Structural settings for hydrocarbon exploration in Canada's Arctic Islands

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INTRODUCTION

One of the many challenges for renewed petroleum exploration in Canada's Arctic Islands is to look beyond the obvious structural features that were so successfully identified and tested in the area prior to 1985. While hydrocarbon accumulations are proven to occur in rocks ranging from Devonian through Cretaceous in age, opportunities for renewed exploration extend from the Proterozoic to the Cenozoic. The present contribution provides a brief overview of the major geological provinces of the Arctic Islands and the identified structural features that may control the present distribution of undiscovered hydrocarbon resources. A repeated theme in this paper is reactivation of long-lived structural features, some rooted in Precambrian basement. In contrast to simple late-formed anticlines, structures that have an earlier history are more likely to have guided hydrocarbon migration and to have influenced present day sites of accumulation and preservation. Most geological and physiographic features named in this account are located in the volume edited by H.P. Trettin (1991).

PROTEROZOIC BASINS

Middle and Upper Proterozoic strata are thickest (more than 4000 m) and most widespread at the surface on Victoria Island and on northern Baffin Island (in Amundsen Embayment and Borden Basin, respectively). Existing seismic profiles indicate additional subsurface accumulations of uncertain Proterozoic ages beneath Prince of Wales Island (over 6000 m thick) and southern Melville Island (over 8000 m). While the Proterozoic is known to produce hydrocarbons in Russia, distribution of oil source rocks and thermal maturity variations are yet to be studied across Arctic Canada. Structural controls are likely influenced by Lower Proterozoic and Archean basement anisotropy (shear zones and gneissic foliation) as indicated by potential field anomalies, and by at least two major Proterozoic dyke swarms. Specific structural targets may include northeast-trending anticlinal culminations associated with a Late(?) Proterozoic phase of compressive deformation that has been identified within Minto Arch on northern Victoria Island. A better understanding of the thickness and distribution of prospective Proterozoic strata would be provided by regional seismic profiles across Victoria and Prince of Wales islands, and the surrounding inter-island channels. Additional opportunities may occur across and east of Somerset Island.

LOWER PALEOZOIC CRATONIC BASINS

Cratonic basins of the Arctic Islands include Foxe Basin (southwest of Baffin Island), Prince Regent Basin (centered east of Somerset Island), M'Clintock Basin (west of Somerset Island), and Wollaston basin (beneath southwestern Victoria Island). Strata are locally faulted in these areas but generally flat lying or very gently inclined. Thicknesses range from 600 m in Foxe Basin to more than 4500 m in northeastern M'Clintock Basin. The best prospects for exploration probably exist in settings similar to those encountered in other Lower Paleozoic cratonic basins such as the Michigan and Williston basins. Ordovician and Silurian carbonate patch reef trends, karst brecciation, and selective dolomitization would appear likely. Potential structural controls are likely to be related to basement-rooted faults. Dominant fault sets strike west-northwest in areas east of Cornwallis and Somerset islands. Northeast-striking faults are more common west of Somerset Island, and northerly-striking faults are mapped in all areas with reverse senses of slip indicated near basement-cored uplifts. Phases of extension are Lower to mid-Cambrian and Cretaceous. Compressive deformation was Upper Silurian, Lower Devonian and Upper Devonian; potentially also Lower Permian and Paleogene. Additional seismic profiles are needed in all areas. There is no seismic data whatsoever in all of Victoria Island; an area nearly half the size of Saskatchewan.

LOWER PALEOZOIC BASEMENT UPLIFTS/HIGHS

Cratonic basins are bounded and separated by northerly-trending basement-cored uplifts that each have a well defined syn-depositional tectonic history in the Upper Silurian and Lower Devonian. These include Boothia Uplift, which separates Prince Regent and M'Clintock basins, and Bache Uplift which may be continuous with Admiralty high between Prince Regent Basin and Foxe Basin. Other highs have an unknown record of tectonic activity in the lower Paleozoic. These include the northerly-trending Duke of York high and northwesterly-trending Wellington high, both on southern Victoria Island, the Minto Arch of northern Victoria Island which defines the northern margin of Wollaston basin, the northerly-trending Prince Patrick Uplift of Prince Patrick and northern Banks islands, and the northerly-trending Cape Lambton high on southern Banks Island which is likely continuous with the Proterozoic Brock Inlier south of Amundsen Gulf. Structural closures may be encountered where these high standing blocks are covered by Paleozoic strata. The basement-rooted uplifts are bound by reverse faults, and footwall structural traps are probable where gneissic-granitoid basement has been tectonically emplaced over the Paleozoic. Promising opportunities exist in these settings on Boothia Peninsula, on Somerset and Prince of Wales islands, and beneath the adjacent marine channels.

LOWER PALEOZOIC CONTINENTAL MARGIN AND DEVONIAN FOREDEEP

The orientation of the Cambrian continental margin of ancestral North America is defined in Cambrian strata by the east northeast-trending shelf-to-basin transition which extends from northwestern Melville Island to northeastern Ellesmere Island and across North Greenland. A similar trend is provided by the Lower Devonian carbonate bank edge which coincides with a major east northeast-trending gravity high that runs from Prince of Wales Strait (east of Banks Island) along the southern margin of Viscount Melville Sound to south of Bathurst Island. The latter anomaly defines the imaged northern limit of northerly-trending basement-related gravity and aeromagnetic anomalies. It follows the line of flexure at the southern limit of the Cambrian to Devonian shelf margin sediment prism and the southern edge of the later Devonian foredeep basin. The east northeast trending gravity anomaly may represent the geophysical response to crustal thinning associated with an Upper Proterozoic or Lower Cambrian rift margin. East northeast striking normal faults, parallel to the linear gravity high in Viscount Melville Sound, are known to have been active in the mid-Cambrian. Opportunities for exploration, mostly in Viscount Melville Sound, are associated with the Lower Devonian carbonate shelf edge. Stratigraphic pinch out traps are possible in underlying Paleozoic strata.

The arcuate axial line of the Devonian foredeep basin extends from southern Prince Patrick Island to northeastern Bathurst Island and continues along the axis of the Schei Syncline from northernmost Devon Island (Grinnell Peninsula) to central Ellesmere Island. Along this line, in the west, the preserved thickness of the entire Lower Cambrian to Upper Devonian succession locally exceeds 15 km. Much of the folded Devonian and older succession west of Bathurst Island is thermally overmature. Upper Devonian quartz sandstones are compositionally mature but lack porosity west of central Melville Island. However, oil source rocks are widespread in the Silurian and Lower Devonian, and there is some indication that fluid migration coincided with the Ellesmerian Orogeny at the end of the Devonian. Excellent opportunities exist for undiscovered hydrocarbons in anticlinal culminations along the southern margin of the Parry Islands Fold Belt throughout northern Viscount Melville Sound. Other promising targets are early-formed (pre-Middle Devonian) anticlines north of Bathurst Island and along the intersection of the Parry Islands Fold Belt with the northerly-trending Cornwallis Fold Belt. Unconformity-related traps are possible in the Upper Silurian and Lower Devonian along the margins of the Boothia Uplift and Cornwallis Fold Belt east and west of Cornwallis Island. Thermal maturities are also favourable in this area. The belt of thermally and structurally favourable lower Paleozoic strata extends farther to the east where the northern and western limb of the Schei Syncline is the roof of a southerly- and easterly-facing triangle zone (analogous to the Alberta Syncline west of Calgary). Forethrusts and backthrusts are approximately end Devonian in age with ramps extending from low in the Cambrian to intermediate detachments in Ordovician evaporites, thence to an upper detachment in Devonian slope mudrocks. Specific prospects may be associated with Lower Paleozoic patch reefs and diapiric Ordovician salt structures. The Paleozoic fold belt continues to the north and is widely exposed throughout northern Ellesmere Island. However, most rocks north of 79o latitude carry a penetrative slaty cleavage and are thermally overmature.

SVERDRUP BASIN

The Sverdrup Basin contains Lower Carboniferous through Paleogene strata probably exceeding 14 km in total thickness in the basin centre. The Carboniferous unconformably overlies previously deformed and peneplained Lower Paleozoic shelf and basin deposits, and accreted terranes (of Pearya) on northernmost Ellesmere Island. The Sverdrup Basin is geologically similar to both the Gulf of Mexico Basin, and the Magdalen Basin in the Gulf of St. Lawrence, but is most apparently distinguished from these basins by a mountainous Paleogene thrust belt that extends across Axel Heiberg and northern Ellesmere Island. The northeastern half of the Sverdrup Basin provides useful geological context for features that are deeply buried in the southwestern half of the basin but is considered less prospective due to logistical difficulties and thermally overmature conditions.

The lower part of the Sverdrup Basin is a Lower Carboniferous rift complex exposed on the northern, eastern and southern basin margins. The rift system is imaged seismically on the southern and northwestern margin. Syndepositional extension is evident in Lower and Upper Carboniferous strata. Rift-bounding normal faults are parallel to thrust-folds in the underlying Lower Paleozoic. On northern Bathurst and northeast Melville islands grabens are perched over, and are kinematically-linked to, specific Devonian thrust-anticlines. Subsequent transtensional deformation and transpressive inversion (Melvillian Disturbance) is associated with the Lower Permian on northwestern Melville Island and northeastern Prince Patrick Island. New exploration plays can be developed in both Carboniferous graben and horst settings, in Permian inversion structures and beneath various Upper Paleozoic unconformities and at stratigraphic pinch-outs. While regional and some detailed seismic coverage is available in many areas, it is all vintage data (pre-1985). Progress would be forthcoming from advanced acquisition and processing techniques.

Existing undeveloped gas and oil discoveries are almost exclusively located in Triassic through Lower Cretaceous strata of the southwestern Sverdrup Basin. Numerous identified closures remain to be tested. Structural settings for new plays are likely to be found beneath basin margin unconformities, and in the vicinity of repeatedly rejuvenated salt pillows, salt diapirs and salt walls. The nature of allochthonous salt in the Sverdrup Basin remains to be fully understood. Sheets of Lower Carboniferous evaporites have intruded Cretaceous strata on western Axel Heiberg Island, and mini-basins bound by thrust-modified diapiric salt walls are mapped on both Axel Heiberg and northern Ellesmere islands. These structural settings are similar to those now well known in the central Gulf of Mexico Basin. Potential for complex sub-salt structure and associated new hydrocarbon plays is to be expected throughout the Sverdrup Islands west of Axel Heiberg Island.

CENOZOIC CONTINENTAL MARGIN BASINS

The last and most hostile frontier for hydrocarbon exploration lies on the modern continental margins of the Arctic Islands. The polar margin to the northwest of the islands is geologically continuous with the Mackenzie Delta and Beaufort Basin. Refraction experiments indicate more than 10 km of Cretaceous, Cenozoic, and Quaternary strata on the offshore continental margin northwest of Axel Heiberg Island. With the exception of a small grid of reflection seismic data known to have been acquired west of northern Banks Island, there has been no industry exploration anywhere along the 2000 km of continental margin from southern Banks Island to northern Ellesmere Island. Favourable structural settings, most readily explored, occur in a Middle Jurassic through Lower Cretaceous rift belt located on the continental margin of Banks and Prince Patrick islands. While Mesozoic strata are thermally immature, source rocks are known in the Upper Cretaceous, there are indications of gas, and opportunities to locate far-travelled hydrocarbons should not be discounted.

Parallel opportunities exist for exploration on the eastern continental margin from the Labrador Sea to Baffin Bay. The Cretaceous and younger succession locally exceeds 12 km in thickness above attenuated continental crust and oceanic crust. This immense region is geologically analogous to the North Sea area of northwest Europe and is comparable in size. Exploration, including some drilling, has already commenced on the opposite margin off southwestern Greenland, and numerous oil seeps have been located in Paleocene flood basalts in central west Greenland. Cretaceous and Paleogene rift-related targets are most likely on the Baffin and Labrador margins. The rift system narrows and branches at its northern limit. Arms of the rift extend into Lancaster Sound, Kane Basin and potentially also Jones Sound. Existing seismic profiles indicate graben inversion features on both the Canadian and Greenland sides of the border. Northwesterly-trending inversion folds have been mapped in Paleocene-Eocene grabens located on southern Ellesmere Island. Multiple phases of deformation are indicated within the Paleogene from southeastern to northeastern Ellesmere Island. Sinuous thrusts adjacent to Nares Strait place Lower Cambrian rocks over Ordovician, Silurian and Paleocene strata. Thermal conditions are suitable for the preservation of hydrocarbons in the sub-thrust footwall Paleozoic succession.

Reference

Trettin, H.P. (Ed.)

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