



BRITISH
COLUMBIA

MINISTRY OF
ENERGY AND MINES

DEEP GAS POTENTIAL IN NORTHEAST BRITISH COLUMBIA



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INTRODUCTION

Deep Devonian reservoirs in northeastern British Columbia (Fig. 1), including the Chinchaga, Keg River, Sulphur Point and Slave Point formations, have been prolific gas producers since the 1950's. However, there is still abundant potential for high-impact gas discoveries along new and established exploration fairways.



Fig. 1 - location of study area

Ministry of Energy and Mines, in collaboration with Petrel Robertson Consulting Ltd., has published an assessment of deep Devonian gas production and exploration potential in British Columbia. This study highlights the importance of hydrothermal dolomite reservoirs as a key component of Devonian exploration potential. Working from existing Petrel Robertson studies, new data from more than 500 wells and the published literature, this project addresses several key issues:

- Regional lithostratigraphic framework of Devonian units, and the distribution of economically important strata
- Paleoenvironments and paleogeographic setting of key units
- Present structural configuration, and the impact of the basement and structural lineaments on sedimentation and reservoir quality
- Dolomitization trends in the Slave Point, Sulphur Point, Upper and Lower Keg River, and Upper Chinchaga reservoirs
- Key stratigraphic and structural features, and how the integration of these elements can be used as an exploration tool.

HYDROCARBON POTENTIAL

Torrie (1973) outlined tremendous hydrocarbon potential in deep Devonian strata of northeastern British Columbia, based upon the few major discoveries and limited drilling of the time. Exploration during the past 30 years has uncovered new reserves, and demonstrated that much more remains to be found. Deep Devonian reservoirs host up to 14 TCF of established gas in place in northeastern British Columbia and adjacent regions, and hold tremendous potential for additional discoveries along traditional exploration fairways, and in more remote, lightly-explored areas (Reinson et al., 1999; Canadian Gas Potential Committee, 2001; Petrel Robertson Consulting Ltd., 2003).

RESOURCE ASSESSMENT STATISTICS

The Geological Survey of Canada (Reinson et al., 1993) and Canadian Gas Potential Committee (2001) have summarized discovered reserves and expected discoveries for Canadian gas plays. The following volumes have been tabulated for Devonian plays of northeastern B.C. (all figures are raw initial gas in place):

- Geological Survey of Canada (Reinson et al., 1993)
 - Discovered $283 \text{ e}^9\text{m}^3$ (10.0 TCF)
 - Ultimate Resource $572 \text{ e}^9\text{m}^3$ (20.2 TCF)
- Canadian Gas Potential Committee (2001)
 - Discovered $401 \text{ e}^9\text{m}^3$ (14.1 TCF)
 - Ultimate Resource $589 \text{ e}^9\text{m}^3$ (20.8 TCF)

In both cases, discovered and ultimate volumes include those associated with play trends extending into adjacent Alberta and Northwest Territories. Gas volumes remaining to be discovered are considerable under both assessment schemes. In addition, the CGPC recognized that potential may occur in Chinchaga and older reservoirs, while the GSC noted that other unspecified gas plays may exist at various stratigraphic levels. Resource potential for these conceptual plays cannot be quantified, but is thought to be large (TCF scale).

With increased well control and knowledge, a more detailed breakdown of plays can be developed, and hence a more accurate projection of resource potential may be justified. At the present time, we question the statistical validity of projections for some play types in which large portions of prospective fairways have not been sampled. For example – there has been no assessment of the western barrier margin of the Keg River / Sulphur Point and Slave Point platforms; the Hotchkiss Embayment is only now being explored; and platform interior embayment margin plays are not even considered as a potential play type in either assessment.

Although the remaining gas resource potential for the Devonian of northeastern B.C. is estimated to be very large, it may be even larger with exploration of new and expanded play trends.

MIDDLE DEVONIAN STRATIGRAPHY AND STRATIGRAPHIC ARCHITECTURE

Stratigraphic architecture along with structural elements of Devonian in Northeastern BC are shown in Figure 2-3.

MIDDLE DEVONIAN	GIVETIAN	FORT SIMPSON	WOODBEND GROUP
		MUSKWA	
		OTTER PARK	BEAVERHILL LAKE GROUP
		SLAVE POINT	
		WATT MOUNTAIN	UPPER ELK POINT GROUP
		SULPHUR POINT	
		UPPER KEG RIVER	
		MUSKEG (evaporites)	
	EIFELIAN	LOWER KEG RIVER	LOWER ELK POINT GROUP
		UPPER CHINCHAGA	
		LOWER CHINCHAGA	
		COLD LAKE	
		ERNESTINA LAKE	
		BASAL RED BEDS	
LOWER	EMSIAN	STONE	
PROTEROZOIC		"PREDEVONIAN QUARTZITE"	

Fig 2 – Stratigraphic table of the middle Devonian in N.E. British Columbia

- THE LOWER ELK GROUP is comprised of four units: the "Basal Red Beds", Ernestina Lake, Cold Lake and Chinchaga formations, formed by restricted and evaporitic lithofacies, and deposited within the topographic lows between the pre-Devonian Quartzite highs.
- THE CHINCHAGA FORMATION is subdivided into two units by a regional unconformity, which follows a period of uplift and adjustment in the basin with a renewed influx of clastic deposition across the basin.
- THE UPPER ELK GROUP comprises a number of lithostratigraphic units deposited in a rimmed carbonate platform setting. The bounding reef topography has traditionally been lumped as the Pine Point (Presqu'île) Formation where dolomitized, and mapped as the "Presqu'île Barrier".
- THE LOWER KEG RIVER (Keg River Platform) is relatively uniform across much of N.E. British Columbia, with thicknesses ranging from 20 to 50 metres. The Lower Keg River marks the beginning of a widespread marine transgression with relatively deep-water deposits, represented by nodular and wavy-bedded mudstones/wackestones and are typically dolomitized.
- THE UPPER KEG RIVER carbonate banks form the northern wall of the Elk Point restricted basin, reaching thicknesses of over 200 metres. Upper Keg River strata consist of stacked cycles, each with a shaly base, shoaling upward to a thick high-energy carbonate at top.
- THE MUSKEG FORMATION ranges in excess of 200 metres in an area of maximum subsidence paralleling the Hay River Fault Zone and consists of interbedded anhydrite, dolostone and possibly halite, deposited within the restricted Elk Point basin. In the north, approaching the Keg River margin, dolomites thicken at the expense of evaporites, and small-scale cycles become more apparent.
- THE SULPHUR POINT carbonates were deposited during a regional transgression over the Keg River and is mappable over much of the study area. In the south, the basal contact is sharp, as relatively high-energy peloidal grainstone-wackestones transgress the evaporitic Muskeg.
- THE WATT MOUNTAIN FORMATION forms a distinct stratigraphic break between the Sulphur Point and Slave Point carbonates and is characterized by waxy green shales. The base of Watt Mountain marks a low-relief regional unconformity, resulting from a basin-wide tectonic adjustment and uplift on the Peace River Arch and other highs in the west.
- THE SLAVE POINT FORMATION was deposited during a basinwide transgression, which ultimately drowned the Middle Devonian carbonate platforms of northeastern British Columbia and Alberta. It forms a thick and complex carbonate platform comprising several stacked shallowing-upward cycles. Reefal buildups and high-energy carbonate banks occur along the edges of the main platform, and also along the margins of platform-interior embayments.

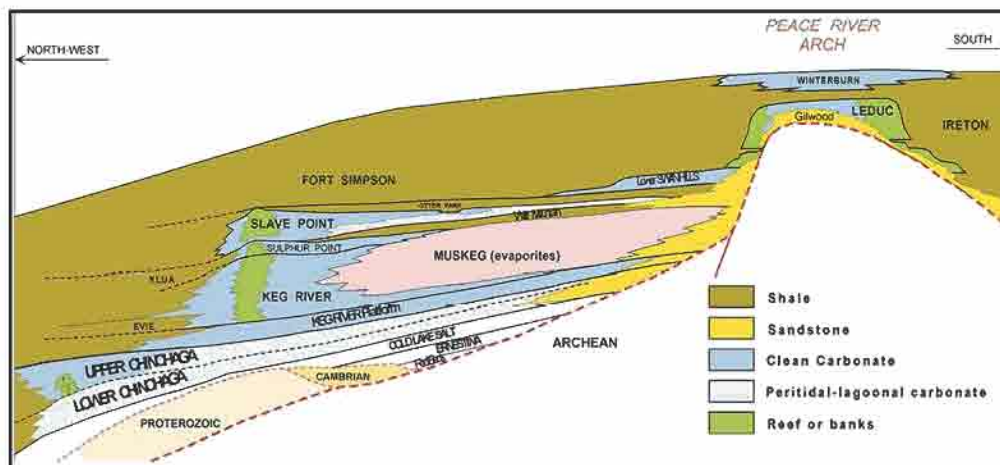


Fig 3 – Stratigraphic architecture of the middle Devonian in N.E. British Columbia

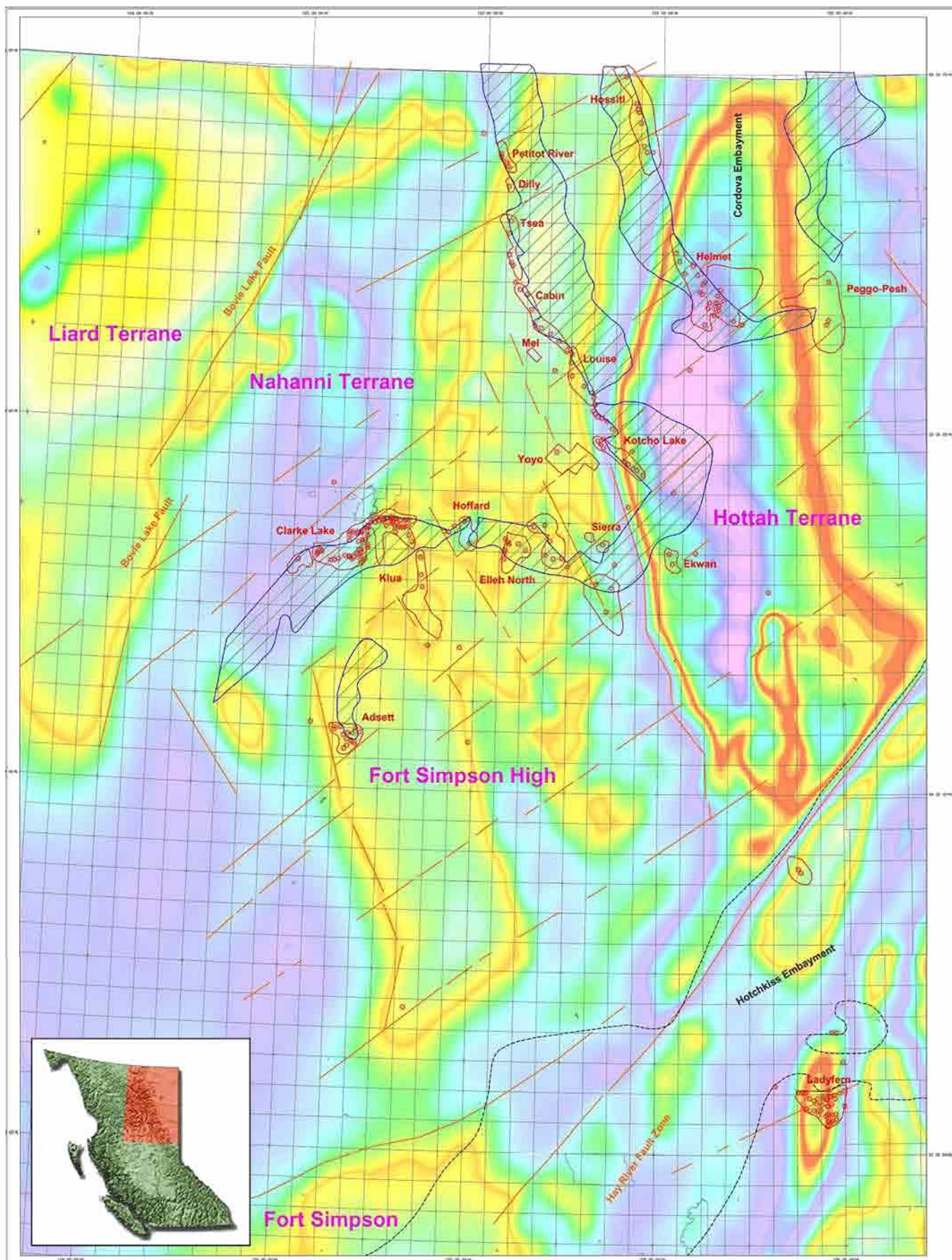


Fig 4. Structural Elements

STRUCTURE FRAMEWORK

Structure played a major role in shaping the paleo-geography and reservoir development of northeastern British Columbia during Devonian time. Basin margins and bank edges were preferentially located along deep-seated faults that were active during deposition. Reactivation of deep-seated fault trends has exerted control over large-scale features such as platform margins and interior platform embayments, and over smaller features such as localization of isolated reefal buildups.

Four main basement magnetic domains Liard Terrane, Nahanni Terrane, Fort Simpson High, and Hotah Terrane have been identified within the study area. Sharp magnetic gradients can be identified as domain boundaries and basement fault trends, such as the Hay River Fault Zone and Bovie Lake Fault Zone. In addition to these two zones, we have identified regional networks of SW-NE and NW-SE faults.

Hydrothermal fluids migrated along these same faults, mapped based on seismic interpretation, surface lineaments or regional isopach maps, and are coincident in many places with aeromagnetic anomalies interpreted as major basement discontinuities.

HYDROTHERMAL DOLOMITE RESERVOIRS

Hydrothermal dolomites (HTD), characterized by coarse crystalline white saddle dolomite, and commonly associated with collapse brecciation, form important components of many Devonian reservoirs in NEBC. Primary lithofacies have a significant influence on the development of HTD reservoirs. In strata with good initial effective permeability and porosity, such as reefal buildups, dolomitization enhances reservoir quality over broad areas. At Clarke Lake, pervasive dolomitization occurred in reefal facies near the platform margin, apparently along a major strike-slip fault. In contrast, where hydrothermal dolomitization occurs in lithofacies with poor primary reservoir quality, reservoir enhancement may be limited to a narrow corridor along the fault zone.

Three factors are important in the genesis of hydrothermal dolomites:

- Carbonate facies with preserved primary porosity and permeability;
- An extensional tectonic setting, giving rise to normal and strike-slip fault motions;
- An elevated geothermal gradient, providing a source for hydrothermal fluids.

The recent key discovery at Ladyfern has initial reserves of 746 BCF and deliverabilities commonly in excess of 50 MMCF/d. The best wells at Ladyfern exhibit initial productive potential of greater than 100 MMCF/d because of porosity enhancement, fracturing, and brecciation.

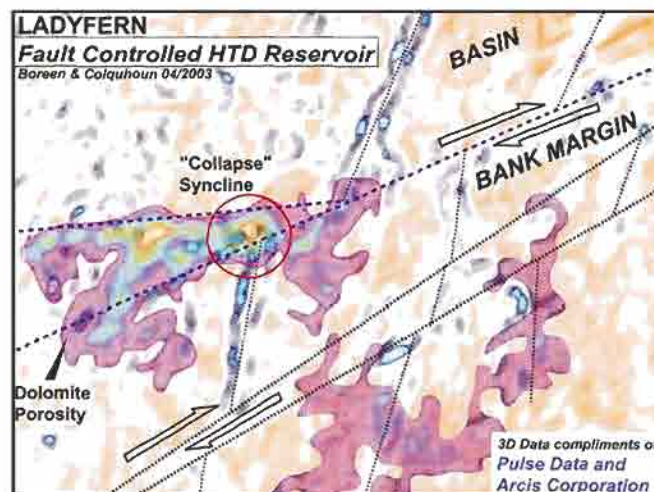


Fig5. Hydrothermal dolomitization associated with faulting at Ladyfern (from Boreen, 2003).

CHINCHAGA FORMATION

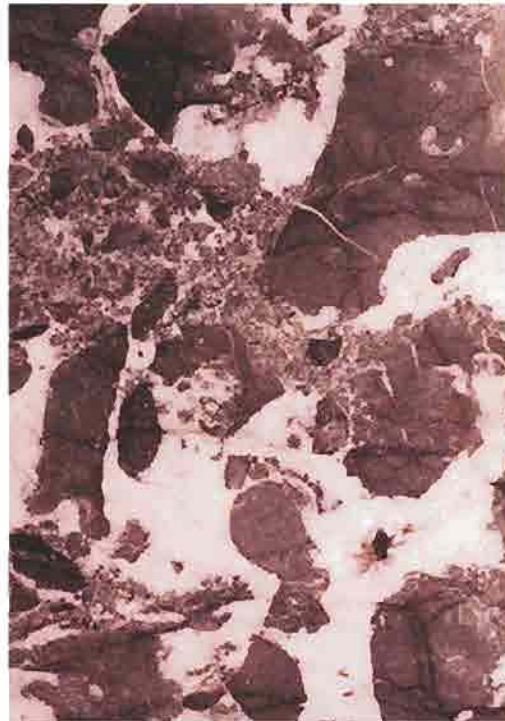
The Chinchaga contains a wide variety of lithofacies including very fine-grained peloidal wackestones and packstones with birdseye fabrics, pebble breccias and dessication fractures. Chinchaga carbonates produce gas at Beaver River (and to the north at Kotaneelee, Pointed Mountain, and Fort Liard), primarily from hydrothermal dolomite reservoirs and structural traps.

The Chinchaga is prospective in northernmost British Columbia where fenestral and intrafossil vug porosity has been observed in platformal facies, and hydrothermal dolomites (Plate 1 – Figure 6) occur along several fault trends. Numerous gas shows occur in the Chinchaga (and younger formations) along the eastern upthrown margin of the Bovie Lake Fault in B.C. and the NWT, as large volumes of gas appear to have been preferentially transported along the axis of the fault, and trapped locally in areas where HTD is well developed.

Another potential play may exist where Chinchaga carbonates shale out northwestward toward the Yukon Territory. The Chinchaga carbonate platform is fully developed at Beaver River, but is absent or drastically thinned northwest of Kotaneelee and Pointed Mountain. Reefal buildups may occur along the carbonate bank edge and would offer more effective matrix porosity and permeability than the fractured reservoirs at Beaver River, Kotaneelee, and Pointed Mountain Fields. Hydrothermal dolomitization would further enhance reservoir potential on this trend.



a. b-14-A/94-O-1 7713.0 ft. Upper Chinchaga
Dolo-packstone with zebroid texture. Note white saddle dolomite cement lining sheet cavity network.



b. a-67-D/94-O-13 17,138.0 ft. Chinchaga
Breccia, microcrystalline dolomite matrix, white saddle dolomite cement dissolution breccia pipe.

PLATE 1 – HYPERHALINE SHELF – UPPER CHINCHAGA

KEG RIVER AND SULPHUR POINT FORMATION

The Keg River produces gas from isolated reefal buildups controlled by basement horst blocks, such as at Yoyo and Sierra fields, and from smaller structural/stratigraphic pools along the major basinal margins.

Sulphur Point strata are difficult to distinguish from the Keg River in many areas so their exploration potential can be assessed jointly. Generally, the Sulphur Point is regarded as a more homogeneous regional aquifer, and trapping situations may not occur as abundantly as in the Keg River.

Keg River / Sulphur Point carbonates are prospective in at least four settings:

- **Faulted Platform Margins:** Conceptually, wherever faults cut across a continuous platform margin at a high angle, a potential structural trapping situation is set up. If the fault is deep-seated, and/or was active near the time of deposition, it may have influenced reef growth and subsequent diagenetic processes. Such traps will likely be small up to several spacing units and tens of BCF but highly productive.
- **Flanks of Platform and Embayments:** Fault lineaments and a poorly-controlled Keg River thin indicate the possible presence of a SW-NE embayment cutting across the Keg River platform. By analogy with the Hotchkiss Embayment (at Slave Point level), Keg River and Sulphur Point reef buildups along the margins may be prospective. Discoveries of this type could range up to several hundred BCF reserves in thick buildup sections, with high productivities from dolomitized reefal buildups.
- **Western Carbonate Banks:** The restricted Elk Point (Muskeg) evaporite basin must have had a western margin. Displacement along regional SW-NE fault trends may have elevated particular structural blocks, thus influencing the paleogeography of the margin trend. Later movement, during the Antler Orogeny, may have influenced fluid movements and hence diagenetic trends. Keg River / Sulphur Point discoveries on the western margin could range up to Clarke Lake size (hundreds of BCF to more than a TCF). Although mapping would be difficult and drilling expensive for deeply-buried targets along this play trend, high reservoir pressures would augment reserves and productivity.
- **Antler Structural Trap:** The Sulphur Point occurs over a considerable portion of the platform. Because of its role as the major regional aquifer, it was not generally considered to be prospective but now, since Antler age deformation is seriously considered, the Sulphur Point can be regarded as a prospective reservoir where it occurs on structure, particularly south of the reefal front where it is sealed by Watt Mountain and or lower Slave Point (Fort Vermilion "Member") shales. Such traps will likely be small up to several spacing units and tens of BCF but could be very productive in the vicinity of strike-slip faults.

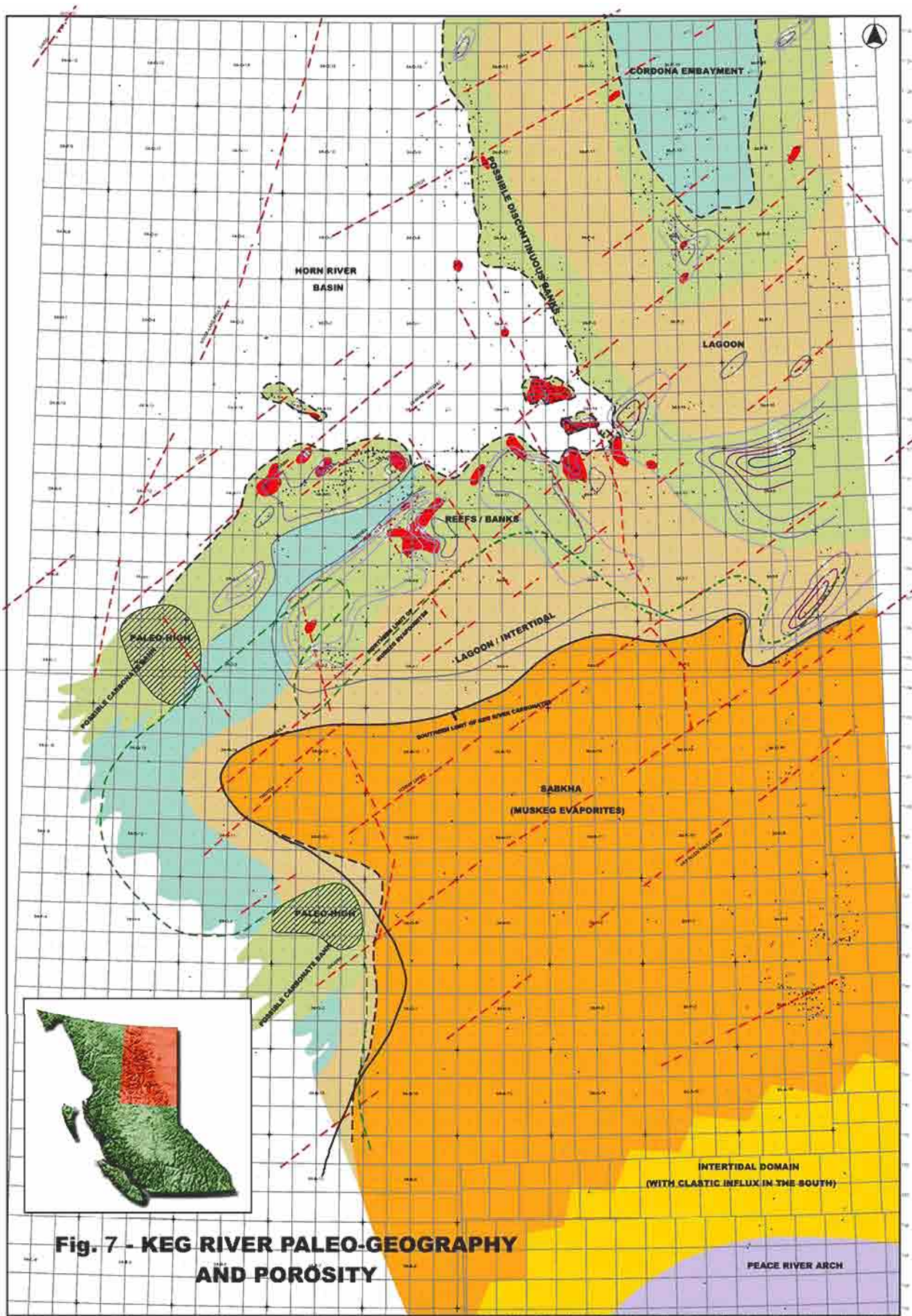


Fig. 7 - KEG RIVER PALEO-GEOGRAPHY AND POROSITY

Fig 7. Keg River Pale-Geography and Porosity

SLAVE POINT FORMATION

Slave Point exploration potential is controlled by many of the same factors as Keg River/Sulphur Point potential, and hence is conceptually very similar. However, capping shales provide better seals for Slave Point reservoirs, and make seismic mapping simpler.

Slave Point carbonates produce from a variety of settings that offers considerable additional potential for substantial discoveries:

- **Barrier Buildups:** The Horn River Basin and Cordova Embayment margins have been drilled fairly extensively, and it is unlikely that large buildups resembling Clarke Lake will be found along these trends in B.C. However, the postulated western margin of the Slave Point platform is essentially unknown, and may be prospective. As for the Keg River / Sulphur Point, discoveries in this area will be difficult to map, but reserves could be on the TCF scale.
- **Faulted Platform Margins:** Deep-seated faults cross-cutting platform margins offer smaller-scale potential reserves, but high productivities where reservoirs are diagenetically enhanced.
- **Interior Embayment Margins:** The Ladyfern discovery extended prospectivity along the Hotchkiss Embayment margin westward into B.C. from Cranberry in Alberta. Slave Point buildups over paleo-highs within embayments, such as Hamburg, may also be prospective. In addition to defining the limits of the embayment, faults along the Hay River Fault Zone have linked deep hydrothermal fluids to Slave Point reservoirs. Exploration along the embayment margins should thus be guided by the presence of faults, as indicated by seismic, reactivation at higher stratigraphic levels, and basement magnetic anomalies. Ladyfern itself is coincident with a strong magnetic feature. Other Slave Point interior embayments have been mapped in 94G and 94J, but have not been extensively explored at the Slave Point level. Several porosity anomalies in flanking wells suggest that opportunity exists for embayment margin plays to be developed. Since the Ladyfern discovery, the Hotchkiss Embayment has been the focus of relatively intense Slave Point exploration activity. Various operators have announced Slave Point discoveries as far west as 94H5, but most appear to be limited in reserve size and initial productivity. Drilling is still sparse, and potential remains for the discovery of new fields on the scale of Ladyfern.
- **Lower Slave Point Cycles:** Discrete fault-bounded areas within the Slave Point platform may develop additional cycles of reef growth, as at Adsett, given appropriate timing of movements on the faults. Detection of these cycles may be difficult without fairly extensive well control, but moderate reservoir potential may occur under the appropriate structural/diagenetic conditions.

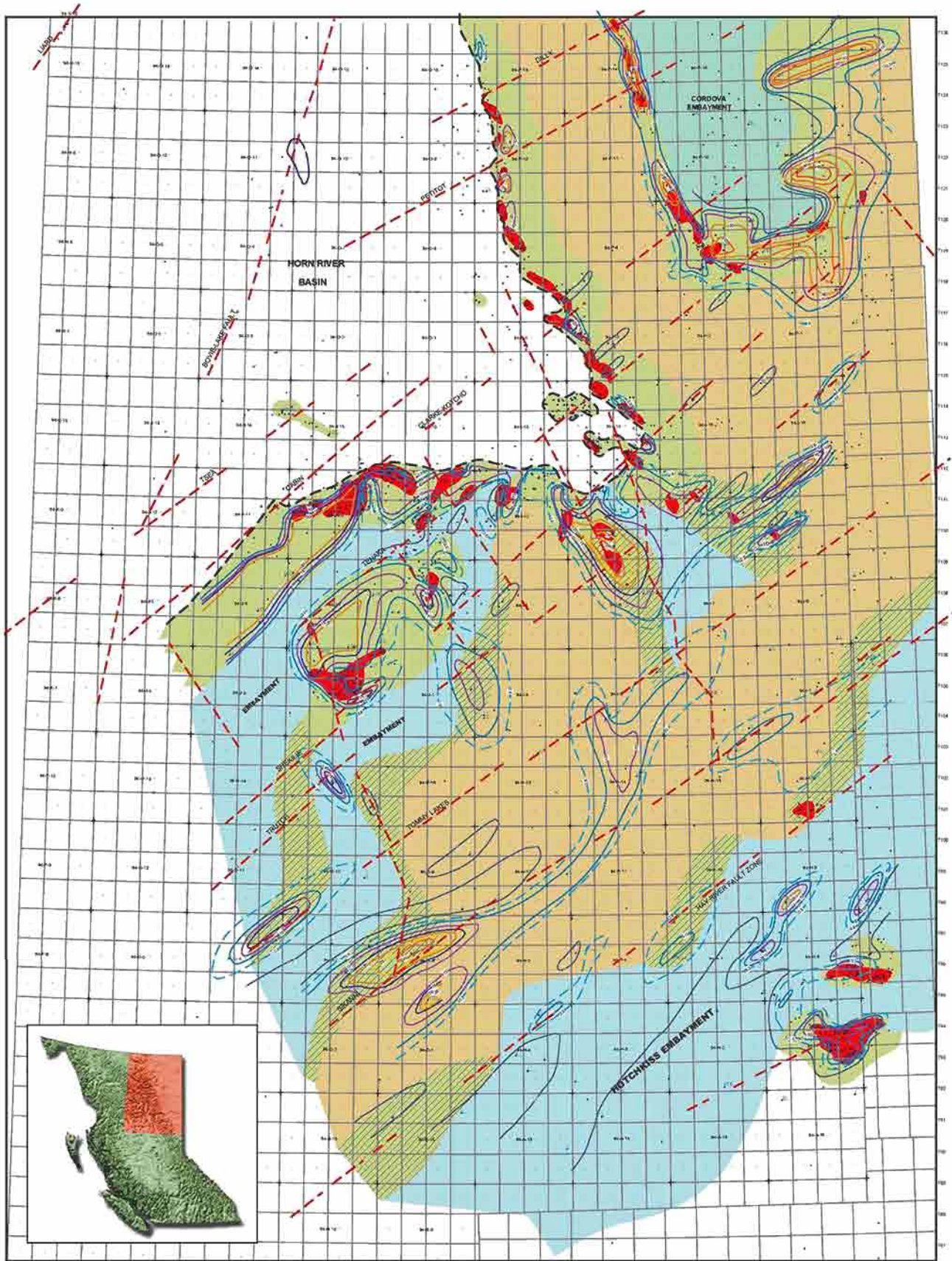


Fig 8. Slave Point Paleo-Geography and Porosity

SUMMARY OF DEEP GAS POTENTIAL IN NEBC

The study done by Petrel Robertson Consulting Ltd. highlights the importance of hydrothermal dolomite reservoirs as a key component of Devonian exploration potential. Dolomitization trends in the Slave Point, Sulphur Point, Upper and Lower Keg River, and Upper Chinchaga reservoirs were highlighted and used as a guide to map the porosity distribution.

1. Three factors are important in the genesis of hydrothermal dolomites:
2. An extensional tectonic setting, giving rise to normal and strike-slip fault motions;
3. Carbonate facies with preserved primary porosity and permeability.
4. An elevated geothermal gradient, providing a source for hydrothermal fluids.

The structural framework of the area played a major role in shaping the paleogeography and reservoir development during Devonian time.

Reactivation of deep-seated fault trends appears to have exerted control over large-scale features such as trends of platform margins and interior platform embayments, and over smaller features such as localization of isolated reefal buildups. Using regional aeromagnetic intensity mapping, surface lineaments, and offsets mapped in younger strata, we have identified regional networks of southwest-northeast and northwest-southeast faults, in addition to the Bovie Lake and the Hay River Fault Zones. Fault movements, particularly those involving strike-slip motion, have allowed deep-sourced fluids access to Devonian reservoirs, causing widespread reservoir enhancement, primarily through hydrothermal dolomitization and associated solution and brecciation.

The primary lithofacies have a significant influence on the development of HTD reservoirs. In strata with good initial effective permeability and porosity, such as reefal buildups and high-energy shoals, dolomitization enhances reservoir quality over broad areas (e.g. Clarke Lake, Adsett, Ladyfern). In contrast, where hydrothermal dolomitization occurs within lithofacies with poor primary reservoir quality, such as tight shaly limestone, reservoir enhancement may be restricted to a narrow corridor along the fault zone.

Paleogeography / porosity maps highlight areas where porosity has been observed on well logs. Some of these areas correspond to known production, but others provide leads to prospectivity in new areas, and require evaluation in terms of the play types outlined above.

The Deep Devonian of northeastern B.C. has been explored thoroughly only along a few play trends, and thus offers abundant potential for high-reserve, high-productivity discoveries along a variety of established and postulated fairways.

A key recommendation that arises from this project is to carefully map and assess regional fault trends, particularly those that appear to be deep-seated, and to have been reactivated throughout Phanerozoic time. Major faults have played a large role in nucleating reef growth along major platform margins, and in determining the locations of intraplatform embayments and isolated carbonate buildups. Deep-seated faults, particularly strike-slip shear zones containing numerous small fault blocks prone to reactivation, have also promoted the movement of deep hydrothermal fluids, accelerating reservoir-enhancing diagenetic processes in carbonate reservoirs. The Hay River Fault Zone is a prime example of such a trend, but several other faults have probably exhibited similar behaviour.

OIL AND GAS DEVELOPMENT STRATEGY

New initiatives under the Oil and Gas Development Strategy for the Heartlands build on the successful program launched by BC government in May of 2003. The strategy is a comprehensive program that develops and expands the province's service sector supporting the oil and gas industry; addresses resource and community road infrastructure; aims to reduce and streamline regulation; and targets royalty incentives to encourage increased exploration and resource development.

DEEP WELL ROYALTY PROGRAMS

To maintain BC's competitive position for attracting energy investment, the government announced deep well royalty on May 30, 2003. Further changes to this deep drilling royalty credit was introduced on November 14, 2003 to encourage greater exploratory drilling activity targeting directional, horizontal, re-entries and super-deep gas wells.

- Deep Well Royalty Credit Amendments
 - Deep Re-entry
 - Direction and horizontal
 - Deep Discovery

The details can be found on MEM OGDS website (<http://www.em.gov.bc.ca/OGDS>) or contacting MEM, Oil and Gas Division.

Reference:

Ministry of Energy and Mines Petroleum Geology Open File 2003-4
"Exploration Assessment of Deep Devonian Gas Plays, Northeast British Columbia"

The Ministry of Energy and Mines and the Oil and Gas Commission are developing attractive fiscal regime and stream-lined regulatory process to increase oil and gas resource development activities in British Columbia. To understand industry needs better, we welcome your views and opinions.

For more information about BC conventional and unconventional oil and gas resources and regulatory process, visit MEM and OGC Website:

www.em.gov.bc.ca

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The complete study is available at:

<http://www.em.gov.bc.ca/subwebs/oilandgas/pub/reports.htm>.



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