74.143
                60.00% = 7.2754     15.00% = 22.303       .00% = 79.719
                55.00% = 8.5181     10.00% = 26.068

   Summary      MEAN   = 19.439     S.D.   = 20.095
   Statistics   B cu m

   Upper       100.00% = .00000E+00 50.00% = 14.049      8.00% = 48.248
   Percentiles  90.00% = .87989     45.00% = 16.277      6.00% = 53.211
                85.00% = 2.0066     40.00% = 18.851      5.00% = 56.783
                80.00% = 3.4842     35.00% = 21.649      4.00% = 60.813
                75.00% = 5.1732     30.00% = 24.251      2.00% = 74.473
                70.00% = 6.7426     25.00% = 27.266      1.00% = 91.603
                65.00% = 8.2662     20.00% = 31.340       .01% = 210.88
                60.00% = 10.013     15.00% = 36.523       .00% = 225.41
                55.00% = 12.122     10.00% = 44.086

   Summary      MEAN   = 1.1600     S.D.   = 2.3665
   Statistics   B cu m
```

```
Upper       100.00% = .00000E+00 15.00% = 2.6436      2.00% = 8.6371
Percentiles  40.00% = .35324     10.00% = 3.5766      1.00% = 10.931
             35.00% = .65255      8.00% = 4.1821       .01% = 31.717
             30.00% = 1.0278      6.00% = 4.9659       .00% = 35.654
             25.00% = 1.4055      5.00% = 5.4226
             20.00% = 1.8725      4.00% = 6.0097
```

C) NO. OF PLAYS DISTRIBUTION

```
-----------------------------
Lower Support     =    3
Upper Support     =    3
Expectation       =      3.00000
Standard Deviation=       .00000
```

D) Summary Statistics for 4000 Simulations

```
-------------------------------------

Basin Resource:   (  B cu m    )
-----------------------------
  Minimum     = .0000000E+00Maximum           = 229.6727
  Expectation = 33.48447    Standard Deviation= 24.17896

EMPERICAL DISTRIBUTION:
----------------------
  Greater than    Basin
  Percentage      Potential
  ------------    -----------
     100.00          .00000E+00
      99.00          1.8667
      95.00          5.8189
      90.00          9.4236
      85.00          12.365
      80.00          15.005
      75.00          17.238
      70.00          19.760
      65.00          22.065
      60.00          24.476
      55.00          26.678
      50.00          29.029
      45.00          31.493
      40.00          34.025
      35.00          36.672
      30.00          39.515
      25.00          42.953
      20.00          47.356
      15.00          53.821
      10.00          61.840
       8.00          65.873
       6.00          72.578
       5.00          75.034
       4.00          78.300
       2.00          93.772
       1.00          115.92
        .01          223.66
        .00          229.07
```