

Geology and Assessment of Undiscovered Oil and Gas Resources of the Sverdrup Basin Province, Arctic Canada, 2008

Chapter I of
The 2008 Circum-Arctic Resource Appraisal



Professional Paper 1824

Cover.

Northwestward view across the southern foothills of the Brooks Range along Akmagolik Creek, approximately 150 miles southwest of Prudhoe Bay, Alaska. Exposed rocks are part of the Mississippian–Pennsylvanian Lisburne Group and include a thrust-fault ramp at left. Photo includes two helicopters for scale, a blue-and-white one near the center and a red one at center-right at creek level. U.S. Geological Survey photograph by David Houseknecht.

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By Marilyn E. Tennyson and Janet K. Pitman

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Edited by T.E. Moore and D.L. Gautier

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Chapter I

Geology and Assessment of Undiscovered Oil and Gas Resources of the Sverdrup Basin Province, Arctic Canada, 2008

By Marilyn E. Tennyson and Janet K. Pitman

Abstract

The Sverdrup Basin Province, an area of 515,000 square kilometers on the northern margin of North America, extends 1,300 kilometers across the Canadian Arctic Islands from near the Mackenzie Delta to northern Ellesmere Island. It consists of an intracratonic late Paleozoic to early Cenozoic rift-sag basin and a Mesozoic rift shoulder that bounds it on the north.

Basin inception was Mississippian, manifested by deposition of nonmarine strata in rift basins, followed by Pennsylvanian marine transgression, which began with evaporites and progressed to Permian carbonate and clastic deposition at basin fringes and organic-rich marine strata in the basin center. Sediment transport was both northward from North America and southward from a now-subsided or rifted-away landmass to the north. Mesozoic strata indicate continued marine deposition, including both organic-rich, fine-grained rocks deposited during highstands and progradational deltaic sequences. A new episode of rifting began in Middle Jurassic time and culminated in the opening of the Canada Basin by Early Cretaceous seafloor spreading. The Sverdrup Rim formed as the rift shoulder between North America and the thinned, subsided crust to the north. Widespread Upper Cretaceous organic-rich shales were deposited during the major transgression induced by Canada Basin opening, followed by an influx of coarser east-derived detritus. In Paleogene time, incipient North Atlantic seafloor spreading caused deformation in northeasternmost North America, producing uplifts that shed detritus westward across the Sverdrup Basin. Tight folding and thrusting resulting from the Eurekan orogeny took place in the eastern part of the basin during the Eocene, with decreasing intensity of deformation westward. Since deformation ended in late Eocene time, little significant tectonism or deposition has taken place.

Two petroleum systems were defined in the Sverdrup Basin Province. Upper Paleozoic marine shale generated petroleum beginning in the Early Triassic, but this petroleum system was

not quantitatively assessed because reservoir quality in adjacent strata is poor, the rocks are mostly overmature, and subsequent deformation likely affected trap integrity. The second petroleum system was sourced by Lower Triassic strata rich in oil-prone organic matter. Oil was generated during Paleogene burial synchronous with Eurekan deformation, and the oil migrated into Triassic and Jurassic deltaic, shallow marine and nonmarine strata. However, most of the oil may have escaped during deformation and subsequent uplift and erosion, which probably caused oil to be displaced from traps by gas expansion. The population of undiscovered accumulations was characterized as likely to include stratigraphically trapped and small, structurally trapped accumulations, with a median size of 80 million barrels of oil (MMBO); the number of undiscovered accumulations was estimated to be between 1 and 50, with the most likely number being 10. The resulting estimate of undiscovered, technically recoverable, conventional oil resources is 61 to 1,255 MMBO, with a mean of 427 MMBO. Undiscovered, technically recoverable, conventional gas resources are estimated at 4.95 trillion cubic feet (TCF), with slightly more than half of that in nonassociated gas accumulations.

A third petroleum system in the adjacent Amerasia Basin Province to the north was considered somewhat likely to contain accumulations on the Sverdrup Rim. Deeply buried Upper Jurassic, Upper Cretaceous, and Eocene organic-rich strata probably generated oil that may have migrated up the continental slope into Triassic to Paleogene sandstones on the Sverdrup Rim. Based on analogy with the Barrow Arch in Alaska, a median of 20 accumulations was estimated, with accumulation volumes as much as 2,500 MMBO and a median of 100 MMBO. The probability of at least one accumulation of the minimum size assessed (50 MMBO) was estimated at 0.22. The resulting estimate of undiscovered, technically recoverable, conventional oil resources is 0 to 2,679 MMBO, with a mean of 424 MMBO. Mean estimates for associated and nonassociated gas are 1.3 and 2.3 TCF, respectively.

Introduction

In 2008, the U.S. Geological Survey (USGS) completed an appraisal of undiscovered, technically recoverable, conventional oil and gas resources north of the Arctic Circle. Results of that assessment, the Circum-Arctic Resource Appraisal (CARA), included aggregate, probabilistic resource estimates for the entire Arctic region (Gautier and others, 2009, 2011) based on geologic evaluation of all the basins located wholly or partially north of the Arctic Circle. Basins considered to have at least a 10 percent chance of hosting an oil accumulation larger than 50 million barrels of oil (MMBO) or a gas accumulation larger than 300 billion cubic feet of gas (BCFG) were assessed using the methodology described in Charpentier and Gautier (2011) and Charpentier (this volume, chap. B). The location and extent of the basins evaluated are delimited in Grantz and others (2010). This report is a summary of the geologic information and evaluation that underlies the assessment of potential undiscovered oil and gas resources in the Sverdrup Basin Province.

Province Description

The Sverdrup Basin Province (fig. 1) consists of upper Paleozoic, Mesozoic, and lower Cenozoic strata within an elongate, gentle synclinorium that extends from Ellesmere Island southwest through the Canadian Arctic Islands to Prince Patrick Island. In addition, it includes the rift shoulder of the Canada Basin that trends southwest from northern Ellesmere Island and the adjacent continental shelf along the northwest flank of the Sverdrup Basin, where it is called the Sverdrup Rim, through western Banks Island to the Tuktoyaktuk Peninsula adjacent to the Mackenzie Delta. The southern province boundary, the unconformity at the base of upper Carboniferous strata on Devonian or older rocks, trends south-southwest through western Ellesmere Island, then curves to a westerly trend through the central and western Canadian Arctic Islands, intersecting the Canadian polar margin in the vicinity of northeastern Prince Patrick Island. Its northern boundary is the edge of thinned, rifted continental

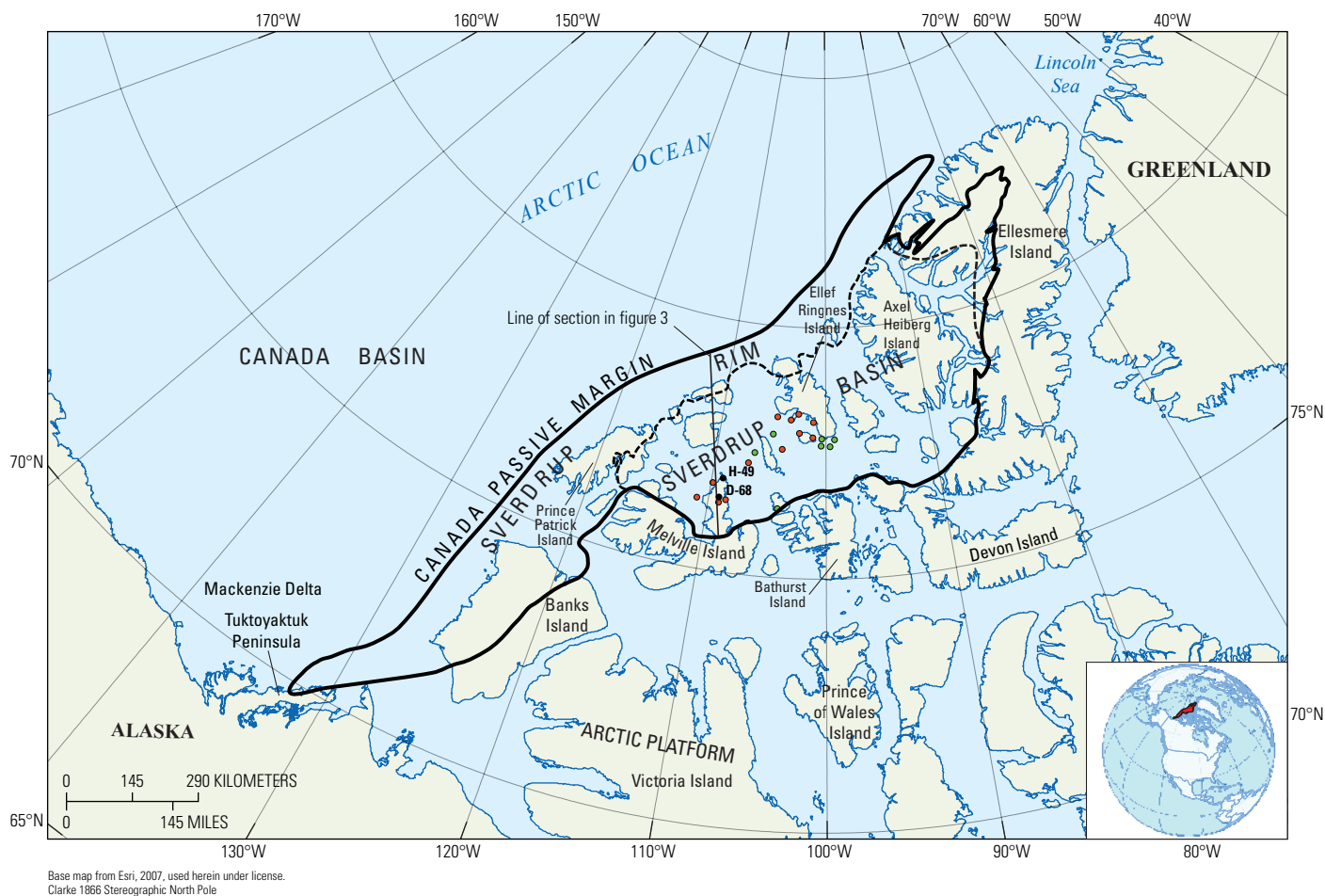


Figure 1. Map of Sverdrup Basin Province, showing province boundary (heavy solid black line) and included assessment unit (AU) boundaries (dashed lines). The Sverdrup Mesozoic AU lies directly above the Sverdrup Upper Paleozoic AU, except for northern Ellesmere Island, where Mesozoic strata are absent. Line of north-south cross section in figure 3 is shown. Discovered oil and gas accumulations indicated by green and red circles, respectively. Wells used for petroleum generation models are D-68, Drake Point D-68; H-49, North Sabine H-49.

crust along the Canadian polar margin, mapped for this study by the location of a steep free-air gravity gradient (Saltus and others, 2011). The basin is about 1,300 kilometers (km) long and about 400 km wide at its widest point. The upper Paleozoic section within the basin is as much as 3 km thick, the Mesozoic as much as 9 km thick, and the Cenozoic as much as 3 km thick (Morrell and others, 1995). The area of the Sverdrup Basin is about 302,000 square kilometers (km²), and the area of the entire province including the Sverdrup Rim-Banks Island rift shoulder is about 515,000 km².

Mississippian and younger strata of the Sverdrup Basin (figs. 2, 3) were deposited unconformably on Devonian and older rocks involved in Late Devonian to Early Mississippian Ellesmerian deformation. A Mississippian to Pennsylvanian rift sequence at the base of the Sverdrup Basin fill indicates crustal extension and rapid subsidence, followed by Permian through Triassic marine deposition during subsidence presumably governed by thermal decay (Stephenson and others, 1987). A brief episode of extensional or transtensional deformation, the Melvillian disturbance, took place at the end of early Permian time, about 275 Ma (Harrison, 1994, 1995; Harrison and Brent, 2005). By Early to Middle Jurassic time, rifting began to affect the northern part of the basin, eventually culminating in an episode of Early Cretaceous (Hauterivian-Barremian) seafloor spreading that opened the Canada Basin by separating Arctic Alaska from northern Canada (Grantz and May, 1982; Embry, 1990; Jackson, 1990; Grantz and others, 1998, 2007). Strata formerly contiguous with the Sverdrup Basin are thought to lie in the area of Hanna Trough in offshore Alaska and on Northwind Ridge in the Chukchi Sea (Embry and others, 1992; Grantz and others, 1998). During and after Canada Basin opening, Cretaceous marine strata were deposited across the rifted margin and throughout the Sverdrup Basin. An early Cenozoic deformational event, the Eurekan orogeny, was associated with relative motion between Greenland and North America. The orogeny caused folding and thrusting in the eastern part of the basin (Miall, 1991; Harrison and others, 1999; Tessensohn and Piepjohn, 2000), along with gentle folding in the central part of the basin. The southwesternmost part of the basin was only mildly deformed.

Nearly complete outcrop exposure on the Canadian Arctic Islands, about 160 exploration and delineation wells, several major gas discoveries and one major oil discovery (table 1), and a fairly extensive seismic dataset (65,000 km according to Trettin, 1989) collected during petroleum exploration in the 1970s and 1980s have resulted in a much higher level of geologic understanding than is typical in most parts of the Arctic. Despite this, there is significant uncertainty about the nature of upper Paleozoic strata in the central part of the basin where they are buried by thick Mesozoic strata and where Paleozoic strata have not been penetrated extensively by exploration wells. The Mesozoic part of the basin fill is more completely understood. Cenozoic strata, though well studied, are only locally preserved, and their unknown original extent results in uncertainty regarding burial and maturation history.

Geologic History and Petroleum Geology

Discontinuous sequences of Middle Mississippian lacustrine, organic-rich mudstone and associated sandstone, conglomerate, and coal (Emma Fiord Formation) are the oldest deposits in the Sverdrup Basin (fig. 2). On the margins of the basin, they are overlain by Pennsylvanian rift clastics (Canyon Fiord Formation) that grade basinward to subaqueously deposited evaporites of the Otto Fiord Formation (Davies and Nassichuk, 1975) and basinal mudstones of the Hare Fiord Formation. By Permian time, the basin had subsided sufficiently that carbonates on the flanks (Belcher Channel and Nansen Formations) rimmed basinal mudstones in the center of the basin (Van Hauen Formation) (Beauchamp and others, 1989a, 1989b; Beauchamp, 1992, 1995; Davies and Nassichuk, 1991a). A poorly understood episode of deformation in middle Permian time (~275 Ma), named the Melvillian disturbance, inverted older rifts by transtension and transpression (Harrison, 1994, 1995; Harrison and Brent, 2005). The upper part of the Permian sequence consists of nearshore to slope sandstones shed from uplifts produced by the Melvillian event, including the Sabine Bay, Trolld Fiord, and Assistance Formations (Davies and Nassichuk, 1991a; Beauchamp and others, 1989b; Beauchamp and others, 2001; Harrison and Brent, 2005).

Clastic deposition prevailed throughout the Mesozoic, punctuated by major sequence-bounding surfaces in earliest Triassic, latest Triassic, and Early Cretaceous time (Embry, 1991, 2007). Sediments were transported both northward from the North American shelf and southward from a now-absent landmass named "Crockerland" by Embry (1992), which foundered or was rifted away when the Canada Basin opened in Cretaceous time. Lowermost Triassic rocks were deposited by braided streams (Bjorne Formation) flowing northward into a shale-dominated marine basin (Blind Fiord Formation). A highstand in Middle Triassic time resulted in widespread deposition of organic-rich mudstones (Murray Harbour and Hoyle Bay Formations), while shelf and delta sands were deposited at the margins of the basin (Eldridge Bay and Pat Bay sandstones). During an Early Jurassic regression, deltaic deposition was prevalent, represented by thick sandstones of the Heiberg Formation (Embry, 1982, 1991), the principal reservoir sequence for discovered gas and oil. A major transgression during Middle and Late Jurassic time resulted in widespread deposition of basinal fine-grained strata (Jameson Bay, McConnell Island, Ringnes, Deer Bay, and Mackenzie King Formations), with coarser shelf deposits of the Upper Jurassic Awingak Formation prograding into the basin from the southeast (Embry, 1991). On the Sverdrup Rim along the northwest edge of the basin, Jurassic to Early Cretaceous extensional basins formed in association with Canada Basin rifting (fig. 3). In Early Cretaceous time, seafloor spreading began, and deposition of the last major sequence commenced with Valanginian to Albian deposition of thick fluvial-deltaic sands and shelf muds of the Isachsen, Christopher, and Hassel Formations, succeeded by transgressive organic-rich Upper Cretaceous shelf mudstones of the Kanguk Formation. Near the end of Cretaceous time,

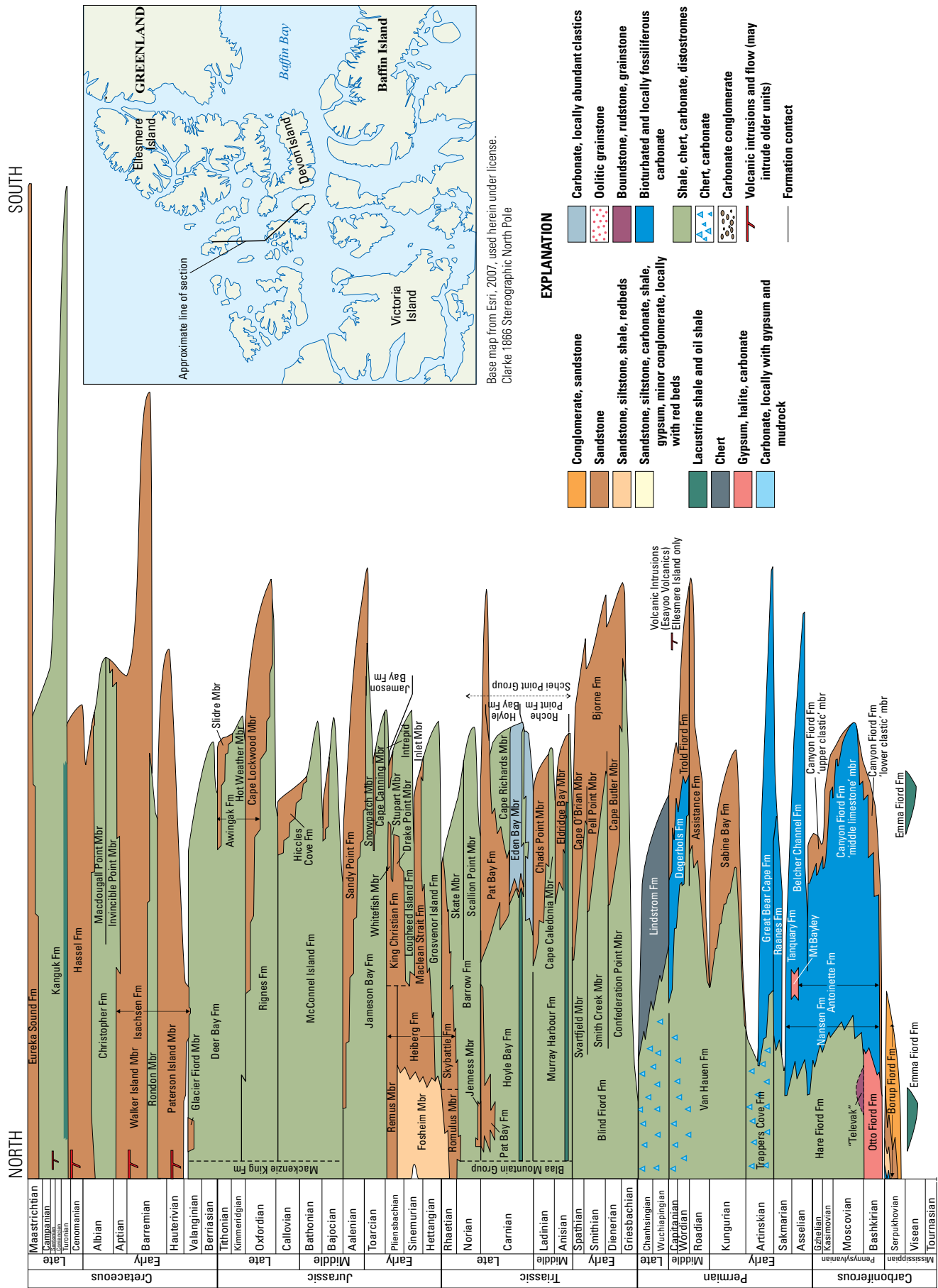


Figure 2. Stratigraphic chart for Sverdrup Basin Province, modified from Dewing and others (2007). Fm, Formation; Mbr, Member.

Table 1. Discovered oil and gas accumulations in the Sverdrup Basin Province.

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas]

Field name	Discovery year	Commodity	Gas in place (BCFG) ¹	Recoverable gas at 85% recovery (BCFG)	Recoverable oil (MMBO) ²	Recoverable gas (BCFG) ²
Drake Point	1969	Gas	5,982	4,786		5,369
King Christian	1970	Gas	677	542		588
Hecla	1972	Gas	4,199	3,359	12	3,720
Thor	1972	Gas	871	697	3	715
Kristoffer Bay	1972	Gas	1,309	1,047		1,107
Wallis	1973	Gas	126	101		98
Jackson Bay	1976	Gas	1,309	1,047		1,074
Roche Point	1978	Gas	520	416		427
Whitefish	1979	Gas	2,637	2,110		2,131
Maclean	1981	Gas	834	667	49	604
Sculpin	1982	Gas	87	70		58
Char	1980	Oil	510	408	3	377
Balaena	1980	Oil			16	
Cisco	1981	Oil	248	198	175	204
Skate	1981	Oil	310	248	29	221
Cape Macmillan	1983	Oil	106	85	0.15	76
Cape Allison	1985	Oil	428	342	44	614

¹Canadian Gas Potential Committee (2001)²Drummond (2006)

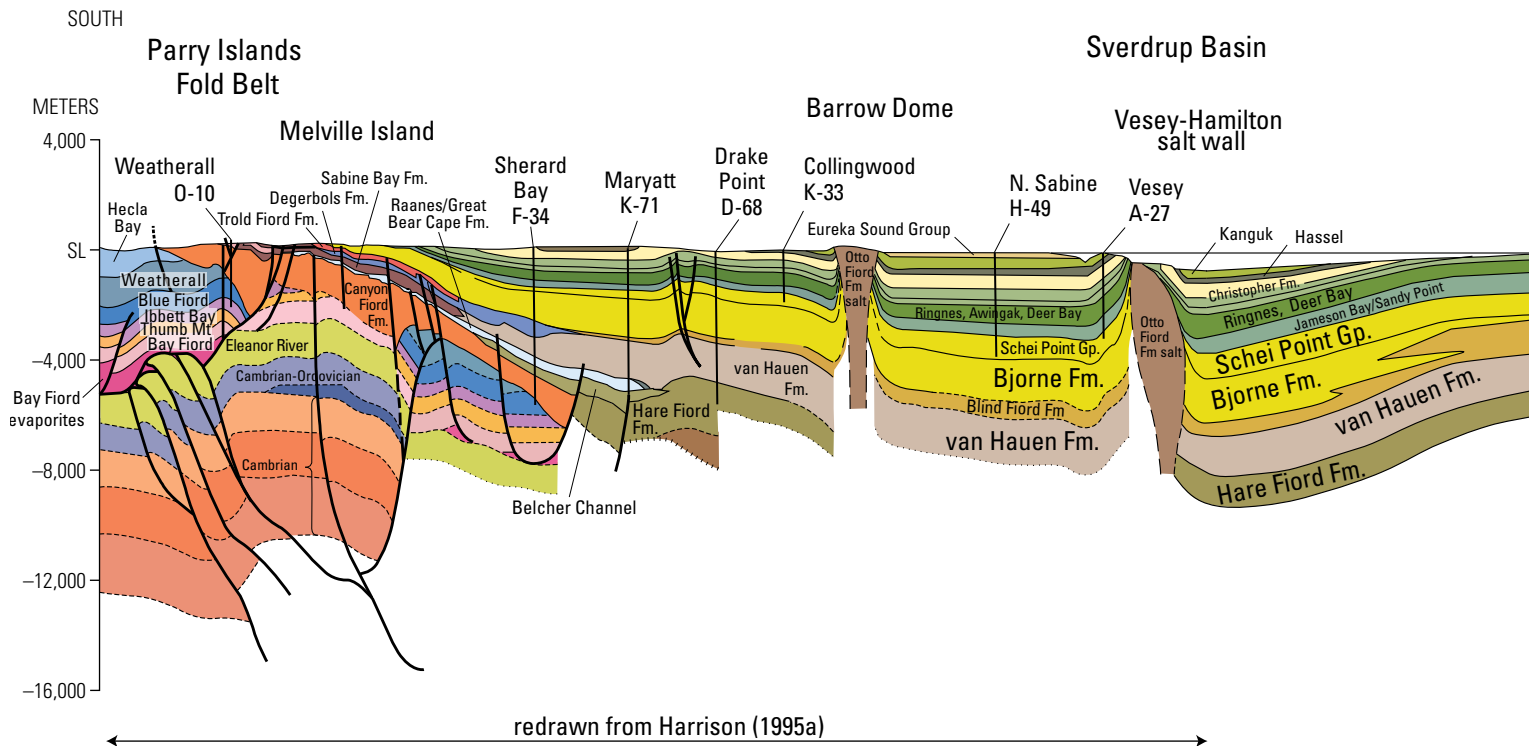


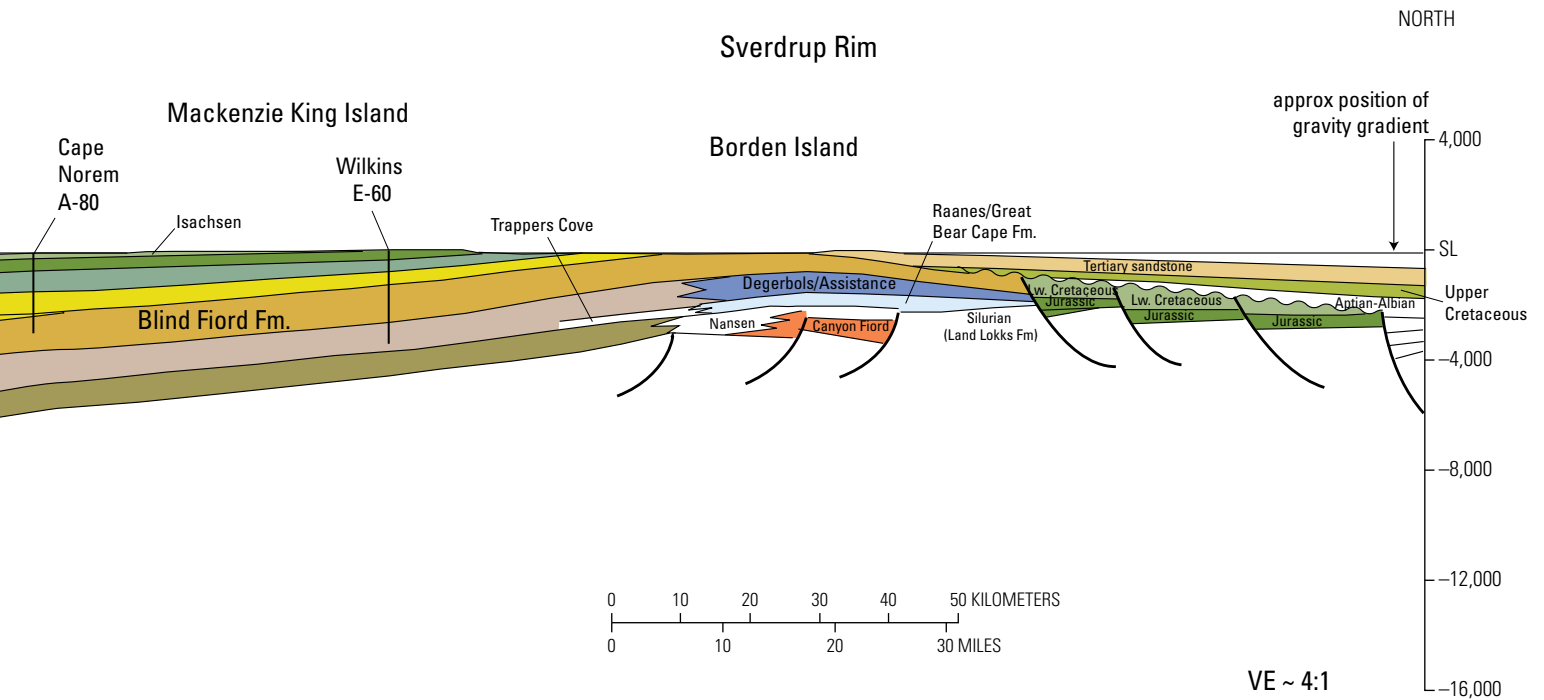
Figure 3. Regional structure cross section across Sverdrup Basin Province. Location of section is shown on figure 1. Southern flank of basin redrawn from Harrison (1995, Section E, sheet 7); vertically exaggerated about 4x. Depiction of the northern flank of the basin and Sverdrup Rim is schematic and hypothetical, based on figure 31 of Rayer and others (1981, extensively modified), on stratigraphy in wells on and near the Sverdrup Rim, and on regional stratigraphic and structural relations. m, meters; SL, sea level; Fm., Formation; Gp, Group, Lw., lower.

sandstones (Expedition Formation of the Eureka Sound Group) began to prograde westward across the basin from uplifted areas in the east (Ricketts, 1994; Ricketts and Stephenson, 1994). Their original depositional extent and the nature of the uplifts from which they were derived are uncertain. One possibility is that the sediments were eroded from uplifts associated with rifting between Canada and Greenland that preceded opening of the Labrador Sea, inferred by Grist and Zentilli (2005, 2006) from fission-track studies.

At about 60 Ma, seafloor spreading between Greenland and Canada began (Chalmers and Laursen, 1995), followed at about 55 Ma by spreading between Greenland and Europe (Mosar and others, 2002). As a result, Greenland rotated counterclockwise with respect to North America, giving rise to intense compressive deformation in northwest Greenland and northeastern Arctic Canada for most of Eocene time (Miall, 1991; Ricketts and Stephenson, 1994; Tessensohn and Piepjohn, 2000). The resulting Eurekan thrust belt on Ellesmere and Axel Heiberg Islands created uplifts that shed Paleogene detritus of the Eureka Sound Group westward across the Canadian Arctic Islands into numerous shifting depocenters (Miall, 1986, 1991; Ricketts, 1994). Eurekan compression ended near the end of Eocene time (Harrison and others, 1999), and since then erosion has prevailed. Estimates of

erosion since maximum burial range from 1 to 4 km in the western Sverdrup Basin (Bustin, 1986; Brooks and others, 1992). Along the northwesternmost part of the province, Miocene to Pliocene nearshore and continental sediments of the Beaufort Formation overlie the wedge of middle Cretaceous to Eocene strata deposited across the Early Cretaceous rifted margin (Fyles, 1990; Fyles and others, 1994; Harrison and others, 1999).

Most of the province is only mildly deformed, with the exception of the Eurekan compressive or transpressive deformation in the northeast end of the basin. Extensional faults are present in the lower part of the Paleozoic section. Folds and faults associated with Melvillian inversion are present at least locally in Permian and older strata, although their regional extent is uncertain. Extensional faults are also present in Jurassic to Lower Cretaceous strata along the northwestern rim of the basin. Structural features produced by deformation of upper Paleozoic Otto Fiord halite include diapirs that were active beginning in Triassic time (Embry, 1991) and intermittently through Mesozoic and Cenozoic time. Salt walls, minibasins, and an evaporite canopy have been described on Axel Heiberg Island, where Eurekan compression produced a variety of salt structures detached on Carboniferous Otto Fiord halite (Jackson and Harrison, 2006; Harrison and Jackson, 2013). The eastern



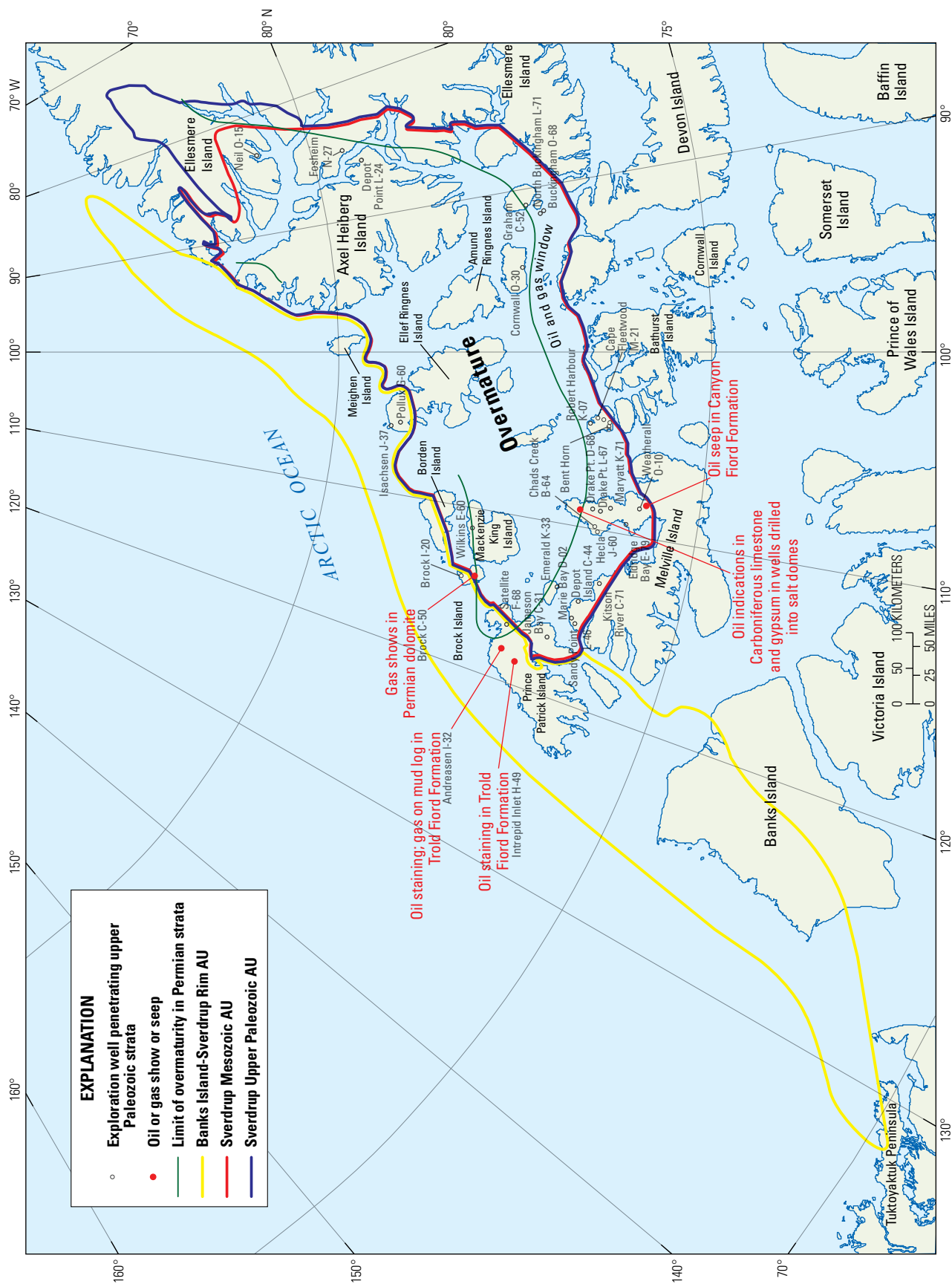
end of the basin, including Ellesmere and Axel Heiberg Islands and the intervening channels, exhibits intense Eurekan fold-thrust deformation. Intensity of folding and associated faulting decreases westward across the basin, with mainly gentle folds and faults in the far western end (for example, Harrison and Brent, 2005).

Petroleum Systems and Assessment Units

A possible but unproven petroleum system may be present in the Carboniferous and Permian part of the Sverdrup Basin fill, referred to in this study as the Upper Paleozoic Composite Petroleum System (fig. 4), with postulated source rocks in upper Carboniferous and Permian basinal cherty mudstones of the Hare Fiord, Trappers Cove, and Van Hauen Formations. These rocks, deposited as slope turbidites (Beauchamp and Henderson, 1994), locally have adequate levels of total organic carbon (TOC) to make them at least marginal source rocks; organic matter is mostly terrestrial (Powell, 1978). Organic-rich lacustrine rocks of the lower Carboniferous Emma Fiord Formation (Davies and Nassichuk, 1991b) that are locally present around the margins of the basin would also be good source rocks if they were widely present, but their distribution in the depths of the basin is unknown. Strata in the central part of the basin are overmature; only around the margins of the basin are upper Paleozoic rocks within the oil and gas window (Utting and others, 1989; fig. 4). Petroleum generation modeling for this study (fig. 5) suggests that lower Carboniferous source rocks would have begun to generate oil in Triassic time as a result of burial by thick Triassic strata, and generation would have continued until Cretaceous time

in any source rocks present in the uppermost part of the upper Paleozoic section. Carbonates and shallow marine clastics on the margins of the basin are potential reservoir rocks, sealed by either interbedded mudstones or by overlying mudstone of the Blind Fiord Formation at the base of Triassic strata. Stratigraphic pinchouts, rift-associated normal faults and rollover anticlines, and faults and anticlines formed during middle Permian deformation are potential traps.

A proven (table 1) and well-explored petroleum system is present in Mesozoic strata of the Sverdrup Basin, deposited during gradual subsidence of the postrift phase of basin evolution. Source rocks consist of Middle and Upper Triassic mudstones of the Murray Harbour and Hoyle Bay Formations. Rich in Type II organic matter, these rocks have attained adequate maturity for petroleum generation in the central part of the basin (fig. 6). Dominantly deltaic Upper Triassic and Lower Jurassic strata of the Heiberg Formation contain most of the discovered oil and gas, although small amounts of petroleum have been discovered in younger Jurassic through middle Cretaceous sandstones. Generation from the Triassic source strata began in Late Cretaceous time, according to both Skibo and others (1990) and the results of petroleum generation modeling carried out for this study (fig. 7). Some workers have concluded that generation began earlier, either during rifting and seafloor spreading in Early Cretaceous time (Gentzis and others, 1996) or during burial by Aptian-Albian strata deposited after breakup (Goodarzi and others, 1992). It seems clear, however, that generation began later and continued until the time of maximum burial, probably in Paleogene time, because maturation levels at present depths of burial are too high to have been attained without deposition and erosion of substantial thicknesses of Upper Cretaceous and



Base map from Esri, 2007, used herein under license.
Clarke 1866 Stereographic North Pole

Figure 4. Map of Upper Paleozoic Composite Petroleum System, showing locations and names of exploration wells that penetrated upper Paleozoic strata, indications of oil or gas in wells and surface outcrops, and boundary between Permian strata from Utting and others (1989). AU, Assessment Unit.

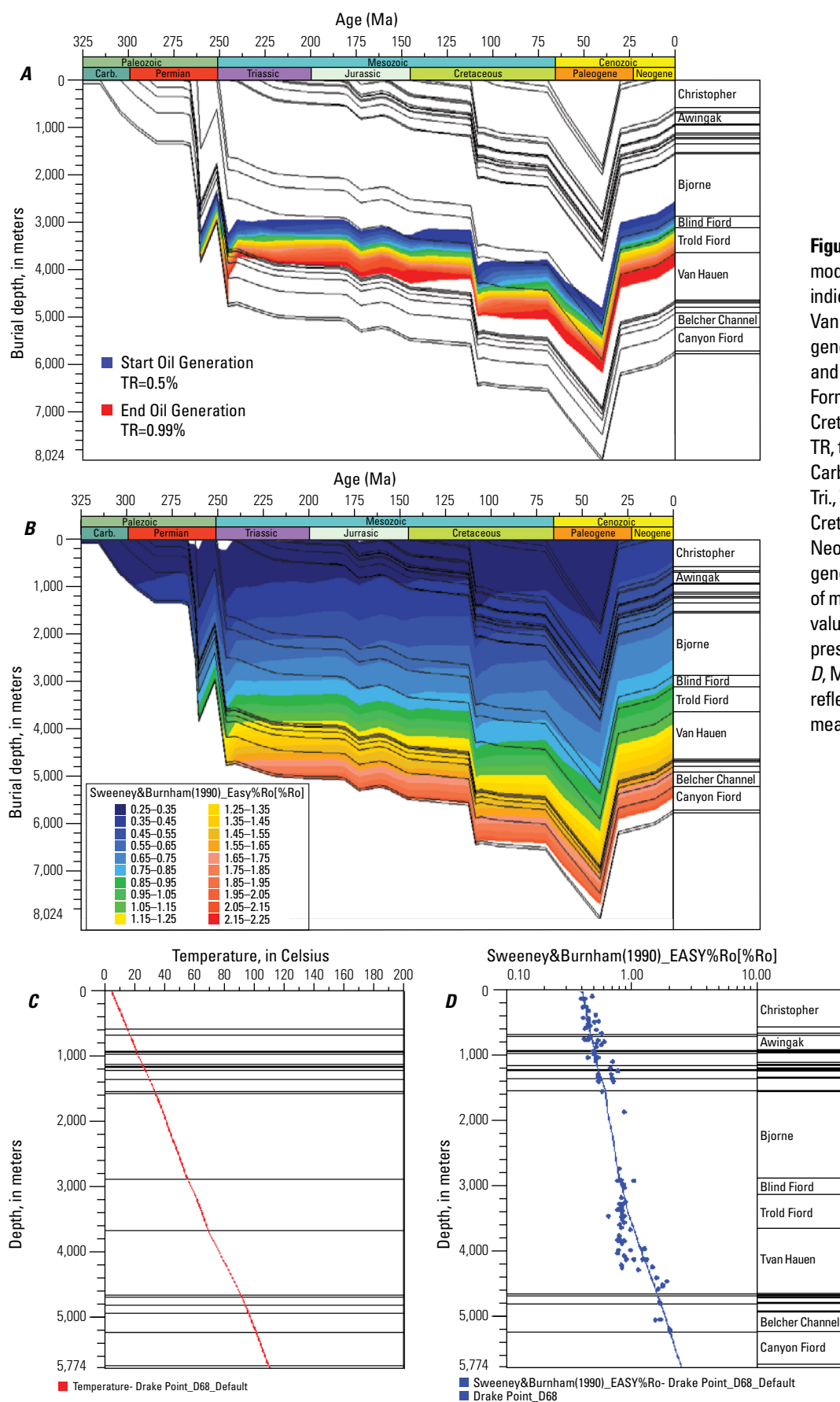
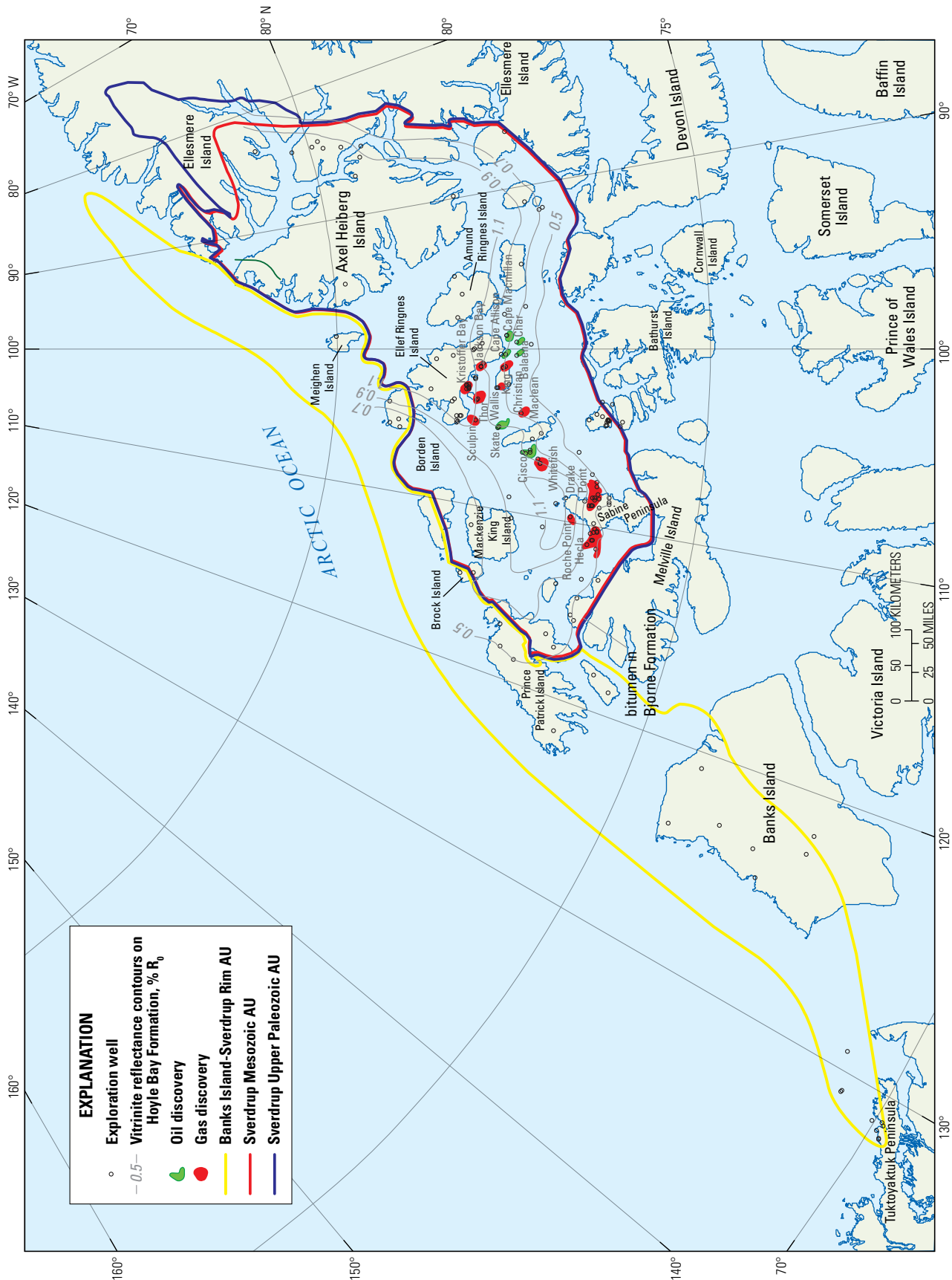


Figure 5. Petroleum generation model for Drake Point D-68 well, indicating that source rocks in the Van Hauen Formation probably generated oil in Early Triassic time and source rocks in the Blind Fiord Formation generated oil in Late Cretaceous to Paleogene time. TR, transformation ratio; Carb., Carboniferous; Perm., Permian; Tri., Triassic; Jur., Jurassic; Crt., Cretaceous; Pg., Paleogene; Neog., Neogene. *A*, Depth of zone of oil generation over time. *B*, Distribution of modeled vitrinite reflectance values over time. *C*, Modeled present-day temperature profile. *D*, Modeled values of vitrinite reflectance (solid blue line) and measured values (blue dots).



Base map from Esri, 2007, used herein under license.
Clarke 1866 Stereographic North Pole

Figure 6. Map of Mesozoic Composite Petroleum System, showing discovered oil and gas accumulations, locations of exploration wells that penetrated Mesozoic strata, location of tar sands in Bjorne Formation on northwestern Melville Island, and vitrinite reflectance contours from the Eden Bay Member of the Upper Triassic Hoyle Bay Formation from Stewart and others (1995). AU, Assessment Unit; Is., Island.

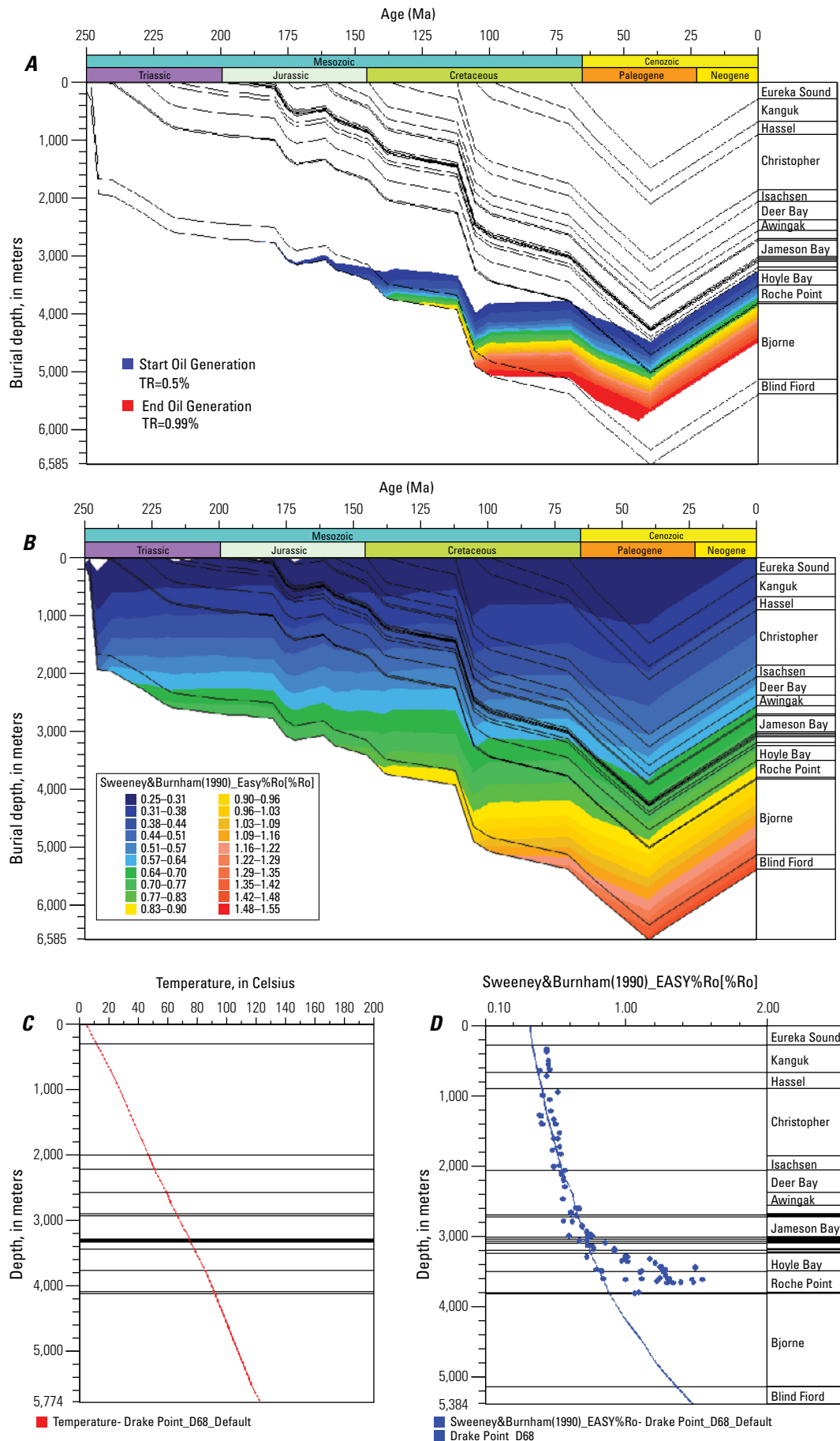


Figure 7. Petroleum generation model for North Sabine H-49 well, indicating that oil source rocks in the Triassic Roche Point and Hoyle Bay Formations probably entered the zone of oil generation near the end of Cretaceous time and reached peak generation in about late Eocene time. Modeling was unable to match high vitrinite reflectance values in the Roche Point and Hoyle Bay Formations near the bottom of the well, probably from recycled vitrinite (Utting and others, 2004; Dewing and Sanei, 2009; Dewing and Obermajer, 2011). TR, transformation ratio; Tri., Triassic; Jur., Jurassic; Crt., Cretaceous; Pg., Paleogene; Neog., Neogene. A, Depth of zone of oil generation over time. B, Distribution of modeled vitrinite reflectance values over time. C, Modeled present-day temperature profile. D, Modeled values of vitrinite reflectance (solid blue line) and measured values (blue dots).

Paleogene strata. This was first observed by Bustin (1986) on the basis of maturity levels in coal deposits within the Eureka Sound Group. Brooks and others (1992) estimated thicknesses of eroded strata in Sverdrup Basin wells, including one (Brock C-50) on the Sverdrup Rim in which more than 3 km of erosion was estimated; they concluded that the central part of the basin had been uplifted 650 to 1,900 meters (m). Petroleum generation modeling for this study (fig. 7) similarly indicates about 2 km of erosion, based on vitrinite reflectance levels in strata near the surface. Timing of deformation and trap formation provides corroborative evidence for Late Cretaceous to Paleogene generation and migration. Low-relief anticlines, faults, and salt diapirs that deform Paleogene strata are part of the trapping system. The presence of oil and gas in these traps thus requires that migration took place in Late Cretaceous to Paleogene time, unless the oil and gas were remigrated.

A third petroleum system is almost certainly present in Cretaceous and Paleogene rocks of the Canada Passive Margin outboard of the Banks Island-Sverdrup Rim rift shoulder. Petroleum generated from this system would have migrated updip to the southeast into traps on the rift shoulder beginning in Paleogene time, assuming that migration pathways were present. This petroleum system is described by Houseknecht and Bird (2011).

Assessment Units

The Sverdrup Basin Province was subdivided into three geologically distinctive entities for the purposes of assessment. These three USGS assessment units (AUs) are the Sverdrup Upper Paleozoic AU, the Sverdrup Mesozoic AU, and the Banks Island-Sverdrup Rim AU. In the following descriptions, decimal fractions refer to the estimated probability that source rock richness and maturity (“charge”), reservoir character and volume (“rocks”), and timing of trap formation relative to petroleum generation and likelihood of trap preservation (“timing and preservation”) are adequate for an accumulation of the minimum size, 50 MMBO or 300 BCFG.

Sverdrup Upper Paleozoic Assessment Unit

Exploration maturity.—Seismic reflection surveys were conducted during a petroleum exploration campaign that spanned the late 1960s through the mid-1980s; no modern or three-dimensional (3D) seismic data had been collected as of the time of this assessment. Twenty-nine wells were drilled, testing many of the more obvious structural and stratigraphic traps, but no accumulations of minimum size were discovered.

Description

The Sverdrup Upper Paleozoic AU encompasses Upper Mississippian through Permian strata deposited as the Sverdrup Basin formed by rifting of the deformed Franklinian passive

margin and its cover of Devonian clastic wedge strata. In map view, it is outlined by the unconformity at the base of Upper Mississippian lacustrine or Pennsylvanian rift strata deposited on older rocks deformed in the Late Devonian to Early Mississippian Ellesmerian orogeny. The rift sequence grades basinward to subaqueously deposited evaporites and upward to carbonates on the margins of the basin and deepwater mudstones in the center; the latter are potential source rocks. At the top of the sequence are shallow water sandstones. Overlying Mesozoic strata are excluded from this assessment unit.

Geologic Analysis of Assessment Unit Probability

Charge.—(0.4) Oil shows are reported from the Canyon Fiord Formation on the southeastern margin of the basin, from carbonate in the Belcher Channel Formation on Melville Island, and from bitumen-impregnated sandstone in the Canyon Fiord Formation strata on Melville Island (Embry and others, 1991). Gas shows were noted in carbonates of the Belcher Channel Formation and turbiditic sandstones of the Van Hauen Formation on Melville Island (Embry and others, 1991), as well as in Trolld Fiord sandstones on Prince Patrick Island (Harrison and Brent, 2005). These occurrences suggest the presence of a petroleum system, but not necessarily an active one. Potential source rocks include Mississippian lacustrine oil shale with as much as 50 percent TOC (by weight percent), marine shale in Pennsylvanian Hare Fiord and Permian Van Hauen Formations, with typical TOC values of 1 to 2 weight percent, but locally more than 2 weight percent, and organic-rich shale interbeds in the Permian Trolld Fiord Formation.

Rocks.—(0.6) Potential reservoir strata of Late Mississippian to early Permian age that could have been sourced by the Hare Fiord Formation include the Belcher Channel and Nansen Formations, shallow water carbonates that include oolitic grainstones and shelf-edge reefs. Dolomitized reef mounds associated with evaporites or built on the edges of normal fault blocks are another potential trap type, although migration pathways to introduce petroleum are problematic. In addition, permeability and porosity are typically limited in the carbonate units, making it likely that only zones with histories of subaerial exposure, during which porosity and permeability might have been enhanced, would have adequate reservoir properties. Potential reservoir sandstones laterally equivalent to and updip from the Van Hauen Formation include the Sabine Bay, Assistance, and Trolld Fiord Formations. The Degerbøls limestone at the top of the Permian section is another potential reservoir that could have been charged by petroleum generated in the Van Hauen Formation.

Potential traps include normal faults and rollover anticlines in the lower part of the basin fill (for examples, see Beauchamp and others, 2001), various types of carbonate buildups, stratigraphic traps in sands at the top of the Permian section, diapirs and other types of salt structures, and Melvillian folds and faults. Seals would include overlying Triassic basinal mudstones for traps in the Degerbøls, Assistance, Sabine Bay, or Trolld Fiord Formations, and Hare Fiord and Van Hauen Formation mudstones for traps in the older carbonate units. Paleogene Eureka folds and faults are mostly too young to have trapped migrating petroleum.

Timing and preservation.—(0.3) Regional source rock studies have shown that potential source rocks are mature around the margins of the basin but overmature in the central part (Powell, 1978; Utting and others, 1989; Dewing and others, 2007). The Van Hauen Formation on northern Cameron Island (Robert Harbour K-07 well), at a depth of 1.8 km, is near the top of the oil window (Utting and others, 1989), but at Hecla Field (northern Melville Island), where it lies at depths of more than 3 km, it is mature to overmature (Gentzis and Goodarzi, 1991). At Brock Island in the northwestern part of the basin, vitrinite reflectance (R_o) values in the Van Hauen Formation are 1.71 to 1.88 percent (Utting and others, 1989). Wells in the deeper parts of the basin were not deep enough to sample potential upper Paleozoic source rocks, but it is probably safe to assume that they are overmature.

Modeling the generation history of the strata penetrated in the Drake Point D-68 well (fig. 5) on northern Melville Island suggests that source rocks in the Emma Fiord Formation, if present, would have begun to generate oil and gas by late Permian time, during burial by the Van Hauen and Trolld Fiord Formations. Generated petroleum could have been trapped in normal fault traps and rollover anticlines dating from basin inception, as well as in structural traps formed during middle Permian Melvillian deformation. Pennsylvanian Otto Fiord Formation halite would be a potential seal for traps in the Canyon Fiord Formation. The most likely source rock, the Permian Van Hauen Formation, would have matured and begun to generate petroleum during Early Jurassic time as a consequence of burial by 2 km of Lower Triassic strata. Generated petroleum could have migrated into Permian sandstone reservoirs, as well as into laterally equivalent carbonate reservoirs. Lower Triassic mudstone of the Blind Fiord Formation would be a potential seal. Potential source rocks in the Trolld Fiord Formation would have entered the oil window in Late Jurassic time and continued to mature gradually until middle Cretaceous time, when they were buried to the lower part of the oil generation window by thick strata of the Christopher Formation. Oil and gas could have migrated into laterally equivalent sandstone reservoirs and been trapped in Melvillian structures and sealed by the Triassic Blind Fiord Formation.

Despite apparently favorable timing for generation, migration, and trapping, preservation risk is considered quite high. In the deeper parts of the basin, maturity values indicate severe overmaturity. Extreme maturity in the northeastern part of the basin, for example, R_o values of 1.5 to 3.46 percent in the Van Hauen Formation in wells on northwestern Ellesmere Island, may also be associated with igneous intrusions and presumed higher heat flow in Cretaceous time (Utting and others, 1989). In addition, and perhaps most importantly, early Cenozoic Eurekan deformation and uplift is likely to have destroyed traps and perhaps spilled oil as gas displaced oil when pressure decreased owing to uplift.

The assigned probabilities result in an overall assessment unit probability of 0.072, less than the minimum probability (0.1) required for quantitative assessment.

Sverdrup Mesozoic Assessment Unit

Exploration maturity.— Seismic reflection data were collected during a petroleum exploration campaign that spanned the late 1960s through the mid-1980s; no modern or 3D seismic data had been collected as of the time of this assessment. More than 160 exploration wells were drilled based on the seismic data or on surface mapping testing most of the major potential traps. Oil and gas shows were widespread, and 13 gas accumulations were discovered, 7 of which are estimated to contain more than 300 billion cubic feet (BCF) of recoverable gas. Six oil accumulations were also discovered, only 1 of which exceeds 50 MMBO of known recoverable oil. No commercial production, which would require installation of extensive infrastructure, has taken place.

Description

The Sverdrup Mesozoic Assessment Unit includes all lowermost Triassic through Paleogene strata within the Sverdrup Basin proper. Its eastern boundary follows the basal disconformity of Triassic strata on Carboniferous rocks through northern Ellesmere Island. The boundary trends south through western Ellesmere Island, turns west into the offshore to parallel the northern coasts of Devon and Bathurst Islands, and emerges westward on Cameron Island and northern Melville Island. It curves northeast on Prince Patrick Island and runs northeast along the southeast flank of the Sverdrup Rim, excluding the Jurassic to Cretaceous extensional basins that transect the crest of the Sverdrup Rim.

Geologic Analysis of Assessment Unit Probability

The likelihood that the Sverdrup Mesozoic AU contains at least one undiscovered accumulation greater than the minimum field size of 50 million barrels of oil equivalent (MMBOE) is estimated to be approximately 100 percent, based on the following interpretation of petroleum system elements:

Charge.—(1.0) Proven source rocks are present in the Murray Harbour and Hoyle Bay Formations of the Schei Point Group. Organic matter in these formations is dominantly Type II, with TOC values typically 1 to 6 weight percent and locally approaching 10 weight percent. They are mature (R_o 1.29 percent) where they have been most deeply penetrated (North Sabine H-49 well; Gentzis and Goodarzi, 1991; Goodarzi and others, 1989) and are presumed to be widely mature in the basin center and near salt bodies. Modeling suggests that they entered the oil window near the end of Cretaceous time (fig 7).

Rocks.—(1.0) Upper Triassic to Lower Jurassic deltaic sandstone reservoirs of the Heiberg Group contain most of the discovered accumulations. Other proven reservoirs include shallow marine sandstones of the Upper Jurassic Awingak Formation and sandstones of the Isachsen Formation. Braided stream deposits of the Lower Triassic Bjorne Formation exposed on northwest Melville Island contain tar sands characterized

as an originally stratigraphically trapped “exhumed oil field” in a 50–100-foot-thick sand, estimated to contain 100 to 250 million barrels of original oil in place (Rayer, 1981); the Bjorne Formation also had shows of gas in the Drake Point field. The largest discovered fields are sealed by Lower Jurassic shales of the Savik or Jameson Bay Formations. Traps for discovered fields are mostly structural and many include a component of recurrent salt movement. Undiscovered accumulations greater than 50 MMBOE will probably be dominantly stratigraphic pinchouts on the basin flanks because almost all of the larger mapped structural and combination traps imaged on seismic sections have been drilled. The largest discovered accumulations are in combination traps. Additional discoveries may be made in salt-influenced structural traps such as those described by Jackson and Harrison (2006).

Timing and preservation.—(1.0) Modeling for this assessment (fig. 7), in agreement with that reported by Skibo and others (1990), suggests that oil generation from Triassic source rocks took place in Late Cretaceous time when the source rocks reached burial depths of about 3.5 to 4.0 km, and that some 2 km of Paleogene strata were deposited and eroded. Brooks and others (1992) concluded that generation required burial depths of about 3.1 to 3.4 km, and that present day burial depths were less than those required, indicating that many of the existing traps have had 0.65 to 1.9 km of strata eroded. The depositional thickness of Eureka Sound Group strata in the western Sverdrup Basin may have been as much as 3–4 km (Bustin, 1986), but present-day thickness is only a few hundred meters. Maximum burial and peak generation, therefore, was probably Paleogene, followed by substantial erosion. These inferences differ from those of Goodarzi and others (1992), who concluded that rapid burial by Aptian to Albian strata caused oil generation and that about 1 km of strata was eroded in the western Sverdrup Basin during the Eurekan orogeny. They also conflict with the conclusions of Gentzis and others (1996), who inferred Early Cretaceous generation triggered by rifting. Trapping anticlines formed or experienced renewed deformation during Paleogene Eurekan tectonism. The more easterly of the discovered accumulations, in the area of Ellef Ringnes Island, only partly fill their traps, suggesting that oil has been lost along faults and fractures (Waylett and Embry, 1992) and that seals and traps were ruptured during Eurekan deformation. These fields lie in a part of the basin where effects of Eurekan deformation were more severe than farther west. Erosion that presumably accompanied deformation may also have removed sufficient overburden to cause dissolved gas to come out of solution, expand, and displace oil from traps. Although it is evident that preservation is at least locally only partial, the discovery of numerous accumulations indicates that preservation is adequate for existence of fields of the minimum size.

Analogues used in this assessment

Numbers of fields.—The Mesozoic Sverdrup Basin has classic rift-sag architecture. Median field density for fields larger than 50 MMBOE in AUs in rift-sag basins in the analog database is about 0.2 fields per 1,000 km²; if three outlier AUs with

significantly greater densities are omitted, the median density is about 0.16 accumulations per 1,000 km². Applying this density to about 139,000 km² in the western half of this assessment unit (the eastern half has not proved prospective) yields about 22 fields larger than 50 MMBOE. As 10 accumulations larger than 50 MMBOE have already been discovered, the most likely number of accumulations remaining to be discovered is considered to be about 10 additional accumulations, many of which will probably be stratigraphically trapped because most mapped large structural traps have been tested. The greatest possible number of undiscovered accumulations that might be discovered was considered to be 50, equivalent to a density of about 0.18 accumulations per 1,000 km² for the entire area of the AU and about 0.36 for just the western half. The choice of the maximum of 50 undiscovered accumulations larger than 50 MMBOE was influenced by the discovery history. All of the most promising prospects have been drilled, but only 10 accumulations greater than 50 MMBOE have been found, so it was considered highly unlikely that field density of undiscovered fields could approach the maximum density in the analog dataset. The proportion of gas fields was estimated to be between 20 and 90 percent of the total number of accumulations, with the most likely value being 80 percent, based on the discovered population.

Field size distribution.—The minimum field size is the CARA-defined 50 MMBOE. Because this AU has a discovered population that has shown a typical discovery history, analogs were not used heavily to guide estimation of sizes of undiscovered accumulations. The median undiscovered field size was estimated to be 80 MMBO for oil fields, somewhat less than the median, 111 MMBO, of the median sizes of oil fields in rift-sag AUs, because the exploration history suggests that undiscovered oil fields will be relatively small. The stratigraphically trapped oil fields that probably predominate in the undiscovered population might be slightly larger than the discovered anticlinal oil field population because they are less likely to have experienced oil loss by trap rupture. The largest possible undiscovered oil field, although highly unlikely to exist, was estimated to contain 800 MMBO, which is more than twice the volume of the largest discovered oil field but much less than the median size of 1,200 MMBO in rift-sag AUs. The median undiscovered gas accumulation size was estimated to be 350 BCFG, close to the minimum size, and the largest possible (but very unlikely) undiscovered gas field was estimated to be 1,500 BCFG, similar in size to some of the larger fields that have been discovered but not the largest.

Province geologist's estimated maximum field size.—The province geologist estimated that the most likely maximum undiscovered field size is about 150 to 200 MMBOE, based more on discovery history (fig. 8) than on analogs, because the sizes of discovered accumulations are a better indicator of potential discoveries than analogs. Larger accumulations are typically discovered early, because they are more readily discerned with exploration technology and because they have larger areas in plan view. The fact that later-discovered accumulations in the Sverdrup Mesozoic AU are generally small indicates that the largest accumulations are likely to have already been discovered.

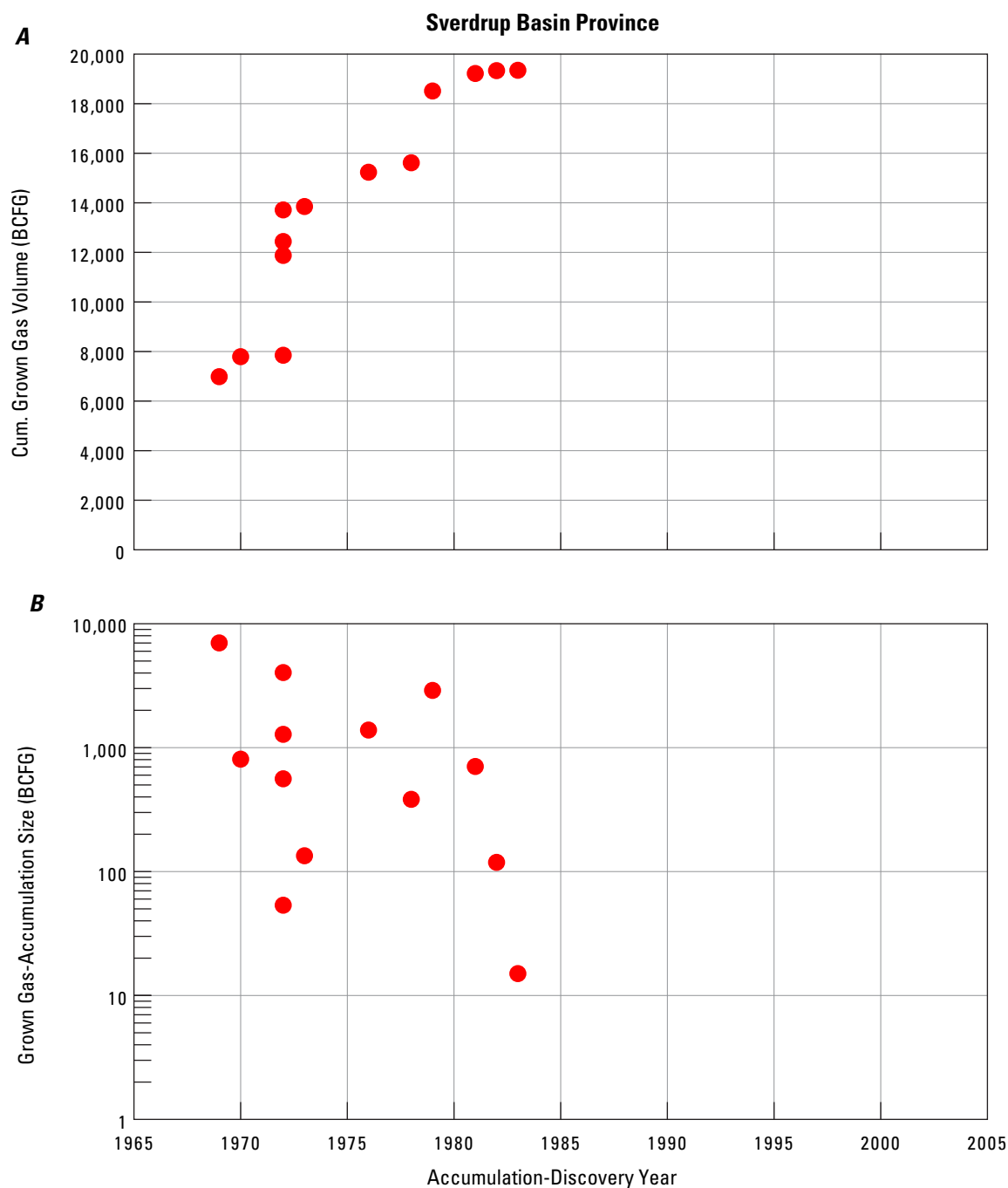


Figure 8. Plots showing history of gas discoveries in Sverdrup Basin Province. *A*, Plot of cumulative known recoverable gas versus year of discovery (known as the creaming curve). Larger accumulations were discovered early in the exploration process and account for the bulk of discovered gas; only relatively small accumulations were discovered as exploration continued. *B*, Plot of gas accumulation size versus year of discovery, showing tendency for sizes of gas discoveries to decrease with time. The gas volume of each field, from a commercial database (IHS), was increased slightly, or “grown,” to account for anticipated increase in expected recovery over time, thus volumes are shown as “grown.”

Ancillary properties and coproduct ratios.—The analog database was not used for ancillary properties and coproduct ratios because they were available from discovered fields and presumably similar fields in northern Alaska.

Banks Island-Sverdrup Rim Assessment Unit

Exploration maturity.—Seismic reflection data were collected between the late 1960s and mid-1980s; 21 wells were drilled, but no accumulations of minimum size were discovered.

Description

The Banks Island-Sverdrup Rim AU includes the structurally elevated rift shoulder landward (southeast) of an inferred boundary between continental and transitional crust that formed during Jurassic rifting and Early Cretaceous opening of the Canada Basin. This boundary, the northwestern limit of the AU, is probably a zone of buried, high-displacement, north-facing normal faults and is presumed to coincide with a steep free-air gravity gradient observed beneath the Arctic continental shelf. Tectonically analogous to the Barrow Arch on the Alaskan North Slope for the pre-Cenozoic part of its history, the Sverdrup Rim of Balkwill (1978) (and its southwest continuation through western Banks Island) consists of an eroded structural high exposing Lower Jurassic to Devonian strata, transected by Jurassic to Cretaceous extensional basins on its crest and overlain on its flanks by Upper Cretaceous to Cenozoic strata. The southeast boundary is drawn to include all known extensional basins along the Sverdrup Rim; in the northeastern part of the province where subsurface geology is poorly known, the southeast boundary follows the landward edge of Miocene to Pliocene strata of the Beaufort Formation or correlative units.

Potential source rocks for petroleum in this assessment unit include prerift, synrift, and postrift mudstones. Reservoir rocks include nonmarine and shallow marine sandstones interbedded with the source strata. Inferred generation and migration of petroleum in latest Cretaceous to Paleogene time resulted from initial burial by strata deposited across the rifted margin after Early Cretaceous seafloor spreading created the Canada Basin, then by sediments eroded from highlands created during Paleogene Eureka compressive deformation.

Although the geology of this AU is similar to that of the Barrow Arch in Alaska, it is more deeply eroded; potential reservoirs are buried by much thinner overburden. Over extensive areas, much of the Mesozoic sequence that was originally present has been eroded from the crest of the rift shoulder or lies at shallow depths immediately below Neogene strata where retention of petroleum is unlikely. The main Upper Triassic to Lower Jurassic reservoir intervals in the adjacent Sverdrup Basin are at the surface of or absent from much of the crest of the Sverdrup Rim. Upper Jurassic to Lower Cretaceous strata are preserved mainly in rift basins.

Geologic Analysis of Assessment Unit Probability

Charge.—(0.6) Proven source rocks for discovered oil and gas within the Sverdrup Basin are Triassic shales of the Schei Point Group, but these rocks are absent from large areas on the crest of the Sverdrup Rim and probably from the northwest flank as well (Okulitch, 1991; Embry, 1992). Migration pathways from sources on the flanks of the Sverdrup Rim to reservoirs on the crest were probably also mostly eroded, along with the best reservoir rocks. The Upper Jurassic Ringnes Formation (Balkwill and others, 1977; Stewart and others, 1992) contains shales that could be good source rocks for gas, but they are too immature to have generated gas southeast of the Sverdrup Rim. Downdip on the northwest flank, in contrast, not only Ringnes Formation shales but also organic-rich shales of the Upper Cretaceous Kanguk Formation (Nunez-Betelu and others, 1994) should be present at sufficient burial depths to have generated petroleum. In addition, unusual *Azolla*-bearing Eocene source rocks that may have been deposited across the entire Arctic Basin could be present seaward of the Sverdrup Rim and may have generated oil and gas that migrated updip on its northwest flank (see Houseknecht and Bird, 2011, for a discussion of potential source rocks on the continental slope). On the crest of the rim, potential source rocks are present within Jurassic to Cretaceous rift basins. However, where the geology of these basins is known from surface geology or subsurface information (Miall, 1975, 1979; Harrison and Brent, 2005), they are not deep enough (maximum about 2 km) or volumetrically adequate to have charged significant petroleum accumulations. On the northwest flank of the rim beneath Cenozoic cover, however, similar rift basins might be buried sufficiently, especially if they are larger than those on the crest. Evidence from seismic data and from a well in the northeastern part of the assessment unit indicates that the thickness of sedimentary rocks of Mesozoic and Cenozoic age increases rapidly northwestward on the seaward flank of the Sverdrup Rim to thicknesses of as much as 10 km (Brent and Embry, 1995; Forsyth and others, 1998). Generation of significant volumes of petroleum during burial of such a thick sequence is probable.

Rocks.—(0.6) The northeastern part of this assessment unit lay along the northern flank of the Sverdrup Basin from late Paleozoic time until the opening of the Canada Basin in Early Cretaceous time and was thus the site of repeated transgressions and regressions that deposited interbedded shallow marine sandstones and offshore shales, shed from a land area (named “Crockerland”) to the north (Embry, 1991, 1992). Although much of the Triassic and Lower Jurassic part of the sequence was thin and subject to erosion during uplift of the Sverdrup Rim in Early Cretaceous time, potential reservoir strata that may be at least locally present include (1) Upper Triassic Pat Bay Formation shelf sandstones; (2) Middle Jurassic nearshore shelf sandstones of the Sandy Point Formation; (3) beach, nearshore, and fluvial-deltaic sandstones of the Hiccles Cove Formation; and (4) Upper Jurassic progradational shelf sandstones of the Awingak Formation in the Prince Patrick Island area. From Prince Patrick Island

southwestward along Banks Island, Triassic strata are absent, and Jurassic or younger strata rest directly on the Devonian strata; in this part of the AU, the most likely reservoir strata are probably Upper Cretaceous and Paleogene sequences deposited across the rifted margin. Potential traps include normal faults and rollover anticlines from Mesozoic rifting, faults and anticlines overprinted on the extensional basins by Eurekan deformation during Paleogene time, and stratigraphic traps throughout the prospective section.

Timing and preservation.—(0.6) Timing of maturation is most likely to be Late Cretaceous to Tertiary because the best chance for adequate burial is associated with deposition of Canada Basin passive margin strata and strata shed from Eurekan uplifts. Traps formed during extensional faulting in the Mesozoic would have been in place during generation. Traps formed by Eurekan deformation are less certain to have been available at the time of generation, depending on whether they are syndepositional or postdepositional. Eurekan deformation also presents risk to preservation of accumulations trapped before deformation.

Analogues Used in this Assessment

Numbers of fields.—The architecture of the Sverdrup Rim-Banks Island area is that of a passive margin, and the trap system is expected to be typical of those associated with extensional grabens. Those analog datasets (median field densities of 0.274 and 0.3 fields per 1,000 km²) suggest 58 and 70 accumulations, respectively, at the median and 1,200 and 587 fields, respectively, at the maximum (5.64 and 2.76 fields per 1,000 km²). However, comparison with the Barrow Arch in northern Alaska, which is a direct analog except for the dissimilarity in thickness of overburden above the prospective strata, suggests significantly fewer accumulations than the analog datasets. Because there are about 20 fields along the Barrow Arch, 20 was chosen as a more likely median. The maximum number of accumulations was considered likely to be significantly smaller than the maximum number, 150 fields, estimated for the adjacent and probably more prospective Canada Passive Margin AU; accordingly, 100 was chosen as the maximum possible number of accumulations for this assessment unit.

Field size distribution.—The median of the median field size (greater than 50 MMBOE) in rifted passive margin AUs in the analog database is 112 MMBOE, and the median of the median size for extensional graben trap systems is 107 MMBOE. The median size for undiscovered accumulations in this AU, accordingly, was chosen as 100 MMBOE. The largest possible (but very unlikely) accumulation that might exist within the AU was chosen as 2,500 MMBOE, the approximate recoverable volume of oil at Kuparuk River field on the Barrow Arch. The largest accumulations in the analog datasets, 9,280 and 140,000 MMBOE for extensional graben trap systems and passive margin architecture, respectively, were considered much too large.

Province geologist's estimated maximum field size.—

The province geologist estimated that the most likely size of the largest accumulation in this AU is about 500 MMBOE, similar in size to the Alpine field (Gingrich and others, 2001) on the Barrow Arch, a stratigraphically trapped accumulation in a reservoir deposited within an incised valley flooded by a subsequent transgression.

Oil versus gas fields, ancillary properties, and coproduct ratios.—In the absence of direct information on the nature of the petroleum system inferred within the Mesozoic and Paleogene strata to the northwest in the Canadian passive margin, the ratio of oil fields to the total number of oil and gas fields was estimated to be between 10 and 90 percent to reflect wide uncertainty. The mode of the distribution was set at 60 percent on the presumption that source rocks in the passive margin stratigraphic sequence are somewhat more likely to contain mostly Type I and II than Type III organic matter, if they are like presumed equivalents on the Sverdrup Rim such as the Kanguk Formation. Because petroleum that might eventually be discovered in this AU is likely to have been sourced by the same rocks as in the adjacent Canada Passive Margin AU to the north, the same values for coproducts and ancillary data were used for both AUs; these values, in turn, are the same as those assigned for the Alaska Passive Margin and Canning-Mackenzie Deformed Margin AUs, which contain discovered fields on which the values are based.

Assessment Results

Results are shown in table 2. The mean total undiscovered resource estimate for the Sverdrup Basin Province is 851 million barrels of oil and 8,596 billion cubic feet of gas, as determined from the two assessment units that were quantitatively assessed—the Sverdrup Mesozoic AU and the Banks Island-Sverdrup Rim AU. In the Sverdrup Mesozoic AU, an assessment unit probability of 1.0 indicates certainty that at least one more accumulation of the minimum size will be found; total undiscovered oil resources are expected to range from 61 to 1,255 MMBO, with a mean of 427 MMBO of undiscovered, recoverable oil. Gas associated with oil in oil accumulations is expected to range from 232 to 6,478 BCF, with a mean of 2,154 BCF, and nonassociated gas in gas accumulations is expected to range from 976 to 6,407 BCF, with a mean of 2,798 BCF. In the Banks Island-Sverdrup Rim AU, probability of at least one accumulation of the minimum size was considered to be only 0.22. Undiscovered oil resources were estimated at 0 to 2,679 MMBO, with a mean of 424 MMBO. Gas associated with oil in oil accumulations was estimated at 0 to 8,269 MMBO, with a mean of 1,319 BCF, and nonassociated gas is estimated to be 0 to 14,666 BCF, with a mean of 2,325 BCF. The wide ranges in the estimates reflect substantial uncertainty regarding resource potential, despite the relatively high level of exploration in this province.

Table 2. Assessment results for the Sverdrup Basin Province.

[Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). Undiscovered gas resources are the sum of nonassociated and associated gas. The fractile F95 represents a 95 percent chance of at least the amount tabulated; other fractiles are defined similarly. AU probability is the chance of at least one accumulation of minimum size (50 MMBOE) within the AU. Gray shading indicates not applicable. MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids; TPS, total petroleum system; AU, assessment unit]

Total petroleum systems and assessment units	AU probability	Field type	Largest expected field size	Total undiscovered resources											
				Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
				F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Upper Paleozoic-Mesozoic Composite TPS															
Sverdrup Mesozoic AU	1.00	Oil	155	61	292	1,255	427	232	1,443	6,478	2,154	1	11	61	18
		Gas	533					976	2,295	6,407	2,798				
Sverdrup Upper Paleozoic AU	0.07	Oil													
		Gas													
Banks Island–Sverdrup Rim AU	0.22	Oil	510	0	0	2,679	424	0	0	8,269	1,319	0	0	62	10
		Gas	2,919					0	0	14,666	2,325				
Total conventional resources				851				8,596				28			

References Cited

- Balkwill, H.R., 1978, Evolution of Sverdrup Basin, Arctic Canada: American Association of Petroleum Geologists Bulletin, v. 62, no. 6, p. 1004–1028.
- Balkwill, H.R., Wilson, D.G., and Wall, J.H., 1977, Ringnes Formation (Upper Jurassic), Sverdrup Basin, Canadian Arctic Archipelago: Bulletin of Canadian Petroleum Geology, v. 25, no. 6, p. 1115–1144.
- Beauchamp, B., 1992, Carboniferous and Permian reefs of Sverdrup Basin, Canadian Arctic; an aid to Barents Sea exploration, in Vorren, T., ed., Arctic geology and petroleum potential: Norwegian Petroleum Society Special Publication 2, p. 217–241.
- Beauchamp, B., 1995, Permian history of Arctic North America, in Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., eds., The Permian of northern Pangea, v. 2, Sedimentary basins and economic resources: Berlin, Springer-Verlag, p. 3–22.
- Beauchamp, B., Harrison, J.C., and Henderson, C.M., 1989a, Upper Paleozoic stratigraphy and basin analysis of the Sverdrup Basin, Canadian Arctic Archipelago; Part 1, time frame and tectonic evolution, in Current research part G, Frontier Geoscience Program, Arctic Canada: Geological Survey of Canada, Paper 89–1G, p. 105–113.
- Beauchamp, B., Harrison, J.C., and Henderson, C.M., 1989b, Upper Paleozoic stratigraphy and basin analysis of the Sverdrup Basin, Canadian Arctic Archipelago; Part 2, transgressive-regressive sequences, in Current research part G, Frontier Geoscience Program, Arctic Canada: Geological Survey of Canada, Paper 89–1G, p. 115–124.
- Beauchamp, B., Harrison, J.C., Utting, J., Brent, T.A., and Pinard, S., 2001, Carboniferous and Permian subsurface stratigraphy, Prince Patrick Island, Northwest Territories, Canadian Arctic: Geological Survey of Canada Bulletin 565, 100 p.
- Beauchamp, B., and Henderson, C.M., 1994, The Lower Permian Raanes, Great Bear Cape and Trappers Cove formations, Sverdrup Basin, Canadian Arctic; stratigraphy and conodont zonation: Bulletin of Canadian Petroleum Geology, v. 42, no. 4, p. 562–597.
- Brent, T.A., and Embry, A.F., 1995, Stratigraphy and structure of Meighen Island, Canadian Arctic Archipelago, in Bell, J.S., Bird, T.D., Hillier, T.L., and Greener, P.L., eds., Proceedings of the Oil and Gas Forum '95, Energy from sediments: Geological Survey of Canada Open File 3058, p. 163–168.
- Brooks, P.W., Embry, A.F., Goodarzi, F., and Stewart, R., 1992, Organic geochemistry and biological marker geochemistry of Schei Point Group (Triassic) and recovered oils from the Sverdrup Basin (Arctic Islands, Canada): Bulletin of Canadian Petroleum Geology, v. 40, no. 3, p. 173–187.
- Bustin, R.M., 1986, Organic maturity of Late Cretaceous and Tertiary coal measures, Canadian Arctic Archipelago: International Journal of Coal Geology, v. 6, p. 71–106.
- Canadian Gas Potential Committee, 2001, Natural gas potential in Canada; 2001: A report by the Canadian Gas Potential Committee, University of Calgary, 570 p.
- Chalmers, J.A., and Laursen, K.H., 1995, Labrador Sea; the extent of continental and oceanic crust and the timing of the onset of seafloor spreading: Marine and Petroleum Geology, v. 12, no. 2, p. 205–217.

- Charpentier, R.R., and Gautier, D.L., 2011, Chapter 8: US Geological Survey Circum-Arctic Resource Appraisal (CARA): introduction and summary of organization and methods: Geological Society of London Memoir, v. 35, p. 145–150.
- Davies, G.R., and Nassichuk, W.W., 1975, Subaqueous evaporites of the Carboniferous Otto Fiord Formation, Canadian Arctic Archipelago; a summary: *Geology*, v. 3, no. 5, p. 273–278.
- Davies, G.R., and Nassichuk, W.W., 1991a, Carboniferous and Permian history of the Sverdrup Basin, Arctic Islands, chap. 13 of Trettin, H.P., ed., *Geology of the Innuitian orogen and Arctic platform of Canada and Greenland*: Geological Survey of Canada, *Geology of Canada*, no. 3, p. 345–367.
- Davies, G.R., and Nassichuk, W.W., 1991b, An early Carboniferous (Viséan) lacustrine oil shale in the Canadian Arctic Archipelago: *American Association of Petroleum Geologists Bulletin*, v. 72, no. 1, p. 8–20.
- Dewing, K., and Obermajer, M., 2011, Chapter 38, Thermal maturity of the Sverdrup Basin, Arctic Canada and its bearing on hydrocarbon potential, in Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V., and Sorensen, K., eds., *Arctic Petroleum Geology*: Geological Society of London Memoir 35, p. 567–580.
- Dewing, K., Obermajer, M., and Goodarzi, F., 2007, Geological and geochemical data from the Canadian Arctic Islands; Part III, organic matter reflectance data: Geological Survey of Canada, Open File 5476, 8 p., 1 CD-ROM, accessed June 9, 2014, at <http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/download.web&search1=R=223574>.
- Dewing, K., and Sanei, H., 2009, Analysis of large thermal maturity datasets; Examples from the Canadian Arctic Islands: *International Journal of Coal Geology*, v. 77, no. 3–4, p. 436–448.
- Drummond, K.J., 2006, Canada's discovered oil and gas resources north of 60°: Search and Discovery article 10102, 7 p., accessed March 21, 2008, at <http://www.searchanddiscovery.net/documents/2006/06022drummond/images/drummond.pdf>.
- Embry, A.F., 1982, The Upper Triassic-Lower Jurassic Heiberg deltaic complex of the Sverdrup Basin, in Embry, A.F., and Balkwill, H.R., eds., *Arctic geology and geophysics*: Canadian Society of Petroleum Geologists Memoir 8, p. 189–217.
- Embry, A.F., 1990, Geological and geophysical evidence in support of the hypothesis of anticlockwise rotation of northern Alaska: *Marine Geology*, v. 93, p. 317–329.
- Embry, A.F., 1991, Mesozoic history of the Arctic Islands, chap. 14 of Trettin, H.P., ed., *Geology of the Innuitian orogen and Arctic platform of Canada and Greenland*: Geological Survey of Canada, *Geology of Canada*, no. 3, p. 371–433.
- Embry, A.F., 1992, Crockerland—the northwest source area for the Sverdrup Basin, Canadian Arctic Archipelago, in Vorren, T., Bergsager, E., Dahl-Stamnes, O.A., Holter, E., Johansen, B., Lie, E., and Lund, T.B., eds., *Arctic geology and petroleum potential*: Norwegian Petroleum Society Special Publication 2, p. 204–216.
- Embry, A.F., 2007, Mesozoic 1st order sequences of the Sverdrup Basin and their relationship to sediment supply and petroleum source rocks [abs.]: Canadian Society of Petroleum Geologists and Canadian Society of Exploration Geophysicists Convention (2007), p. 92–93.
- Embry, A.F., Mickey, M.B., Haga, H., and Wall, J.H., 1992, Correlation of the Pennsylvanian-Lower Cretaceous succession between northwest Alaska and southwest Sverdrup Basin; implications for Hanna Trough stratigraphy: *International Conference on Arctic Margins Proceedings* (1992), p. 105–110.
- Embry, A.F., Powell, T.G., and Mayr, U., 1991, Petroleum resources, Arctic Islands, section A of chap. 20 in Trettin, H.P., ed., *Geology of the Innuitian orogen and Arctic platform of Canada and Greenland*: Geological Survey of Canada, *Geology of Canada*, no. 3, p. 517–525.
- Forsyth, D.A., Asudeh, I., White, D., Jackson, R., Stephenson, R.A., Embry, A.F., and Argyle, M., 1998, Sedimentary basins and basement highs beneath the polar shelf north of Axel Heiberg and Meighen Islands: *Bulletin of Canadian Petroleum Geology*, v. 46, no. 1, p. 12–29.
- Fyles, J.G., 1990, Beaufort Formation (Late Tertiary) as seen from Prince Patrick Island, Arctic Canada: *Arctic*, v. 43, no. 4, p. 393–403.
- Fyles, J.G., Hills, L.V., Matthews, J.V., Jr., Barendregt, R., Baker, J., Irving, E., and Jetté, H., 1994, Ballast Brook and Beaufort Formations (late Tertiary) on northern Banks Island, Arctic Canada: *Quaternary International*, v. 22/23, p. 141–171.
- Gautier, D.L., Bird, K.J., Charpentier, R.R., Grantz, A., Houseknecht, D.W., Klett, T.R., Moore, T.E., Pitman, J.K., Schenk, C.J., Schuenemeyer, J.H., Sorensen, K., Tennyson, M.E., Valin, Z.C., and Wandrey, C.J., 2009, Assessment of undiscovered oil and gas in the Arctic: *Science*, v. 324, no. 5931, p. 1175–1179. <https://doi.org/10.1126/science.1169467>.
- Gautier, D.L., Bird, K.J., Charpentier, R.R., Grantz, A., Houseknecht, D.W., Klett, T.R., Moore, T.E., Pitman, J.K., Schenk, C.J., Schuenemeyer, J.H., Sorensen, K., Tennyson, M.E., Valin, Z.C., and Wandrey, C.J., 2011, Oil and gas resource potential north of the Arctic Circle, chap. 9 in Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V., Sørensen, K., eds., *Arctic Petroleum Geology*: Geological Society of London Memoir, v. 35, p. 151–161.

- Gentzis, T., and Goodarzi, F., 1991, Thermal maturity and hydrocarbon potential of the sedimentary succession from the Hecla field in Sverdrup Basin, Arctic Canada: *International Journal of Coal Geology*, v. 19, no. 1–4, p. 483–517.
- Gentzis, T., Goodarzi, F., and Embry, A.F., 1996, Thermal maturation, potential source rocks and hydrocarbon generation in Mesozoic rocks, Loughheed Island area, central Canadian Arctic Archipelago: *Marine and Petroleum Geology*, v. 13, no. 8, p. 879–905.
- Gingrich, D., Knock, D., and Masters, R., 2001, Geophysical interpretation methods applied to Alpine Oil Field, North Slope, Alaska: *The Leading Edge*, v. 20, no. 7, p. 730–738.
- Goodarzi, F., Brooks, P.W., and Embry, A.F., 1989, Regional maturity as determined by organic petrography and geochemistry of the Schei Point Group (Triassic) in the western Sverdrup Basin, Canadian Arctic Archipelago: *Marine and Petroleum Geology*, v. 6, no. 4, p. 290–302.
- Goodarzi, F., Gentzis, T., Embry, A.F., Osadetz, K.G., Skibo, D.N., and Stewart, K.R., 1992, Evaluation of maturity and source rock potential in the Loughheed Island area of the central Sverdrup Basin, Arctic Canada, *in* Vorren, T., ed., *Arctic geology and petroleum potential: Norwegian Petroleum Society Special Publication 2*, p. 147–157.
- Grantz, A., Clark, D.L., Phillips, R.L., Srivastava, S.P., Blome, C.D., Gray, L.B., Haga, H., Mamet, B.L., McIntyre, D.J., McNeil, D.H., Mickey, M.B., Mullen, M.W., Murchey, B.I., Ross, C.A., Stevens, C.H., Silberling, N.J., Wall, J.H., and Willard, D.A., 1998, Phanerozoic stratigraphy of Northwind Ridge, magnetic anomalies in the Canada Basin, and the geometry and timing of rifting in the Amerasia Basin, Arctic Ocean: *Geological Society of America Bulletin*, v. 110, no. 6, p. 801–820.
- Grantz, A., Hart, P.E., and Childers, V.A., 2007, Tectonic history of the Amerasia Basin, Arctic Ocean [abs.]: *Eos Transactions of the American Geophysical Union*, v. 88, no. 52, Abstract T11E–02.
- Grantz, A., and May, S.D., 1982, Rifting history and structural development of the continental margin north of Alaska, *in* Watkins, J.S., and Drake, C.L., eds., *Studies in continental margin geology: American Association of Petroleum Geologists Memoir 34*, p. 77–100.
- Grantz, A., Scott, R.A., Drachev, S.S., Moore, T.E., and Valin, Z.C., 2010, Map showing the sedimentary successions of the Arctic region (58–64° to 90°N) that may be prospective for hydrocarbons: American Association of Petroleum Geologists, Tulsa, Oklahoma. [Available at <http://www.datapages.com/gis-map-publishing-program/gis-open-files/geographic/sedimentary-successions-of-the-arctic-region-by-grantz-et-al-2010>.]
- Grist, A.M., and Zentilli, M., 2005, The thermal history of the Nares Strait, Kane Basin, and Smith Sound region in Canada and Greenland; constraints from apatite fission-track and (U-Th-Sm)/He dating: *Canadian Journal of Earth Sciences*, v. 42, no. 9, p. 1547–1569.
- Grist, A.M., and Zentilli, M., 2006, Preliminary apatite fission track thermal history modeling of the Nares Strait region of eastern Ellesmere Island and northwestern Greenland: *Polarforschung*, v. 74, nos. 1–3, p. 113–127.
- Harrison, J.C., 1994, A summary of the structural geology of Melville Island, Canadian Arctic Archipelago, *in* Christie, R.L., and McMillan, N.J., eds., *The geology of Melville Island, Arctic Canada: Geological Survey of Canada Bulletin 450*, p. 257–283.
- Harrison, J.C., 1995, Melville Island's salt-based fold belt, Arctic Canada: *Geological Survey of Canada Bulletin 472*, 331 p.
- Harrison, J.C., and Brent, T.A., 2005, Basins and fold belts of Prince Patrick Islands and adjacent areas, Canadian Arctic Islands: *Geological Survey of Canada Bulletin 560*, 173 p.
- Harrison, J.C., and Jackson, M.P.A., 2013, Exposed evaporite diapirs and minibasins above a canopy in central Sverdrup Basin, Axel Heiberg Island, Arctic Canada: *Basin Research*, v. 25, p. 1–30.
- Harrison, J.C., Mayr, U., McNeil, D.H., Sweet, A.R., McIntyre, D.J., Eberle, J.J., Harington, C.R., Chalmers, J.A., Dam, G. and Nohr-Hansen, H., 1999, Correlation of the Cenozoic sequences of the Canadian Arctic region and Greenland; implications for the tectonic history of northern North America: *Bulletin of Canadian Petroleum Geology*, v. 47, no. 3, p. 223–254.
- Houseknecht, D.W., and Bird, K.J., 2011, Chapter 34, Geology and petroleum potential of the rifted margins of the Canada Basin, *in* Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V., and Sorensen, K., eds., *Arctic Petroleum Geology*, Geological Society of London Memoir 35, p. 509–526.
- Jackson, H.R., 1990, Evolution and regional stratigraphy of the northeastern Canadian polar margin: *Marine Geology*, v. 93, p. 179–92.
- Jackson, M.A., and Harrison, J.C., 2006, An allochthonous salt canopy on Axel Heiberg Island, Sverdrup Basin, Arctic Canada: *Geology*, v. 34; no. 12; p. 1045–1048.
- Meneley, R.A., Henao, D., and Merritt, R.K., 1975, The northwest margin of the Sverdrup Basin, *in* Yorath, C.J., Parker, E.R., and Glass, D.J., eds., *Canada's continental margins and offshore petroleum exploration: Canadian Society of Petroleum Geologists Memoir 4*, p. 531–544.

- Miall, A.D., 1975, Post-Paleozoic geology of Banks, Prince Patrick and Eglinton Islands, Arctic Canada, *in* Yorath, C.J., Parker, E.R., and Glass, D.J., eds., *Canada's continental margins and offshore petroleum exploration: Canadian Society of Petroleum Geologists Memoir 4*, p. 557–587.
- Miall, A.D., 1979, Geology, Banks Island, District of Franklin: Geological Survey of Canada Map 1454A, scale 1:1,000,000.
- Miall, A.D., 1986, The Eureka Sound Group (Upper Cretaceous–Oligocene), Canadian Arctic Islands: Canadian Society of Petroleum Geologists Bulletin, v. 34, no. 2, p. 240–270.
- Miall, A.D., 1991, Late Cretaceous and Tertiary basin development and sedimentation, Arctic Islands, chap. 15 *of* Trettin, H.P., ed., *Geology of the Innuitian orogen and Arctic platform of Canada and Greenland: Geological Survey of Canada, Geology of Canada*, no. 3, p. 437–458.
- Morrell, G.R., Fortier, M., Price, P.R., and Polt, R., contributors, 1995, Petroleum exploration in northern Canada, a guide to oil and gas exploration and potential: Northern Oil and Gas Directorate, Indian and Northern Affairs Canada, 110 p.
- Mosar, J., Eide, E.A., Osmundsen, P.T., Sommaruga, A., and Torsvik, T.H., 2002, Greenland-Norway separation; a geodynamic model for the North Atlantic: *Norwegian Journal of Geology*, v. 82, p. 282–299.
- Nunez-Betelu, L.K., Hills, L.V., and MacRae, R.A., 1994, Palynostratigraphy and hydrocarbon potential of the Upper Cretaceous Kanguk Formation; an integrated multidisciplinary analysis of the northeastern Canadian Arctic Archipelago: *International Conference on Arctic Margins Proceedings (1994)*, p. 54–61.
- Okulitch, A.V., comp., 1991, Geology of the Canadian Archipelago and North Greenland; Figure 2 *of* Trettin, H.P., ed., *Innuitian orogen and Arctic platform—Canada and Greenland: Geological Survey of Canada, Geology of Canada*, no. 3 (also Geological Society of America, *The Geology of North America*, v. E), scale 1: 2,000,000.
- Powell, T.G., 1978, An assessment of the hydrocarbon source rock potential of the Canadian Arctic Islands: Geological Survey of Canada Paper 78–12, 82 p.
- Rayer, F.G., 1981, Exploration prospects and future petroleum potential of the Canadian Arctic Islands: *Journal of Petroleum Geology*, v. 3, no. 4, p. 367–412.
- Ricketts, B.D., 1994, Basin analysis, Eureka Sound Group, Axel Heiberg and Ellesmere Islands, Canadian Arctic Archipelago: Geological Survey of Canada Memoir 439, 119 p.
- Ricketts, B.D., and Stephenson, R.A., 1994, The demise of Sverdrup Basin; Late Cretaceous–Paleogene sequence stratigraphy and forward modeling: *Journal of Sedimentary Research*, v. 64, no. 4b, p. 516–530.
- Saltus, R.W., Miller, E.L., Gaina, C., and Brown, P.J., 2011, Chapter 4, Regional magnetic domains of the circum-Arctic—A framework for geodynamic interpretation, *in* Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V., and Sorensen, K., eds., *Arctic Petroleum Geology: Geological Society Memoir No. 35*, p. 4960.
- Skibo, D.N., Osadetz, K.G., and Goodarzi, F., 1990, Models of organic maturation and hydrocarbon potential; application to Loughheed Island drillholes, Sverdrup Basin, Canadian Arctic Islands: *Current Research Part D, Geological Survey of Canada Paper 90–1D*, p. 201–211.
- Stephenson, R.A., Embry, A.F., Nakiboglu, S.M., and Hastaoglu, M.A., 1987, Rift-initiated Permian–Early Cretaceous subsidence of the Sverdrup Basin, *in* Beaumont, C., and Tankard, A., eds., *Sedimentary basins and basin-forming mechanisms: Canadian Society of Petroleum Geologists Memoir*, v. 12, p. 213–231.
- Stewart, K.R., Embry, A.F., Goodarzi, F., and Skibo, D.N., 1992, Evaluation of organic maturity and hydrocarbon source potential of the Ringnes Formation, Sverdrup Basin, Arctic Canada: *Organic Geochemistry*, v. 18, no. 3, p. 317–332.
- Stewart, K.R., Gentzis, T., Goodarzi, F., and Embry, A.F., 1995, Regional maturity of rock from the Triassic of the Canadian Arctic Islands, *in* Bell, J.S., Bird, T.D., Hillier, T.L., and Greener, P.L., eds., *Proceedings of the Oil and Gas Forum '95, Energy from sediments: Geological Survey of Canada, Open File 3058*, p. 395–399.
- Sweeney, J.J., and Burnham, A.K., 1990, Evaluation of a simple model of vitrinite reflectance based on chemical kinetics: *American Association of Petroleum Geologists Bulletin*, v. 74, no. 10, p. 1559–1570.
- Tessensohn, F., and Piepjohn, K., 2000, Eocene compressive deformation in Arctic Canada, North Greenland and Svalbard and its plate tectonic causes: *Polarforschung*, v. 68, p. 121–124.
- Trettin, H.P., 1989, The Arctic Islands, *in* Bally, A.W., and Palmer, A.R., eds., *The geology of North America—An overview: Boulder, Colorado, Geological Society of America, The Geology of North America*, v. A., p. 349–370.
- Utting, J., Goodarzi, F., Dougherty, B.J., and Henderson, C.M., 1989, Thermal maturity of Carboniferous and Permian rocks of the Sverdrup Basin, Canadian Arctic Archipelago: Geological Survey of Canada Paper 89–19, 20 p.
- Utting, J., Spina, A., Jansonius, J., McGregor, C., and Marshall, J.E.A., 2004, Reworked miospores in the upper Paleozoic and Lower Triassic of the northern circum-polar area and selected localities: *Palynology*, v. 28, no. 1, p. 75–119.
- Waylett, D.C., and Embry, A.F., 1992, Hydrocarbon loss from oil and gas fields of the Sverdrup Basin, Canadian Arctic Islands, *in* Vorren, T., ed., *Arctic geology and petroleum potential: Norwegian Petroleum Society Special Publication 2*, p. 195–204.

Appendixes

Appendix files are available online only, and may be accessed at <https://doi.org/10.3133/pp1824I>.

1. Input data for the Sverdrup Upper Paleozoic Assessment Unit.
2. Input data the Sverdrup Mesozoic Assessment Unit.
3. Input data for the Banks Island-Sverdrup Rim Assessment Unit.

