1990 CSPG CONVENTION
May 27 to 30, 1990

PROGRAM
MONDAY, MAY 28

Speakers’ Breakfast 6:30 a.m. to 8:30 a.m.
Registration Desk Opens 7:30 a.m.
Exhibition Hall 8:00 a.m. to 5:00 p.m.

MORNING TECHNICAL PROGRAM
8:15 a.m. to 11:30 a.m.

Introduction
Maclean Hall A

8:15
Greetings
F.G. Young, General Chairman
8:25
Introductory Remarks
J.E. Klovan, C.S.P.G. President

Geological Atlas — Framework/Early History
Chairmen: F.G. Young and G.D. Mossop Maclean Hall A
8:30
9:00
R.A. Price: Cordilleran tectonics and the evolution of the Western Canada Sedimentary Basin
9:30
G.N. Wright, M.E. McMechan and M.E. Holter: Structure of the Western Canada Sedimentary Basin
10:00
G.M. Ross: Geophysical expression of the Western Canada Sedimentary Basin — implications for crustal structure and tectonic assembly of the crystalline basement
10:30
R.A. Burwash, C.R. McGregor and J.A. Wilson: Precambrian basement beneath the Western Canada Sedimentary Basin
11:00

International
Chairmen: A.J. Jenik and T. Koning Maclean Hall B
9:30
J. Ipbal: Offshore Pakistan: geology and petroleum prospects
10:00
F.A. Stoakes and P. Ramanamison: Hydrocarbon potential of the Moronnda Basin, west Madagascar
10:30
D.J. Cairns and J.C. Hopkins: Depositional and diagenetic evolution of a Holocene bank interior ooid-grapestone shoal complex, Turks and Caicos islands, B.W.I.
11:00
M.M. Roksandic and H. Jabra: Geology and hydrogen carbon potential of the Rharb Basin, Morocco

Sedimentology
Chairmen: G.P. Smith and P.E. Putnam Maclean Hall C
9:00
A.M.C. Chow and C.W. Stearn: Silurian reefs of the Attawapiskat Formation, James Bay, northern Ontario
9:30
H. Sabry: Fan-delta and interdeltaic shoreline sediments of Middle Devonian ‘Granite Wash’ and Keg River clastics, Red Earth Field, North Alberta Basin, Canada
10:00
M.K. Halim-Dihardja and E.W. Mountjoy: Diagenesis of the Upper Devonian (Famennian) Wabamun Group, north-central Alberta
10:30
I. Banerjee: The Basal Colorado Sandstone and other tidal sandsheets formed during the Joli Fou Transgression
11:00
D.A. Leckie and R.J. Cheel: A new interpretation for the Oligocene Cypress Hills Formation, southern Alberta and Saskatchewan

Poster Sessions
Atlas
Atlas and General
Maclean Hall D

TECHNICAL LUNCHEON
Location: Palliser Hotel
Time: 11:45 a.m. to 1:30 p.m.
Speaker: Dr. W.S. Fyfe, Dean, Faculty of Science and Professor of Geology, University of Western Ontario
Title: "The Global Environment and Sustainable Energy Resources"
Background: Dr. Fyfe is a representative on the International Geosphere/Biosphere Project.

AFTERNOON TECHNICAL PROGRAM
1:30 p.m. to 5:00 p.m.

Geological Atlas — Paleozoic to Triassic Cratonic Succession
Chairmen: D.M. Kent and A.M. Blackie Maclean Hall A
1:30
D.M. Kent: Overview of the Paleozoic history of the Western Canada Sedimentary Basin
2:00
2:30
B.S. Norford, R.K. Beysy, M.P. Cecile, F.M. Haidi, H.R. McCabe and D.F. Paterson: Middle Ordovician to Silurian strata of the Western Canada Sedimentary Basin
3:00
N.C. Meijer Dees: Elk Point Group strata of the Western Canada Sedimentary Basin
3:30
R.J. Munday, S. Oldale and K. Ma: Beaverhill Lake Group strata of the Western Canada Sedimentary Basin
4:00
4:30
H.L. Halbertsma: Wabamun/Palliser strata of the Western Canada Sedimentary Basin

Frontier Geology
Chairmen: J.R. Hogg and M.F.J. Cooper Maclean Hall B
1:30
J.R. Dietrich, R. Higgs and K. Rohr: The geology and petroleum potential of the Tertiary Queen Charlotte Basin, British Columbia continental margin
2:00
G.P. Smith: Kee Scarp or not Kee Scarp — that is the question?
2:30
E.C. Prosh: Lower Devonian reefs, Disappointment Bay formation, Arctic Islands
3:00
C.E. Keen, I. Reid and R. Bouillier: Crustal structure and geodynamic models for the south Jeanne d’Arc basin; offshore Eastern Canada
3:30
M.E. Enachescu: Jeanne d’Arc and southeastern Beaufort (Kugmallit Trough) basins: a tectonic and structural comparison
4:00
P.K. Mukhopadhyay, J.A. Wade, M.G. Fowler and M. Avery: Source-rock potential and maturation of Jurassic-Cretaceous sediments and their relationships to hydrocarbon occurrence and overpressuring
4:30
V.H. Noguera and L.F. Jansa: Geology and diagenetic history of overpressured sandstone reservoirs in the Venture Gas Field offshore Nova Scotia, Canada
MORNING TECHNICAL PROGRAM
8:00 a.m. to 12:00 noon

Western Canada

Chairmen: P. Goetz and A. V. Payne Macleod Hall A
8:00 E. Tawadros: Cambrian facies and paleogeography, subsurface of southern Alberta
8:30 M. Armannious: Depositional environment and stratigraphy of the Middle Devonian Keg River carbonates: Trout area, north central Alberta
9:00 C. Grujenschi: Synclinal truncation traps in southeastern Saskatchewan – Canada (Williston Basin)
10:00 R. Higgs: Sedimentology and petroleum geology of the Artex Member (Charlie Lake Formation), northeast British Columbia
10:30 L. Núñez-Betelu and M.S. Shawa: Diagenesis of the Charlie Lake Formation, northwest Alberta
11:30 H. Sabry: Lithofacies, depositional environments and reservoir quality of the basal Belly River sands in south-central Alberta, Canada

Basin Resources and Evaluation

Chairmen: P.J. Lee and M. Marchand Macleod Hall B
8:30 P.J. Lee: Petroleum resource estimations – an overview
9:00 Z. Chen and R. Sindling-Larsen: The application of successive sampling models for hydrocarbon resource assessment in the North Sea
9:30 J.C. Davis and T. Chang: Regional assessment based on models of field-size distributions
10:00 L.J. Drew and J. Schuenemeyer: Realtime validation of an oil-and-gas resource assessment for the offshore Gulf of Mexico
10:30 W. James: EXXON methods for assessing future field sizes
11:00 G.M. Kaufman: Spatial statistics and exploration drilling
11:30 J.D. Grace: An information theoretic approach to resource assessment

Geological Atlas – Jurassic to Tertiary Foreland Basin

Chairmen: D.G. Smith and G.D. Williams Macleod Hall C
10:00 D.G. Smith and D.A. Leckie: The paleogeographic evolution of the Western Canada Foreland Basin
11:00 D.J. Cant and G.S. Stockmal: Stratigraphy of the Alberta Foreland Basin: relationships to Cordilleran terrane-accretion events

Poster Sessions

Macleod Hall D 
Exhibition Hall

AFTERNOON TECHNICAL PROGRAM
1:30 p.m. to 5:00 p.m.

Peace River Arch Project – Hydrogeology, Basin Modelling and Petroleum Source Rocks

Chairmen: J.S. Bell and S.C. O’Connell Macleod Hall A
1:30 B. Hitchon, S. Bachu and J.R. Underschultz: Overview of the regional subsurface hydrogeology, Peace River Arch area, Alberta and British Columbia
2:00 S. Cao: A quantitative study of the thermal history and hydrocarbon generation in the Peace River Arch area
3:00 G.R. Dix: Postulated source(s) and controls of petroleum accumulation in the Leduc Formation, Peace River Arch
3:30 C.L. Riediger, M.G. Fowler, P.W. Brooks and F. Goodarzi: Lower and Middle Triassic source rocks and thermal maturation in the Peace River Arch area, Alberta and British Columbia

Basin Resources and Evaluation

Chairmen: R. Sindling-Larsen and N.J. McMillan Macleod Hall B
1:30 D.J. Forman, A.L. Hinde and A.P. Radlinski: Importance of the reservoir/cap rock contact in assessment of undiscovered petroleum resources
2:00 J. Burres, B. Doligez, P. Joseph, P. Ungerer and S. Wolf: The use of deterministic basin models in basin evaluation
2:30 K.D. McAlpine and M.G. Fowler: Quantitative assessment of hydrocarbon potential of Jeanne d’Arc Basin source rocks using geological and geochemical data
3:00 Panel Discussions

Geological Atlas – Jurassic to Tertiary Foreland Basin

Chairmen: D.G. Smith and G.D. Williams Macleod Hall C
2:00 J. Bhattacharya: Allostratigraphy and depositional systems in the Cenomanian Dunvegan Formation, northwestern Alberta
3:30 J. Bhattacharya: Applications of sequence stratigraphy in the Alberta Foreland Basin: examples from the Upper Cretaceous
4:00 M.M. Fenton, B.T. Schreiner, E. Nellsen and J.G. Pavlovicz: Quaternary geology of the Western Plains
ABSTRACTS

Chairmen:
9:00 W.G. McCloskey and R.M. Bustin: Organic sedimentology and
8:30 D.A.W. Keith, D.M. Wightman, J.R. MacGillivray,
8:00 D.R. Suchy and C.W. Stearn: Silurian sea level history of the

General Geology
9:30 G.M. Ross: Deep crust and basement structure of the Peace
9:00 S.C. O'Connell, G.R. Dix and J.A. Wilson: Structural controls
10:30 R. Trotter: The sedimentology and depositional setting of the
11:00 H.H.J. Geldsetzer: The influence of the Peace River Arch upon sedimentation in the Peace River Arch region
11:30 J.W. Keith: The Beaverhill Lake Group (Devonian) - Peace River Arch

Tectonics

Exhibition Hall
Registration Desk Opens
Speakers' Breakfast

MORNING TECHNICAL PROGRAM
8:00 a.m. to 12:00 noon

Peace River Arch - Stratigraphy, Sedimentology and Tectonics
Chairmen: S.C. O'Connell and J.S. Bell
9:00 S.C. O'Connell, G.R. Dix and J.A. Wilson: Structural controls upon sedimentation in the Peace River Arch region
9:30 G.M. Ross: Deep crust and basement structure of the Peace River Arch
10:00 H.L. Halbertsma: Extension faulting in the Western Canada Sedimentary Basin and the collapse of the Peace River Arch
10:30 R. Trotter: The sedimentology and depositional setting of the Granite Wash, Utkuma and Red Earth area, north-central Alberta
11:00 H.H.J. Geldsetzer: The influence of the Peace River Arch on Devonian sedimentation
11:30 J.W. Keith: The Beaverhill Lake Group (Devonian) - Peace River Arch

Geological Atlas

Reservoir Geology
Chairmen: J. Dolph and P. Frydl
3:00 E.S. Rosenstein: The Claresholm Gas Field - a significant gas pool in the deep portion of the southern Alberta Basin
1:00 M.G. McMurray: Recognition and correlation of reef interior carbonate cycles: production implications for Norman Wells, Northwest Territories
2:00 T.J. Hurley: The Pegasus Ellenburger Field - a multidisciplinary study of a fractured and karsted Ordovician reservoir in west Texas
2:30 A. Hartling and G. Wasser: A geological model for the Foremost unit, Judith River Formation, at Ferrybank, central Alberta
3:00 J.W. Kramers, S. Bachu, D.L. Cuthiell and L-P Yuan: Quantitative reservoir characterization, a case study (the Provost Upper Mannville B Pool)
3:30 D.A. Steffes and M.Z. Farshori: Integrated reservoir analysis of the Upper Mannville (Glaucionic Sandstone) in the Countess "D" Pool area – evidence of varying Lower Cretaceous paleoenvironments
4:00 F.J. Longstaffe, G.A. Robb and B.N Fialka: Clay mineralogical studies of post-steam core from the near-well bore region in an oil sands reservoir, Alberta
4:30 K. Hirsche, L. Matthew, Z. Wang and G. Sedgwick: The emerging role of seismic data in reservoir development and production

Geological Atlas
General Geology

Chairmen: J.M. Bever and A.J. Hepburn
Macleod Hall C

3:00 D.R. Issler: A new approach to shale compaction and its geological significance

3:30 H.D. Munroe and T.F. Moslow: Reservoir quality and architecture of tidal inlet sandstones, Halfway Formation, northeastern British Columbia

4:00 C. Grujenschi: Devonian Prairie Evaporite salt flowage in southeastern Saskatchewan (Williston Basin)

4:30 V.B. Lyatsky: Computer-assisted regional mapping for petroleum exploration modelling in the Western Canada Sedimentary Province

POSTER SESSIONS
Macleod Hall D (Atlas)
Exhibition Hall (Atlas and General)

There are 35 posters on the Geological Atlas of the Western Canada Sedimentary Basin, 33 of which are accompanied by an oral presentation. The abstracts for these combined poster – oral presentations are listed under the oral abstracts. The two posters for which there are no accompanying oral presentations are as follows:


The following poster presentations will be displayed in the Exhibition Hall under the General category:

J.C. Hickey, S.P. Trimble and S.L. Durfee: Adapting desorption mass spectrometry and pattern recognition techniques to petroleum fluid correlation studies

V.B. Lyatsky: Computer-assisted regional mapping for petroleum exploration modelling in the Western Canada Sedimentary province (accompanying oral presentation)

C.E. Keen, B.C. MacLean and W.A. Kay: Deep seismic reflection profiles across the Nova Scotia continental margin, offshore Eastern Canada

E. Tawadros: The effect of Cambrian paleogeography on the distribution of the overlying Beaverhill Lake carbonate, southern Alberta

H. Raddysh: Evolution of the Sawn Lake Reef Complex, Middle Devonian, Slave Point Formation, northeastern British Columbia

M.B. Enderlin and D.K.T. Hansen: A fundamental approach to dipmeter analysis

G.R. Dix: Geologic importance of fleshy algae in the Iretion Formation, central Alberta

J. Bloch and I. Hutcheon: Meteoric diagenesis of a Cretaceous marine mudstone: evidence from the Harmon Member (Peace River Formation)

J.S. Bell: Perspectives on Mesozoic and Cenozoic basins in the Labrador Sea

K. Wallace-Dudley and D.A. Leckie: Petroleum geology of the Cenomanian Doe Creek Member, northwestern Alberta

S. Cao: A quantitative study of the thermal history and hydrocarbon generation in the Peace River Arch area (accompanying oral presentation)

M.B. Enderlin, D.K.T. Hansen and B.R. Hoyt: The role of rock volumes in log to core integration

R. Higgs: Sedimentological study of the Artex Member, Charlie Lake Formation, northeastern British Columbia (accompanying oral presentation)


B.C. Richards: Tectonic and depositional history of the Early Carboniferous Peace River Embayment, Alberta and British Columbia

I.R. Mayers and D.G. Cook: Reflection seismic interpretation of the Proterozoic geology, Coeville Hills region, N.W.T.

P. Wu, F.F. Krause and R. Spiteri: Implications for the lack of a forebulge within the Alberta Foreland Basin

S.W. Dawson, D.L. Sturrock and N.R. Weyns: The Ring/Border Field: a significant gas discovery in the Triassic Montney Formation

K.B. Deutch and F.F. Krause: A marine to terrestrial sedimentary succession in the Cardium Formation, Kakwa region, west-central Alberta: implications for relative sea level movements

S.D. Joiner and F.F. Krause: Cardium Formation stratigraphy in the Pembina Field and surrounding area

D.R. Paul and T.J. Filthaut: An integrated workstation study of the Winnipegosis Formation in the Tablerand area of southeastern Saskatchewan

ARMANIOUS, M., Westcoast Petroleum Ltd., Calgary T2P 0T8

Depositional environment and stratigraphy of the Middle Devonian Keg River carbonates: Trout area, north central Alberta

The Trout Field (Tp. 89 Rge. 3 W5M) produces oil from the Middle Devonian Elk Point Group Keg River Formation. Regional mapping shows that the Trout is located between the eastern margin of the Keg River ‘Bank Edge’ and the western pinchout against the Peace River Arch. The Keg River isopach shows a wedge of carbonates thickening from the Peace River Arch to the 65m-thick ‘Bank Edge’. The Keg River Reservoir is composed of dolomites that lie conformably between the Chinchaga anhydrite facies and the younger Muskeg evaporite sequence. It occasionally overlies the Precambrian evaporial surface. From Trout to Senex (Tp. 96 Rge. 6 W5M), the Precambrian topography has discontinuous northwest trending evel-etchn ridges, which influenced Keg River deposition. Several stages of tectonism have reajusted the Precambrian topography to a present-day southwest dipping surface upon which relict Precambrian ridges remain.

Flooding over the Chinchaga during Lower Keg River time left an expansive argillaceous carbonate unit overlapping Precambrian islands. Rare stromatoporoids in this unit indicate a deeper water facies not capable of supporting reef-associated organisms. Microkarst topography at the top of this unit suggests bathymetric fluctuation and subaerial exposure. Middle and Upper Keg River carbonates are a succession of shallow water shoals supporting large communities of reef-associated fauna, predominantly tabular and encrusting stromatoporoids, and dendritic Amphipora, with cyclical and large coastal corals. Precambrian tectonic highs provided the substrate for shoaling while regional paleo wind-wave patterns influenced major Keg River lithofacies distribution.

Porosity development was by matrix-selective early dolomitization of original limestone with later dolomitization of stromatoporoids and corals. Porosity development is facies specific with those facies that exhibit abundant biotic diversity having greater vuggy and moldic porosity. Interstratified facies are prevalent in grainefacies and in sandy lithic reefal facies. Fracture porosity occurs predominantly in fine crystalline dolomites with little or no matrix porosity.

BACHU, S., Alberta Geological Survey, Edmonton T6H 5X2

BURWASH, R.A., University of Alberta, Edmonton T6G 2E1

Geothermal regime in the Western Canada Sedimentary Basin

The main feature of the geothermal pattern in the Western Canada Sedimentary Basin is an increase in the value of the integral geothermal gradient (the gradient over the entire sedimentary column) from the Cordillera to the Shield. Radiogenic heat production in the sediments is about one order of magnitude less than the total heat flow. Past hydrogeological studies have shown that the permeability of the rocks and the velocity of formation waters are too low to transport the terrestrial heat from recharge areas in the southwest to discharge areas in the northeast. Also, because the area is relatively undisturbed, there are no large-scale changes in thermal conductivity of the various sediments to account for the regional distribution of the integral geothermal gradient. Therefore, the geothermal field in the Western Canada Sedimentary Basin is interpreted as being controlled on a regional scale by heat flow from the crystalline basement. The increase in basement heat flow, as expressed by the distribution of the integral geothermal gradient, can be explained by a probable combination of crustal thickness and increased radiogenic heat production by crustal rocks. The analysis of core samples from the top of the basement in Alberta indeed shows a north-northeast increase in the radiogenic heat production of Precambrian rocks.

Some “geothermal anomalies” are superimposed over the regional basin-wide trend. These anomalies may be due to granitic intrusions in the basement and/or to variable heat production in the crust. Due to the relatively small and smooth variation in thermal conductivity of the sediments, the temperature distribution at the top of the Precambrian shows a regional trend of increased values as the thickness of the sedimentary cover increases. Only at an intermediate scale is the geothermal field controlled by topography and lithology.

BANERJEE, I., Geological Survey of Canada, Calgary T2L 2A7

Stratigraphic significance of shell beds in the Ostracode Zone in south-central Alberta

Detailed study of shell beds in the Ostracode Zone of the Lower Cretaceous Mannville Group in south-central Alberta has been made in
three wells in the Alberta Plains and four outcrop sections in the Foothills. Most of these shell beds occur within black shales except a few, which are included within lime mudstones. The thickness of these shell beds ranges in the centimetre to decimetre scale. These shell beds comprise disarticulated and broken pelecypods, and mostly entire gastropods, as well as sinteric mud, are common constituents.

Four types can be recognized in these shell accumulations:
1. Shell concentrations above submarine hardground (minor hiatal accumulation).
2. Shell concentration below submarine hardground (major hiatal accumulation).
3. Scour-based, graded, and laminated shell bed (event bed).
4. Complex bioturbated shell accumulation (major hiatal accumulation?).

Sequence stratigraphic analysis of the Mannville Group suggests the existence of a maximum flooding surface within the Ostracode Zone, which has yielded an open marine, dinoflagellate assemblage. Stratigraphic analysis of the shell beds shows that Type 2 or Type 4 shell beds will provide the required documentation of such a flooding surface. Vertical variations of total organic carbon content, carbon/sulphur ratio and dinoflagellate diversity in the screen sections studied, provide additional data for stratigraphic analysis.

BANERJEE, I., Geological Survey of Canada, Calgary T2L 2A7
The Basal Colorado Sandstone and other tidal sandsheets formed during the Joli Fou Transgression

A detailed subsurface sedimentological study of the Basal Colorado Sandstone (BCS) in the Cessford Field in southern Alberta has revealed various features of tidal deposition, such as mud cuestas, tidal bundles, heterolithic bedding, flaser bedding, mud-draped foresets, etc. A facies model constructed from this study illustrates a northwestern-trending transgressive tidal sand sheet lying unconformably over the northwestern shelf lagoonal sediments of the Mannville Group. The sheet was deposited by a southeast flowing tidal current and was buried by the open marine black shales of the Joli Fou Formation.

Vertical sampling through the Mannville-BCS-Joli Fou interval reveals a trend of variation in diversity indices of foraminifers and dinoflagellates and glauconite content across the transgressive surface. This trend documents the relative rate of sea level rise.

Regional stratigraphic equivalents of the BCS were studied in the outcrop belts of the southern Foothills (Sunkay Member, Blackstone Formation and Mill Creek Formation, Blairmore Group) and in the Great Falls area of Montana (Lower Flood Member, Blackleaf Formation). All three rock units exhibit tidal structures similar to those found in the BCS and form an assemblage, as documented by their dinoflagellate assemblages. From these data, reconstruction of regional palaeogeography has been made and compared to a modern analogue in the Celtic Sea of Great Britain.

BELL, J.S., Geological Survey of Canada, Calgary T2L 2A7
Perspectives on Mesozoic and Cenozoic basins in the Labrador Sea (Poster)

Current information on the geology, geophysics, geochemistry and biostratigraphy of the Labrador Sea and Shelf has recently been compiled in an atlas format that illustrates basin evolution. In Early Cretaceous time a complex of coast-parallel rift grabens developed along the Labrador Shelf. They were filled with continental clastics, coals and some marine shales. These sediments were then covered with a blanket of marine shales in Late Cretaceous time. Subsequent Cenozoic shelf deposition consisted of a series of seaward-prograding clastic wedges that contained sandstones along their western margins. The best gas-bearing reservoirs are the Lower Cretaceous rift graben sandstones and underlying Paleozoic carbonates topping horst blocks. Geochemical evidence suggests that the main source rocks were Lower Cretaceous coals, and that the traps were filled in late Cretaceous time.

The Labrador Shelf is an excellent example of a simple passively subsiding rift margin. The poster portrays its evolution through seafloor spreading, highlights the seismic expression of its structure, illustrates the deposition of reservoir sandstones and shows the present configuration of organic maturity in Mesozoic sediments. The atlas from which this material is derived also contains extensive information on Quaternary geology, deep water sediments on the floor of the Labrador Sea, biostratigraphy, paleogeography and geophysics.

BELL, J.S. and McCALLUM, R.E., Geological Survey of Canada, Calgary T2L 2A7
In-situ stress in the Peace River Arch area

Breakout orientations measured in 35 wells in northern Alberta and British Columbia show that the principal horizontal stresses are deflected over the Peace River Arch. Instead of the regional northeast-southwest axis for SHmax, the larger horizontal principal stress is directed north-northeast – south-southwest.

Two-dimensional finite element modelling of this stress refraction shows that the cause could be lateral variations in the elastic properties of the rock. On the other hand, faults that are acting as free surfaces could also be locally deflecting the stresses. However, the consistency of the data, which comes mainly from Paleozoic sections, points to a regional cause.

Micro-fract and mini-fract records from some 30 wells on and around the Peace River Arch give indications of the magnitudes of SHmin, the smaller horizontal principal stress. The magnitudes appear to be laterally variable, with a tendency to be larger toward the Rocky Mountains, but there is insufficient information to recognize trends.

BELL, J.S., PRICE, P.R., Geological Survey of Canada, Calgary T2L 2A7
In-situ stress in the Western Canada Sedimentary Basin

This poster shows our current understanding of the in-situ stress regime of the Western Canada Sedimentary Basin. Earth stresses are vector quantities characterized by direction and magnitude. Generally it may be assumed that the principal stress is vertical. Horizontal stress directions are indicated by borehole breakouts, hydraulic fracture orientations, over-coring measurements, special core analyses, and various geological indicators. Of these data, the most abundant in the basin are breakouts. Mean breakout azimuths from 175 wells have permitted the contemporary stress trajectories to be mapped for Paleozoic and Mesozoic rocks for the entire sedimentary section. An overall northeast – southwest direction is indicated for the larger horizontal principal stress with local variations around the Peace River and Sweetgrass arches.

Reliable stress magnitudes are more difficult to obtain. Vertical stress magnitudes may be equated with the weight of the overburden, thus their gradients are a function of rock density. Horizontal stress magnitudes appear to be sensitive to rock type and pore pressure. They generally increase with depth, although this increase is not necessarily linear at the formation scale. Quite often there is considerable variability in the measured stress magnitudes even over a short vertical interval. The most reliable horizontal stress magnitude measurements made in the basin are the smaller or minimum horizontal stress values obtained from microfracture tests (injected volumes typically less than 1 m³). Unfortunately, there are relatively few such records available since the practice of measuring in situ stress profiles in the petroleum industry is relatively new. There are, however, an abundance of less reliable mini-fracture data, which are pre-fracture stimulation tests pumped with viscous fluids at high rates and volumes usually in excess of 10 m³. Stress magnitude data from overcoring and strain relaxation techniques account for a small percentage of the available dataset. At the present time, it is difficult to discern how the horizontal stress magnitudes vary spatially across the basin.

BHATTACHARYA, J., Alberta Geological Survey, Edmonton T6H 5X2
Allostratigraphy and depositional systems in the Cenomanian Dunvegan Formation, northwestern Alberta

The Dunvegan Formation represents a sandy clastic wedge deposited from northwest to southeast in the actively subsiding west Alberta Foreland Basin during the waning stages of the Columbian Orogeny (mid-Cenomanian). The Dunvegan is subdivided into seven allmembers, A through G, each separated by regionally widespread transgressive surfaces. Each allmember represents a progradational event and contains several overlapping shingled units.

The facies relationships and sand body geometry of individual shingles within the southeastern portion of the Dunvegan indicate that they represent various types of shallow marine depositional systems. These range
from highly river-dominated deltas in the lower allmembers (G, F, and E) to storm- and wave-dominated prograding deltas, barriers, and transgressive sheet sands in the upper allmembers (D, C, and B). The northwestern (landward) portion of the Dunvegan is characterized by up to 300m of thick, nonmarine facies, which grade into coarse alluvial fans in outcrops to the far north.

Progradation of the Dunvegan clastic wedge was probably related to erosion of newly uplifted portions of the western Cordillera and may also have been influenced by a global drop in sea level during the mid-Cenomanian. The seven transgressions that punctuate progradation of the allmembers were probably related to episodic thrusting events, which induced times of more rapid subsidence. Autocyclic processes (river avulsion and delta switching) may control the position of channels and deltas in the individual shingled units within allmembers.

BHAVACHARYA, J., Alberta Geological Survey, Edmonton T6H 5X2

Applications of sequence stratigraphy in the Alberta Foreland Basin: examples from the Upper Cretaceous

The basic approach used to interpret sedimentary sequences in the context of sequence stratigraphy is the recognition of changes in coastal onlap patterns. On passive continental margins, this approach is the most useful since the basin margin which sediments onlap (i.e. the landward margin) is frequently preserved and available for study. In a foreland basin, coastal onlap patterns are often not preserved.

The portion of a foreland basin most easily studied is the distal end, which often comprises marine lithofacies. The analytical approach most easily applied in clastic wedges is the determination of the position of relative basinal downlap based on the distal progradational limits of sandstone into the basin (i.e. seaward) and the parasquence stacking patterns. Regional unconformities and systems tract boundaries may be recognized by the truncation of log markers, by changes in parasquence stacking patterns, and by paleontological data. Using an example from the Upper Cretaceous Dunvegan Formation, this data is used to construct Wheeler diagrams from which the basin history is inferred.

BLOCH, J. F. and HUTCHIEON, J. The University of Calgary T2N 1N4

Metamorphic diagenesis of a Cretaceous marine mudstone: evidence from the Harmon Member (Peace River Formation) (Poster)

The Albian Harmon Member is a marine mudstone that was deposited in a restricted basin beneath anoxic to dysoxic conditions. Petrographic observations by back-scattered electron scanning electron microscope (BSE-SEM), in conjunction with stable isotopic data, indicate the following paragenetic sequence of diagenetic minerals: pyrite, kaolinite, siderite concretions and calcite cement, dolomite, disseminated siderite, kaolinite cement, illite, and quartz.

Pyrite, siderite concretions, and early calcite cement formed under conditions of low water-rock ratios. The δ18O values of the early authigenic carbonates indicate mineral formation from mixed meteoric-marine fluids. The isotopic composition of later, but still early disseminated dolomite and siderite indicates formation from fluids of dominantly meteoric origin. This suggests that compacting Harmon sediments were recharged by meteorically-derived fluids during early compaction.

Kaolinite cement occludes up to 30 per cent pore space in silt laminae that, in conjunction with porosity-loss data, indicates cementation at less than 400 m burial depth. The precipitation of kaolinite and the isotopic composition of later, but still early disseminated dolomite were probably related to episodic thrusting events, which induced times of more rapid subsidence. Autocyclic processes (river avulsion and delta switching) may control the position of channels and deltas in the individual shingled units within allmembers.

Link, A., Geological Survey of Canada, Calgary T2L 2A7

The principle advantage of using these models is 1) the possibility of introducing sensitivity analysis; and 2) to address petroleum occurrence through dynamic processes.

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Local and global controls on the occurrence of reservoir facies.

The Belloy Formation (Wolfcampian-Guadalupian) in the Eagle, West Eagle, and Stoddiar areas of northeast British Columbia, produces oil and gas from dolomitic sandstone and coquina reservoirs in tidally influenced west-prograding shoreline sequences. Collapse of the Peace River Arch produced a hinge-zone separating these deposits from thicker, deeper water, fine grained, mixed carbonate-siliciclastic rocks to the southwest (Belloy Formation and Ithiel Group).

In south-central Idaho, the Wood River Basin (Desmoinesian-Wolfcampian Sun Valley assemblage) provides an excellent model of a tectonically controlled, epicratonic, mixed carbonate-siliciclastic sedimentary basin that formed during late stages of the ancestral Rockies orogeny. Here, carbonate "apron-type" facies are recognized in rocks composed of sub-equval amounts of carbonate and siliciclastic sediment. The Wood River Formation (2000 m) records the evolution of the basin from inner apron facies, where siliciclastic conglomerates intertongue with marginal marine biostromes, through outer apron, fine grained, mixed carbonate-siliciclastic turbidites. The Wood River Basin received carbonate sediment from the east (coeval Snaky Canyon Formation), which mixed in an inner apron environment with sand and silt from another (northern?) source.

Deep-water mixed carbonate-siliciclastic rocks are overlooked by most explorationists because they are usually tight. The Belloy and Wood River formations demonstrate, however, that a genetic relationship between outer and inner shelf/apron deposits can be used to predict the occurrence of reservoir facies.

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Precambrian basement beneath the Western Canada Sedimentary Basin

The buried Shield consists of five divisions: Northern Interior Plains, Athabasca Polymetamorphic Terrain, Creek Lake-Calgary Zone, Trans-Hudson Orogen, and Superior Province. These are separated by four regional shear zones: Great Slave Lake, Virgin River, Needle Falls and Churchill-Superior Boundary Zone.

Northern Interior Plains has north-trending belts related to the 1.9 Ga Wopmay Orogen. This Aphebian basement is overlain to the west by
Middle and Upper Proterozoic clastic sediments and diabase sills, Athabasca Polymetamorphic Terrain contains Archean remnants and Middle and Upper Proterozoic clastic sediments and diabase sills. The Cree Lake-Calgary Zone resembles the Cree Lake Zone of northern Saskatchewan. A variety of dating methods give values from 1.8 to 2.5 Ga.

The metasomatic and metasedimentary assemblages of the Trans-Hudson Orogen may be analogous to modern island arcs although recognition of this units in basement oil-well cores remains speculative due to the limited sampling; more is known from the approximately 1500 diamond drill cores available. Archean isotopic ages are diagnostic of the Superior Province. Its western boundary is marked by shear low-grade rocks with a negative aeromagnetic signature.

Two Phanerozoic cratonic arcs in the Western Canada Sedimentary Basin have trends that parallel basement divisions. The axis of the Peace River Arch in northern Alberta corresponds to high K-U-Th rocks in the Athabasca Polymetamorphic Terrain. The North Battleford-Sweetgrass Arch parallels and lies within the western foreland of the Trans-Hudson Orogen.

The Steen River astroblime is an example of a small-scale Phanerozoic basement structure. It is complex, consisting of a central uplift, a rim syncline and at least one raised rim. It is 25 km in diameter and exhibits 1700 m of relief.

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Depositional and diagenetic evolution of a Holocene bank interior ooid-grapestone shoal complex, Turks and Caicos Islands, B.W.I.

Caicos Bank is a shallow water, sub-circular carbonate platform about 100 km across. The northern shore is fringed with islands that shelter interior tidal flats. Seaward of the tidal flats, within the bank interior, is an ooid-grapestone shoal complex 20 km long and 10 km wide. Individual shoals are 300 to 2000 m wide, up to 4 m thick, and are separated by straight tidal channels up to 800 m wide and 2.5 m deep. Both shoals and tidal channels are asymmetrical in cross-section. Parts of the shoals are emergent and form small, low relief islands.

Twenty-five vibracores recovered from the shoals and adjacent sediments show a general coarsening-upward sequence characterized by increasing grain size and grapestone content, and decreasing proportions of ooids, pellets and mud. The sequence is interpreted as a shallowing-upward cycle that began as a series of ooid shoals flanked by pelleted packstone and evolved into the present grapestone shoal complex. Sedimentation was initiated during Holocene flooding of a gently south sloping ramp. Sediment accumulation rates exceeded sea level rise so that the shoals lengthened and emerged with time.

Shoal growth is promoted by: 1) lateral accretion of longshore derived beach sets; 2) elongation at down drift shoal terminations; 3) storm and hurricane generated surges; 4) tidal channel abandonment and shoal coalescence.

Synsedimentary diagenesis plays an important role in shoal stabilization. Sediments exposed on emergent islands have been cemented by equant meniscate calcite of vadose origin. Irregular, biologically stabilized, cemented patches up to 1 m across and 15 cm thick occur on the surface and within submerged shoals. Cements are micritic, peloidal and isopachous fibrous aragonite formed in submarine phreatic environments.

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Stratigraphy of the Alberta Foreland Basin: relationships to Cordilleran terrane-accretion events

Accretion of an allochthonous terrane onto a pre-existing continental margin results in flexural loading of the lithosphere and development of a foredeep on the edge of the craton. An unconformity-bound shallow-upward sequence like the classic Alpine Bysch to molasse is generated within the foredeep. The shallowing is a result of low sediment supply rates from the initially submarine oogenetic belt, followed by higher rates of sediment supply as thrusting uplifts material above sea level. The lower unconformity is a result of uplift caused by passage of the peripheral bulge across the pre-existing platform sequence. The upper unconformity results from "rebound" of the basin as the accretion phase wanes, and the tectonic load is eroded.

The Cordilleran is composed of a number of terranes accreted in succession, which resulted in repeated influxes of coarse clastics into the foreland. Later accretionary events are not associated with deep-water facies because the subsequent accretions translated already accreted terranes and telescoped miogeoclinal rocks farther onto the continental margin, initiating sedimentation nearly coincident in time with subsidence.

The evolution of the Alberta Foreland Basin can therefore be interpreted in terms of the history of terrane accretion events in the Canadian Cordillera. Six major clastic wedges (Fernie-Kootenay, Mannville, Durvegan, Belly River, Edmonton, and Paskapoo) correlate roughly in time to the accretion of the six principal terranes mapped in the Cordillera (Intermontane, Bridge River, Cascadia, Insular, Pacific Rim – Chugash, Olympic). Unconformities representing long time intervals are interpreted as resulting principally from basin "rebound", but shorter intervals may have been the result of the peripheral bulge retreat or eustatic fluctuations.

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Habitat of natural gas in the Comox and Trent River formations, Georgia Basin, Vancouver Island

An indigenous energy supply for Vancouver Island has been the object of intensive exploration for the past 130 years. More than 1,000 wells have tested the Upper Cretaceous Nanaimo Group of eastern Vancouver Island, resulting in the discovery of numerous shows of natural gas. Most of the gas shows are concentrated in the Comox and Trent River formations, in the central portion of the Comox sub-basin, south of the city of Courtenay.

Natural gas in the Comox sub-basin has been historically regarded as an unwanted by-product of coal mines, and as a severe hazard to exploratory drilling.

Despite a history of blowouts, explosions and fires, production of gas commenced in the 1940's, when farmers near the village of Royston constructed crude wellheads and used gas for light and heat.

In addition to the gas-charged coals of the Comox Formation, several conventional clastic reservoirs contain natural gas in the Comox sub-basin. Trent River Formation reservoirs include fractured marine shales of the Royston Member and submarine-channel conglomerates of the Table Member. Comox Formation reservoirs include shoreface sandstones of the Dunsmuir Member, point-bar sandstones of the Cumberland Member and aluvial-fan conglomerates the Benson Member.

Structural traps probably account for most of the gas shows near Royston village, where long, narrow anticlines overlie northeast dipping listric normal faults. These faults probably flatten within the Comox Formation, thus confining fold closure to the overlying Trent River Formation. Near the outcrop of the reservoirs, groundwater recharge provides a barrier to updip gas migration.

In the course of this study, we have developed a detailed lithostratigraphic framework for the Comox and Trent River formations, which will assist further exploration for energy resources in the Comox sub-basin.

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The application of successive sampling models for hydrocarbon resource assessment in the North Sea

The objective of this paper is to compare three successive sampling models using nine simulated data sets and a Norwegian petroleum play. The three models are: the Geological Survey of Canada's lognormal discovery process model, Kaufman's anchored discovery process model, and a Norwegian discovery process model. Nine sub-samples were taken from a population with field size mean and variance known. The three
values of the “discoverability” parameter β were selected to be 0.25, 0.50, and 0.75; and three percentages (25%, 50% and 75%) of discovered fields were used in the sampling process. For example, a sub-sample was taken by applying the β value of 0.25 and up to 25% of the number of fields in the population. Similarly, a second sub-sample was taken by applying the β value 0.5 up to 25 per cent of the number of fields in the population. This process was repeated seven more times. The three discovery process models were tested using these nine data sets.

The applicability of these three discovery process models and the statistical assumptions required were tested by the discoveries in a Jurassic play in the Norwegian part of the North Sea.

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Silurian reefs of the Attawapiskat Formation, James Bay, northern Ontario

The Attawapiskat Formation outcrops along a 50 km stretch of the Attawapiskat River in northern Ontario. The rocks consist of a series of patch reefs and their associated sediments. The age of the reefs is late Llanian, with possible early Ludlovian, as determined by the Attawapiskat fauna. This fauna is similar to that found in the Guelph Formation of southern Ontario. The distribution and size of the patch reefs are similar to those in the modern Capricorn Reef complex, Australia. The Attawapiskat Formation in the study area is completely limestone. Five mappable facies are identified. The Framestone facies constitutes the main framework of the reefs, consisting of tabular stromatoporoids and corals bound together by alge and Bryozoa. The centre of the larger patch reefs may be occupied by a sparsely fossiliferous zone that represents a Lagoonal facies. The reefs are capped by a fossiliferous Crinoidal facies, which grades laterally to the Off-Reef facies. In some patch reefs, bedded units of the Off-Reef facies drape over or are truncated against the reefs. The Attawapiskat Formation is the most important reservoir rock in the Hudson Bay Platform, but the distribution of the Attawapiskat is poorly understood. Geochemical evaluation indicates a low maturity level throughout the Hudson Bay Platform.

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A quantitative study of the thermal history and hydrocarbon generation in the Peace River Arch area

The Peace River Arch area in northwestern Alberta and northeastern British Columbia is one of the most active petroleum exploration areas in the Western Canada Sedimentary Basin. Hydrocarbons have been found in units ranging from Devonian to Cretaceous. A computer-based Quantitative Basin Analysis System (QBAS) has been developed and applied to the study area to provide a quantitative description of basin evolution and the potential for hydrocarbon generation, migration and accumulation. Data from about 27,000 wells have been processed and analyzed to give present-day stratigraphy, lithology, and hydrogeological and geothermal regimes. Regional burial history and thermal history have been reconstructed through modelling of sediment compaction and fluid flow to investigate basement subsidence, sediment deposition and thermal maturation of sediments. Hydrocarbon generation has been simulated through kinetic modelling of kerogen degradation to estimate the hydrocarbon potential and timing of hydrocarbon generation and migration. Hubbert's method has been used for the evaluation of hydrodynamic entrainment of hydrocarbons.

The results obtained, so far, show that: 1) paleoheat flow in most of the region is lower than present-day heat flow; 2) paleoheat flow on the Arch was higher than off the Arch, supporting the proposed Paleozoic rifting origin of the arch; 3) most of the source rocks entered the “oil window” during Late Cretaceous time; and 4) maturation of the source rocks has been influenced by the regional subsidence, uplift and subsequent erosion associated with the Cretaceous-Tertiary unconformity, during which time source rocks reached their deepest burial depth and highest temperature.

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Hydrocarbon generation and migration in the Western Canada Sedimentary Basin

Multiple marine, oil-prone source rocks (at least ten) ranging in age from Middle Devonian to Late Cretaceous exist within the Western Canada Sedimentary Basin. Principle hydrocarbon reserves occur in the Lower Cretaceous Mannville Group and subcropping Paleozoic carbonates. The largest light oil field is the Canadian (270 x 10^14 m^3) and the largest heavy oil field one of the largest deposits of oil on Earth. Biomarker analysis of these heavy oils, many conventional oils, and most source rocks in the basin, have been analyzed to give present-day stratigraphy, lithology, and hydrogeological characteristics, where 270 x 10^14 m^3 (1.7 trillion barrels) of heavy oil form one of the largest deposits of oil on Earth. Biomarker analysis of these heavy oils, many conventional oils, and most source rocks in the basin, have been combined with basic geology to establish the source and migration history of the Western Canada Sedimentary Basin.

Below the Joli Fou, several families of oils can be differentiated. Most of these are restricted geographically and/or stratigraphically, and can be easily correlated to specific source rocks. One group of conventional oils is more widespread and found in Lower Cretaceous Mannville and older, subcropping reservoirs. This group is related to the heavy oils, also found in subcropping Paleozoic and Mannville reservoirs. No single source has been unequivocally assigned to these hydrocarbons, and mixed sourcing is a possibility. Meteoric water incursion at the eastern limb of the basin permitted biodegradation, which converted the conventional Mannville crude oil to heavy oil (API gravities <25°). The Joli Fou shale and equivalents overlying the Mannville provide a regional seal for the Mannville and older strata. Oils present in the Viking, Cardium and Belly River sands are all from the one family, are sourced from the Colorado shale section, and are quite distinct from the oils in the Mannville and older section.

The Western Canada Sedimentary Basin also contains an estimated 5 x 10^15 m^3 (180 TCF) of gas. Gas sources are marine, oil-prone source rocks over which gas is overmature, as well as Lower Cretaceous Mannville coals and Paleozoic carbonates. None of the other source rocks are characterized by an unknown size distribution. Discoveries are samples from this distribution, and form a posterior distribution of field sizes. The remaining potential of a basin is the difference between these prior and posterior distributions. Field sizes in mature basins tend to follow a lognormal distribution, as first noted by Arps in 1958. Most explorationists have since assumed that the prior distribution of pool sizes was lognormal. However, the posterior distribution results from sampling without replacement when probability of discovery is proportional to size, with rejection of small, subeconomic discoveries. Almost any prior distribution will yield a skewed, approximately lognormal distribution under these conditions.

Discovery process models suggest the prior distribution is J-shaped (Pareto or exponential), implying the existence of large numbers of small pools even after exploration has reached a mature stage. If the prior distribution is lognormal, the potential number of small pools is much lower. In mature basins, the right tails of the prior posterior distributions are almost identical because larger fields have been found. The prior distribution can be modelled by fitting a general family of distributions to the right-hand side of the field-size distribution, and estimating the small size classes. Models of field-size distributions in Central Kansas and the Denver-Julesburg Basin are either inconclusive or favour the lognormal alternative as a prior distribution. This unfortunately implies that forecasts of large numbers of undiscovered small oil pools in mature basins may be unrealistic.

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Uppermost Cretaceous-Tertiary strata of the Western Canada Sedimentary Basin

The stratigraphic interval of Upper Cretaceous to Tertiary sediments extends from the Foothills of Alberta eastward to the southwestern corner of Manitoba, and from the 49th parallel northward to the erosional edge in northern Alberta and northeastern British Columbia. The wedge-shaped geometry is the most striking feature of this predominantly clastic succession, ranging from less than 400 m in the east to greater than 900 m in the west. Sediment supply into the basin was primarily derived from the episodic uplift and subsequent erosion of rocks associated with the
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The clastic wedge can be subdivided into three progradational pulses of marine (Pakowki and Bearpaw formations), or lacustrine origin (Battle Triassic, and during the last stages of erosion, valleys were incised. In tidally-influenced shoreface sands, silts, and shales. The reservoir sands through the integration of geology, petrophysics, and hydrodynamics. The exploration and development program has resulted in the drilling of 90 wells with possible reserves up to 1 TCF (28.3 x 10^9 m^3), and initial delivery of greater than 100 MMcf/d (28.3 x 10^5 m^3). The Ring/Border Field is a complex stratigraphic-subcrop trap that has been delineated through the integration of geology, petrophysics, and hydrodynamics.

The Triassic Moncy Formation, the main reservoir, is a sequence of tidally-influenced shoreface sands, silts, and shales. The reservoir sands are mature, very fine grained sublitharenites with excellent secondary porosity. The Triassic dips to the southwest, and is cut by numerous north-south trending faults parallel to the Hay River Fault System. The pre-Cretaceous unconformity erosionally truncates the Triassic, and during the last stages of erosion, valleys were incised. In Gething time, these valleys were filled with flood-plain coaly sands, silts, and shales. Sands within the valleys are of reservoir quality, but are thin and discontinuous. The Bluesky Formation is a transgressive lag deposit that blankets the area. It is up to 4 m thick, and varies from a medium grained, glauconite-rich litharenite to conglomerate. Although the Bluesky Formation is laterally continuous, good reservoir within the Bluesky is sporadic.

Early recognition of this subcrop trap was due to creative integration of modern seismic-sedimentological studies, high-resolution logging techniques, and innovative depositional interpretation. The size and trap potential of the Ring/Border Gas Field demonstrates that giant conventional fields may still be found within the Western Canada Sedimentary Basin.

The Upper Cretaceous (Turonian–Coniacian) Cardium Formation within the Kasko region of west-central Alberta contains strata deposited in marine, marginal marine and terrestrial environments. These environments are represented in the Main sandstone (Ram Barrier) and the overlying C-unit (Ram Back Barrier) as an upward progression displaying the following nine facies: 1) bioturbated mudstones; 2) sharp-based centimeter to decimeter-scale, finning upward rhythms with gutter casts; 3) low-angle, inclined cross-stratified sandstones; 4) trough cross-stratified, planar bedded and massive sandstones; 5) rooted sandstones; 6) massive, black, carbonaceous mudstones with oyster beds; 7) sharp-based, massive to ripple cross-stratified sandstones; 8) incipient palaeosols; and 9) millimeter to centimeter, wavy to lenticular, interlaminated mudstones and sandstones. This sequence of facies is interpreted as representing a series of mixed-sediment (sand-mud) sequences, with the overall upward trend indicating sea-level rise.

In detail, the observed facies association may be fit into a barrier island and back barrier/lagoon depositional system. Significant here is that over time, this depositional system may have been exposed to controls on accommodation that operated under two different states: 1) sea level low-stand, where barrier morphology is modified by autogenic processes dominated by progradation, inlet migration and or mining and excavation during storms; and 2) rapidly falling sea level, where barrier morphology is modified predominantly by excavation and deposition as sea level retreats.

The Queen Charlotte Basin is a 50,000 km^2 upper Paleogene-Neogene basin underlying the Queen Charlotte Islands, Hecate Strait and Queen Charlotte Sound region of the British Columbia continental margin. The basin formed as a result of Eocene to Pliocene extension along and adjacent to a transform segment of the Pacific–North America plate boundary. Oblique subduction along the plate boundary since Pliocene time has resulted in uplift and (transpressive?) folding of portions of the northern half of the basin. Well-log correlations, outcrop studies, and new offshore seismic profiles indicate that the basin is a composite of half-grabens and sub-basins separated and underlain by complexly structured pre-Tertiary rocks. Most of the offshore sub-basins contain siliciclastic sediments in excess of 3,000 m thick, and strata as thick as 6,000 m occur locally. The older (pre-Pliocene) part of the basin-fill locally contains volcanics, commonly interbedded with clastics. Potential hydrocarbon reservoirs within the basin include alluvial fan, fan-delta and tidal-shelf sandstones. Potential hydrocarbon source rocks include Upper Triassic-Lower Jurassic shales and limestones locally preserved below the basin, and Tertiary shales within the deeper portions of the basin-fill. Possible hydrocarbon traps include compressive folds, rollover anticlines, basement fault blocks, and a variety of combined structural-stratigraphic traps. The Queen Charlotte Basin is considered to be one of the most prospective areas for hydrocarbon resources along the northeast Pacific margin.

The Queen Charlotte Islands, Hecate Strait and Queen Charlotte Sound region of the British Columbia continental margin. The Queen Charlotte Basin is a 50,000 km^2 upper Paleogene-Neogene basin underlying the Queen Charlotte Islands, Hecate Strait and Queen Charlotte Sound region of the British Columbia continental margin. The basin formed as a result of Eocene to Pliocene extension along and adjacent to a transform segment of the Pacific–North America plate boundary. Oblique subduction along the plate boundary since Pliocene time has resulted in uplift and (transpressive?) folding of portions of the northern half of the basin. Well-log correlations, outcrop studies, and new offshore seismic profiles indicate that the basin is a composite of half-grabens and sub-basins separated and underlain by complexly structured pre-Tertiary rocks. Most of the offshore sub-basins contain siliciclastic sediments in excess of 3,000 m thick, and strata as thick as 6,000 m occur locally. The older (pre-Pliocene) part of the basin-fill locally contains volcanics, commonly interbedded with clastics. Potential hydrocarbon reservoirs within the basin include alluvial fan, fan-delta and tidal-shelf sandstones. Potential hydrocarbon source rocks include Upper Triassic-Lower Jurassic shales and limestones locally preserved below the basin, and Tertiary shales within the deeper portions of the basin-fill. Possible hydrocarbon traps include compressive folds, rollover anticlines, basement fault blocks, and a variety of combined structural-stratigraphic traps. The Queen Charlotte Basin is considered to be one of the most prospective areas for hydrocarbon resources along the northeast Pacific margin.

The Upper Devonian insular fringing reef complex, Peace River Arch

The Leduc Formation (Frasnian in age) forms a northeast-convex, "horseshoe"-shaped dolomite trend comprising mid-shelf through slope facies around what was a large, northeast-trending continental island, the Peace River Arch. Together with inner-shelf siliciclastics (arkose, feldspar, biotite), the Leduc represents an insular fringing reef complex. Geometry and thickness of the Leduc Formation has been controlled by pre-depositional topography, encroachment of siliciclastics, local tectonic, oceanographic events, and relative changes in sea level. The Leduc comprises three depositional sequences, the youngest (Seq1) being the
best constrained in terms of facies and geometry. The sequence succession backsteps onto the PRA, with little change in position of the Leduc seaward margin. SeqII represents a low-relief shelf or ramp, ten's of metres in thickness, facies-equivalent of basinal shales and shoreward siliciclastics. Most of the Leduc carbonate (up to 200 m) accumulated during SeqII time: where cored, the sequence contains shallow-water platform carbonates. The southeast margin of SeqII appears erosional or nondepositional, with relief of ten's of metres, against which was deposited the southwest margin of Leduc strata. The SeqII boundary along part of the northern margin (T87, west of 3W6M) is marked by siliciclastics (locally with vadose cement) and indicates across-shelf transport coincident with a short-term sea level lowstand. Influence of siliciclastics throughout the demise of the reef complex. Leduc is overlain by shales and basinal limestones; the upper two sequences suggest a deepening-upward succession leading to the demise of the reef complex.

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Geological importance of fleshy algae in the Ireton Formation, central Alberta (Poster)

Five types of noncalcareous (fleshy) algae - probable red, brown, and green macrophytes - comprise abundant fragments along two bedding planes in a core taken from basinal argillaceous limestones (Ireton Formation) that abruptly overlie a stepped-back margin along the northwest side of Sturgeon Lake (Leduc) platform. These fossils are flattened and brown; organic detritus of similar colour, and possibly similar origin, is common in the Ireton core and in green shale of the Leduc strata near the Peace River Arch. Fossil algae have been found throughout core at twelve well sites in central Alberta, including east of the Rimley-Meadowbrook reef trend where algae also occur in Duvermay strata. Algal fragments indicate substantial off-bank or downslope transport. If some fragments are in situ, then Frasnian slopes were within the photic zone. Fleshy algae appear to have formed an integral part of the biomass and leading to the formation of intra-platform marine hardgrounds. Geographic and temporal differences in macrophytic abundance in basin sediments calls for caution in interpretation of petroleum source and migration using biomarkers, because stearane (C27;29) proportions derived from macrophytes versus planktonic organic matter can differ.


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Realtime validation of an oil- and gas-resource assessment for the offshore Gulf of Mexico

The accuracy of a forecast made in 1980 of the number and the sizes of oil and gas fields expected to be discovered in the Miocene-Pliocene trend and the Pleistocene trends in the offshore Gulf of Mexico was determined by comparing the predicted and the actual results from the drilling of 1,832 wildcat wells in the Miocene-Pliocene trend and 682 wildcat wells in the Pleistocene trend between 1977 and 1985. This forecast used a two-stage procedure that was based on a discovery process model and the concept of economic truncation. An estimate of the number of larger fields remaining to be discovered in each field size class (the untruncated portion of the field size distribution) was made by using a modified version of the Arps and Roberts discovery process model. The number of fields remaining to be discovered in the truncated portion of the distribution to the left of the mode, including fields containing as few as (116x10^3 m^3) of oil equivalent (165x10^6 m^3 of oil equivalent based on 1988 reserve estimates) was made through seismic growth factors were not applied to estimate the contribution to field growth through the extensions and revisions processes. During the 1980-88 period, the reserves in the 293 fields upon which the 1980 forecast for the Miocene-Pliocene trend was based increased by 8.7 trillion cubic feet (529.7x10^9 m^3) of natural gas and 1.57 billion barrels (249.6x10^6 m^3) of crude oil and condensate as a result of extensions and revisions. The parallel growth in the Pleistocene trend added 7.2 trillion cubic feet (204.3x10^9 m^3) of natural gas and 698 billion barrels (110x10^9 m^3) of crude oil and condensate. The growth in reserves of the oil and gas fields discovered before future discovery rates can be forecast.

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Jeanne d'Arc and southeastern Beaufort (Kugmallit Trough) basins: A tectonic and structural comparison

The Jeanne d'Arc Basin off Newfoundland and the Kugmallit Trough in the southeastern Beaufort-Mackenzie Basin are two Canadian offshore basins where important hydrocarbon discoveries have been made. Thick successions of evaporite, carbonate and clastic rocks in the Jeanne d'Arc, and an exclusively clastic sequence in the Beaufort Sea, have been encountered in the wells drilled to date. The better known Jeanne d'Arc Basin was formed by extension along a deep crustal detachment during two successive Mesozoic rifting phases. The existence of this down-to-the-east 'Wemicke' detachment zone was first suggested by exploration data and later confirmed by deep seismic reflection profiles. A similar tectonic evolution is proposed for the Kugmallit Trough, an elongated northeast-southwest trough filled with Upper Cretaceous to Recent sediments. For this region, extension took place on a down-to-the-west crustal detachment and the rifting can be traced to mid-Miocene time.

In both basins, the rift-stage sediments are fragmented by two intersecting systems of extensional faults, one parallel and the other perpendicular to the basins' margins. As illustrated by several geophysical and seismic surveys, these faults are linear in any vertical section, and there is periodic growth associated with them. However, in plan view, they deviate significantly from the classical concave, “scoop” model of listric synsedimentary faults by being generally linear, sometimes convex and only rarely concave in shape. This implies that the faults are of tectonic, rather than depositional origin, even when they are formed in deltaic environments.
A fundamental approach to dipmeter analysis

Historically, in dipmeter analysis, depositional patterns are delineated for environmental, structural, and stratigraphic interpretations. The proposed method is a more fundamental approach, which uses raw data measurements from the dipmeter sonde to aid the geologist or log analyst in describing subsurface structures on a stratigraphic scale. Raw data are available at the well site, requiring only a basic understanding of sedimentary features and facies, and can be combined with computed results. A case study illustrates the reconstruction of sedimentary features from a raw data log recorded by a six-arm dipmeter.

The dipmeter is a wireline tool with a series of evenly spaced focused electrodes applied to the circumference of the borehole wall. The raw data are presented as curves representing the electrode response and tool orientation. In outcrop, the geologist can often see an entire sedimentary feature in 3 dimensions relative to its depositional environment. Therefore, a large range of features can be resolved. However, in the borehole environment the perspective is reduced to the borehole diameter, thus reducing the range of recognizable features. In this study, a table was assembled that identifies the features distinguished by the proposed method as a function of borehole diameter.

The role of rock volumes in log to core integration

As more wireline logging tools are developed and core becomes more available, the necessity of integrating this information into a coherent picture has taken on increased significance to many geologists and log analysts. When reservoir parameters derived from log analysis do not correspond with those derived from core analysis, the results from either or both may be suspect. The difficulty encountered in log-to-log and log-to-core correlation can, in part, be attributed to ambiguities about the volume of rock investigated by downhole wireline logging tools and core analysis.

A marginal correlation from log-to-log or log-to-core may be the result of poor depth control, bad hole conditions, or neither of these. Small differences may instead reflect the influence of microscopic and mesoscopic formation heterogeneity. The vertical resolution and depth of investigation of the sampling device can be used to estimate the volume of rock investigated by the device. The degree of correlation between diverse measurements of differing rock volumes provides an insight into the degree of homogeneity or heterogeneity of the larger volume. The closer the correlation, the greater the homogeneity of the larger volume. A variety of rock volumes have been estimated and those volume estimates should be used as a first pass at comparison between logs and cores.

Triassic strata of the Western Canada Sedimentary Basin

Within the Western Canada Sedimentary Basin, twenty different formation names have been assigned to the various facies of Triassic strata. For the purposes of the Atlas, four major subdivisions are recognized – Lower Triassic (Montney, Vega-Phospho), Middle Triassic (Halfway-Doig), Upper Triassic (Charlie Lake, and Baldydonnel-Pardonoon). Various structural features are present, including drape over faults associated with the Peace River area block fault system and faulting related to the Laramide Orogeny. Triassic strata were deposited along a wave-dominated, tidally influenced coastline with a low relief interior. Four major sedimentary provenances are represented in outcrop and in the subsurface. These are:

1. Prograding deltaic clastics deposited on an extensive low angle shelf (e.g., Montney fms.).
2. Shoreline and prograding barrier island clastics (e.g., Halfway Fm.).
3. Sabkha – evaporite environmental system (e.g., Charlie Lake and lower Watrous fms.).
4. Shelf carbonate depositional system (e.g., Baldonnel Fm.).

This material was presented as an oral presentation at CWLS, 1989.

The Triassic system includes abundant source rocks associated with the deltaic, barrier island and sabkha environments. Organic-rich Jurassic shales lie immediately above. Reservoir rocks occur in the deltaic, barrier island, sabkha and shallow water carbonate rocks. Traps are found associated with the various stratigraphic facies and structural elements within the system.

Quaternary Geology of the Western Plains

Quaternary age sediment covers almost all of the bedrock within the Western plains. Prior to glaciation, the plains consisted of low uplands cut by generally northeast-trending valleys. The Laurentide glaciers advanced across the plains at least five times depositing during both the glacial and nonglacial events produced, in many areas, a complex stratigraphy composed of glacial diamiction (till), and stratified, predominantly lacustrine and fluvial, sediment. This sediment, characterized by clasts from Precambrian and Paleozoic units, varies from 300 m thick in a few pre-glacial valleys to less than a metre on some of the interfluvies.

Multiple till sequences can be traced over wide areas utilizing compositional and downhole geophysical data. These diamictites generally form aquicludes confining a series of aquifers in the stratified sediment. The Sand River map area, for example, which covers much of the Cold Lake Oil Sand Deposit, includes eight glacial and nonglacial formations. Drift thickness varies from about 50 m to 300 m. The coarser grained portions of a number of the stratified units, such as the Muriel Lake and the Sand River formations, contain aquifers that represent a major source of groundwater.

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Importance of the reservoir/cap rock contact in assessment of undiscovered petroleum resources

Most petroleum migrates into traps along the contact between the reservoir and cap rocks. The number and size of petroleum accumulations that result depend largely on the interaction between the geometry of this surface and the quantity of hydrocarbons migrating upward to it, and then along it. In a simple trap, the petroleum migrating within the area of drainage will be funnelled into the area of closure. The funnelling effect is proportional to the ratio of the area of drainage to the area of closure, which in turn depends on the type of trap, its shape, and its tilt. Petroleum may also be added or lost by over-spilling from, or into, an adjacent trap. In more complex traps with a number of accumulations, petroleum will initially be funnelled into a number of small accumulations. As more petroleum is added, these will coalesce into one accumulation, which may then overflow.

Where there are sufficient data, plays can be outlined by regional drainage divides drawn onto structure contour maps that also show the areas of drainage and closure of the traps and the likely migration paths. Plays containing complex traps can be further subdivided. Where a trap has two or more accumulations, the enclosing trap belongs to the one play and the accumulations within it belong to another. Further fractal plays are possible if there are accumulations within the accumulations. A better assessment is obtained if each play is assessed separately.

The influence of the Peace River Arch on Devonian sedimentation

The Peace River Arch did not become an obvious tectonic element until the Devonian. During the Late Silurian and Early Devonian, the western part of the North American craton was a large landmass except for thick peritidal deposition along its margin. In late Early Devonian time (Emsian), the western craton started to subside and was covered by carbonate shelves and evaporite basins. However, the southern part (south of 58°N) largely remained a landmass until late Eifelian (early Middle Devonian) when it assumed the form referred to as the Peace River Arch and West Alberta Ridge. Subsidence of the surrounding areas (Elk Point Basin to the east and Golden Mountain to the west) continued into early Givetian (late Middle Devonian).

The lower Paleozoic carbonate-dominated sediments on the Peace River Arch and West Alberta Ridge were gradually eroded, with the
result that Lower and Middle Devonian sediments transgressed across increasingly older units to the east. The lower Paleozoic cover was only partly removed from the west Alberta Ridge, whereas it was entirely stripped along the Peace River Arch by late Eifelian time as documented by Granite Wash in Elk Point sediments immediately adjacent to the Arch.

During the mid-Givetian, a strong regressive event (Watt Mountain hiatus) affected most of the western craton. For this brief interval, the Peace River Arch became an active source of detritus, forming the up to 240 km wide Gilwood Delta Complex. Following this positive pulse, the Peace River Arch remained a passive high fringed by ringed reefs during latest Givetian and early Frasnian, and was gradually buried during late Frasnian and Famennian.

The Devonian succession in the Rocky Mountains to the west shows no influence of the Peace River Arch. In fact, siliciclastics of Middle Devonian age, when the Arch was identifiable as a tectonic entity, were consistently transported from a western or southwestern direction, suggesting a western source area. Radiometric work in progress on detrital zircons from these siliciclastics may elucidate the age of the western source area.

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An information theoretical approach to resource assessment

Most geological information leading to the discovery of new oil and gas fields in a play is produced by drilling exploratory wells. The amount of information that each well contributes to an overall understanding of the play’s petroleum geology, and to the discovery of the next field in particular, depends on the number and location of previous wells, the complexity of the regional geology, and the quantity and characteristics of the remaining undiscovered fields. In most plays, the information gained per well follows three distinct phases. First is an initial period of gaining insight into regional geology and testing preliminary exploration strategies, characterized by low exploration efficiency, as measured in volumes of hydrocarbons discovered per foot (metre) of exploratory drilling. The second phase begins with discovery of the “key” exploration concept which governs the trapping of most of the hydrocarbons in the play. Exploration efficiency rises in this phase and reaches its maximum. The final phase is controlled by the average size and “visibility” of the fields that remain in the play after the discovery of the few largest and medium size fields that, in most instances, contain two thirds to over three quarters of the play’s resources. Exploration efficiency either drops to zero, or in some plays, depending on economic considerations and the average size and characteristics of small fields, reaches a low, stable value.

The fact that the results of exploratory drilling in a play exhibit serial, as well as spatial correlation, suggests a Markovian process, which is susceptible to analysis through the constructs of information theory. In that context, the “state” of the play before drilling a given well is defined by the number of successful and dry holes drilled, and the quantity of resources discovered. There are a finite number of states the play can take after each additional well is drilled. These are defined by the same variables, though their values (e.g., the number of dry and successful wells, volumes discovered) will have changed. If all potential traps in the play were tested in the course of exploration, the ratio of dry to productive wells and quantity of resources discovered will be the same, independent of the order of wells or discoveries. The exploration process is therefore considered ergotic. For ergotic processes, entropy, as a measure of the information content of each exploratory well, can be measured by examining the succession of probabilities of state transitions as a function of cumulative drilling.

Exploitation of information content of exploratory wells in this framework provides a new approach to measurement of exploratory efficiency and to the estimation of future efficiency and the ultimate resources of the play. Such an approach is orthogonal to most of the traditional methods of assessment, and is unique in that it incorporates into a single system of analysis the impacts of geological complexity, field characteristics and exploration technology applied in the play. Examples taken from simulations and the exploration of plays in the United States are used to illustrate this approach to analysis of the exploration process and assessment of undiscovered resources.

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Devonian Prairie Evaporite salt flowage in southeastern Saskatchewan (Williston Basin)

The Middle Devonian Prairie Evaporite, comprising up to 215 m of halite and potash minerals, and no more than 3200 m deep, overlies the Winnipegosis Formation in southeastern Saskatchewan. Numerous Winnipegosis reef-like accumulations up to 110 m thick have been found surrounded and covered by salt. The main structural pattern of the Williston Basin’s northeastern flank is a homocline moderately deformed by faults, hinge lines and folds. Elongate trough and sub-circular (chimneylike) salt-collapse structures and structural depressions over the Winnipegosis reefs are superimposed on the main homocline structure. The structures have been generated as a result of multistage collapse, reflecting salt solution. The elongate trough structures have been initiated by Laramide faults and hinge lines, reflecting rejuvenation of basement linear features, or differential subsidence in the Williston Basin. The sub-circular collapse structures and the structural depressions over the Winnipegosis reefs have been initiated by salt flowage. The salt compressed between the Winnipegosis reefs and the Dawson Bay carbonates flows laterally. The salt’s lateral flow generates structural depressions over the reef and salt pools next to the reefs. Consequently, some of the salt pools are developed as sub-circular collapse structures. The salt movement and the features of the Williston Basin’s salt structures generated by salt flowage have some similarities to the salt structures of the southern British Sea.

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Extension faulting in the Western Canada Sedimentary Basin and the collapse of the Peace River Arch

Extension faults are normal cross faults that are sub-parallel to a collision front and commonly cut into the asthenosphere. During periods of uplift and high heat flow, faultblocks become mobile along the deeply cutting longitudinal faults, resulting in extension of the crust sub-parallel to the collision front. Significant is the role of longitudinal faults in pervasive dolomitization during periods of high heat flow. During the Devonian, the East Pacific Plate may have collided more than once with the North American Plate, but the effect of subduction, if any, was probably minimal. However, uplift started when the Western Alberta Ridge may be a product of mid-Devonian subduction of the continent by the east Pacific Plate. During its long history, the Peace River Arch always represented a tectonic or structural anomaly in the Western Canada Basin. Its crest did not line up with the northwest-southeast trend of the basin but paralleled the regional northeast-southwest strike of the tectonic belts within the Precambrian Shield. The demise of the Peace River Arch began in the late Famennian and was completed during the Early Carboniferous with the development of the Peace River Embayment. Complete to partial removal of the Famennian strata in southeastern British Columbia west of 124° longitude in latest Devonian-post Wabammun time suggests a major eastward push of the East Pacific Plate. This resulted in uplift of the Peace River Arch accompanied by considerable heat flow and possible thermal thinning of the lower crust. During the Early Carboniferous, continued lithospheric stretching and extension faulting resulted in the collapse of the Peace River Arch. The collapse started with the forming of the Fort
The effect of the longitudinal faults acting as extension faults may have been to re-align the axis of the newly formed Peace River Embayment in such a way that it turned parallel to the main trend (northwest-southeast) of the longitudinal faults.

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Wabamun/Palliser strata of the Western Canada Sedimentary Basin

Wabamun/Palliser strata of the Western Canada Sedimentary Basin consist of shallow water carbonates and evaporites that were deposited on a broad shelf in latest Devonian (Famennian) time. Thickness in the Southern Rocky Mountains reaches 600 m. In the Northern Rocky Mountains, thickness is considerably less due to Late Devonian uplift and erosion.

The Wabamun Formation can be subdivided into a lower transgressive sequence, a middle regressive sequence and an upper transgressive sequence. Lithofacies distribution is similar to a carbonate ramp transition from shelf to basin. Sakkha facies are preserved in southern Alberta, but correlation with similar facies in Saskatchewan (Williston Basin) is difficult.

For the purpose of regional correlation, the Wabamun carbonates are the subdivided into six members: (1,2) Dixonville and Whitelaw; (3,4) Normandville and Cardinal Lake; and (5,6) Last Lake and Big Valley. The Dixonville Member is correlated with the Techo Formation in northeast British Columbia. The overlying five members are correlated with the Kotcho Formation, which was partly eroded during latest Famennian time. The Big Valley Member is correlated with the Big Valley Formation in east-central Alberta. Subdivision of the Palliser is somewhat simpler: Lower Morro, which correlates with (1,2) of the Wabamun; Upper Morro (3,4) and Costigan (5,6). Boundaries of all members are slightly diachronous.

In northwestern Alberta and northeastern British Columbia, the unformable contact between the Wabamun carbonates and the overlying Exshaw shales and Banff siliciclastics gradually cut downsequence toward the west until it reaches Frasian strata at 124° W longitude, indicating regional epeirogenic uplift. Complete to partial erosion of the Wabamun/Palliser interval has taken place from Jasper to the Liard Basin. Contact with the Exshaw Formation (where present) and the overlying Banff Formation is unformable, but in the Liard Basin the systematic boundary between the Devonian and the Carboniferous is well above the base of the Banff. Late Famennian underthrusting of the North American plate may have caused the epeirogenic uplift and related erosion recorded by the sub-Exshaw unconformity in the north. In the south, minor erosion took place prior to and after deposition of the Exshaw.

The stratigraphic correlations discussed in this paper are well illustrated in several regional cross-sections, facies maps and isopach maps.

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Diagnosis of the Upper Devonian (Famennian) Wabamun Group, north-central Alberta

The Wabamun Group consists of cyclical, shunting upward, shallow water carbonates and evaporites deposited on a wide shelf. Data from the subsurface Tangent, Eaglesham, and Normandville fields indicate that these originally nonporous, subtidal carbonates have undergone a complex diagenetic history resulting in the highly variable distribution of reservoir rocks.

Primary porosity was reduced by sea floor and early burial diagenesis. Limestone diagenesis includes micrite, syntaxial overgrowth, granular, blocky, and fracture-filling cements. Mechanical compaction, minor dissolution, and early fracturing occurred prior to significant dolomitization.

Dolomites consist of: 1) early microdolomite and floating rhombs; 2) intermediate mosaic and styloite -- precipitated dolomites; and 3) later sucrosic, saddle, fine crystalline, and cap dolomites. Fracturing, brecciation, and dolomitization occurred in several stages, possibly associated with faults. The porosity and permeability of these rocks were increased locally, thereby creating potential hydrocarbon reservoirs.

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Mineral resources of the Western Canada Sedimentary Basin

Minerals other than oil, gas and coal occur in abundance and variety in the Western Canada Sedimentary Basin. They include the industrial (or nonmetallic) and metallic minerals and together account for a significant proportion of Western Canada’s wealth. By far the largest tonnage and value are the industrial minerals – a diverse array of more than two dozen different mineral kinds. Metallic minerals are much less developed; known deposits are few and generally small, although they include the world-class Pine Point (Pb-Zn) orebody.

For the industrial minerals, most production comes from the Interior Plains region, where Phanerozoic rocks form a northeast-tapering wedge of undeformed strata. These strata include Paleozoic carbonates and evaporites that give rise to rich resources of sulphur, potash, salt, gypsum, limestone and dolomite. The Paleozoic strata are succeeded by Mesozoic and Tertiary clastic rocks that are sources for economic deposits of kaolin and structural clays, bentonite, silica sand, and constructional sands and gravels. Important production also comes from the Cordilleran region, where deformed and upthrust basin strata in the Rocky Mountain belt expose economic deposits of limestone, magnesite, gypsum and quartzite.

For the metallic minerals, except for Pine Point, most deposits have been found in the Cordilleran region. These are mainly lead-zinc deposits of the Mississippian type, few in number and widely separated; limited past production came from small localized orebodies in southeastern British Columbia. In the Interior Plains, the Pine Point lead-zinc deposit is the largest and only significant economic deposit. Some smaller deposits are still produced from Tertiary and recent gravels. Sedimentary iron deposits (in the Clear Hills region of Alberta) are large, but remain undeveloped.

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A geological model for the Foremost unit, Judith River Formation, at Ferrybank, central Alberta

The Judith River (Belly River) Formation of central Alberta (Twp. 41 to 50, Rge. 26 W4M to Rge. 7 W5M) is informally subdivided into the Foremost and overlying Oldman units. The Foremost contains eight recognizable sandstone-shale sequences, with sand deposition occurring in detrital and nearshore bar environments.

Most Judith River oil pools in the area produce from sandstone reservoirs developed during one of these Foremost cycles. Oil production rates are highly variable, being directly related to reservoir quality. Factors critically affecting this quality are grain size, calcite cementation, shale volume, rock composition, and water saturation.

The Ferrybank (Twp. 43, Rge. 27 to 28 W4M) oil pool is an example of the effect that localized heterogenieties can have on reservoir performance. Deposition during Foremost cycle 5, the oil-bearing sandstone body at Ferrybank can be traced into an upper, reservoir unit and a lower, non-commercial unit based on sedimentological and petrophysical characteristics. The trapping mechanism is the result of reservoir deterioration and eventual pinchout, as the depositional edge of the sandstone is approached. Primary oil recovery from this field is expected to be 1,300,000 cubic metres.

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Mannville Group strata of the Western Canada Sedimentary Basin

Strata of the Mannville Group and equivalents are recognized across the entire Western Canada Sedimentary Basin. Continental sediments dominate the Mannville, except for a limited marine transgression in the mid-Mannville, which affected sedimentation basin-wide, and marine deposition of equivalent units in the cratonic seaway to the north.

In the Atlas, the Mannville is split into Lower Mannville and Upper Mannville units. The boundary is related to the mid-Mannville transgression, generally separating fresh to brackish strata below from fully marine
deposits above, and is placed at the top of the Calcareous, Ostracode, Cummings, McMurray, Getting or McCloud in various parts of the basin. Even this basic subdivision is difficult to make in places because of the extreme geographic variability of Mannville strata.

Although finer subdivisions of the Mannville cannot be made basin-wide, examination of several more local depositional situations clarifies the overall sequence and style of sedimentation. These situations include the following:

1. Erosion at the basal Cretaceous unconformity, immediately beneath the Mannville, features several major valley and ridge systems. Certain Lower Mannville units, such as the McCloud and Cut Bank members, were deposited as valley-filling successions.

2. Deposition of shoreline sand complexes (e.g. the Hoadley-Strachan complex) is associated with minor relative sea-level changes in the mid-Mannville (Moosebar) seaway.

3. Major structural features, such as the Peace River Arch, Sweetgrass Arch and Swift Current Platform, influenced Mannville sedimentation patterns.

4. Development of the Pense Basin across Saskatchewan and parts of eastern Alberta in latest Mannville time, produced consequent deposition of the Pense Formation.

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Proterozoic-Lower Cambrian strata of the Western Canada Sedimentary Basin

Proterozoic and Lower Cambrian sedimentary successions are dominantly clastic and virtually absent to the east of the Rocky Mountain Front Ranges, suggesting nondeposition and/or a profound sub-Middle Cambrian period of erosion in the autochthonous region of the Western Canada Sedimentary Basin. The observed stratigraphy consists of a series of stacked passive-margin sequences (separated by unconformities) which record several periods of rifting, thermal cooling, and continental margin separation.

The initial Purcell sediments (maximum: 20 km thick; dated: 1570-1200(?)) ma are mainly shallow-marine and nonmarine in origin. They overlie fine grained basinal deposits to the west and thinned carbonates and clastics to the east. In Canada, these strata are interpreted mainly as deposits from delta progradation onto a subsiding miogeocline. This contrasts with various interpretations of the Belt Basin in the United States, including a two-sided intracratonic basin setting. The younger Windermere Supergroup (maximum: 9 km thick; dated 730-760 ma) are deep water grits and pelites unconformably overlain by the fluvial/shallow-marine Hamill Group or the shallow-marine Gog Group.

The subsequence of cyclicity, based on the facies association of fine clastics, carbonates and evaporites. One such cycle is the Artex Member, which is subdivided into several formations that generally conform to the boundaries of at least three transgressive-regressive sequences. Biostratigraphic data, obtained mainly from occurrences of conodonts, brachiopods, and foraminifers, are used to date these sequences.

Oil and gas plays are generally restricted to structural and stratigraphic traps where rocks of the Belloy Formation are involved in fault-bounded structures in the Peace River Embayment; proven oil reserves account for about 1 per cent of the total for the Western Canada Sedimentary Basin. The Belloy Formation consists of three informal members: middle carbonates, middle sandstone, and upper carbonate. The thickness of the Formation varies from a zero edge in the east to more than 200 m near the foothills. Isseps demonstrate northwestern trends related to facies distribution, which appear to parallel pre-Belloy or syndepositional block-faulting trends, with carbonates developed on the highs. Phosphate is common in parts of the Permian succession, but does not appear to be of immediate economic value.

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Adapting desorption mass spectrometry and pattern recognition techniques to petroleum fluid correlation studies

Petroleum explorationists are often faced with determining the relationship between the products of wells completed in rock types that may have some spatial or temporal relationship. Conventional methods of sampling and analysis are often time-consuming and expensive. A new method for sampling, analysis, and computerized data interpretation of the C2-C16 fraction of crude oil and natural gas is reported here.

Controlled temperature headspace sampling of crude oils and direct pressure-equilibrated natural gas exposure of carbon adsorption wires have been successfully applied to the sampling of volatile fractions of petroleum fluids. Thermal vacuum desorption followed by mass spectrometric analysis of these volatile organic compounds is a rapid and accurate method for obtaining detailed information about the distribution (fingerprint) of the components in a given sample. Techniques of computerized chemical pattern recognition, such as principal components analysis (PCA) with graphic rotation, discriminant analysis and similarity analysis (SIMCA) have proven useful in establishing inter-relationships between samples via the fingerprints of their volatile fractions.

Studies have been conducted on multiple samples from numerous continental basins. The results of several of these studies are presented to demonstrate the applicability of this new, rapid, cost-efficient approach to correlation studies.

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Sedimentology and petroleum geology of the Artex Member (Charlie Lake Formation), northeast British Columbia

The subsurface Charlie Lake Formation (Upper Triassic) is interpreted as a succession of sabkha cycles, based on the facies association of fine clastics, carbonates and evaporites. One such cycle is the Artex Member, which is up to 5 m thick, and occurs throughout the Peace River area of northeast British Columbia. In the Brassy Field, the Artex Member has been interpreted as aeolian sandstone by Canadian Hunter geologists. The present study, based on well-log correlations and core examination, suggests that the Artex Member consists of (coastal?) dune-field sandstone which passes eastward, at about 121°W longitude, into playa-flat sandstone and mudstone. Toward the west, muddy strata above and below the Artex grade into a continuous sandstone sequence within which the Artex can be differentiated on wireline data.

The Artex Member shows abrupt lateral changes in thickness and is locally missing at Brassy. This reflects neither primary dune-field topography, nor post-Artex erosion, since log markers above and below the Artex show no lateral thickness changes, truncations, or onlap. This suggests that the Artex Member was essentially tabular upon burial. Thin artex are therefore interpreted as interdune and playa areas, where ephemeral lakes deposited halite, which was subsequently dissolved after burial.

Hydrocarbons are stratigraphically trapped in the Artex Member at Brassy (oil), Stoddart West (oil and gas), Buick Creek (gas), and Wilder (gas). Hydrocarbon pools coincide with Artex "thicks" (i.e. dunes); the intervening interdune and playa sandstones are tight. Discovery and development of further Artex pools will be optimised by an integration of surface mapping, sedimentology and refined seismic techniques.
Technologies relating to seismic data collection and processing have improved greatly over the past 10 years. Advances in three dimensional imaging and the development of borehole techniques have extended seismic capabilities into the realm of reservoir description and monitoring. The inherent value in three dimensional seismic lies in the spatial resolution that is several orders of magnitude higher than that possible with well data alone.

New methods have now been devised that allow the systematic integration of 3-D seismic data with well-bore petrophysical data to a level that has not been possible previously. Co-kriging techniques, for instance, statistically merge the spatial variations present in the seismic data with the petrophysical properties measured at well locations. This technology has the potential of greatly improving the initial reservoir descriptions that are used in production simulation.

Seismic techniques have also proven successful in monitoring the movement of flood fronts in some EOR (Enhanced Oil Recovery) processes. This monitoring is possible when the EOR process alters the acoustic properties of the reservoir rocks. Surveys recorded prior to EOR initiation capture the initial reservoir heterogeneity, while monitor surveys recorded after the EOR process has been implemented measure the change in the acoustic response of the reservoir. Differences between the base and monitor surveys can then be used to determine the areal and vertical dimensions of the flooded zones. This technology has been successfully applied in heavy oil thermal pilots, and research has now been completed that suggests miscible flooding and gas production by water drive can also be monitored. Further, it is possible that water-flooding of oil reservoirs may produce enough acoustic contrast for monitoring under some conditions, but present research indicates this is not expected to be widespread.

Currently, investigations are underway to determine the technical and economic feasibility of using 3-D and borehole seismic techniques in reservoir management. In order for the seismic data to be technically successful, there must be an integration of geophysical techniques with reservoir geology and engineering to a much greater level than the majority of these operations, plus 36 years of production and reservoir data, indicate stratified production in a complex paleocave or karsted reservoir system. Vertical communication is limited.

Primary storage capacity is located within an apparently extensive solution-collapse and cave-fill breccia interval, which occurs approximately 46 to 61 m (150-200 ft.) below the unconformity surface. Interclast porosity ranging from 3 to 20 per cent typifies this interval. Production from the overlying dense, non-brecciated Ellenburger cave roof is fracture controlled. A relatively minor interval of porosity occurs approximately 30 m (100 ft.) below the prominent cave-fill horizon. Bottom-hole pressure data, well tests, and fluid analyses data confirm vertical isolation of these 3 productive intervals.

This multidisciplinary approach to reservoir description has provided a model for future field evaluation by integrating field performance data with geological interpretations. The revised reservoir model has identified considerable opportunity for incremental oil production by defining the distribution of remaining oil reserves. Modifications to the existing crestal gas injection program are being implemented to improve recovery efficiency.

In the Offshore Indus Basin, prospects of giant field potential have been identified within the continental crust of onshore Indus Basin, and partly by the oceanic crust of the Arabian Sea. The Makran Offshore Basin is an active subduction zone and accretionary prism.

In the regional context, offshore Pakistan is an anomalously high in the prolific petroliferous belt extending from Oman and Iran in the west, to the giant offshore Bombay High complex in the east. However, this gap is probably due to lack of exploration rather than the absence of attractive prospects, as giant fields have been discovered in similar geological settings elsewhere in the world, (i.e. Canada’s Mackenzie-Beaufort Basin and offshore east coast, and Eastern Venezuela-Trinidad).

Only 9 wells have been drilled in this vast area, 8 offshore Indus and one offshore Makran. From this total, 4 wells were abandoned (including the only one off Makran) for technical reasons prior to reaching target depths. One well, drilled with Canadian assistance, tested gas at 3.7 MMCF/D (104.8 x 10^3 m^3) from Miocene sands. Others were drilled on poorly defined prospects and encountered minor shows.

Fairly extensive seismic coverage is available: 28,545 km offshore Indus, and 8,883 km offshore Makran. Most of this is 24 to 60 fold data of good to excellent quality. Another 10,000 km is planned. In the Offshore Indus Basin, prospects of giant field potential have been seismicity identified. These relate to various Tertiary deltaic and
submarine fan environments well documented in the areas mentioned above. In addition, carbonate bank development analogous to the Bombay shelf environment, and reefal facies all along the northwestern margin of the offshore shelf have been postulated. Deepwater prospects in Cretaceous rocks, similar to the adjacent productive southern onshore Indus Basin, cannot also be ruled out.

The hydrocarbon potential of offshore Makran has not yet been substantiated by drilling. One onshore well had tested oil geochemically similar to some Oman fields. There are numerous oil and gas seepsages along the entire Makran coastline, associated with mud volcanoes; some are also visible on offshore seismic. Attractive structural and stratigraphic prospects exist in the shelf to slope and turbidite environments. Some large structures have been seismically identified, and await confirmation by drilling.

Substantial long-term Canadian assistance in the public petroleum sector, some already used in offshore seismic and drilling, has created respect for Canadian technology and general goodwill toward this country.

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A new approach to shale compaction and its geological significance

Shale compaction is generally considered to be an irreversible process resulting from the mechanical rearrangement of sediment grains in response to overburden stress. Under ideal conditions, the sonic log provides a sensitive measure of sediment porosity ($\phi$) change with depth. However, compositional variations in the pore fluid and sediment matrix can affect sonic transit time ($\Delta t$) readings and distort the normal compaction trend. The Beaufort-Mackenzie Basin (BMB) provides a unique opportunity to study shale compaction, because it contains shales with uniform physical and chemical properties, deposited under highly variable sedimentation rates.

Previous compaction studies have been biased by variations in sediment composition and the incorrect assumption that $\Delta t$ is linearly related to $\phi$. A new $\Delta - \phi$ equation, calibrated using mudstone and shale core porosity measurements from the BMB, is characterized by an Acoustic Formation Factor (2.19) and matrix $\Delta$ (220 $\mu$m). This $\Delta - \phi$ transform, which is valid for organically-lean shales ($< 2\%$ avg. TOC), was used to calculate $\phi$ from $\Delta t$ data.

Compaction trends in the BMB are strongly correlated with structural features and depositional history. Data are coherent over broad geographic regions and show a significant change from undercompacted, overpressured sections in the offshore, to normally-pressured sections onshore. A linear compaction rate of approximately 1%/100m in normally-pressured Tertiary shales of the BMB and in Devonian and Cretaceous-Paleocene shales of the Ft. Norman area, Northwest Territories, illustrate that compaction is insensitive to temperature. These data suggest that shales may approach a steady-state compaction profile, a result that has broad application to reservoir characterization.

Evidence for anomalous Tertiary heating in the Peace River Arch region from apatite fission track analysis

Phanerozoic strata of the Peace River Arch (PRA) region, northern Alberta Basin, record a complex succession of uplift and subsidence events. In an effort to obtain quantitative constraints on the thermal evolution of this tectonically important area, outcrop and subsurface core samples were collected for apatite fission track analysis. Sedimentary rocks (Devonian and Cretaceous sandstones) and Precambrian basement samples were taken along a transect through the axis of the PRA extending from the Rocky Mountains-Foothills region west of Chetwynd, British Columbia, to an area east of Fort McMurray (Twp. 87, Rge. 22W4M). Fission track parameters were used to constrain burial history models based on geological reconstructions and present temperature data. The majority of samples processed to date have Mesozoic and younger ages with mean confined track lengths of 10-11 $\mu$m, indicating a significant residence time in the 80 to 100°C temperature zone. Therefore, published kinetic models for track length annealing were used to interpret the data.

Preliminary results suggest that, during the Cenozoic, thermal gradients may have remained relatively stable directly over the PRA (as outlined by the Leduc Reef). Combined vitrinite reflectance and fission track data from a thermally immature Cretaceous sample constrain its maximum paleotemperature to be less than 70°C. Assuming a time-invariant geothermal gradient, this provides an erosion estimate of approximately 1.2 km centred on the PRA at 118°W. East and north of the PRA, there is strong evidence for an anomalous Tertiary heating event that occurred close to or was coeval with peak Laramide burial. Inferred paleothermal gradients are at least two to three times higher than present values and are opposite to the present-day pattern, which shows thermal gradients decreasing from approximately 35°C/km to 20°C/km from west to east. This paleotemperature distribution is best explained by regional groundwater flow discharging hot fluid along the flank of the basin.

JAMES, W., Exxon Production Research Company, Houston, Texas

Exxon methods for assessing future field sizes

In geological play assessment, it is necessary to estimate the size distribution of undiscovered fields. Exxon currently uses four modelling approaches:

1. fitting of discovered sizes within the play, honouring trends in size with discovery sequence
2. compositing of assessments of untested prospects within the play
3. convolution of statistical models for measured closure sizes with play-wide reservoir and fillup models
4. use of in-house tables relating the potential field size distribution to the expected size of the largest prospect

Size distributions from geological analogs are occasionally used where no discovery history is present and data are too sparse to identify any prospects. Each method has some unique strengths and weaknesses. Confidence can be gained by finding agreement between different methods. Moreover, a size distribution of appropriately screened fields can be used to tune play parameters for prospect-based methods, which may then be extended with more confidence from mature areas into frontier areas.

Modelling progresses in four steps:

1. geological definition of plays and classification of known fields and prospects
2. choice of the minimum size of fields and prospects to be included in the count, and culling of fields and prospects to be excluded from the first step
3. fitting mathematical models to the selected populations
4. assessing the potential contribution from smaller fields

The assessment process is assisted with an interactive graphics computer program to extract field and prospect data from on-line databases, and cull and fit models to the selected populations. One important output of this system shows composited projections of future field size distribution for aggregations of plays, with overlays of the distributions of known fields and inventoried prospects.

JOINER, S.D. and KRAUSE, F.F., The University of Calgary, Calgary T2N 1N4

Cardium Formation stratigraphy in the Pembina Field and surrounding area

Cardium Formation stratigraphy has been the subject of much study in recent years. Our work indicates that the Cardium Formation in the Pembina area constitutes a major regressive-transgressive couplet. The regressive portion culminates in sandstone deposition, whereas overlying conglomerates and mudstones represent the transgressive portion of the couplet. Separating sandstone from conglomerates is a widespread unconformity that developed in response to rising sea level. Conglomerates were scoured during ravinement and incision of shoreline deposits to the west. The regressive interval at Pembina is equivalent to the Moosehound Formation (a member of the Leduc Reef). Combined vitrinite reflectance and fission track data from a thermally immature Cretaceous sample constrain its maximum paleotemperature to be less than 70°C. Assuming a time-invariant geothermal gradient, this provides an erosion estimate of approximately 1.2 km centred on the PRA at 118°W. East and north of the PRA, there is strong evidence for an anomalous Tertiary heating event that occurred close to or was coeval with peak Laramide burial. Inferred paleothermal gradients are at least two to three times higher than present values and are opposite to the present-day pattern, which shows thermal gradients decreasing from approximately 35°C/km to 20°C/km from west to east. This paleotemperature distribution is best explained by regional groundwater flow discharging hot fluid along the flank of the basin.

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Spatial statistics and exploration drilling

Outcomes of exploratory well drilling in a petroleum play form a spatial point pattern evolving in both space and time. The characteristics of such patterns provide important clues about magnitudes and locations of undiscovered petroleum deposits. Projects of wildcat successes and failures in a play or basin are reasonably based on the assumption that drilling history influences future drilling outcomes. But how? Very little empirical statistical work that might suggest an answer is available in the published literature. One possible reason is that drilling data, even data as simple as wildcat successes and failures, have a spatial dimension. The spatial character of such data renders it more difficult to analyze systematically than non-spatial data.

The objective here is to suggest one possible approach to modelling the evolution of exploratory drilling in a play that allows us to test the hypothesis that wildcat drilling outcomes are spatially interdependent, and to show how this interdependence, if present, can be displayed.


Deep seismic reflection profiles across the Nova Scotia continental margin, offshore Eastern Canada

Two deep seismic reflection profiles, which record both sedimentary stratigraphy and the deep structure of the underlying crystalline crust and upper mantle (maximum two-way time of 24 s), were obtained across the continental shelf, slope and rise offshore Nova Scotia. This continental margin was initially formed by rifting between Africa and North America in Triassic-Early Jurassic time. The objective of this study is to delineate both the deep structure associated with the formation of the sediment-filled Scotian Basin and the transition from continental to oceanic crust. One profile, which crosses the central Nova Scotian shelf through the Emerald and Naskapi sub-basins and the Scotian Basin, shows that these half-graben basins are at least 4 s (two-way travel time) deep. Unlike the basins on the Grand Banks, the basin-bounding listric normal faults bordering these basins dip landward, and we speculate that this change in fault polarity may be due to a difference in the fabric of the underlying basement. These faults appear to flatten at depths of about 5 to 6 s. Reflection Moho is clearly delineated on this line, as is the base of a reflective zone in the lower crust. There are spectacular "faults" within the upper mantle and lower crust, the origin of which is uncertain. The crystalline crust thins toward the ocean basin, and is obscured by salt structures below the lower continental slope. Seaward of the salt lies presumed oceanic crust, which displays peculiar internal layering and faulting. How far offshore these unusual characteristics persist is unknown, as they extend to the seaward end of our profile. However, similar changes in the reflection character of oceanic crust have been attributed to changes in the amount of melt production at ancient mid-ocean ridges.

A second profile crosses the margin through the Orpheus graben, and the Abenaki and Sable sub-basins. Preliminary results are included in this presentation.


Crustal structure and geodynamic models for the south Jeanne d'Arc Basin, offshore Eastern Canada

The Grand Banks area, offshore eastern Canada, contains several deep half-grabens that were formed by extensional forces during Mesozoic rifting of the North American plate with respect to Africa, Iberia and Europe. We understand these plate tectonic motions that led to rifting, we do not understand how the lithosphere deformed under extension to produce these basins, and other Triassic-Jurassic half-grabens of this same type in northern North America. In order to investigate the lithospheric and deep crustal controls on basin development, deep crustal reflection and refraction seismic studies have been undertaken across the south Jeanne d'Arc Basin. Results show that Moho is almost flat beneath the basin, and that most of the crustal extension may have been accommodated by the basin-bounding fault, which extends into the lower crust but does not appear to cut the Moho. Extension in the lower lithosphere may have been via penetrative flow. A distinct lower crustal layer, with a velocity of 7.2 km/s, is observed and is interpreted as supporting evidence for rift-related magmatic intrusion and/or underplating of the crust in the vicinity of the basin. These results were used to constrain geodynamic models of the extension of the lithosphere. Models of the lithosphere include a layered, temperature-dependent rheology, conduction and advection of heat, and isostacy. A "fault" or pre-existing zone of weakness is incorporated in the crust and this localizes deformation. The progressive deformation of the lithosphere is computed from the onset of rifting. Results of modelling are compared with observed deep structure, and with the shape and generalized stratigraphy of the basin. These models provide a good fit to the observations, and are more powerful than earlier models in that they give a physically meaningful representation of lithospheric deformation both during and after rifting. The results show that the mode of deformation is more complex than earlier kinematic "pure" and "simple" shear models would suggest. This additional complexity will affect the heat input and therefore the thermal maturity predicted for the sediments.

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The Beaverhill Lake Group (Devonian) – Peace River Arch

The Beaverhill Lake Group ranges in thickness over the subject area from a maximum of about 200 m to the northeast and southeast of the Peace River Arch, to zero where it onlaps the Arch. The Arch strongly influenced sedimentation in a surrounding 500 km wide belt.

The youngest Beaverhill Lake unit, the 5 to 10 m thick Stave Point Formation, conformably and gradationally overlays the evaporite Fort Vermilion Formation. Both were deposited during a time of tectonic stability. The Fort Vermilion is composed of dense, thin, laterally uniform sedimentation, of mostly lime mudstone.

At the end of Stave Point time, the Arch and surrounding area became tectonically active. Rapid subsidence combined with little sedimentation resulted in the Stave Point top becoming a submarine erosional surface. On this surface in a "starved" basin, the lowermost Waterways Firebag clay and lime muds were deposited, prograding from the east. The main Firebag reached only the most easterly part of the area, where it averages 1 m in thickness. The base of the overlying Calumet carbonate slope forms a clinoform in the eastern part of the area, the slope is relatively horizontal, producing westward thickening. During Calumet time, the stabilizing influence of the Arch resulted in belts of reefs (Skan Hills) refined on its surface. The uppermost Calumetmerges laterally into the upper Swan Hills reef platform. The younger Waterways Moberly carbonate unit forms a fringing complex of small reefs around the Arch, inside the Swan Hills belt.


Lower Mannville Sedimentology – south and central Athabasca

Regional study of the Lower Mannville Group (McMurray Formation and overlying Wabiskaw Member of the Clearwater Formation) in the Central (Townsips 80-90, Ranges 1-18W4 M) and Southern (Townsips 67-79, Ranges 10-18W4 M) Athabasca oil sands area, reveals a diverse and complex array of sedimentation styles and resulting reservoir geometries. Over 1000 well logs and 100 cores were examined along with information from palynological and mineralogical samples.

Recognition of distinct sedimentation patterns allows informal McMurray Formation subdivision into the McMurray B (approximating the lower and middle McMurray) and overlying McMurray C (approximating the upper McMurray). The best reservoirs in this area occur in the McMurray B sandy facies, where up to 65 m of greater than 3 weight percent bitumen-saturated sands occur. The sands show blocky or fining-upward wireline log profiles. Palynological and ichnological indicators in the McMurray B show an upward increase in paleosalinities from continental to marginal marine environments. These deposits are interpreted as fluvial channel systems progressing upward to fluvial-estuarine channel systems.

The overlying McMurray C typically shows a 1 to 5 m coarsening-upward wireline log signature and good lateral continuity (tens of km). Paleosalinities of the McMurray C are higher than the McMurray B; however, ichnology, palynology and sedimentary structures such as synestheric cracks suggest abrupt salinity fluctuations. McMurray C deposits are interpreted as shelfal shoaling sequences within brackish bay settings.

The McMurray Formation to Clearwater Formation transition represents a relatively flat ravinement or erosion surface developed during
transgression by the Boreal sea. An interval with high glauconite concentrations and locally occurring transgressive ichnology suite overlies this surface. Semi-mature litharenite to feldspathic litharenite marine shoaling sands are regionally thin and randomly distributed in most of the study area. In the North Primrose area of Athabasca South, pronounced relief occurs on this surface as an east-west oriented scour. The North Primrose scour is interpreted to have formed by fluvial incision during a relative sea level lowstand prior to the region’s inundation by the Boreal sea. The best Wabiskaw Member reservoirs occur in the North Primrose scour, where delta front sands reach thicknesses in excess of 40 m with greater than 3 weight percent bitumen saturation.

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Overview of the Paleozoic history of the Western Canada Sedimentary Basin

The opening of the Iapetus Sea in the Late Proterozoic initiated a 400 m.y. period of passive margin sedimentation that influenced the depositional history of much of western North America. In the Western Canada Sedimentary Basin, that history is recorded in three packages of rocks. The oldest package includes the Sauk and Tippecanoe sequences, the second, the Kaskaskia, and the youngest, the Absaroka and lowest part of the Zuni sequences.

The Sauk and Tippecanoe are marked by rapid thermal subsidence and initial growth of the continental margin, constructed of shelf marginal carbonates and inner shelf siliciclastics that onlap the craton. There were two phases of craton inundation. The peak occurred in the Tippecanoe and resulted in craton-wide carbonate deposition.

The Kaskaskia is marked by a slowing of thermal subsidence and dominance of loading subsidence. It consists of two depositional phases, the earlier dominated by carbonate and evaporite deposition, including considerable reef growth. The second phase was another period of widespread craton inundation by a carbonate sea, peaking in the Late Devonian and gradually dwindling during the Mississippian. Both are marked by shelf to basin transitions but only the former has any major reef development. Proximal to the craton, termination of both of these first two packages is predicted by short-term cycles of transgression and regression.

The third package anticipates the growth of a convergent margin and is marked by erosion on the craton and mixed carbonate/evaporite and siliciclastic deposition on the continental margin. Offshore is represented by deep-water and volcanic accumulations.

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Geological history of the Williston Basin

The depositional history of the Williston Basin was significantly influenced by the events that resulted in passive margin and later convergent margin foreland basin sedimentation in western North America. The basin was an actively subsiding structure during much of the Phanerozoic, but its geological history can be divided into five sequence packages, each separated by a major unconformity. The first three sequences represent the influence of the passive margin, and the later two, the effects of foreland basin sedimentation.

The earliest sequence, Sauk, marks the initial inundation of the craton and is represented by a coarse to fine clastic succession. The next two sequences, Tippecanoe and Kaskaskia, were dominated by carbonate-depositing seas. Tippecanoe rocks suggest that the sedimentation rate and rate of subsidence in the basin kept pace, but with indications of marked shallowing in the late middle Silurian. In the Kaskaskia, the basin was coupled to a much larger structural feature, the Elk Point Basin, in which, finally, evaporites and reef growth dominated, followed by shelf carbonate and evaporite sedimentation. In late Kaskaskia (Mississippian), the basin was uncoupled and a distinct paleobathymetric zonation developed, from peritidal-shallow shelf conditions at the margins to deep water in the basin centre. The Zuni sequence marks initiation of the convergent margin. In the earliest phase (Jurassic), paleobathymetry changed to control sediment distribution but was dominated by fine and coarse siliciclastics. Late Zuni is marked by cycles of the same siliciclastic marine transgressions and continental progradations that are evident throughout western North America.
strata. In the central area, gravels are finer grained (boulder to pebble), thinner bedded and are rarely interbedded with sands. In eastern outcrop, more than 50 per cent of the deposits are gravel, interbedded with current and wave rippled sand, intriformational breccias (containing bones), silcretes, marls, silts, and rare bentonites. At one site, a 9 m deep gravel-filled channel cut into the finer sediments.

Vector paleocurrents vary over 100° with a grand vector mean to the north-northeast, perpendicular to the east-west outcrop trend. Clast lithology throughout the study area is dominated by quartzites, with a possible source in the Laramide-thrusted rocks to the west and southwest. Other lithological types, notably intrusive and extrusive igneous rocks, were probably derived from Eocene intrusions of the Sweetgrass Hills to the south, and/or the Highwood, Little Rocky and Bearpaw mountains to the south.

We attribute the sedimentology of the Cypress Hills Formation to deposition of multi-cycled gravels and finer sediment on a braided plain fed by valleys extending from highlands produced by intrusion of igneous bodies in northern Montana. Western outcrop of the Cypress Hills Formation is dominated by gravels laid down in an extensive, braided channel system proximal to the mouth of a valley. The central region preserves braided channel gravels deposited, perhaps more distally, under shallower, less competent flows. Eastern outcrop preserves mid-to distal-braidedplain deposits characterized by incised channels and extensive interchannel areas, which were locally occupied by lakes. Vast amounts of bone material are concentrated in locally derived debris flow breccias. The presence of silcrete, and the paleontology of the deposits, suggest an arid to semiarid climate.

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Colorado/Alberta Group strata of the Western Canada Sedimentary Basin (Poster)

The Colorado/Alberta Group is a predominantly shale unit, which exceeds 1100 m in thickness in the northwestern portion of the Western Canada Sedimentary Basin and thins to less than 200 m in the east. The base of the group immediately overlies the top of the Mannville Formation. In the west, the top of the group is at the top of the Milk River Formation; in the east, it is at the top of the First White Speckled Shale. Coarse clastic units within the group are commonly major hydrocarbon producers. They include the Turonian Cardium, the Cenomanian Dunvegan and the Albian Viking formations. These formations are related to major fluctuations in relative sea level, and are described in detail elsewhere. Finer sandy units include the retrogradational shelf sandbodies of the Doe Creek Member, the shelf to coastal plain sandbodies of the Bad Heart Formation and Chinook Sandstone in northwestern Alberta, the shelf to shoreline sandbodies of the Medicine Hat Formation, the Milk River Formation (commonly placed in the Montana Group), the Chungo Member and the Barons Sand of southern Alberta, and the shelf deposits of the Medicine Hat and Newcastle formations in southern Saskatchewan. Several units are of particular economic importance as producers of nonassociated, sweet, dry, biogenic shallow gas.

During deposition of Colorado Group sediments, warm marine waters extended north from the Gulf of Mexico and intermixed with boreal waters extending south from the Arctic. The First White Speckled Shale, the Second White Speckled Shale and Fish Scale Zone occur as regional markers across most of the basin. They represent stratigraphically condensed marine sections related to maxima in marine transgressions. These condensed sections are characterized by high TOC contents and, where mature, form good potential hydrocarbon source rocks.

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Petroleum resource estimations – an overview

Geologists, geochemists, and statisticians have performed petroleum resource estimations for many decades. The procedure for resource evaluation varies greatly because of different statistical, geochemical, and geological perspectives. Consequently, a variety of methods have been developed in past years. Methods that have been published and have significant influence on the subsequent developments are described as follows:

Geological methods:
1. Volumetric yield method
2. Basin classification method

Geochemical methods:
1. Mass balance method
2. Source rock evaluation
3. Burial history on timing for formation of oil and gas windows

Statistical methods:
1. Regression model
2. Arps-Roberts model
3. Monte Carlo model
4. Creaming model
5. Discovery Process model

Specific data and assumptions can be applied to each of these ten methods. Some of the assumptions can be verified by resultant data and others cannot. All of these methods have their own merits and disadvantages. The approach using the Discovery Process Model, for example, has a long history of development, and does not only account for all available information, but also links geochemical data as an integral component.

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Clay mineralogical studies of post-steam core from the near-well bore region in an oil sands reservoir, Alberta

A post-steam core was recovered from the near-bore region of an Alberta oil sands reservoir that had been subjected to cyclic steam stimulation. The upper portion of the core has remained heavily bitumen-saturated. The lower portion of the core comprises three zones, which are essentially bitumen-free but made up of a matrix of shale fragments and partially lithified sand clasts. The upper and lower portions of the core are separated by a calcite-cemented interval, as are two of the three zones within the bitumen-extracted interval. The mineralogy of the bitumen-extracted zones are the focus of this paper.

Quartz and lesser amounts of plagioclase, dolomite, K-feldspar and clay minerals characterize the bulk mineralogy of the bitumen-extracted material. The <2μm separates from both the sand and shale clasts are dominated by smectite, kaolinitic and chloritic clay minerals. Berthierine was not detected. Relative to shale separates from the same sample, the sand clasts are generally poorer in smectitic clay minerals, and richer in illitic, chloritic and kaolinitic clay minerals. The smectitic clay abundance in the sand clasts generally increases with depth.

The smectite clay mineral present in both the sand and shale separates is a mixed-layer phase, containing an average of 65 per cent smectitic layers in the sands and 71 per cent in the shales. Only the sample closest to the top of the uppermost bitumen-extracted portion of the core behaves like a "normal" smectite/illite clay mineral, and it is the only sample with 80 per cent expandibility. All remaining samples exhibit anomalous behaviour, failing to collapse to an illite-type structure upon heating. Such behaviour is characteristic of smectitic clay minerals that have become intercalated with a cationic complex, hydroxy-interlayer material or organic molecule that is not readily removed or destroyed during heating. Formation of this interlayer material may reflect stabilization of smectitic clays in an expanded position by precipitation of "chloritic-like" material in the smectite interlayer region. The formation of such interlayer material would limit smectite swelling.

The resistance to collapse of the smectitic clay mineral within the bitumen-extracted zones increases with depth. The depth-dependent, increased penetration and improved crystallinity of the intercalated material may reflect higher temperatures and/or more extensive oil/sand/steam interaction at greater depths within the bitumen-extracted interval.

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Computer-assisted regional mapping for petroleum exploration modelling in the Western Canada Sedimentary Province

In 1989-90, 20 regional maps were generated at Home Oil to provide explorationists with a synopsis of the Paleozoic petroleum geology of the Western Canada Sedimentary Province. The principal goal was to summarize the most reliable data in a visual manner, and at a reasonable scale of 1:1,500,000, to encourage more regional and local exploration
modelling. Another aim was the identification of new approaches and new plays for finding significant hydrocarbon concentrations in Precambrian sedimentary rock. The method is based on the principles of integrated geological basin analysis, as formulated by Potter and Pettijohn (1977), and Lytikas (1988). Ideally, all available geological, geophysical and geochemical data should be incorporated in this analysis. Unfortunately, some types of data (such as borehole logs, geothermal, geochemical and lithological) are either unreliable in a regional context and too controversial, or too costly to acquire (lithological data). As a result, the following regional maps have been chosen: for geochemistry – differential relief of the most consistent surfaces and isopachs between them; for geophysics – Bouguer gravity and total magnetic intensity and derived third-order residual and horizontal gradient maps. The horizontal gradient maps are the most useful for interpreting geology because they represent a combined presentation of magnitude and direction of the gradient values. Several limitations are imposed by the existing databases, such as the lack of flexibility of the Petroldata file, and the unsurveyed areas in the GSC datasets. ZYCOR and CAD systems were used for numerous calculations in the production of the final maps.

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Quantitative assessment of hydrocarbon potential of Jeanne d'Arc Basin source rocks using geological and geochemical data

Rock-Eval/TOC analysis of cutting samples, taken at 10 m intervals from over 20 wells in the Jeanne d'Arc Basin, defines three zones with significant hydrocarbon source potential. These are the upper part of the Voyager Formation (Callovian-Oxfordian), the Egret Member (Kimmeridgian) of the Rankin Formation, and the upper part of the Jeanne d'Arc Formation (Tithonian). Of these, the Egret Member of the Rankin Formation has the greatest potential. Oil-source rock studies have indicated that with the exception of one restricted area, the Egret Member is the sole source of the Jeanne d'Arc Basin oil.

Combining geological and geochemical data for the Egret Member source interval enables a quantitative evaluation of the oil that could be geologically trapped within the Jeanne d'Arc Basin. To characterize the source rock and obtain parametric data for the calculations, isopachs and geochemical maps were constructed. Two different methods were used to calculate the potential oil yield of the Egret Member, a geochemical mass balance method and a more direct technique employing Hydrogen Index values. Both of these provided similar results. Allowing for expulsion, migration and trapping inefficiencies, our calculations indicate that the current best estimate of discovered recoverable oil reserves (195.2 million cubic metres, or 1.2 billion barrels) may represent as little as 10 per cent of the ultimate recoverable Jeanne d'Arc Basin potential. This figure does not allow for contributions from other source intervals.

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Organic sedimentology and source rock characteristics of Colorado shales, southwestern Alberta

The transgressive deposits of Albion to Turonian age that lie between the top of the Viking Formation and the top of the Second White Speckled Shale in southwestern Alberta comprise a diverse sequence of mudstones and argillaceous siltstones up to 175 m thick. A combination of Rock-Eval pyrolysis, stable isotope geochemistry, organic petrology and iron-sulphur studies has been used to characterize the organic constituents and to examine the relationship between depositional conditions and organic facies of these important petroleum source rocks. The vertical (stratigraphic) and lateral organic facies variations are interpreted in terms of both the paleo-oceanography and paleogeography. The kerogen, which has maximum concentrations of 4 per cent, is dominantly Type II. A good correlation is generally exhibited between total organic carbon (TOC) and hydrogen index (HI), typical of marine source rocks. The rocks within the lower portion of the study interval were deposited in a shallower and episodically higher-energy environment than those in the upper portion. The lower zone is relatively deficient in organic matter and the kerogen that is present is hydrogen-poor. The upper portion of the interval contains the richest source rocks. Within this upper zone, sub-intervals occur characterized by common, coarser interlaminations of both quartz silt and bioclastic limestone. TOC is low within the coarser laminae, however the organic matter within the adjacent mudstones is more abundant and more hydrogen-rich than that present in mudstones of more homogeneous sub-intervals.

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Recognition and correlation of reef interior carbonate cycles: production implications for Norman Wells, Northwest Territories

The Middle Devonian Norman Wells atoll reef complex contains 90 million cubic metres of original oil-in-place, of which production of approximately 5,000 cubic metres makes it the largest contributor of conventional crude for Imperial Oil.

Detailed description of 33 cores recovered from the reservoir increased understanding of the facies and stratigraphic framework of the reef. Horizontal and vertical heterogeneities within the Kee Scarp reef demand an integrated geological design and workover approach to enhance sweep efficiency. Reservoir heterogeneities are nowhere more prevalent than in the reef interior. The application of sequence stratigraphic concepts has resulted in the ability to differentiate and correlate significant surfaces within the thick monotonous succession of reef interior cycles. Groupings of four to seven stacked cycles, displaying an overall thinning-upward and shallowing-upward character, were correlated field-wide. The resultant reservoir framework constrains genetically-related facies distributions and spatially related reservoir units. Reservoir management is enhanced when this geological understanding is applied to workover strategies and reservoir pressure management, thus optimizing expected sweep of the reservoir.

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Reflection seismic interpretation of the Proterozoic geology; Colville Hills region, Northwest Territories

Subsurface Proterozoic strata in the Colville Hills region, Northwest Territories, occur in two major successions separated by a regional unconformity (C). The deeper succession, I, comprising three sub-units, is tentatively correlated with units mapped on Coppermine Homocline to the east. Succession II is correlated with the Mackerzie Mountains supergroup to the west, and the Rae Group to the east. Some sub-horizontal discordant reflections are considered to be intrusive sheets. Phanerozoic formations, unconformably overlying the Proterozoic, have not been examined.

Four compressional deforming deformational phases are inferred. First, large structures offsetting the deeper succession include rotated blocks, both eastward and westward verging, (vertical offsets of 5-6 km), and an anticline 20 km wide and 4 km high. The fault blocks are interpreted as being underlain by steep, curved, reverse faults that detach at a minimum depth of 14 km. They are truncated by unconformity C, but have a vertical post-unconformity reactivation of 1 to 2 km. Second, east-verging thrusts (maximum 6 km displacement) also offset unit I. They are flatter and shallower than the larger structures, and are considered to represent a separate phase of deformation. These may be related to a regional orogeny interpreted by F.A. Cook (1988), although cumulative displacements are measured in the order of 50 km, much greater than identified by him. Third, small thrust faults cut succession II. These features may be reactivated phase 2 structures although phase 1 structures were also reactivated at this time. A final deformational event affecting Phanerozoic and older strata resulted in the development of the structures that form the present-day Colville Hills.

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Elk Point Group strata of the Western Canada Sedimentary Basin

The Lower to Middle Devonian red beds, evaporites and carbonates of the Elk Point Group are widely distributed in western Canada. In the subsurface of the Interior Plains, they overlie rocks of Precambrian or Lower Paleozoic age with an erosional unconformity that includes considerable relief. The upper boundary of the Elk Point Group is drawn at the top of a thin, transgressive shale unit that is widely distributed in the subsurface of the southern Plains. In the northern part of the Interior Plains this shale unit is not present and the upper boundary coincides with the late Givetian hiatus.

Because the Elk Point Group includes several economically important mineral deposits, geologists have described a relatively large number of map units, both formal and informal. In order to summarize the depositional history of the Elk Point Basin from a new perspective, the succession is subdivided into six informal units. Each unit resembles a depositional sequence and includes a nearshore detrital, an evaporitic, a carbonate, and a basal shale facies. Some depositional sequences have a transgressive character, others are regressive.
The transgressive sequences onlap older paleotopographic or paleo-bathymeric high features. Prominent pre-Devonian high features are the Western Alberta Ridge, the Peace River Arch, the Tathom Uplift and the Keele Arch. Prominent paleobathymeric features are reefs, and include the Presqu'ile Barrier, Ram River Reef complex and the Rainbow, Horn Plateau, Methy and Winnigeposis reefmounds. These features are surrounded by nearshore flank deposits or evaporites.

The regressive sequences prograde seaward across the various basins and form laterally extensive carbonate platforms. The wedge composed of the Humen, Nahanni, Keg River and Winnigeposis formations is a prominent example.

An analysis of the small- and large-scale sedimentation patterns in the Elk Point Basin suggests that the sediments and evaporites were deposited during a general relative rise in sea level. The general rise is punctuated by a large number of small-scale fluctuations, and three basin-wide falls.

Two types of porosity exist in the reservoir rocks: 1) centimetre-scale reduced fracture porosity in brecciated areas, and 2) pinpoint to vuggy porosity in grainstone interbeds. The former is facies independent and termed fracture porosity, while the latter is facies dependent and termed grainstone porosity. Both types of porosity are partially to completely reduced fracture porosity in brecciated areas, and 2) pinpoint to vuggy porosity in grainstone interbeds.

The compilation of a new Geological Atlas of the Western Canada Sedimentary Basin is a multi-institutional, multi-disciplinary endeavour involving scores of individuals throughout the west – project sponsors, donors, patrons, parons of publications, participant’s employers, and on the order of 150 authors and contributors from industry, government and academia. Initiated in 1986, the project is scheduled for completion in 1991.

The stated objective of the project is “as a community of geologists in Western Canada, to compile and produce a new atlas of the subsurface geology of the Western Canada Sedimentary Basin”. There are two overall objectives: 1) to establish an electronic database of consistently interpreted subsurface information, with associated data processing capability; and 2) to produce a printed volume, published jointly by the Canadian Society of Petroleum Geologists and the Alberta Research Council.

The printed Atlas volume will contain 20 chapters dealing with individual cross-basin stratigraphic slices, three chapters on the Phanerozoic history of discrete tectonic domains (arches and sub-basins), and 14 chapters outlining modern thinking on the geological processes that gave rise to the strata and their contained resources. The essential elements of the individual chapters are: maps (1:5,000,000) of structure and paleogeology, isopach and lithofacies, and basic paleogeography; master stratigraphic sections, along regional lines that are common from one chapter to the next; discretionary cross-sections and maps, as examples of the facies-scale character of strata; reference logs and correlation charts; and a limited amount of explanatory text. The electronic version of the Atlas will contain the stratigraphic picks from all of the selected Atlas control wells, together with digital versions of the contour maps and regional structural sections. Software for processing the Atlas data also will be made available.

The new Atlas is based on subsurface information distilled from over 200,000 wells. With modern computer data processing, coupled to vital human verification, correction and interpretation, the new compilation is designed to achieve a level of rigour and comprehensiveness that should bode well for significant advancements in our regional understanding of the geology.

This Middle Ordovician succession of bioclastic carbonate mudstones, wackstones, packstones and grainstones represents deposition in typical supratidal through shallow subtidal settings. Overall, these strata are interpreted as an upward-deepening sequence. As depth increased during subsequent deposition of the Blue Mountain shales, the Trenton-Black River carbonates were cemented by shallow burial, non-ferroan cements and then later by ferroan burial calcite cements. These occur as finely crystalline isopachous rims around grains, syntaxial overgrowths on echinoderm fragments, and equant sparry cements occluding remaining pore space. This latter is the most important volumetrically. Further burial resulted in minor pressure solution followed by pervasive dolomitization. Porosity developed in limestones adjacent to fractures developing in this progressively buried sequence.

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### Fracture-related diagnosis as a control on Middle Ordovician carbonate reservoirs, southwestern Ontario

One half of the producing wells in southwestern Ontario were drilled into Middle Ordovician carbonates of the Trenton and Black River groups in the Michigan Basin. Production occurs where these limestones have been fractured in the vicinity of the southwest to northeast trending Algonquin Arch.

This Middle Ordovician succession of bioclastic carbonate mudstones, wackstones, packstones and grainstones represents deposition in typical supratidal through shallow subtidal settings. Overall, these strata are interpreted as an upward-deepening sequence. As depth increased during subsequent deposition of the Blue Mountain shales, the Trenton-Black River carbonates were cemented by shallow burial, non-ferroan cements and then later by ferroan burial calcite cements. These occur as finely crystalline isopachous rims around grains, syntaxial overgrowths on echinoderm fragments, and equant sparry cements occluding remaining pore space. This latter is the most important volumetrically. Further burial resulted in minor pressure solution followed by pervasive dolomitization. Porosity developed in limestones adjacent to fractures developing in this progressively buried sequence.

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related to oxic, dysoxic, and partially anoxic organic associations. These variations in organic facies reflect source-rocks of Kerogen Type IIA-IIB, IIB-IIB, II-B, III, and IIIIV. Liquid chromatography, isotope and gas chromatography of both low and high molecular weight hydrocarbons of the source rock extract, condensate, and crude oil show various types of organic input classifying them into different families. Fluorescence data indicate a high extension of the oil-wet gas-floor in the overmature (>1.4% Ro) zone, below 5400 m, because of overpressuring. Relationships between gas generation, vitrinite reflectance, and overpressuring are re-evaluated.

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Beaverhill Lake Group strata of the Western Canada Sedimentary Basin

Sediments of the Beaverhill Lake Group were deposited following a relative sea level rise during the Late Givetian. An extensive carbonate platform known as the Slave Point Formation developed, upon which grew the cyclic platform reefs of the Souris River Formation in northeastern Alberta and the southwest part of the Northwest Territories. Peace River Arch. A barrier reef development approximately coincided with the underlying Givetian Elk Point Group barrier reef complex, forming the “Presqu’ile Barrier” of northeast British Columbia, northwest Alberta and the southwest part of the Northwest Territories.

The basin was subsequently infilled by argillaceous carbonates of the Waterways Formation, which depositionally onlap pre-existing reef margins. This formation is subdivided into five members, which are regionally correlatable throughout Alberta, and are equivalent to the restricted marine carbonates and evaporites of the Souris River Formation in Saskatchewan and Manitoba.

Beaverhill Lake Group reefs host prolific hydrocarbon reservoirs, such as Swan Hills, Peace River Arch fringing reefs, and the barrier trend of central Alberta. Several backstepping reef margins flanked the emergent Peace River Arch. A barrier reef development approximately coincided with the underlying Givetian Elk Point Group barrier reef complex, forming the “Presqu’ile Barrier” of northeast British Columbia, northwest Alberta and the southwest part of the Northwest Territories.

Regional stratigraphic cross-sections illustrate the difficulty of utilizing lithostratigraphic information for chronostatigraphic correlations. Our well file databases should be modified to better accommodate stratigraphic principles defined by time rather than “tops”.

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Reservoir quality and architecture of tidal inlet sandstones, Halfway Formation, northeastern British Columbia

A subsurface investigation of the mid-to-Upper Triassic Halfway Formation in northeastern British Columbia has identified a series of wave-dominated tidal inlet sandstones associated with transgressive and prograding barrier island shoreline trends. Depositional mode facies reconstructions were based on sedimentological analysis of approximately 60 cored sequences and 1,200 wireline logs within the Halfway.

Tidal inlet sequences are very fine to coarse grained quartzose sandstones ranging from 4 to 10 m in thickness. Facies with greatest reservoir quality are contained within the lower half of the sequence. Fine to medium grained, stacked, fining-upward units with scoured lower contacts and planar to trough crossbedding characterize this facies. Molluscan shell moulds and casts can compose up to 60% per cent of an inlet sequence. Porosity is about 25% per cent associated with these coquinas.

The upper half of most sequences is a planar to ripple laminated and burrowed (Skolithos), fine grained sandstone of poorer reservoir quality. Where preserved, the uppermost 0.5 to 1.0 m is interbedded with backbarrier sandstones and mudstones that are wavy, bedded, and burrowed. The mudstones serve as an important stratigraphic seal. Bedding plane surfaces display symmetrical ripples, desiccation cracks, algal laminae and root casts. These mudstones are interpreted as being of hypersaline lagoonal origin.

Tidal inlet sequences have a laterally discontinuous basal lag deposit (0.1 to 0.2 m thick) of poorly-sorted, pebbly sandstone and angular mudstone rip-up clasts. The lags are formed by current scour and transport at the base of the inlet channel. As a result, the basal contact of the inlet sequence forms an erosional unconformity with underlying shoreface sandstones of the Halfway, or silty shelf sandstones of the Doig Formation. Overall, bed thickness, grain size, and frequency of cross-bed sets decrease upward. Deposition in a laterally accreting channel by wave and tidal processes is indicated by the following: 1) an upward decrease in bed thickness, grain size, and frequency of crossbed sets; 2) the lack of a mud plug; and 3) the presence of associated backbarrier facies. Relative to the paleo-strandline, the orientation of Halfway tidal inlet deposits is a function of the: 1) temporal landward or seaward migration of the barrier shoreline; 2) sediment supply to the littoral zone; and 3) downdrift tidal inlet migration. The best modern analogues to the observed halfway tidal inlet sequences and geometries are mixed energy, wave-dominated barrier shorelines of New Brunswick, Canada and North Carolina, U.S.A.

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Geology and diagenetic history of overpressured sandstone reservoirs in the Venture Gas Field, offshore Nova Scotia, Canada

Overpressured formations with pressure gradients of nearly twice the normal hydrostatic gradient occur over an area of approximately 10,000 km2 in the Scotian basin, offshore Nova Scotia. In the Venture Field, the overpressured zone is confined below a depth of 4,500 m, and contains prolific gas-condensate sandstone reservoirs and hydrocarbon source shales of Late Jurassic-Early Cretaceous age. The Venture Field exemplifies a high-pressure overpressured system developed within normally compacted strata. Late hydrocarbon generation and migration at depth are chiefly responsible for the overpressuring.

Venture overpressure differs from U.S. Gulf Coast-type overpressure in that the former occurs within normally compacted shales interbedded with thick, vertically-stacked sandstone reservoir beds.

The diagenetic history of the shales and sandstones in the Venture Field has been investigated through petrographic and SEM work. Clay studies show the overpressured shales are well indurated and display similar composition and texture above and below the onset of overpressure. Progressive shale diagenesis over time with compaction has led to total loss of permeability. The overpressured sandstones exhibit textures and fabrics diagnostic of normal compaction with secondary reservoir porosity developed at depth via leaching of aluminosilicates and pore-filling calcite cement. Three depth levels of secondary porosity generation are recognized across both normally and abnormally pressured strata.

Hydrocarbon generation and migration lead to pore pressure buildup at depth and are postulated to be the main driving force behind Venture-type overpressure. Peak gas generation was initiated late in the compaction history of the basin. Diagenetic seals, such as impervious shales, sandstones and limestones, within and above the zone of peak gas generation ("hydrocarbon cooking machine"), are believed to behave as aquitards ("pressure cooker"). This results in net increments in rock pore pressure and the establishment of an overpressured zone.

The recognition of Venture-type overpressure is important in that it provides clues as to the mechanisms of hydrocarbon generation and migration in the basin. It also defines a model that may assist in understanding overpressured regimes in other frontier basins.

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Middle Ordovician to Silurian strata of the Western Canada Sedimentary Basin

This stratigraphic package corresponds to the Tippecanoe Sequence but includes older and younger rocks in the mountains. Its present distribution is severely constrained by erosion prior to the sub-Devonian Unconformity. The entire package is missing from virtually all of the basin north of the Meadow Lake Escarpment, and locally the Devonian rests directly on Precambrian. The base of the package is a regional unconformity (on Deadwood, Franklin Mountain and Precambrian units) except in the Rocky Mountains, where it is conformable with the McKay and Keckha groups. Unconformities are also present within the package, with significant downcutting in the extreme northwest.

The outcrop sequences of British Columbia, Mackenzie and Alberta disappear abruptly eastward in the subsurface below the sub-Devonian Unconformity. Nonda carbonates (up to 270 m) are the only rocks with any significant subsurface distribution. Preserved in the subsurface of southern Saskatchewan and Manitoba are a basal arenaceous unit...
ABSTRACTS

The stratigraphic package is thickest (about 500 m) in southeastern Saskatchewan adjacent to thicker developments in Montana and North Dakota. Above the Winnipeg (up to 75 m), the Red River, Stony Mountain, Stonewall, and Interlake units represent subtidal to supratidal environments with deposition of small water carbonates. Thin evaporitic, argillaceous and sandy intervals provide stratigraphic marker horizons that can be traced for considerable distances in the subsurface.

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Diagnosis of the Charlie Lake Formation, northwest Alberta

The Charlie Lake Formation (Carnian) of the Peace River Arch area has a complex depositional and diagenetic history. The Charlie Lake sediments were deposited in tidal and associated environments in a nearshore setting. Lithofacies commonly consist of shallowing-upward sequences of subtidal, intertidal, and supratidal sediments. These sediments are predominantly dolomite, stromatolitic carbonate, reddish fine-grained sandstone and siltstone, and massive and interbedded anhydrite.

Porosity development in the Charlie Lake sediments ranges from 0 to 20 per cent. The best porosities and permeabilities are often associated with relatively large crystal sizes in dolomites and algal mats. Fracturing and faulting also played a major role in porosity development by serving as conduits for undersaturated ground water solutions.

Good porosity and permeability are also associated with the fine grained sandstone restricted mainly to the upper half of the Charlie Lake Formation. Sandstone porosity is commonly patchy and formed as a result of the dissolution of feldspar and other unstable mineral grains, as well as cements.

Diagenetic modifications of the Charlie Lake sediments include dolomitization, minor silica replacement and cementation, carbonate and anhydrite cementation, and dedolomitization. Gypsum ghosts in anhydrite indicate that at least part of the anhydrite was deposited subaqueously. Dedolomitization fabrics include 1) incomplete replacement of dolomite crystals by calcite; 2) polycrystalline rhombic pseudomorphs of calcite after dolomite; 3) rhombohedral pores; and 4) calcite zones in dolomite crystals.


The Mississippian Peace River Embayment: the influence of the Peace River Arch upon Banff and Rundle Group deposition

Two tectonic episodes are associated with the Peace River Arch during deposition of the Mississippian Banff and Rundle groups. Each of these episodes gave rise to local basin developments, collectively known as the Peace River Embayment, which were subsequently infilled by shallow-upward carbonate sequences.

The first Mississippian basin developed between the lower and early middle Touraisian and was infilled by the Lower to mid-Banff units. The basin had an east-west axis and opened toward the west. Lower Banff carbonates and fine grained terrigenous clastics formed a series of south-westernly prograding clinoforms produced by the lateral migration of upper, middle, and lower slope deposits. These carbonate units encircled the embayment and passed into basinward shales toward the centre. The Middle Banff consists of shallow carbonate platform deposits, and the Upper Banff of supratidal carbonates and silicilastics. These units prograde over the Lower Banff deposits with little evidence of local basin influence.

The second episode of basin formation occurred during a time of regional subsidence and transgression in the late middle Touraisian to the late Mississippian. This episode marks the basin by an episode of the Rundle Group in this area. The resulting basin was more local in its development than the Banff embayment. It was semi-enclosed and had an east-west axis of development that approximated the axis of the Banff embayment. Pekisko platform carbonates encircled the basin while deeper water carbonates, shales and silicilastics locally infilled the basin. The Pekisko Formation is overlain by the regressive shallow water and supratidal carbonates, anhydrites and silicilastics of the Shunda and Debolt formations.

The depositional and structural axes of these basins were developed to the north of the axis of the Devonian Peace River Arch. The Devonian axis remained stable during Banff and Rundle Group times, and basin subsidence was centred on the Peace River Arch northern boundary fault. This fault marks the northern margin of the Peace River Arch throughout the Devonian.

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The distribution and origin of Bluesky and Gething facies (Lower Cretaceous) in the region of the Peace River Arch

Depositional facies and facies sequences in the Gething and Bluesky alloformations of northwestern Alberta are documented in the region of the Peace River Arch. Facies variation is interpreted in terms of relative regional sea level rise and local tectonic influence due to the reactivation of the Peace River Arch and associated structures.

Gething sediments record the slow relative rise in sea level of the southwestern transgressing Boreal Sea. They begin with mainly fluvial and delta plain sediments, which become interstratified with brackish, intertidal, and marine shoreface units in the upper part of the formation. The main body of the Gething was deposited in a broad, northwest-southeast trending trough; at the eastern edge of this trough, a transgressive estuarine system was developed during deposition of the upper Gething. A regionally extensive transgressive erosion surface forms the bounding discontinuity between the Gething and the overlying Bluesky Formation.

The Bluesky Formation is an allostratigraphic unit that records a period of stillstand. The formation consists mainly of storm-dominated shallow shelf sandstones, with local shoreface development in the transgression of the Moosonee Sea; the upper surface of the Bluesky is a transgressive erosion surface with an associated marine lag deposit, and is overlain by marine Meesebar/Wilrich Formation shales.

Local subsidence in the area overlying the Peace River Arch appears to have led to anomalously east-west thickening of the Gething Formation. Later subsidence during Bluesky deposition may have caused the localization and preservation of shoreline deposits. The eastern extent of the sub-basin in which the units were deposited is limited by a northwest-southeast trending high, which may be associated with the rejuvenation of an underlying basement structure.


Structural controls upon sedimentation in the Peace River Arch region

The Peace River Arch (PRA) is a major northeast-southwest trending crustal structure in northwest Alberta consisting of uplifted Precambrian igneous and metamorphic rock. The feature has strongly influenced Phanerozoic structure and sediment distribution. The PRA was a positive feature during the early Paleozoic; its trend was imposed upon the pre-existing, north-northeast trending basin-structural fabric created by the accretion of several terranes during the Precambrian.

Contacts between these lithologically distinct terranes are probably deep-seated crustal fault zones or geosutures, representing sites of reactivation throughout the Phanerozoic.

The PRA has an asymmetric north-south profile, with a steeply dipping northern flank and a more gently dipping southern margin. The northern edge is marked by a distinct east-northeast - west-southwest fault zone, here referred to as the northern boundary fault (NBF). The NBF defines the northern limit of recognizable PRA structural influence, which includes: 1) Granite Wash and Gilwood clastic distribution; 2) location of the northern margin of the Ledue fringing reef trend; and 3) location of the structural and depositional axes of the Peace River Embayment of early Mississippian age. Since the late Mississippian (Stoddart Group), the NBF appears to have remained inactive. Elsewhere in the region, pre-existing basement, and superimposed PRA structural and depositional trends have influenced: 1) the overall structural offset of the PRA into eastern and western blocks; 2) the east-west dispersal pattern of the Granite Wash clastics; 3) the Danvegan fault zone (including the location of the Sturgeon Field); 4) the Wabamun dolomite trend; 5) the eastern margin of the Permo-Triassic basin; and 6) the Cretaceous Fox Creek Escarpment.

Available data suggest that following latest activity of the NBF, the axis of the Peace River Embayment moved southwards and became more NE-SW in orientation. This shift aligned it parallel to the Devonian PRA crest and the future axis of the Cretaceous deep basin. The nature of the NBF is poorly understood at this time, although this zone probably provides the key understanding the origin of the PRA.

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A detailed core and well log study of the Viking sediments in the Crystal field reveals three broad facies associations: 1) fluvial and tidal sandstone and conglomerate; 2) estuarine sandstone; and 3) estuarine mudstone. These three facies associations combine to form two separate cut-and-fill deposits (No. 1 and No. 2) within the Crystal valley-fill.

Fill No. 1 consists predominantly of facies associations (2) and (3), and is observed in the majority of Crystal cores. From bottom to top, fill No. 1 consists of fluvially derived estuarine sands, central basin estuarine muds, and marine-sourced estuarine sands, forming an excellent transgressive vertical facies sequence. Laterally, the fluvially derived estuarine sandstones are concentrated in the southern part of Crystal, while the estuarine muds are located in the north. Both the vertical and lateral contacts between facies associations (2) and (3) are gradational.

In contrast to fill No. 1, fill No. 2 consists primarily of facies association (1) and is confined to a relatively narrow area within the valley margins. The fluvial sands and conglomerates are located in the southern part of fill No. 2, while the tidal sandstones and conglomerates are located farther north. Sharp vertical and lateral contacts are observed between fill No. 1 and fill No. 2.

The two cut-and-fill deposits at Crystal are encased by bounding discontinuities. These surfaces provide a record of relative sea level fluctuations during the Viking interval and, therefore, add to our understanding of the Viking allostratigraphy. Future work will attempt to correlate these surfaces with other bounding discontinuities in Viking valley-fill deposits.

An integrated work-study project of the Winnipegosis Formation in the Tableland area of southeastern Saskatchewan (Poster)

The Upper Winnipegosis Formation of the northeastern portion of the Williston Basin has been the subject of considerable exploration interest over the past five years. The prediction and delineation of these carbonate mound / pinnacle reef features has, however, proven difficult. The objective of this display is to generate an integrated study of the Winnipegosis anomaly in the Tableland area of southeastern Saskatchewan using workstation technology. The Tableland prospect is ideally suited to this type of study as quality data such as well log digits, and 2D and 3D seismic exist over the anomaly. This display recreates the exploration history of this area from regional 2D seismic exploration and wildcat drilling, through the acquisition of 3D seismic and subsequent development drilling. The manner in which geological lithofacies are related to seismic amplitudes and complex attributes is examined at well locations, and subsequently correlated throughout the seismic coverage of the prospect. Time to depth conversions and seismic techniques are incorporated through all phases of the study in order to maintain an integrated model of the anomaly. Final prospect structure, isopach, and reserve estimate maps are then generated using the capabilities presently available on a standard geophysical workstation.

Jurassic (“Fernie-Kootenay”) strata of the Western Canada Sedimentary Basin

The transition from platform/mio-geocline to orogenic foreland basin occurs within the Jurassic. It is marked in the west by a change in sediment source from cratonic (east) to orogenic (west) in the Upper Jurassic, and by subsidence of the foredeep. To the east, the Williston Basin is characterized in the Middle Jurassic by pronounced downwarping and eventual inversion in the Upper Jurassic.

Seven stratigraphic packages are regionally significant in the Jurassic databases. From youngest to oldest, these are:

7. Kootenay, Nikanassin, Minnes, Success, “Detrital”, Waskada (part) (package includes some lowest Cretaceous strata);

6. Green beds, upper Fernie shale, Swift, Masefield (= upper Vanguard), Waskada (part);

5. Grey beds and equivalents, Riorden, Roseray (= middle Vanguard), Rush Lake, upper Melita;

4. Highwood, Sawtooth, Shaunavon, upper Gravelbourg, lower Melita;

3. Rock Creek, lower Gravelbourg, Reston, upper Wairous, upper Amaranth;

2. Poker Chip shale;

1. Nordegg, Red Deer, and associated units of the Fernie Formation.

The Lower Jurassic packages (packages 1,2) are thin, starved shelf deposits with many discontinuities, deposited only on the western mio-geocline and adjacent shelf. The early Middle Jurassic strata (3) are clastic in the west, but in the Williston Basin (where they are the oldest Jurassic strata), they contain evaporites and limestones. Younger Middle Jurassic beds (4,5), somewhat thicker, are shale, with minor sandstone and limestone. The first deposits in the foredeep are the Green beds of the Fernie Formation (6), a starved shelf assemblage overlain by a coarsening- and shallowing-upward foredeep-fill succession. Equivalent strata farther east on the craton are the Swift and Masefield formations. The youngest strata (packages 6,7), continuous into the Early Cretaceous, constitute the first of several Mesozoic foreland-basin clastic sequences.

Jurassic, northeastern British Columbia and northwestern Alberta

The Jurassic of northeastern British Columbia and northwestern Alberta consists of two parts separated by a disconformity, at which the Middle Jurassic is absent or reduced north of about 54°N latitude. The magnitude of the hiatus (presumably indicating uplift) between the stable craton deposits below (Lower Jurassic) and the initial deposits of the Columbian foredeep above (Upper Jurassic), is thus much greater than it is farther south in the Western Canada Sedimentary Basin.

The lower package is a thin, starved shelf succession of cratonic platform/mio-geocline origin, disconformably overlying a relatively smooth surface on top of Upper Triassic rocks in the west and Carboniferous rocks in the east. Over most of its subsurface distribution, the lower package is platy, organic-rich, dark, phosphatic siltstone, generally (but incorrectly in strict terms) referred to the “Nordegg Member” of the Fernie Formation. In the Rocky Mountain Foothills to the west, additional beds near the base of the Jurassic yield Lower Hettangian ammonites, while a platy, dark siltstone unit (perhaps equivalent to the northern subsurface “Nordegg” of common usage) contains Pliensbachian ammonites.

The upper part (Upper Jurassic) is a thin, widespread shale-sandstone package over most of its subsurface extent. It thickens dramatically westward within the Rocky Mountain Foothills, where both cherty, orogenically (westerly) derived foredeep-fill deposits and quartzose, cratonic (easterly) derived sandstones are present. In outcrops in northeastern British Columbia, a thin, dark, upper Fernie shale is overlain gradationally by the Monteith Formation (sandstone). The Jurassic-Cretaceous transition is low in the Monteith. In the adjacent subsurface, and southward within northeastern British Columbia and western Alberta, this interval is generally referred to as the Nikanassin Formation.

Cordilleran tectonics and the evolution of the Western Canada Sedimentary Basin

The Western Canada Sedimentary Basin (WCSB) is the thinnest part of the same northeast-tapering wedge of supracrustal rocks that forms the eastern part of the Cordillera. The deformed southwest part of the wedge is an accretionary prism. It was scraped off the under-riding North American plate, and was tectonically prograded northeastward while an over-riding collage of tectonic flakes, comprising various displaced terranes, converged obliquely with North America. Palinspastic reconstructions of the accretionary prism provide the framework for stratigraphic analysis of the pre-collisional tectonic history of the continental margin, and of its implications for the concurrent tectonic evolution of the WCSB.

Subsidence and uplift in the basin were controlled mainly by isostatic flexure of the Early Proterozoic continental lithosphere in response to “loads” created by changing plate tectonic regimes at the continental margin. Late Proterozoic rifting defined the configuration of the margin.
sub-Cambrian "break-up" unconformity marks the rift-drift transition. Cambrian to Middle Ordovician passive margin thermal subsidence ended with Middle Ordovician Middle Devonian unstable shelf deformation (block faulting with >5 km of local sub-Fairholme stratigraphic relief), which was accompanied by widespread epeiric basin and arch formation on the North American craton, and was associated with the establishment of an unstable outboard volcanic arc and marginal basin regime that persisted until terrace accretion began.

Westward subsidence of the floor of the marginal basin and of the
eastern part of the continental terrace sedimentary prism during Early and Middle Jurassic time resulted in the collapse of the marginal basin and the obduction of marginal basin and oceanic arc strata, but had little effect on the WCSD. Late Jurassic-Early Cretaceous left-hand oblique
terrane convergence involved tectonic wedging of dislocated terranes between the North American supracrustal rocks and their crystalline basement.

It produced tectonic thickening along the continental margin, iso-

discontinuity of the North American lithosphere, and a broad foreland basin that extended from Montana to Alaska, and far into the WCSD. Late Cretaceous to earliest Eocene right-hand convergence between North America and the displaced terranes was transformed, north of 54°N, into strike-slip on the Tintina-Northern Mountain Trench fault system. A large accretionary prism, involving substantial crustal thickening and deep foreland basin subsidence, formed south, but not north of 54°N, until unloading and large crustal flexuring within the accretionary prism and the foreland basin was greatest during the Early and Middle Eocene (59-42 Ma) when the strike-slip faulting was transformed into right-hand transtension of the Cordillera south of 54°N. However, it also continued after 42 Ma when the North American plate boundary had shifted to the vicinity of the present continental margin.

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Lower Devonian reefs, Disappearance Bay Formation, Arctic Islands

The Disappearance Bay Formation (Emsian) on Lowther Island, North Slave Territorities, consists of an >5 to 90 m thick sequence of upward-shoaling limestones and dolomites. Within the upper two thirds of the formation, exhumed reef mounds, about 50 m thick, are exposed. Four principal, vertically-successive reef facies can be distinguished: a basal stromatolite mudstone-wackestone; an allegedly-bound wackestone; a stromatoporoid-coral framestone; and a capping, crinoidal grainstone. Reef growth occurred in response to passive sedimentary shoaling, with the reefs nucleating upon small mounds of aggregated brachiopods. Following deposition of a thin stromatolite-mudstone, a thick sequence of dominantly algally-bound wackestone accumulated on the reefs. Ubiquitous, heavily-dispersed, large fibrous calcite cements within this wackestone can be shown to be early replacement products after algal crusts, on the bases of overgrowth relationships, fossil inclusions, cathodoluminescence, algal and other criteria. Steeplly dipping, reef-flank deposits are also accumulated at this time and show evidence of over-

steepening through syndepositional fissuring. With the transgression of an unknown age, reef deposition changed dramatically to a stromato-

poral-coral framestone. Thin, capping, crinoidal grainstones indicate reefal senescence at the end of Disappearance Bay deposition. Partially

penetrative dolomitization, affecting only the uppermost reef facies and margins, occurred under shallow burial conditions.

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Evolution of the Sawn Lake Reef Complex, Middle Devonian, Slave Point Formation, northwestern Alberta

The upper Givetian Slave Point Formation of the Sawn Lake area reflects four major shoaling-upward stages or cycles of sedimentation. Each stage occurred in response to accelerated rates of relative sea level rise and subsequent stillstand.

The four stages correspond to two major depositional units, which abruptly overlie the laminated platform carbonates of the basal Slave Point Formation. The first stage, equivalent to the Biostromal unit, is characterized by increased algal growth and a poorly defined lateral zonation of facies. The second, third and fourth stages, which make up the Reef unit, are commonly separated by subtidal marine hardgrounds and a mas-

sive deeper water facies. Each of these stages is represented by a range of laterally correlative facies, including reef interior to foreslope and basininal limestones. The second stage is marked by progradation of the reef margin and represents the period of optimum growth for the carbonate complex. The best porosities are developed in the higher energy environments, typically the reef margin. Reef interior sediments com-

prise smaller-scale shoaling-upward cycles consisting of subtidal and tidally-influenced facies. The third and fourth stages of the Reef unit correspond to a backstepping of the reef margin and an area of carbonate sediment production in comparison to the second stage.

Shoaling-upward stages govern the distribution of reservoir-quality depositional facies; therefore, the recognition and delineation of these stages may better define reservoir continuity.

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Viking Formation strata of the Western Canada Sedimentary Basin (Poster)

The Viking Formation consists of an interbedded succession of mud-

stone, bioturbated muddy sandstone, sandstone, and conglomerate encased in thick marine shales of the Middle to Late Albian Lower Colorado Group. The formation ranges from 20 to 35 m thick in the central part of the basin, increasing to 50 m in the southwest, where it merges with the Bow Island Formation in southern Alberta, and is indistinguishable from the Blairmore Group westward in the Foothills Belt. The Viking thins rapidly in subcrop northward to the eastern margin of the basin, tending to "shale-out" almost completely in some regions. Strata correlate with the Viking interval north of the Peace River Arch include the Puddy Member of the Peace River Formation (approximately 15 m thick and dominated by sandstone), and the Pelican Sandstone in northeast Alberta.

The Viking Formation has previously been interpreted as comprising a single clastic wedge that prograded basinward in response to orogenic activity to the west. It can be demonstrated that the Viking consists of at least two principal stratigraphic sequences separated by a major unconformity. The lower progradational succession (highstand systems tract) consists of a sequence of stacked coarsening-upward shelf-to-shoreface units. The upper succession records transgressive depositional conditions punctuated by lowstand intervals, with a ravinement surface superimposed on an unconformity at the base. This separates the highstand systems tract from the overlying lowstand and transgressive systems tracts. In the distal or central part of the basin, lowstand and transgressive deposits consist of thin interbedded units of layered mudstone-sandstone, sandstone and granular sandstone-conglomerate. Near the western margin of the basin, antecedent linear valleys are filled with thick eustatic sediments deposited during the transgression.

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Tectonic and depositional history of the Early Carboniferous Peace River Embayment, Alberta and British Columbia (Poster)

The Early Carboniferous Peace River Embayment, which opened northward into Prophet Trough, was a broad, fault-controlled re-

entrant in the western cratonic platform. An anomalously thick succes-

sion of Lower Carboniferous siliciclastics and ramp-to-platform carbonates was deposited along the embayment's axis, which generally lay slightly north of the Late Devonian Peace River Arch. The Sukunka Uplift, extending southeastward from the western Peace River Embayment, partly restricted the embayment's connection with the Peace River Arch. Embayment development began with late Famennian to

Early middle Tournaisian blockfaulting during deposition of the Exshaw Formation and overlying Banff Formation. The embayment, clearly differen-
tiated by the late Tournaisian, was probably best developed during deposition of the upper Viséan and Serpukhovian Stoddart Group.

The Carboniferous succession records four principal episodes of block-

faulting: 1) after deposition of the upper Famennian Exshaw Formation, 2) during sedimentation of the middle Tournaisian Lower Banff Formation, 3) during and after deposition of the upper Viséan Golata Formation, but prior to that of the upper Viséan Kiskatinaw Formation, and 4) after deposition of the upper Viséan to Serpukhovian Taylor Flat Formation. The first phase of blockfaulting began with the late Tournaisian blockfaulting during deposition of the Exshaw Formation and overlying Banff Formation. The embayment, clearly differentiated by the late Tournaisian, was probably best developed during deposition of the upper Viséan and Serpukhovian Stoddart Group.
Carboniferous and uppermost Devonian strata are mapped from southwestern Manitoba into southwestern District of Mackenzie. Carboniferous tectonic elements included the Prophet Trough, Peace River Embayment, cratonic platform, and the intracratonic Williston Basin. Transgressive basal deposits in the southwestward-thickening package (over 1850 m thick in the west) disconformably overlie Fennian strata, and are overlain by a progradational sequence containing second- and third-order, transgressive/regressive cycles corresponding largely to the units mapped. Late Carboniferous and subsequent erosion removed much of the succession. Remaining deposits, bevelled northeastward below Permian and Mesozoic strata, range from uppermost Fennian to Mississippian in the west and uppermost Fennian to Viséan elsewhere.

The succession is divided into three principal map units that are separated locally by unconformities and consist of basinal-to-supratidal deposits. From east-central British Columbia to southeastern Yukon, these three map units overlie and pass southwestward into basinal shale deposits. From east-central British Columbia to southeastern Yukon, these three map units overlie and pass southwestward into basinal shale deposits. From east-central British Columbia to southeastern Yukon, these three map units overlie and pass southwestward into basinal shale deposits.
distributed as an extensive blanket sand with an overall north-south linear arrangement. The unit displays a high degree of consistency over a geographically extensive area and is believed to record the regressive advance of an ancient tidal flat. Reservoir-quality sands have been preserved in the lower part of the unit, which likely was deposited by a system of rapidly migrating tidal channels. Most of the original porosity has been occluded by syntaxial quartz overgrowths, such that the maximum preserved porosity rarely exceeds 14 per cent. Associated permeabilities are moderate, commonly approaching or exceeding 50 millidarcies.

Although the presence of hydrocarbons was detected in earlier boreholes, the commercial significance of the pool was not demonstrated until MLC and its partner DeKalb completed the drilling of nine wells during the past three years. The limits of the pool have yet to be accurately defined, but appear to be controlled by a regional updip shaleout and a downdip loss of permeability resulting from excessive induration. Discontinuities within the pool have been observed where younger channels, infilled with relatively impermeable material, locally cut the blanket sandstone. The reservoir appears to be ubiquitously gas-saturated and no true updip water has yet been encountered.

A gas field covering at least 64 km² (25 sq. miles) is indicated by the present well control, from which an estimated 1.8 billion cubic metres (60 BCF) of sweet gas may be recovered.

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Deep crust and basement structure of the Peace River Arch

The crystalline basement of the Peace River Arch (PRA) is characterized by north trending, curvilinear aeromagnetic highs and lows. These correspond to distinct tectonic domains that have been recently “mapped” and subdivided using potential field data and U-Pb geochronology of samples from cored basement. From east to west, these domains are the Buffalo Head Terrane (2.32-1.99Ga), Chinchaga Low (2.17-2.08Ga) and the Kstuan High (1.99-1.90Ga). The juxtaposition of these domains is believed to be the result of tectonic collisions that occurred between 2.0 and 1.9Ga, as these tectonic elements were accreted to the western edge of the Canadian Shield.

Recent seismic refraction studies have confirmed the earlier interpretation of low pass filtered gravity anomaly data that indicated no dramatic crustal anomaly associated with the PRA. The refraction data also demonstrate a slight thinning of the crust along the axis of the arch (approx. 44-38 km), the presence of gently outward-dipping (away from the Arch) lower crustal structure, and the presence of several kilometres of intermediate velocity lower crust beneath the Arch.

The magnitude and wavelength of the PRA and its orientation at a high angle to basement fabric suggest that its origin lies at the crustal or lithospheric scale. The presence of intermediate velocity lower crust has been interpreted as reflecting the presence of mafic sills that may be the mark of a thermal driving force for the anomalous behavior of the PRA. At a smaller scale, it appears that basement anisotropies between and within domains have acted to localize sedimentation and diagenetic processes in the area (i.e. the Watson dolomite trend, Tangenter-Normanville reservoirs and the marked reentrant in the South Kaybob reef complex).

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Geophysical expression of the Western Canada Sedimentary Basin – implications for crustal structure and tectonic assembly of the crystalline basement

The mosaic of crustal domains comprising the Canadian Shield extends westward beneath the prairies to form the foundation of the Western Canada Sedimentary Basin (WCSB). Extrapolation of Shield domains and tectonic relationships into the subsurface is provided by interpretation of potential field data (aeromagnetic and gravity anomalies) and isotopic studies of cored basement (U-Pb and Nd-Sm) of the WCSB.

The western Canadian Shield, including that beneath the WCSB, can be viewed as several Archean “nuclei” or continental blocks (Superior, Rae, Hearne and Slave Provinces) that have been brought together and locally modified during Early Proterozoic collisional tectonics. The inferred history of collision is recorded by relative plate motion and going structural discontinuities such as the Tabbernor Fault, Hay River Fault and Snowbird Zone that extend beneath the WCSB. The Trans-Hudson Orogen is a complex belt of Early Proterozoic crust in Manitoba and Saskatchewan that comprises the orogenic belt between the Superior Province and the Hearne Province. The Rae Province in northeastern Alberta was the western cratonic edge along which terranes of central and western Alberta were accreted during the Early Proterozoic.

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Basement structure, in-plane stresses and the rise and fall of the Rimby-Meadowbrook trend

The curvilinear reef trends of the Middle to Late Devonian of the Alberta Basin, such as the Rimby-Meadowbrook trend, are, in addition to hosting prolific hydrocarbon reservoirs, some of the most enigmatic structures in the basin. The reason why the Alberta Basin underwent rapid evolution from a nearly featureless carbonate shelf to a mosaic of reefs and basinal sediments remains unknown. The recently documented anisotropic nature of the basement suggests that some basement weaknesses may have been susceptible to reactivation. Basement control of reef structures has been a long-held hypothesis, although the recognition of a mechanical rationale for the linkage between basement and cover has been a neglected element of the “basement-control” model.

In-plane stresses are gaining wide recognition for their potential significance in controlling sea level fluctuations and contributing to subsidence patterns in basins. A variety of processes may contribute to in-plane stress fields, including shoreface, basin floor, and interreef areas. Within this system, six mappable units are defined. These are, in ascending order: 1) Granite Wash A sand member, 2) Granite Wash B sand member, 3) Granite Wash shale member, 4) Keg River A member, 5) Keg River B member and 6) Keg River C member.

A conceptual depositional model for the sequence depicts four main events:

1. Erosion of the Peace River Arch uplifted fault blocks producing coarse grained fan-delta sediments in the adjacent fault-bounded basins. Subsequent fluvial reworking resulted in the deposition of thick, lenticular and wedge-shaped alluvial fans of Granite Wash.

2. Tectonically triggered progradation of alluvial fans seaward into the Keg River Sea.

3. Transgression by Middle Devonian seas from the east, reworking alluvial fans and leading to deposition of discontinuous linear sand bodies represented by the landward (backstepping) migration of Keg River shoreline sediments westward.

4. Restriction of the sea by the Presqu’ile Barrier Reef to the north, depositing evaporites of the Muskeg Formation over the whole sequence.

A modern analogue to this fan-delta system is the system of coastal fans in the Gulf of Aqaba, Red Sea (Hayward, 1985). The Red Earth
Field contains over 27 million barrels (4.29 × 10^9 m^3) of recoverable oil in a combination structure-stratigraphic trap. The main production is from the Keg River B member marine sand. Potential for future oil discoveries similar to the Red Earth Field is very high, provided certain conditions for oil entrapment are met: 1) sand source provided by both "Granite Wash" and Precambrian inclusions; 2) basement ridges (highs) oriented normal to the Keg River marine transgression; 3) strike - parallel base- ment faults that are more favourable potential hydrocarbon traps; 4) favourable timing of faults.

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Lithofacies, depositional environments and reservoir quality of the basal Belly River sands in south-central Alberta, Canada

The Basal Belly River sands of south-central Alberta are diachronous sand bodies reflecting the eastward (seaward) progradation of a deltaic clastic wedge, being older to the west and younger to the east. In this area, these sands are informally subdivided, in an ascending order, as follows: Basal (traditionally known as the Basal Belly River Sandstone), Lower, Middle, and Upper sands.

Detailed sedimentological and palynofacies investigation of over 3000 feet (915 m) of core in south-central Alberta, has led to the recognition of the following lithofacies: 1) nearshore marine bar and interbar; 2) prodelta; 3) distal delta-front; 4) proximal delta-front; 5) swamp; 6) fluvial channel; 7) fluvial overbank; 8) estuarine channel; 9) back- barrier tidal channels; 10) barrier bar; 11) sub-tidal channels: 12) tidal flats; 13) lagoon; and 14) transgressive tidal sand ridges. The following depositional history was responsible for the regeneration of the four sand units of the Basal Belly River:

1. Development of the subaqueous deltaic facies, represented by the Basal Sand unit.
2. Modification of river-dominated into tide-influenced delta, repre- sented by the Lower Sand unit.
3. Dominance of fluvi-deltaic sediments, represented by the Middle Sand unit.
4. Continuation of fluvi-deltaic sediments, represented by the Upper Sand unit, which prevailed until the close of Belly River time.

Considering the thinness, relative position and widespread nature of the subaqueous deltaic lithofacies of the Basal Belly River Sand, one can conclude that: a) Structural effects were minimal during the deposition of Belly River sediments; b) the depositional basin was relatively shal- low; c) the rate of sediment supply was high and therefore the fluvial processes overpowered marine processes and subsidence. Consequently, the Basal Belly River delta(s) was river-dominated and tide-wave influ- enced.

Porosity preservation, to a varying degree, is influenced by geothermal gradient and chloride grain coatings, while porosity reduction with depth is controlled by diagenesis. Major diagenetic trends appear related to depositional facies. The best exploration targets and reservoir develop- ments are found in fluvial and subtidal channels, and shoreline sand- stones.

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Compaction history and porosity evolution of Tertiary sandstones, Beaufort/Mackenzie Basin

Litharenites of Paleocene to Oligocene age are well consolidated at the onshore margin of the Beaufort-Mackenzie Basin. At comparable depths, litharenites of the basin centre offshore are much less consolidated and more porous. Petrographic analysis of cores and drill cuttings from 21 wells ranging in depth to 4,900 m, and of outcrop samples, shows fairly uniform detrital composition. Ductile grains are very abundant: syndepo- sital clastics, illite, muscovite, chlorite, ilmenite, metamor- phosed altered volcanic rock fragments, mica, and carbonaceous debris. Quartz, chert and other competent grains average two thirds of the grain framework.

Deformation of ductile grains destroyed most of the primary intergran- ular porosity at palaeoburial depths of less than 2 km. During the progres- sive destruction of primary porosity, dissolution of detrital and authigenic constituents created considerable secondary porosity. Virtually no prima- ry porosity is preserved at the basin margin because of burial followed by erosion.

Postdating the destruction of most primary porosity, the following over- lapping diagenetic events modified porosity and altered composition:

1. multiple episodes of extensive cementation and replacement by calci- cte and dolomite
2. several phases of fracturing
3. extensive dissolution of chert, matrix, labile grains and authigenic carbonate creating mainly secondary intergranular pores
4. chemical compaction at grain contacts, and subordinate mechanical compaction reducing secondary porosity
5. progressive cementation by quartz; and
6. episodic cementation and replacement by kaolinite and minor pyrite.

Secondary dissolution porosity is best developed in the geopressured basin centre. It is suggested that this exceptional porosity enhancement resulted from maturing organic matter that generated acid reactants and methane, possibly facilitating overpressuring and fluid convection.

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Automated data processing for the Geological Atlas of the Western Canada Sedimentary Basin

Atlas mapping is fundamentally based on a number of existing digital data bases, both public and private. The most important of these are the provincial files for index and stratigraphic data, and the Canstrat files for lithology. Integrated computer processing of these data bases is designed to perform automatic distillation of raw geological data into map input information. In geological investigations, this basic task is routinely undertaken manually by a geologist. However, given the size of the Atlas project, the vast volume of data (~ 200,000 wells), the disparity of provincial data bases, and the degree of redundancy and inconsistency in the data, manual evaluation and filtering of the well data would require commitment of time and effort far exceeding the available resources. Consequently, a series of programs has been developed for the purpose of automating as many steps of the preliminary data assessment as possible. These programs comprise an electronic data processing system that transforms the raw data into first-cut map input, practically without human interaction. The geologist is requested only to supply a few parameters at the programs' initiation.

The core of the system is made up of about 50 procedures that inte- grate, filter and organize the data for further processing. They perform an integrity check, eliminate redundant and unusable data, correct errors, evaluate and merge revised (cloned) wells, identify stratigraphic syn- onyms, and build data structures.

The filtered raw data may be directed into one of three streams:

1. Selection of an optimized set of control wells (Atlas data base).
2. Selection of an optimized set of control picks (Atlas standard set).
3. Generation of map input from the entire bank of clean data.

The data derived by options (1) and (2) can be used directly for the generation of map input, or can be dispatched to a set of programs that evaluate data conformity and variability through neighbourhood cross-reference and surface modelling. Reports on missing or potentially erro- neous data also can be produced. Feedback to the system (geologists' cor- rections) is assessed in the same way. Analysis and hierarchical classification of sequence types within a specified stratigraphic slice is yet another option offered by the system, for both the raw and derived data.

To perform the above tasks, the system requires some built-in analyti- cal and pattern recognition capacities. When the program attempts to eliminate an inconsistency in the pick sequence, or to isolate stratigraphic synon- yms, it must make a decision that requires some understanding of stratigraphic relationships. Yet the diversity and complexity of the region- al stratigraphy precludes the usage of reference tables as the system's guide. Thus, the programs extract the stratigraphic knowledge directly from the data, by examining and storing the adjacency relations between picks, then using the stored information, together with a few optimization algorithms and heuristic rules, to arrive at geologically sensible decisions.

It should be emphasized that although most of the post-selection process- ing concentrates on the 10,000 Atlas control wells, the system undertakes continuous evaluation of each well in the context of its neighbourhood (horstanship). This allows for properly assessed supplemental data to be brought to bear on the mapping, and minimizes the loss of information induced by selection.
The Cambrian succession is subdivided, correlated, and mapped in the subsurface from the Foothills of Alberta east through the Plains to its edge in Manitoba. An attempt is also made to correlate stratigraphic sections exposed in the Front and Main ranges with the subsurface.

The Cambrian and Lower Ordovician carbonate succession exposed in the Front and Main ranges forms a carbonate facies belt of cyclic peritidal dolomite and limestone. The succession extends eastward into the Foothills of Alberta and to some distance in the subsurface of the Plains before gradually changing facies, within Alberta, to shallow basin clastics. To the west, within the Main Ranges, the carbonate facies belt, with the exception of the Mural-Badshot and Ottertail Formations, abruptly changes along an ocean-facing submarine escarpment to dark, deep-water, fine-grained basinal elastics and carbonates.

In the subsurface of the Plains, the Cambrian rests unconformably on the Precambrian. It covers most of southern Alberta, as far north as Township 75, and southern Saskatchewan as far north as Township 65. North of these areas, the Sub-Devonian unconformity rests on the Precambrian. It is only present in Manitoba over a small area in the extreme southwest. A remnant of Cambrian strata is preserved in the Fort Nelson area of British Columbia.

In eastern Alberta and western Saskatchewan, the Cambrian and Lower Ordovician are represented by the Middle Cambrian Basin Sandstone unit, clastics of the Earlie Formation, and upper Cambrian – Lower Ordovician clastics of the Deadwood Formation. The Cambrian section is overlain unconformably by Upper Ordovician carbonates in the east-central part of southern Alberta and western Saskatchewan. In eastern Saskatchewan and Manitoba, only the Deadwood persists and is overlain by the clastic Winnipeg Formation (Middle Ordovician). Where the Ordovician is eroded, the Cambrian is overlain by either Middle or Upper Devonian sediments.

In the subsurface of the Plains and Foothills of Alberta, and in the Front and eastern Main ranges, the succession is composed of the Middle Cambrian Basin Sandstone unit, clastics of the Earlie Formation, and Upper Cambrian – Lower Ordovician clastics of the Deadwood Formation. The Cambrian section is overlain unconformably by Upper Ordovician carbonates in the east-central part of southern Alberta and western Saskatchewan. In eastern Saskatchewan and Manitoba, only the Deadwood persists and is overlain by the clastic Winnipeg Formation (Middle Ordovician). Where the Ordovician is eroded, the Cambrian is overlain by either Middle or Upper Devonian sediments.

The paleogeographic evolution of the Western Canada Foreland Basin

Foreland basin style deposition began in Western Canada during Oxfonian time with the appearance of sediments derived from the west in southwestern Alberta (Passage Beds). By Kimmeridgian time, a major landmass was well established in the west, shedding coarser clastics eastward into a narrow, rapidly subsiding trough (Kootenay/Ninnes/Nikanassin). A major relative sea level fall near the end of Valanginian time precipitated basin-wide erosion, which lasted until Barremian time (post-Cadotte unconformity). Fluvial sedimentation resumed by the Barremian (Cadotte/Gething/Ellerslie/Dina) with rivers flowing northward. The initial phases of the Ramparts Formation, which are separated by the widely correlatable and readily recognizable Carcajou Marker or not Carcajou? That is the question

Confusion surrounds the nomenclature of upper Givetian-lower Frasnian carbonates in the Norman Wells-Fort Good Hope region. The structural framework within which these coals occur ranges from complexly folded and faulted strata in the mountains to relatively uncomplicated flat-lying strata in the Interior Plains. Coal rank may be influenced to some extent by stacking of thrust sheets in the mountains, but seems mainly to be a function of depth of stratigraphic burial, increasing from east to west.

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Using a sequence stratigraphic approach, the Lower Ramp Member of the Ramparts Formation represents the undifferentiated component of a large, prograding clastic lobe comprising black shale of the Lower Bluefish Formation (fondothem) and greenish grey shale and limestone of the Upper Member (clinothem) of the Hare Indian Formation. This depositional sequence was terminated by a drowning event, with later deposition of the Carcajou Member black shale. The overlying sequence (Upper Platform-Reef Member) consists of carbonate platform growth followed by reef inception and aggradation. A sea level rise resulted in reef drowning and termination of the sequence. Thus, the Ramparts Formation straddles two separate major depositional sequences, with the Lower Ramp Member being genetically related to the Hare Indian Formation clastic beds to the Ramparts Formation, and has relegated the term Kee Scarp Formation informal, representing the producing platform-reef at the norman Wells oilfield.

The Ramparts Formation consists of argillaceous limestone and shale of the Lower Ramp Member separated from the Upper Platform-Reef Member by the Carcajou Marker black shale (Muir, 1988). At Norman Wells, the Kee Scarp Formation consists solely of the Upper Platform-Reef Member equivalents, as no Lower Ramp Member developed in this region.

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Integrated reservoir analysis of the Upper Mannville (Glaucocitic Sandstone) in the Countess “D” Pool area — evidence of varying Lower Cretaceous palaeoenvironments

The Glaucocitic Sandstone reservoir in the Countess “D” Pool (Twp. 18, Rge 15, W4M), is currently in the later stages of secondary recovery by waterflood. As part of a detailed reservoir analysis to determine the “D” Pool’s enhanced recovery potential, the geology of the Countess Field has been evaluated.

Throughout the life of the reservoir, relatively simple geological models have been used to describe the geometry of the reservoir sands in the “D” Pool area. However, owing to small-scale perturbations in production/injection history during 25 years, it became evident that a more complex geological model was needed to describe the pool.

Results of a detailed core study indicate that the productive interval comprises two major lithofacies. Lithofacies I is composed of light grey to brown, fine to medium grained, well-sorted quartzarenites with a slightly fining-upward grain size distribution. The bases of the sand bodies within this lithofacies are erosional, while the top grades into coal. Tidal couplets, mud drapes, reactivation surfaces, flaser beds and trace fossils are observed. Lithofacies I is interpreted as a meso-to macrotidal estuarine deposit.

Lithofacies II comprises dark grey to light brown, fine to coarse grained, poorly-sorted litharenites. The bases of sand bodies within this lithofacies are erosional, with abundant rip-up clasts. Near the top of these lithofacies, the sandstone grades upward into floodplain sediments. High angle trough crossbeds with carbonaceous laminae on the foresets, lag deposits, rip-up clasts, and a fining-upward grain size occur commonly. Absent are tidal couplets, reactivation surfaces and bioturbation. Lithofacies II is interpreted as a fluvial meandering channel deposit.

Stratigraphic correlation of wireline logs supports the interpretation that the Glaucocitic estuarine facies has eroded pre-existing Upper Mannville sediments, sometimes to the Ostracod Beds, and was later eroded by the fluviately-dominated facies. Both lithofacies are of good reservoir quality. However, the presence of erosional boundaries between the lithostratigraphic units may obstruct flow patterns, resulting in heterogeneous production behaviour. Through proper delineation of the two lithofacies and adequate modelling of barrier effects at erosional contacts between the units, a detailed geological model, necessary for EOR purposes in the “D” Pool, has been achieved.

Hydrocarbon potential of the Morondava Basin, west Madagascar

Detailed seismic stratigraphic analysis, tied to available well control, has revealed that the Morondava Basin of west Madagascar holds considerable hydrocarbon potential. The area contains a thick sequence of rift-valleys into the pre-existing shelf margin. This sand-prone valley-fill comprises two major lithofacies. Lithofacies I is composed of light grey to brown, fine to medium grained, well-sorted quartzarenites with a slightly fining-upward grain size distribution. The bases of the sand bodies within this lithofacies are erosional, while the top grades into coal. Tidal couplets, mud drapes, reactivation surfaces, flaser beds and trace fossils are observed. Lithofacies I is interpreted as a meso-to macrotidal estuarine deposit.

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Event stratigraphy within the Winterburn-Woodbend strata of the Western Canada Sedimentary Basin

The Winterburn-Woodbend succession has been redefined using event stratigraphy as opposed to the traditional lithostratigraphic approach. Carbonate reservoirs in the Upper Devonian Woodbend-Winterburn succession collectively account for approximately 66 per cent of Western Canada’s initial conventional oil reserves. Consequently, utilization of event stratigraphy could lead to new exploration opportunities within the Western Canada Sedimentary Basin.

An event-stratigraphic framework has been developed that closely approximates the division of the Woodbend-Winterburn sequence into time-bounded units. This framework was established by repicking and correlating 10,000+ wells on the basis of traceable “time-synchronous” log events which give a better illustration of the macro-depositional processes and overall basin evolution.

Six major bounding events with associated basin infill and/or reef development are recognized. The upper-bounding event for the Woodbend-Winterburn succession, used in this study, is congruent with the Frasnian-Famennian boundary as defined from outcrop in the Northwest Territories. In the subsurface, this event correlates with a marker just below the base of the Graminia Silt. The second major event corresponds to the base of the Calmar Formation, and the third is equivalent to the base of the Nisku Formation as defined in the Chevront Norcen 7-4-49-12 W5M reference well. Specifically, this event correlates with the industry defined ‘Z’ marker within the basin-fill sequences and can be confidently correlated over much of the basin. The fourth major event approximates the termination of the traditional Woodbend reef-building and basin-fill sequence. The top of the Cooking Lake Formation and its equivalents represent the fifth event. The final, lower-bounding event for the Woodbend-Winterburn succession corresponds approximately to the base of the Cooking Lake Formation and equivalents.
Cambrian facies and paleogeography, subsurface of southern Alberta

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Cambrian rocks in Western Canada occur in three facies belts; an inner detrital belt, a middle carbonate belt, and an outer detrital belt. The Cambrian in the Rocky Mountains and Front Ranges displays a cyclical pattern in which strata characteristic of the inner detrital and middle carbonate belts formed "grand cycles". The grand cycles can be recognized in well data from the westernmost part of Southern Alberta. However, as the carbonates give way eastward to clastics, the cycles become difficult to recognize. Nine lithofacies have been recognized in the Cambrian rocks of this region: 1. mottled dolomitic mudstone and wackestone; 2. mudstone, wackestone, and packstone; 3. oolitic grainstone; 4. cryptalgalaminate and cryatalgalaminate breccia; 5. flat-pebble conglomerate; 6. glauconitic sandstone; 7. quartzarenite; 8. hybrid sandstone and iron formations; and 9. coquina. These facies were deposited in environments ranging from supratidal to subtidal, with storms playing a major role in sediment distribution. Iron typically occurs in amounts exceeding 15 per cent by volume of the iron-formation facies and is interpreted to be diagenetic in origin.

Facies mapping of the Cambrian in the subsurface of southern Alberta shows that the paleogeography during the Cambrian consisted of a very shallow basin surrounded by shoal areas on three sides. The shoal areas bordered the Peace River Arch, the West Alberta Ridge, and the Sweetgrass Arch. The shallow basin was dominated by glauconitic sandstone and shale, quartzarenite, flat-pebble conglomerate, coquina and minor carbonate. Shoal areas were dominated by mottled dolomitic mudstone, oolitic grainstone, cryptalgalaminate, flat-pebble conglomerate, coquina, and minor clastics. Mud cracks are abundant, especially in the shoal area on the south side of the Peace River Arch.

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The effect of Cambrian paleogeography on the distribution of the overlying Beaverhill Lake carbonate, southern Alberta

Facies mapping of the Cambrian in the subsurface of southern Alberta shows that the Cambrian paleogeography has a marked influence on the distribution of the Middle to Upper Devonian Beaverhill Lake carbonates.

During the Cambrian, southern Alberta was a shallow marine basin surrounded by shoal areas on three sides. These shoal areas bordered the Peace River Arch to the north, the West Alberta Ridge to the west, and the Sweetgrass Arch to the south. Sedimentary rocks originating in the shallow basin consist of glauconitic sandstone and shale, quartzarenite, flat-pebble conglomerate, coquina and minor carbonate. Shoal areas are reflected predominantly by mottled dolomitic mudstone to packstone, oolitic grainstone, cryptalgalaminate, flat-pebble conglomerate and coquina. Mud cracks are abundant in places.

Initial Cambrian paleogeography controlled the distribution of subsequent Cambrian sedimentation. Resultant facies distribution impacted on the paleotopography of the Cambrian. Carbonate facies in shoal areas were more resistant to pre-Devonian erosion than the basinal carbonate facies. It is possible that the Cambrian clastic section has suffered more compaction than the carbonate section. The combination of these factors resulted during late Givetian, early Frasnian time in a topographic depression bordered by relatively high areas that exerted a primary control on sedimentation (Beaverhill Lake Formation).

Beaverhill Lake paleogeography across southern Alberta was dominated by a carbonate bank composed of limestone, dolomite, and evaporites, a large shale basin, and a carbonate platform with reefal development (the Swan Hills reef complex). These major Beaverhill Lake paleogeographic features are closely related to the paleogeographic and lithofacies patterns of the underlying Cambrian rocks.

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The sedimentology and depositional setting of the Granite Wash, Utikuma and Red Earth areas, north-central Alberta

Granite Wash is an informal term applied to the Paleozoic basal siliciclastic unit associated with the Peace River Arch, northwestern Alberta. The Granite Wash, which unconformably overlies Precambrian igneous and metamorphic rocks, consists of conglomeratic sandstone, sandstone and mudstone. The lithofacies distribution and depositional history of the Granite Wash have been determined in the Utikuma and Red Earth field areas. In these areas, Granite Wash clastics interfinger with open marine carbonates of the Keg River Formation (Middle Devonian) and form elongate trends that correspond to Precambrian structural trends.

Initial Granite Wash sediments in the Utikuma area consist of poorly sorted, dominantly unstratified, red, conglomeratic sandstone probably deposited in alluvial fans. The overlying succession consists of stacked, 10 to 20 m, coarsening-upward sequences interpreted as prograding fan deltas. The widespread lateral extent of these sequences suggests a probable alluvial control on their development.

In the Red Earth area, initial Granite Wash sediments were confined to narrow, northeast-southwest trending paleovalleys that opened into a wider basin to the northeast. Conglomeratic sandstones were deposited in braided fluvial channels, alluvial fans(?), and deltas with a possible tidal influence. A transgressive event subsequently drowned the paleovalleys and resulted in the deposition of a widespread, black mudstone unit. Renewed progradation is indicated by the deposition of a 5 to 16 m coarsening-upward fluvio-deltaic sequence capped by a mudflat/tidal flat succession.

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Mass accumulation rates of Foreland Basin sediments, Peace River Area

Volumetric sedimentation rates have been used previously to quantify the dynamics of sedimentary processes. Their calculation is usually done on one- or two-dimensional local scales, and requires compaction of strata, which introduces approximations in the results. The use of mass accumulation rates avoids the need for decompaction and provides the same information (except for lithospheric loading) on a three-dimensional regional scale. Moreover, by avoiding the need for decompaction, the uncertainty inherent in sedimentation rates is reduced. The regional distribution of mass accumulation rates for a specific unit pinpoints the source areas and gives a general indication of the depositional environment. The magnitude of the mass accumulation rates can be related to the tectonic conditions in the adjacent deformed belt.

Mass accumulation rates in the Peace River Arch area were calculated for Foreland Basin units based on porosity and grain density data from core analyses at approximately 22,000 wells. They show that tectonism can result in either the deposition of a sand or shale, depending on the rock type being exposed to erosion. During the Albian, Cordilleran deformation lead to the rapid accumulation of the Bluesky and Upper Spirit River sands. Deformation from late Cenomanian to late Coniacian time resulted in the rapid accumulation of the Puskwaskau and Muskiki shales. The results show that deposition of a shale does not necessarily imply slow accumulation during a period of quiescence. Conversely, the deposition of a sand does not always imply rapid sedimentation and associated tectonism. The source rock controls the sediment lithology, and the state of tectonism controls the accumulation rate.


Petroleum geology of the Cenomanian Doe Creek Member, northwestern Alberta

The Cenomanian Doe Creek, Pouce Coupe and Howard Creek members of the lower Kasappaun Formation are hydrocarbon-bearing sandstones that outcrop in northeastern Alberta. The Doe Creek Member produces light gravity oil and gas from 6 fields, although the majority of production is from the Valhalla Field. The Doe Creek Member is the only Cretaceous unit from which commercial oil is presently being produced on the Peace River Arch.

Regional cross-sections show that the Doe Creek Member consists of a series of thin, lenticular sandstones encased in shale 15 to 40 m above the top of the Dunvegan Formation. Hydrocarbon production from the A and l sandstones is concentrated along the eastern updip pinch-out edge of each sandstone body. Hydrocarbon production from the middle N sandstone is limited and irregularly distributed. The Pouce Coupe Member outcrops at the northwest corner of the study area but does not extend eastward into the subsurface of Alberta. The Howard Creek Member is traceable into the northern part of the study area (section A-A') as a silty zone approximately 35 to 45 m above the Doe Creek Member. Overall, the sandstone units form a retrogradational fan delta complex capped by a deep-water, condensed section ("Second White Specks"). Each sandstone unit appears to be unconformity-bounded.

Rock-Eval pyrolysis indicates that the shales fall into two groups. The shales that encase the Doe Creek sandstones have poor hydrocarbon
source-rock potential; the overlying Second White Specks has good source rock potential with the ability to generate gas and oil.

Eleven facies described from outcrop and core record the nature of the transgression, which involved deposition of sandstones between fair-weather and storm wave base on a shallow marine shelf, probably similar to lee-side shoals in the Alaska Bering Sea.

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Structure of the Western Canada Sedimentary Basin
The Western Canada Sedimentary Basin contains two major features: 1) a thick western section stretching from Montana to the southern Northwest Territories, and 2) the Williston Basin, centered in North Dakota. The Phanerzoic wedge, clearly more than 6 km thick at the mountain front, thins northeastward above the crystalline Shield. Deformation of the Foreland Thrust Belt (FTB) affected strata varying in age from Helikian to Tertiary. The sedimentary wedge produced loading, subsidence, and a series of geographically different depocentres.

The Peace River Arch and Western Alberta Ridge were topographically high features in the Devonian, but the former became a basin in the Early Carboniferous. Two other ridges are discussed: the Tathlina Arch and the ill-defined axis between the Alberta and Williston basins (often called the Sweetgrass Arch, which is best seen south of Alberta where it was a positive element in the Paleozoic and the Cenozoic).

One dramatic feature in northeast British Columbia and the Northwest Territories is a fault complex, which shows over 1000 m of vertical displacement at the Devonian level. Other features include the Northern Rocky Mountain Trench, with over 400 km of Cretaceous-Tertiary dextral displacement; and the northeast trending Great Slave Lake Shear Zone between the Peace River Arch and the Tathlina Arch, with up to 700 km of displacement, again dextral.

Other features present include salt solution and reef compaction phenomena. Muskeg/Prairie Evaporite salt has been dissolved around reefs; and solution is also evident at the sub-Mesozoic unconformity. Compaction associated with reefs is present at several horizons and can be mapped residually.

Sections show the estimated shortening across the FTB (150 km in southern Alberta). However tectonic style, grain, thrust sheet thickness and displacement within, and adjacent to the FTB, change to the north. Details of the geology in this western deep frontier will become better understood as deeper exploration continues with the expanding demand for natural gas. One question to be resolved is the relationship between ancient axes and currently visible structures.

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Implications for the lack of a forebulge within the Alberta Foreland Basin
It is well known that the evolution of the Alberta Foreland Basin was influenced by extrinsic and intrinsic factors operating at different scales. It is widely believed that on a continental scale the Alberta Foreland Basin was influenced by the mechanical properties of the lithosphere and the tectonic events that telescoped the Rocky Mountain Fold-Thrust Belt along the basin's western margin. This geological scenario has been modelled by Beaumont (1981) using thin plate theory. His models indicate clearly that, as progressively increasing and advancing loads deform the lithosphere along the margin of the plate, a forebulge develops and migrates within the basin. This particular model has been widely accepted and has found application in sedimentological studies that have attributed a forebulge origin to the localization of the "shelf sandstone ridges" of the Albian-Campanian seaway (Tankard, 1986). However, the stratigraphy of the Alberta Foreland Basin does not support the existence of a forebulge. If such a forebulge exists, it must lie farther east of the basin. It will be shown that in order to explain the observed stratigraphy, a lithosphere that thickens eastward to more than 250 km beneath the North America Craton is required. This thick "Root" is also required by the post-glacial rebound data and is supported by recent seismic data. The notion of a deep, strong "root" that travels coherently with the continents, however, challenges some of the basic tenets of plate tectonic theory and forces us to rethink the evolution of continents.